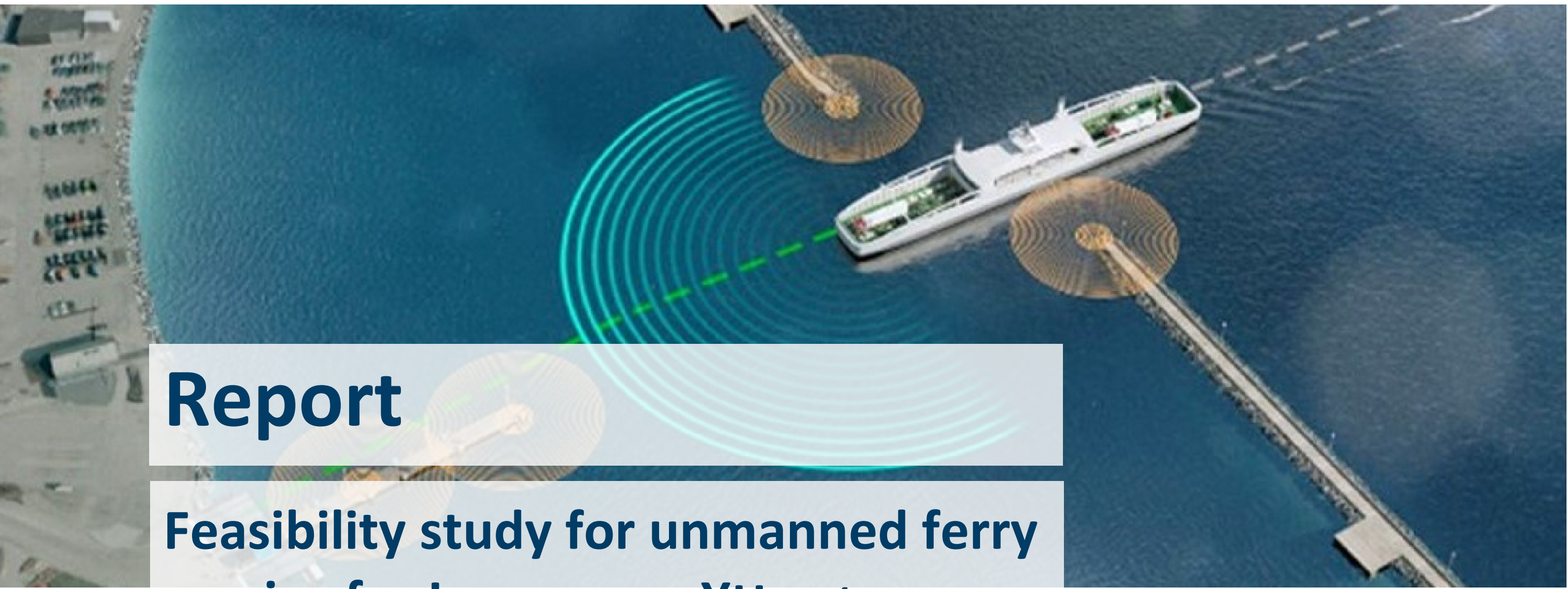

Report

Feasibility study for unmanned ferry service for Levanger – Ytterøy

Technical requirements, Retrofit opportunities and Safety Considerations

Author(s):

Mariann Merz, Esten Ingar Grøtli, Odd Erik Mørkrid

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Client(s) (pos partner):

SFI Autoship

SINTEF Digital
Postal address:
Postboks 4760 Torgarden
7465 Trondheim, Norway
Switchboard: +47 40005100
info@sintef.no

Enterprise /VAT No:
NO 919 303 808 MVA

Report

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Mariann Merz, Esten Ingar Grøtli, Odd Erik Mørkrid

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Anastasios Lekkas

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ABSTRACT
As unmanned ships undergo global field testing, assessing their technical maturity and regulatory readiness is crucial. This study focuses specifically on the Levanger-Ytterøy ferry service, evaluating the technical and regulatory feasibility of unmanned operation for passenger ferries. The analysis covers three operational phases (at port, near port, and coastal sailing) and five key functionalities: navigation and control, engine room operation, communication, mooring, and car and passenger handling. The results show that some potential exists to automated certain functions to offload crew. But to achieve fully unmanned operation, the construction of a purpose-built vessel is necessary, where risk analysis determines required system redundancies and where the design minimizes the need for repair and maintenance. A significant challenge lies in digitally replacing the physical handling of passengers and vehicles. The insights presented in this report contribute to a broader understanding of the feasibility and challenges associated with unmanned passenger ferry operation.

PREPARED BY
Mariann Merz

SIGNATURE
Mariann Merz
Mariann Merz (Sep 4, 2023 10:24 GMT+2)

CHECKED BY
Even Ambros Holte

SIGNATURE
Even Holte
Even Ambros Holte (Sep 4, 2023 10:57 GMT+2)

APPROVED BY
Sture Holmstrøm

SIGNATURE
Sture Holmstrøm
Sture Holmstrøm (Sep 4, 2023 10:59 GMT+2)

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0.9	2022-10-03	First draft of the report that is distributed to relevant SFI Autoship partners for review and possibility to provide additional input. Still missing the section on "Commercial feasibility".
0.95	2023-06-04	The Commercial feasibility scope has been scrapped as it was deemed to complex and inaccurate to do with the available information. Abstract and Conclusion sections have been added. The report is ready for internal review.
1.0	2023-09-04	The report has been updated based on the comments that were provided during the internal review.

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SINTEF

Executive Summary

With unmanned ships undergoing field testing in several locations across the world, it is prudent to assess the maturity of technical solutions and the readiness of regulatory frameworks. In this study we identify the current gaps for a specific operation, the Levanger – Ytterøy ferry service. Norway relies on both large and small ferries to transport cars and passengers to and from locations separated by large bodies of water. This has become a popular use case for unmanned ships due to significant economic incentives, stemming from the considerable number of ferries in operation and the potential of unmanned ferries as a cost-effective alternative to building expensive infrastructure like bridges. Moreover, since international regulations for autonomous ships are still years away, it is currently of most interest to study use cases that are confined to operation in Norwegian waters.

To achieve a mature and robust design for an autonomous ship, extensive testing in real-life operational conditions is crucial, as is the case with any new technology. Hence, this study primarily focuses on unmanned operation rather than fully autonomous operation, with specific focus on the possibility of automating (or remotely control) certain tasks or functions that are typically performed by onboard crew. A comprehensive testing phase is necessary, involving a human operator who monitors the automated systems and remains prepared to assume control in case of technological failures or unforeseen events. Initially, it is advisable for the human operator to stay onboard the ship. However, once the risk analysis permits, the operator could monitor the operation from a Remote Operation Centre onshore. Nonetheless, before eliminating the crew from a passenger ship, it is essential to consider the safe and acceptable handling of all passengers. This factor adds an extra layer of consideration to the transition process.

The current report has a key goal of assessing the potential to reduce the number of manual tasks performed onboard a small passenger-car ferry such as Levanger – Ytterøy, by:

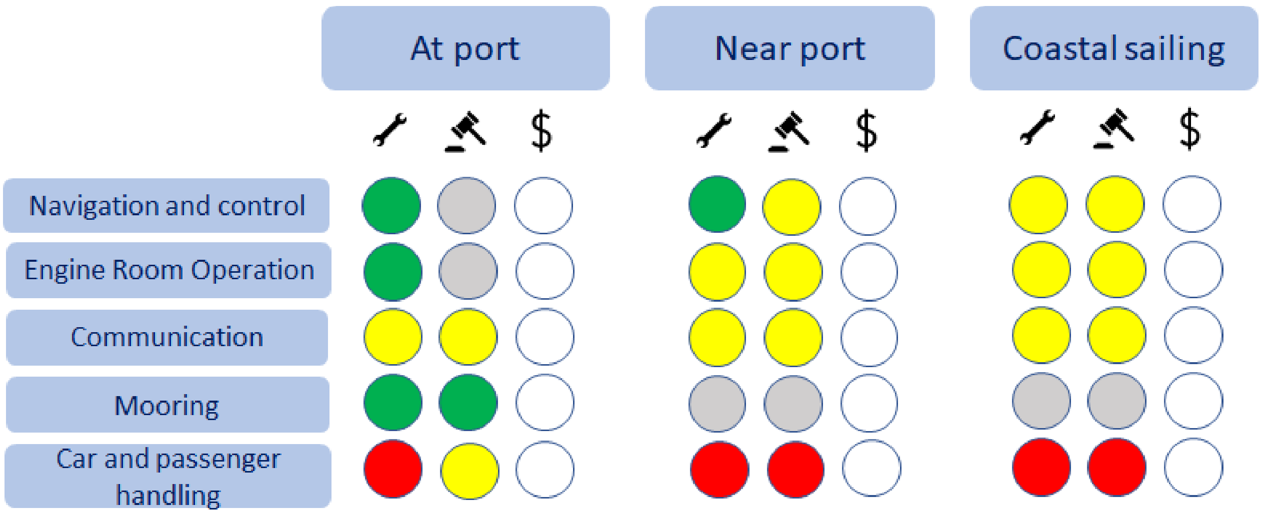
- Conducting a comprehensive analysis Performing a mapping of the current crew actions and responsibilities
- Reviewing the relevant state-of-the-art technical solutions
- Identifying the relevant regulatory challenges

The feasibility assessment encompasses three primary operational phases (at port, near port, and coastal sailing) and covers five key functionalities: navigation and control, engine room operation, communication, mooring, and car and passenger handling.

The analysis suggests that achieving fully unmanned operation would necessitate a significant overhaul of the existing ferry or, more likely, the construction of a new ferry specifically designed for unmanned operation. The systems involved should be engineered to incorporate the required level of reliability and redundancy as determined by the risk analysis. Important factors can include material selection (components with increased durability), installation of new safety systems as well as incorporation of relevant fail-safe mechanisms. Optimization efforts should focus on minimizing repair and maintenance requirements that require the physical presence of a human, while also implementing mitigating factors such as an onboard system capable of analysing the need for predictive maintenance. However, it is important to acknowledge that the physical handling of passengers and vehicles presents considerable challenges in terms of replacement with digital solutions. One challenge lies in people's tendency to not follow auditory instructions effectively, and on the other hand, there is a limited availability of autonomous emergency handling solutions that are sufficiently intuitive to deploy or use without guidance from crew. Addressing these complexities will be crucial in realizing the goal of unmanned operation for passenger ferries.

Introducing a new electric ferry equipped with cutting-edge automation for the Levanger-Ytterøy service holds significant advantages. Foremost, it would alleviate the crew's current responsibilities and potentially allow for a reduction in manning levels. Particularly, the need for a "Dagmann" that has commonly been used, will most likely no longer be needed. Furthermore, the merging of the Able Seaman and Chief Engineer positions could be considered if the new engine room necessitates minimal day-to-day monitoring. An additional benefit of the introduction of a new electric ferry with state-of-the-art systems would be the potential to optimize route planning to e.g., minimise fuel burn.

The feasibility analysis is summarized in the traffic-light illustration in Figure 12 which is reproduced at the end of this Executive Summary. The **red light** indicates that unmanned operation is unfeasible for the foreseeable future, **yellow light** indicates that unmanned operation is expected to be feasible in the near term (less than 5 years from now) assuming targeted technology development, **green light** indicates that the operation is feasible with technology that is available today, and **grey light** indicates that the option is not relevant. The feasibility is evaluated from a technical () and regulatory () viewpoint. The commercial viewpoint is clearly of major interest but was too complex to address within the confines of the study. However, due to the importance of this perspective the table includes a commercial ($) viewpoint where the traffic lights are left blank, to indicate they have not been assessed. Each of the crew tasks are evaluated for each applicable operational phase.



Abbreviations

Expressions and abbreviations	Description
AI	Artificial Intelligence
AIS	Automatic Identification System
COLREG	Convention on the International Regulations for Preventing Collisions at Sea
CONOPS	CONcept of OPerationS
DP	Dynamic Positioning
ECR	Engine Control Room
FSA	Functional Safety Assessment
GNSS	Global Navigation Satellite System

GSM	Global System for Mobile communication
HazID	Hazard IDentification
HMI	Human Machine Interface
IMO	International Maritime Organization
IR	InfraRed
LIDAR	Light Detection and Ranging
LOA	Level Of Autonomy
LTE	Long Term Evolution (It's a standard for wireless data transmission)
MASS	Maritime Autonomous Surface Ship - A ship which, to a varying degree, can operate independent of human interaction
MGO	Marine GasOil
MOB	Man OverBoard
MRC	Minimum Risk Condition
NMA	Norwegian Maritime Authority
NUC	Not Under Command
PA	Public Address
SOLAS	Safety Of Life At Sea
SOPEP	Shipboard Oil Pollution Emergency Plan
ROC	Remote Operation Centre
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
UHF	Ultra High Frequency
UMS	Unattended Machinery Spaces
WP	Work Package

1 Introduction

The report investigates the potential for improving the availability and sustainability of the Levanger-Ytterøy ferry service. It explores two key avenues: the adoption of innovative autonomous operational modes and the integration of technologies to support environmentally friendly practices. A primary objective of this development is to reduce the onboard crew, either by automating tasks that currently rely on physical presence, manual actions, or specialized expertise, or by shifting these responsibilities to a Remote Operations Center (ROC). By prioritizing these areas for automation, the aim is to optimize operational efficiency while simultaneously advancing the service's environmental performance.

Enhancing the level of autonomy in ferry services is driven by several key motivations, including the desire for increased competitiveness, improved service availability, enhanced service quality, reduced emissions, and addressing the projected shortage of seafarers. To conduct a comprehensive feasibility analysis, the Levanger-Ytterøy ferry service was selected based on input from key stakeholders. The stakeholders have identified the main research challenges specific to this service, encompassing autonomous sailing/crossings, autonomous ferry docking, and passenger/car handling with reduced onboard crew. Although these challenges are applicable to most autonomous ferries, understanding the context of the specific use case is crucial for evaluating relevant solutions accurately.
It is crucial to address these challenges while ensuring safety levels are maintained at a minimum requirement and, ideally, improved.

The goals of increased automation can be achieved through two approaches: 1) retrofitting the existing ferry and 2) replacing the existing ferry with a new one. While the ultimate aim is to establish a fully autonomous ferry service, the key stakeholders acknowledge the importance of a gradual implementation of autonomous functionality. This phased approach may also involve the integration of remote operation capabilities, allowing for a combination of autonomous and remotely operated operations.

1.1 Background

The work presented in this report is performed as part of SFI Autoship, a research-based innovation center aimed at advancing the development of autonomous ships for safe and sustainable operations. Spanning from 2020 to 2028, this initiative seeks to position Norwegian stakeholders as leaders in the field. The ongoing research is characterized by its multidisciplinary nature and focus on specific use cases. The selected Use Cases include 1) deep-sea bulk shipping, 2) short-sea container shipping, 3) urban ferries and 4) offshore support operations. The relationship between the Work Packages (WP) and use cases for SFI Autoship is illustrated in Figure 1.

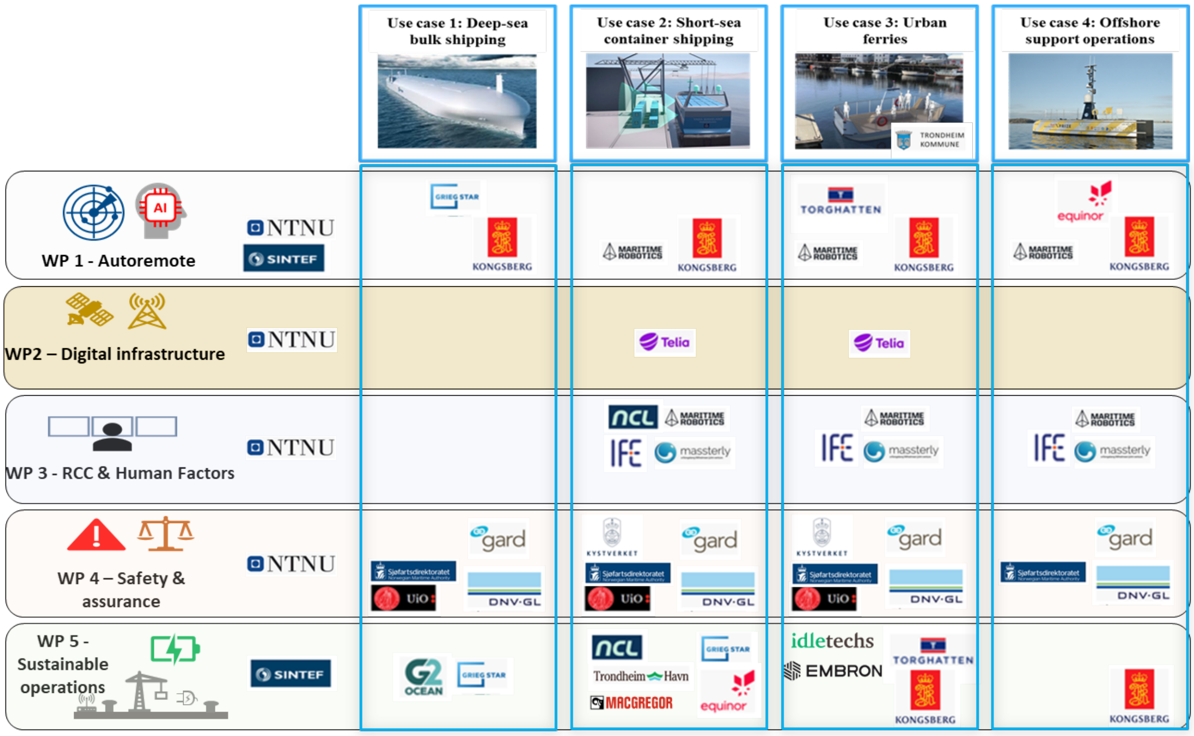


Figure 1: Overview of WPs and Use Cases for SFI Autoship

This feasibility study directly supports Use Case 3 which aims to *further develop the idea of flexible and environmentally friendly passenger ferries as alternatives to bridges and the traditional ferries*.

1.2 Scope of the Report

- The main goal of this report is to assess the feasibility, within the next 5 years, of minimizing or eliminating the crew requirements for a small passenger-car ferry like Levanger-Ytterøy either by automating existing tasks or by moving the responsible personnel to an ROC. This objective will be accomplished by undertaking the following steps: Conducting a comprehensive analysis of the current crew actions and responsibilities.
- Reviewing the relevant state-of-the-art technical solutions.
- Identifying the relevant regulatory challenges.

The primary objective of the report is to consider what can be accomplished assuming a new ferry instrumented with currently available solutions is launched. A secondary objective is to consider if any of the identified solutions are promising candidates for a possible retrofit of the existing ferry. Undoubtedly, a commercial feasibility assessment holds significant importance; however, due to the limitations of the study, it was deemed too intricate to be fully explored within its scope.

1.3 The Team behind the Report

The partners involved with SFI Autoship Use Case 3 on Urban Ferries have contributed to this report based on their respective areas of competence as outlined below.

- Torghatten (Use Case 3 owner):
  - Owner of the Levanger – Ytterøy ferry and operator of the Levanger – Ytterøy ferry service with a key role of describing the current operations and related challenges.

- Help to brainstorm the potential for automation of sub-operations and help to review and comment on the content of the report from an operator point of view.

- Maritime Robotics:
  - Participated in an interview-style workshop to collect relevant input.
  - Provided a nice overview of their philosophy on autonomous systems and presented ongoing work related to autonomous systems and related regulatory aspects.
- DNV:
  - Participated in an interview-style workshop to collect relevant input.
- Norwegian maritime Authority:
  - Participated in an interview-style workshop to collect relevant input.
- Norwegian Coastal Administration:
  - Participated in an interview-style workshop to collect relevant input.
- SINTEF (Ocean and Digital):
  - Responsible for writing the report and collecting inputs from other partners.

1.4 Previous work on Autonomous Ships and Ferries

The recent push to develop autonomous ships gathered momentum during the MUNIN project (Maritime Unmanned Navigation through Intelligence in Networks), that was funded through the EU Seventh Framework Programme between 2012 and 2015. The scope of this project was to develop and verify a concept for an autonomous ship by combining onboard decision support with remote control via a shore-based station. In the following years several new initiatives for autonomous ships were launched by different types of stakeholders including the unmanned, zero-emission, shortsea vessel concept ReVolt[1] by DNV GL; the Mayflower Autonomous Ship[2] developed by main partners ProMare and IBM that used an AI captain to cross the Atlantic Ocean autonomously in the summer of 2022 (albeit with some technical difficulties); Yara Birkeland[3] which will be the world's first fully electric and autonomous container vessel (once the 2-year manned test period is over) and is developed by Yara and Kongsberg; and ASKO Maritime which has just received 2 fully electric autonomous (following a 2-year manned test-phase) roll-on/roll-off cargo ferries to carry truck trailers across the Oslo Fjord[4].

A lot of challenges and implementation details are common for all autonomous ships, hence a lot of the lessons learned from the already mentioned autonomous ship projects also apply to the development of autonomous ferries to carry people. However, there are also a few challenges that apply to ferries only, the most obvious one being issues related to passenger handling and safety in the absence of an onboard crew.

The world's first fully autonomous ferry demonstration took place in 2018 (with the crew present onboard to monitor the operation) and was the result of a collaboration between Finferries and Rolls-Royce through the projects Advanced Autonomous Waterborne Applications (AWAA) and Safer Vessel with Autonomous Navigation (SVAN)[5] . The demonstration was made with the car ferry *Falco* which used a combination of "Rolls-Royce Ship Intelligence technologies" to autonomously navigate between Parainen and Nauvo in Finland. The functionalities included object detection, collision avoidance and automatic berthing. It should be noted that the return journey was conducted under remote control from Finferries' land-based remote

[1] DNV ReVolt project website: https://www.dnv.com/technology-innovation/revolt/
[2] Mayflower Autonomous Ship Webpage: https://mas400.com/
[3] Yara Birkeland technical information: https://www.kongsberg.com/no/maritime/support/themes/autonomous-ship-project-key-facts-about-yara-birkeland/
[4] Information about the ASKO cargo ferries: https://www.massterly.com/news-1
[5] https://www.rolls-royce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomous-ferry.aspx

operation centre in Turku about 50 kilometres away. The Remote Control Station (RCS) included interchangeable layers of insights presented on a curved video wall in front of the captain who was allowed to take control of the vessel if necessary[6]. The communication was based on a combination of 4G cellular, Wi-Fi and satellite technologies.

A part of the system that was demonstrated during the SVAN project, referred to as Autocrossing, was sold to Fjord1 and Fosen Namsos Sjø and is now used operationally[7]. As the name indicates, the Autocrossing software leaves the operations near the linkspan (i.e., the bridge linking the ship to shore) to be performed manually but automates the acceleration up to transit speed, the actual transit segment, and the deceleration as it approaches the terminal. The solution aims to cut cost by optimizing the energy consumption subject to vessel load and weather while also keeping to the scheduled departure and arrival times. Note that Rolls Royce Maritime was acquired by Kongsberg Maritime in 2018, hence the latest version of this system is now delivered by Kongsberg Maritime.

Shipping company Bastø Fosen and Kongsberg Maritime have collaborated in the effort to develop the "ferries of the future" for the Horten – Moss service by electrifying the ferries as well adding full autonomy. Additional close-proximity sensor (laser- and radar-based) are added to measure exact distances to infrastructure and obstacles. Also, "ferries of the future" includes a digital integration of existing and new systems, to allow the systems as well as the different ferries to exchange data both for real-time applications and for the purpose of offline operational optimization (e.g., route planning). The anti-collision system for the ferries will be added later, as Kongsberg Maritime develops this system in parallel with the system for the autonomous container vessel Yara Birkeland. The officially stated goals for the Horten – Moss ferry service is to improve the safety and efficiency of the operations by providing enhanced situational awareness and decision-making, and not to remove the crew from the ferry.

On January 17th 2022, what was claimed to be the world's first demonstration of a fully autonomous large vehicle ferry, was performed with Japanese 222m long *Soleil* on its 240km Iyonda Sea run[8,9]. The demonstration was performed as part of the Smart Coastal Ferry project which again is part of The Nippon Foundation's MEGURI2040, an autonomous ship navigation development project. The incorporated technology has primarily been developed by the Mitsubishi Shipbuilding Company and the Shin Nihonkai Ferry Company (owner of the Soleil ferry). The test ferry was equipped with a high-precision sensor image analysis system that is fed by an array of infrared cameras that can detect other ships even in darkness, the *Super Bridge-X* autonomous navigation system that includes collision avoidance functionality, an engine monitoring system, advanced cyber security system and an automated berthing/unberthing system that can turn and reverse the vessel, allowing it to dock at and disembark from the two ports. It should also be noted that MEGURI2040 project Designing the Future of Full Autonomous Ship (DFFAS) is working to develop solutions for the fully autonomous ships of the future and performed a 790km sea trial between Tokyo Bay and Ise Bay demonstrating the latest technology related to autonomous route planning, collision avoidance and remote fleet operation centre (including remote emergency response system) with the containership Suzaku in February 2022. A documentary of the effort has been released[10], and unless otherwise stated, this is the source for all the information about the DFFAS project that is included in this report.

[6] https://breakingwaves.fi/wp-content/uploads/2019/06/SVAN-presentation.pdf
[7] https://www.kongsberg.com/no/maritime/about-us/news-and-media/our-stories/the-pioneer-trail/
[8] https://newatlas.com/marine/smart-coastal-autonomous-ferry/
[9] https://www.nippon-foundation.or.jp/en/news/articles/2022/20220118-66716.html
[10] https://www.nyk.com/english/news/2022/20220425_01.html

Another "world's first" autonomous ship demonstration was announced recently by South Korean shipbuilder Hyundai Heavy Industries (HHI) and its autonomous navigation subsidiary Avikus[11]. The companies claim the cargo ship Prism Courage, an "ultra-large" liquid natural gas tanker operated by SK Shipping, completed the first (partly) autonomous transoceanic journey in a large merchant ship in May 2022[12]. Other efforts to develop autonomous ships for commercial use are led by Samsung Heavy Industries Co[13] and China[14].

1.5 Overview of Related Projects

The following table provides a brief summary of relevant recently completed and ongoing Research and Development projects related to autonomous passenger ferries.

Project Acronym / Duration	**Brief Description with focus on the relevance to this study**
Autosafe	The Knowledge-building Project AutoSafe contributes to realise the approval of lower or no onboard safety manning for small and medium sized autonomous passenger vessels operating near-shore.
ROMAS / 2017 - 2019	The *Remote Operations of Machinery and Automation Systems (*ROMAS) project aims to establish a framework of regulations, rules and verification methods for remote (shore-based) operations of ship machinery and automation systems. The idea behind the ROMAS project is to move the Engine Control Room (ECR) from the ship to a shore-based Engine Control Center (ECC), where competent engineers can operate the propulsion and auxiliary machinery systems on a fleet of vessels.
FLEKSFerge	The *Fleksibel, Lavbemannet autonom, Energieffektiv, Kapasitetsøkende og Smart Fergekonsept* (FLEKSFerge) project looks into how a flexible, (partly) autonomous, energy efficient and smart ferry concept can increase the ferry capacity. Partners are Trøndelag Fylkeskommune, Ocean Autonomy Cluster, SINTEF Ocean.
RAPP project / 2019 - 2023	The *Realization of an Autonomous and Predictive Passenger* (RAPP) ferry project has as a main goal to develop and test a passenger ferry equipped for autonomous operation to replace the "Sundbåt" ferry in Kristiansund. The project is managed by Maritime Robotics.
Smartare Transport – Møre og Romsdal	Project funded by the Norwegian Ministry of Transport to investigate the feasibility of using autonomous passenger ferries for transportation of people in cities. A collaboration between SINTEF, NTNU, Ålesund and Kristiansund municipalities.
TrAM / 2018 - 2023	*Transport: Advanced and Modular* (TrAM) is a H2020 project that aims to develop a zero-emission fast passenger vessel through advanced modular production.

[11] https://safety4sea.com/hhi-navigates-fully-autonomous-passenger-boat/
[12] https://www.offshore-energy.biz/hyundai-heavy-conducts-worlds-first-transoceanic-voyage-of-lng-carrier-on-autonomous-navigation/
[13] Samsung Autonomous Ship (SAS): https://www.kedglobal.com/shipping_shipbuilding/newsView/ked202110170002
[14] https://maritime-executive.com/article/china-reports-first-autonomous-containership-entered-service

MEGURI2040 / 2020 – 2025(?)	The MEGURI2040 program is a Nippon Foundation sponsored Japanese effort to implement fully autonomous ships. The effort is split into 5 different consortia[15]: 1) Designing the Future of Full Autonomous Shipping (DFFAS) which provides the grand design with help from diverse specialists. Includes demonstration tests with land-based Fleet Operation Center and the coastal container ship Suzaku. 2) Verification testing of fully autonomous technologies using coastal container vessels and car ferries. Includes automated harbour navigation, automated berthing/un-berthing, and mooring support using drones. Demonstrations involve container ship Mikage and the carferry Sunflower Shiretoko. 3) Development of fully autonomous amphibious driving technology: Yanba Smart Mobility. 4) Fully autonomous navigation at Sarushima, Yokosuka 5) Smart ferry development with demonstration testing onboard the Soleil ferry.
Autoferry (Autosea) /	The *autonomous all-electric passenger ferries for urban water transport* (Autoferry) project aims to develop groundbreaking new concepts and methods which will enable small autonomous ferries for urban water transportation. The project is a successor of the Autosea project and NTNU is the project owner.
Autosit / 2019 - 2023	The *Autonomous ships, intentions and situational awareness* (Autosit) project will deliver algorithms for situational awareness that enable ASV's to guess and predict the intentions of other vessels. NTNU leads the project and DNV GL, KONGSBERG and Maritime Robotics are partners.

[15] https://www.nippon-foundation.or.jp/en/what/projects/meguri2040

2 Overview of Current Ferry Operations

The ferry service Levanger – Ytterøya is operated by Torghatten AS. The company owns 58 ferries that services 40 different ferry connections in Norway.

2.1 The Route – Distance, Schedule and Environment

The Levanger – Ytterøya ferry service covers a total distance of about 9 km and is serviced 12 times a day during weekdays and 10 times per day on the weekend. The timetable of the ferry today is determined by the tender owner but is made to fit the crew rest requirements. The ferry service can be divided into 3 operational phases that each involve a different operating environment - at port, near port and coastal sailing - as illustrated in Figure 2 and described in the following subsections.

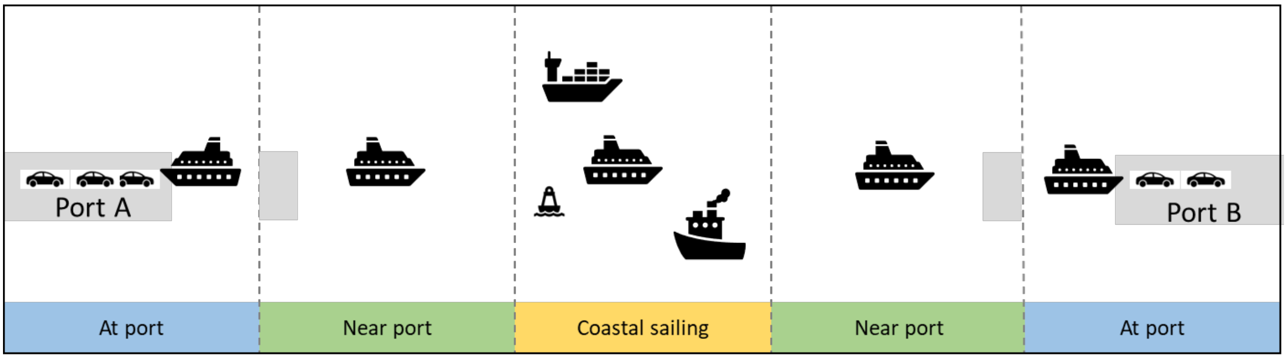


Figure 2: Operational phases for Levanger – Ytterøy ferry service

2.1.1 At Port

We define the "at port" operational phase as the phase where the ship is stationary at a port. Typical tasks performed in this phase includes mooring of the vessel and handling of the passengers and cars. To achieve a reliable service the time spent at port is a critical parameter, as the ferry should arrive and depart in accordance with the time-schedule. The present ferry, M/F Ytterøy, is particularly sensitive to precise loading procedures, necessitating a thoughtful arrangement of vehicles to achieve optimal trim/list. It is preferable to sort the vehicles in an appropriate order well in advance to ensure the best possible distribution and balance. For this ferry, as well as the majority of ferries, it is advantageous to ensure efficient loading (i.e., a fast loading process) in order to allocate more time to transit at a lower speed, thus achieving fuel savings.

2.1.2 Near Port

We define the "near port" as the phase where a ship sails from the fairway area to a dock where it stops and vice versa (un-docking). Docking can be a challenging task as high precision is required and the ferry, like other large vessels, react slowly to changes in propulsion/thrust. The harbour area will also often involve consideration of other traffic and shallow areas which makes good situational awareness critical. The M/F Ytterøy ferry is outfitted with 2 azimuth propulsion thrusters that should provide the ferry with ample manoeuvrability at slow speeds. However, the approach into Levanger involves navigating a slightly narrow channel and potentially significant current due to the mouth of the river. Currently, the Captain conducts a mental risk analysis prior to arrival or departure.

2.1.3 Coastal Sailing

We define "coastal sailing" as the phase where the ship operates in a congested traffic area or confined waters. In this phase, the crew can typically rely on good communication connectivity with shore if required (something that will be important if remote operation is considered), and reliable GNSS coverage for higher accuracy navigation. But there will typically be other traffic nearby and few opportunities for the crew to let their guard down. The crew may have to make quick decisions based on new obstacles/vessels that appear or based on environmental factors such as weather and currents and may not always be able to select the most efficient route given all the different constraints.

2.2 Capability and Performance of the Existing Ferry Service

The ferry connection is currently serviced by M/F Ytterøy; a small car ferry (38 cars, 150 people) with less regularity and complexity than the bigger ferries serving the larger ferry connections. The ferry is too small with respect to current capacity needs, meaning that there are cars left behind at peak times during the week. Furthermore, the ferry runs on MGO (Marine GasOil) so major modifications (e.g., onshore charging infrastructure) must take place to meet future expectations of "greener" operations.

2.3 Crew and their Tasks and Responsibilities

To reduce the number of onboard crew required to operate the ferry, it is critical to ensure that all the tasks that are currently performed by the crew can still be performed in a satisfactory manner (either by the automation or the remaining crew - onboard or at the ROC). We have identified the following main tasks that the crew performs today:

1. **Navigation and control**: Navigation involves the process of safely manoeuvring a vessel from one location to another, including docking at the destination port. Typically conducted from the vessel's bridge, navigation requires careful observation of the surroundings to maintain a high level of situational awareness. This awareness is crucial for route planning and adjustments based on the current conditions. Controlling the vessel entails applying the necessary control inputs, such as managing thrust and course, to keep the vessel on the desired route. Currently, onboard the M/F Ytterøy, navigation and control tasks are supported by a radar and chartplotter only.
2. **Engine room operation**: The chief engineer is responsible for monitoring, maintaining, and repairing the propulsion and supporting systems as well as tending to key systems such as ballast and bilge.
3. **Communication:** The crew perform different types of communication onboard the ship. This includes ship-ship communication (e.g., to avoid possible conflicts), and ship-shore communication (e.g., with the port authority). In the future, a lot more data will need to be communicated for a ship to operate safely unmanned.
4. **Mooring**: When the ship has reached its destination, it needs to be moored before it can start off-loading the passengers and vehicles. Upon arriving, the crew of the M/F Ytterøy ferry lowers the gate/flap onto the linkspan and the "slisse" on the car bridge is locked into place on the ferry. The stern of the ferry can move a bit. Mooring lines are not used for a short turnaround, but for longer duration stays (30 minutes or more) or in case the captain struggle to stay in position with the use of a thruster, a mooring line ("trosse") may be used.
5. **Car and Passenger handling:** The crew is responsible for loading and offloading passengers and vehicles (cars, trucks, motorcycles) once the ferry is safely moored at the port. Furthermore, the crew is responsible for securing the cars and cargo enroute and to oversee the safety of the passengers the whole time they are onboard the vessel and in case of an evacuation. For M/F Ytterøy the passenger handling does not require a lot of crew involvement during normal operations, beyond keeping track of the exact count. The crew have the possibility to lash down vehicles, but it is typically not necessary except for the occasional motorcycle.

The current ferry has 4 crew shifts, each with 3 crewmembers, but a fourth "Dagmann" is optionally used to assist the crew as needed. The duties and responsibilities of each crewmember is summarized in Table 1.

Crew member	Phase	Description of Duties and responsibilities
Captain	At port*	• Mainly observing that the ship is properly positioned and that the correct amount of thrust is applied. • Monitor the loading and offloading of vehicles and passengers and in that way be of assistance (if needed) to the crewmember on deck. • Receive the "all clear" from the Chief Engineer via UHF. • Start the engines and point the thrusters with the correct angle relative to the quay. • Tell the Able Seaman "TA FORTØYNING" to raise the loading ramp and remove any mooring equipment. • Check and prepare navigational equipment, insert route into chartplotter and switch AIS to "Underway" and log into the "ship-log" system. • Turn the steering position around and also turn the chair and the lanterns. • Check the fire-control-system.
	Leaving port	• Maneuver away from the quay and confirm that the Autopilot is engaged. • As long as the ship is in motion, controlling the ship from the bridge should be the only task performed (per company procedure handbook).
	Coastal sailing	• As long as the ship is in motion, controlling the ship from the bridge should be the only task performed (per company procedure handbook). • Follow the normal route, adapt the speed to the ferry schedule, communicate intent and deviations, actively consult the radar and use lookout per the regulations.
	Arriving port	• Prepare aborted arrival scenario. • Select appropriate radar VRM (Variable Range Marker). • Take manual control 0.25 NM from the quay. • Turn the rear engine around and manage speeds according to the recommended speed-schedule. • Apply thrust with both engines against the quay.
Chief engineer	At port*	• Prior to startup of engine, perform checks of access to and the overall state of the machine rooms (check lubricants, cooling fluids and the fuel level). Monitor UHF. • Start the engines and pumps (cooling fluids and heat exchanger) and fans by following the recommended sequence. Turn off shore power. • Confirm the number of passengers and receive the "all clear" from the deck (can also be performed by the Captain). • Notify to crew on deck that the ship is departing (can also be performed by the Captain).
	Leaving port	• Monitor UHF and contribute actively as a member of the bridge crew.
	Coastal sailing	• Monitor UHF and Contribute actively as a member of the bridge crew. • One time per roundtrip a machine room check is performed (check for deviating sounds, scents, sign of leaks, log pressure and temperatures).

	Arriving port	• Engine shutdown: Turn on shore power and stop pumps, fans and engines per the procedure.
Able seaman	At port*	• Monitor UHF and report any safety concerns. • Perform deck inspection (check lanterns, sign of leaks or damages, snow/ice, closed position of key doors/hatches). • Verify that the windlass control is in the "remote" position. • Upon receiving "TA FORTØYNING" command, raise the loading ramp and remove any mooring equipment, and confirm to bridge. • Notify the bridge that the ferry is ready for boarding/loading. • Plan the boarding/loading with the captain and consider de-icing/securing of heavy vehicles. • Guide the passengers along the intended corridors and assist physically impaired persons as needed. • Register number of passengers (consider the number of available lifewests for children) and report to the bridge. • Consider placement of vehicles with dangerous cargo (verify cargo with the Ship log and ensure driver remains in vehicle) and placement of emergency vehicles.
	Leaving port	• Confirm the ship is leaving port. • Verify the operating area is empty, start hydraulic pump, lower the gate and raise the trapdoor and loading ramp.
	Coastal sailing	• Serve as lookout as needed.
	Arriving port	• Lower the loading ramp to the right height, lower the trapdoor and raise the gate.
Dagmann (Optional)		Relieves the crew by taking on some of their tasks. Particularly the lone navigator (Captain) benefit from some assistance with other tasks. The current "dagmann" is on temporary leave and has not been replaced.

Table 1: Summary of MS Ytterøy Crew Duties and Responsibilities

*Some additional tasks and equipment checks applies to the first trip of the day and when a full shutdown is required.

2.4 Emergency Handling

To make educated decisions regarding the removal of crew from the ferry, it is important to understand the associated impact to the emergency handling. The current emergency handling tasks that involve the crew are summarized in Table 2.

Passenger/vehicle handling task	Detailed task description
Emergency response: Evacuation	CAPTAIN: Lead the operation from the bridge. Inform the passengers (brief instructions such as where to go and what to wear/bring). Order the evacuation. ABLE SEAMAN / CHIEF ENGINEER: Send emergency call notification about evacuation. Man the evacuation stations and launch the liferaft. Order evacuation of vessel. Assist persons with physical disabilities as needed. Verify number of evacuated persons against the passenger count and perform a search for any missing passengers.

Emergency response: Man overboard (MOB)	CAPTAIN: Lead the operation from the bridge. Inform the passengers (brief instructions such as where to go and what to wear/bring). Press MOB button on the chartplotter, consider the danger presented by the propeller and stop the ferry or return to the person in the water. ABLE SEAMAN / CHIEF ENGINEER: Serve as Lookout, keep the captain informed and send emergency call. Follow procedure to launch and man a MOB vessel. Bring overboard person into MOB vessel and start to perform life saving/support.
Emergency Response: Shipboard fire	CAPTAIN: Lead the operation from the bridge. Inform the passengers (brief instructions such as where to go and what to wear/bring). Start the fire pumps and stop fans as needed. Order activation of fire extinguishing system. ABLE SEAMAN / CHIEF ENGINEER: Activate fire extinguishing systems (along with supporting actions) upon command, keep the captain informed, search for missing persons and provide first aid.
Emergency response: Loss of propulsion / loss of control	CAPTAIN: Lead the operation from the bridge. Inform the passengers (brief instructions such as where to go and what to wear/bring). ABLE SEAMAN / CHIEF ENGINEER: Consider anchoring, use of life jackets and evacuation. Alert Joint Rescue Coordination Centres.
Emergency response: Grounding / Collision / Flooding	CAPTAIN: Inform the passengers (brief instructions such as where to go and what to wear/bring). Consider need for beaching or evacuation. ABLE SEAMAN / CHIEF ENGINEER: Evaluate the damages, the ability to stay afloat and maintain stability. Initiate bailing and (temporary) repairs of relevant. Send emergency call. Assess passenger injuries. Prepare evacuation but stay onboard if sufficient ability to stay afloat and stable. Consider anchoring or beaching the ferry and also consider SOPEP and closing off fuels.

Table 2: Overview of Emergency Handling onboard MS Ytterøy

3 Technical Feasibility of Unmanned Operation

The overall objective with the technical feasibility study is to establish an understanding of the technological state-of-the-art and remaining gaps to realize an increased level of autonomy that allows reduced crew workload (related to operating the ship) and/or reduced manning. This can be achieved either by fully automating certain tasks and functions or by moving some tasks and functions to an ROC. The key drivers for this development are ***increased safety***, ***reduced long-term operating costs*** and ***increased availability*** [1].

- Increased safety: An increased level of autonomy can help to reduce the number of maritime accidents by eliminating sources of human errors. While most accidents typically have more than one cause, human errors are a contributing factor to well over 60%. If organizational aspects are considered the number is higher, by some estimated to over 90% [2].
- Reduced long-term operating costs: The introduction of autonomy can enable a reduced crew size and lead to lower long-term operating costs (even though the technology investments up-front will be high). Furthermore, an increased level of autonomy could be exploited to optimize the route-planning from a fuel-burn as well as use of machinery perspective while honouring the hard constraint of keeping to the timetable.
- Increased service availability: Ferry operators see a potential to expand the operating hours for the ferry service without a tremendous increase in crew cost. Options include to keep limited crew onboard to maintain the required safety level (i.e., for cases where human intervention is required for the foreseeable future), but an increased level of autonomy may allow crew resting time while sailing. Additionally (or alternatively), some of the crew tasks can be moved to a remote operation centre where one operator may be responsible for multiple vessels. Both these options can support an optimized sailing schedule or possibly enable on-demand service. On-demand service would contribute to make (partly-) autonomous ferries a realistic alternative to bridges.

In the next subsections, we review the feasibility of performing each of the main crew tasks from Section 2.3 in an unmanned fashion, either through automated/autonomous functions supported by remote monitoring by a human operator or fully autonomously onboard the vessel. All the operational phases defined in Section 2.1 (at port, near port and coastal sailing) will be considered.

For each task we have defined different acceptance criteria to evaluate whether the particular task is technically feasible or not. It should be noted that a solution is not considered as "Technically feasible" unless it is probable that the relevant available technologies are sufficiently robust and has seen some operational use. Also note that regulatory considerations will be addressed in more detail in Chapter 4.

3.1 The role of a Remote Operation Centre (ROC)

The concept of remote navigation of a vessel only makes sense if the ship operates with a high level of autonomy. If remotely navigating a ferry requires the remote operator to constantly monitor screens and information from ship systems and provide inputs to the onboard systems, little is gained. In fact, there will be large costs involved with the development and setting-up of the onshore remote operation centre and the willingness to make these investments will depend on the ability to justify reduced future operating costs. The ability of one onshore operator that can remotely monitor several vessels that navigates (mostly) autonomously may prove cost effective.

For the remote operator to operate in a safe manner, there should be requirements and procedures available that specify the level of monitoring as well as the sources of information (e.g., sensor data) required during the different phases of operation. How the data should be presented to the operator for acceptable situational awareness will also be important to define. To further reduce risk, the remote operator could be alerted by digital monitoring systems if operating anomalies are detected, to prevent unforeseen situations from escalating into incidents/accidents. The specific requirements that will apply to the remote monitoring will be a function of the safety record of the autonomous onboard systems. Once operational data on the reliability and robustness of such systems are available, it can be considered if the system is capable and mature enough to operate under less stringent monitoring, and ultimately, if the remote operator can be completely removed from the loop. But as most such systems are in their infancy, remote monitoring is likely the only way to achieve an acceptable risk analysis for the near term.

In the recent sea trial of the DFFAS project (Designing the Future of Full Autonomous Ship), which is part of the MEGURI2040 initiative, the Fleet Operation Centre included an *Integrated display block* as well as an *Emergency response block (refer to Figure 3).* During normal operations, the onshore captain and the chief engineer will monitor the operation from the integrated display block. In case of an onboard system or telecommunication malfunction, the ship can be piloted manually from the emergency response block that provides a 360-degree view of the ship surroundings.

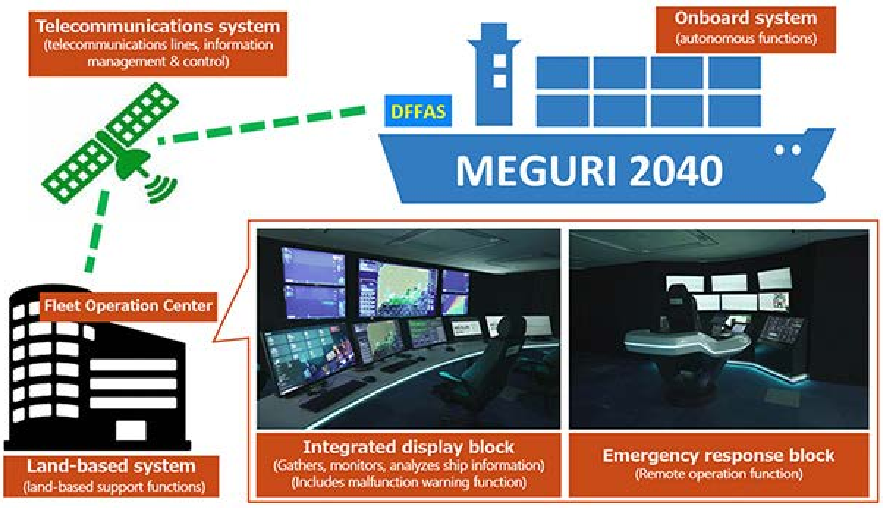


Figure 3: Illustration of MEGURI2040 DFFAS Key System Components[16]

Care must be taken to design such a manual backup solution to be available in the event of a critical fault in any of the systems that it intends to provide a backup for. The details for how this is solved for the DFFAS solution is not clear from the available project information. However, to clarify the responsibilities of the onshore personnel, the MEGURI2040 project defined 4 different ship navigation statuses based on the condition of all the critical ship systems[17]:

- ***Normal*** – The status is shown in green colour which means that the DFFAS system is in control and that all key systems operate normally.
- ***Active monitoring*** – The status is shown in yellow colour to indicate caution which means that the DFFAS system is in control but that the onshore captain is required to monitor the ship closely.
- ***Remote fallback*** – The status is shown in red colour to indicate danger which means that the onshore captain needs to operate the systems and maintain navigation from the emergency response block.
- ***Independent fallback*** – The status is shown in purple colour and indicates that an onboard captain is operating the systems and maintaining navigation.

[16] https://www.furuno.co.jp/en/news/general/general_category.html?itemid=1127&dispmid=961
[17] NYK Line documentary following the DFFAS project: https://youtu.be/9-X8TZvLrAY

Based on the discussion with various partners as part of the work with this report, it is likely that some type of ship navigation status will be required for ROC developed for use in Norway.

The detailed architecture and requirements that should apply to ROC is beyond the scope of this report, but the needed connectivity/communication with the unmanned ship is discussed in a bit more detail in Section 3.4 and some regulatory aspects are further discussed in section 4.5.4.

3.2 Unmanned Navigation and Control

The major challenge the human or digital navigator faces is to maintain an adequate situational awareness that takes all relevant information about obstacles, other vessels, weather, winds, currents and vessel performance into account to select the best path forward. By removing the crew from the vessel, it is critical that onboard sensors and associated algorithms are able to maintain the same level of perception and situational awareness for the new decision-making entity, i.e., either the remote human operator or the autonomous navigation algorithms that generate the inputs to the propulsion and steering systems onboard the fully autonomous vessel. As discussed in the previous section, it is likely that any system that is developed for fully autonomous navigation will require an operational period with crew onboard to gather the necessary operational experience and to prove that the solution is sufficiently safe and robust. This test phase should reveal any unforeseen consequences related to things like sensor uncertainties, calibration of sensors and various failure cases.

For unmanned operation, or operation without a chief engineer or navigator, it is expected that redundant solutions will be required to reach the needed availabilities and robustness of critical systems. If portions of the voyage have poor GNSS coverage, the onboard navigation algorithms may be able to "coast" using e.g., inertial and visual sensing only for some maximum-allowed duration. Furthermore, e.g., inertial-visual sensing can be used to safeguard against faulty or tampered with GNSS signals. 5G has recently emerged as another possible input to fuse with the GNSS data for increased positioning accuracy.

The following aspects should be noted regarding state-of-art ships and ongoing projects on autonomous ships:

- The navigation and autonomous operations of YARA Birkeland will be supported by a number of proximity sensors, including a radar, a light detection and ranging (LIDAR) device, an automatic identification system (AIS), a camera system and an infrared (IR) camera[18].
- The solution developed for the MEGURI2040 DFFAS project bases the autonomous navigation on cameras and 3 types of radars capturing 3 different frequency bands, including mm-wave radar to detect small targets. The collision detection and avoidance functionality is provided by the Advanced Routing Simulation and Planning (ARS) unit that bases the decision-making on a *Preference model* that captures the ship's captains navigational preferences in an attempt to generate the most appropriate manoeuvre for each situation based on extensive data of past voyages[19].

In the next subsections we will discuss the feasibility of unmanned navigation and control during each of the operational phases defined in Figure 2; near port, coastal and at port. High level acceptance criteria that are relevant for unmanned navigation and control of the ferry during these phases are summarized in **Table 3**.

[18] https://www.kongsberg.com/no/maritime/support/themes/autonomous-ship-project-key-facts-about-yara-birkeland/
[19] NYK Line documentary following the DFFAS project: https://youtu.be/9-X8TZvLrAY

#	Operational phase(s)	Criteria for feasibility of unmanned navigation and control
Nav1	At port	It is possible to generate a conflict free planned path (based on current charts and other available inputs) for the upcoming crossing that considers the performance envelope of the autonomous ship as well as the comfort of the passengers and it is also possible to share the route with other authorized stakeholders if needed.
Nav2	Near port, Coastal sailing	The vessel can maintain the planned path autonomously without human assistance.
Nav3	Near port, Coastal sailing	The vessel can detect all obstacles in its path and can plan and execute avoidance maneuvers with the expected (like manned operation) level of comfort, safety and robustness under all foreseeable operating conditions, but the vessel is allowed to fall back on human (remote) assistance if the COLREGs are ambiguous and the system generates an alarm to the (remote) captain/navigator.
Nav4	Near port	The vessel can dock and un-dock without human assistance and without causing any of the following: a) Material damage (to vessel or port infrastructure). b) Discomfort or injuries to persons onboard or in the vicinity of the vessel.

Table 3: High-level criteria for unmanned navigation and control feasibility

3.2.1 At Port

At the port, the captain or responsible (human or electronic) navigator is responsible for planning the crossing. This task can vary in complexity depending on the specific details of the crossing, but in either case, this work can be replaced by a state-of-the-art route planner or be performed by a remote Captain assuming acceptable situational awareness. Such systems already exist and are expected to be tested in fully autonomous operating conditions in the near term (e.g., Kongsberg system for the Yara Birkeland and Asko drones). For the Levanger – Ytterøy ferry service the onboard captain typically applies some thrust while the ferry is docked to keep the ferry properly aligned. This task can be replaced with help of an autonomous mooring system as will be discussed in later sections of the document.

3.2.2 Near Port

Autonomous docking has been demonstrated several times over the past 5 years and the first solutions are entering the market. Notable solutions include:

- The Wärtsilä SmartDock system that was first tested onboard the ferry Folgefonn at Stord Harbor in Norway in April 2018. In 2019, the SmartDock solution became the first commercially available auto-docking solution on the market. It is now offered as an option in the Wärtsilä SmartMove Suite; a solution suited for retrofitting existing vessels. It has been installed on the 194-m self-unloading bulk freighter MV American Courage (owned by American Steamship Company) since March 2020.
- At the end of 2018, Rolls Royce demonstrated their automatic berthing system as part of the previously mentioned demonstration with Finferries (refer to Section 1.4).
- Kongsberg now offers "all-speed" autopilot with an automatic docking function.[20]

[20] https://www.kongsberg.com/maritime/solutions/pax/ferry/

- Other commercial solutions are in various stages of development, including the Australian system MAID (Marine Autonomous Intelligent Docking)[21] and Yanmar's Auto-Docking System[22].

Note that none of the systems mentioned above have been developed for use onboard an unmanned ship. Without the fallback of an onboard crew taking over in case of any difficulties (for instance caused by weather exceeding the design criteria for the autonomous docking system), such a system may need to be made more robust and potentially require a redundant solution and/or additional sensors to support remote operations. Indeed, some partners that were interviewed as part of the work with this study indicated that the currently available autonomous docking systems are based on Dynamic Positioning (DP) systems that were never optimized for the type of scenarios the system faces during docking in challenging conditions. While the exact navigational performance requirements for autonomous docking is outside the scope of this study, some guidance can be found in [1]. For this study it is assumed that the recently developed systems will have acceptable performance for the operating conditions that the system is approved for. If the ship is exposed to conditions outside the approved operating conditions for the system, the ship will have to be manned or the operations will have to be temporarily halted.

In summary, achieving autonomous docking for the M/F Ytterøy ferry is technically feasible under normal operating conditions. This can be accomplished by installing a suitable autonomous docking system on the current ferry or by replacing the ferry with a new one equipped with a state-of-the-art autonomous docking system. However, it is essential to conduct a test phase to validate the system's capability to handle various operating conditions, including adverse weather, strong winds, and currents. If the autonomous docking system encounters challenges in delivering acceptable performance during severe weather conditions, an alternative approach could be to limit the use of autonomous navigation and control to normal operating conditions only. In such cases, autonomous operations can be restricted to favorable weather conditions. Additionally, remote operation could be considered as an option during degraded conditions, provided that robust and reliable communication links are in place to ensure safe and effective control of the ferry.

3.2.3 The Coastal Sailing Phase

Currently, there are no known instances of completely autonomous navigation of a ship in regular operation. Therefore, a human operator has to be in the loop (either onboard or remote) for the near-term to handle unforeseen or unplanned events. Most modern ships utilize Dynamic Positioning (DP) systems that have gradually replaced traditional helmsmen in applying ship control inputs to keep the ship on the planned path/route. Route planning, typically conducted before departure, involves the determination of waypoints that consider environmental factors such as weather conditions, aiming to optimize fuel consumption. To this end, computer-aided voyage optimization that takes the ship response performance into account is becoming increasingly popular.

Presently, sophisticated AI-based systems that aim to handle autonomous near real-time path planning based on the current environmental conditions, ship capability and crew expectations are being developed. Up until now, the lack of robust collision avoidance in compliance with COLREG has prevented the removal of navigators from the ship. The first systems that includes collision detection and avoidance are currently in the early phase of testing under realistic conditions. Notable efforts include:

- The first fully autonomous ferry run was performed by Rolls Royce Maritime and Finferries back in 2018 and included both collision detection and avoidance as well as autonomous docking[23].

[21] https://maidsystems.com/

[22] https://www.yanmar.com/global/about/technology/vision2/auto_navigation_docking_system/

[23] https://www.tu.no/artikler/verdens-forste-helt-autonome-fergeseilas-gjennomfort-teknologien-er-100-prosent-klar/452610

- During the recent 5.5 hours sea trial of the Soleil Autonomous ship (refer to section 1.4), 10 other vessels were successfully avoided enroute using a collision detection system based on radar, automatic identification and target image analysis via infrared cameras[24].

With the emergence of early-phase autonomous navigation systems, the primary responsibility of the human operator will shift to managing uncommon and unforeseen situations that fall outside the capabilities of the system. Therefore, the onboard autonomous navigation systems should be designed to notify the human supervisor (whether onboard or remote) if the situation becomes too complex for the algorithms to handle. Adopting this design philosophy will not only relieve the future remote operator but also allow them to monitor multiple ships simultaneously, which is crucial for optimizing the business case.

The current level of automation on M/F Ytterøy is limited. The crossing is relatively short and has minimal other traffic, and Torghatten suggests that implementing advanced route optimization for this route might not yield significant benefits. However, they highlight a few possibilities for improvement. By adjusting the heading by a few degrees, they can enhance the comfort of the transit for passengers and reduce fuel consumption. Additionally, they can consider sailing closer to the shore to take advantage of more favorable currents.

3.2.4 Summary of Unmanned Navigation Feasibility for Levanger – Ytterøy

By utilizing state-of-the-art voyage planning and autopilot systems, it is realistic to envision the ferry navigating autonomously with the assistance of a remote operator. The remote operator can make real-time updates to the planned route if the onboard systems encounter complex situations beyond their autonomous capabilities. However, this assumes that the onboard systems are demonstrated operationally to have sufficiently low critical failure rates as well as sufficiently robust communication between the onboard systems and the onshore control center. In practice, this means that an onboard navigator will likely be necessary even after the installation of autonomous navigation systems. They may be required for an extended period, especially during challenging operational conditions like adverse weather or unusual traffic. The maturity level of autonomous docking surpasses that of a comprehensive autonomous navigation solution capable of handling all possible transit scenarios.

The assessment indicates that the Levanger – Ytterøy ferry service is a relatively straightforward crossing in sheltered waters, typically encountering minimal traffic. Each autonomous ferry service will likely need individual approval based on specific operating conditions and risk profiles. For instance, small open ferries with few passengers and shorter distances present lower risk profiles compared to M/F Ytterøy, making it easier to gain operational acceptance. Additionally, it is likely that crew members will be required to remain onboard for an initial period to accumulate operational experience.

The technical feasibility assessment, summarized in **Figure 4** utilizes a color-coded system. A red light indicates that unmanned operation is currently unfeasible, a yellow light indicates that unmanned operation is expected to be feasible in the near term (within the next five years) with targeted technology development, a green light indicates that the operation is feasible using today's available technology, and a grey light indicates that the option is not applicable to the given context.

[24] https://bachmanngroup.com/successful-trial-of-autonomous-ship

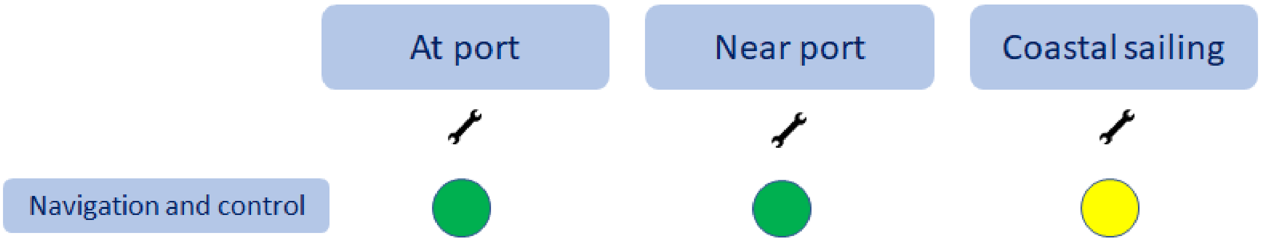


Figure 4: Technical feasibility assessment of unmanned navigation and control of the Levanger - Ytterøy ferry service.

3.3 Unmanned Engine Room

A key uncertainty for unmanned operation is the availability and the critical failure rates of the different components involved in actuating the ship in accordance with the commands from the bridge. Frequent failures will prevent effective and safe unmanned operation of the vessel. A potential solution to this issue could involve installing redundant components or systems, similar to the approach taken in other safety-critical transportation modes like commercial aircraft. The level of redundancy required should be determined through a thorough risk analysis. Additionally, the risk analysis would likely highlight the importance of implementing condition monitoring and fault detection mechanisms to minimize the occurrence of failures and reduce repair time. The DNV Guideline DNVGL-CG-0264 [2] for Autonomous and Remotely operated ship from 2018 provides some guidance on this matter. Particularly the Guideline specifies:

Any single failure in control, safety or automation systems should not prevent the vessel from entering and maintaining safe state (MRC). Systems and components should be arranged with redundancy, separation and/or independency as needed to ensure this principle.

The following aspects should be noted regarding state-of-art ships and ongoing projects on autonomous ships:

- Onboard Yara Birkeland the batteries are split into four separate battery rooms, where just one of these are capable of providing the power to return to port in an emergency[25]. Furthermore, the ship includes 2 Azimuth pods and 2 Tunnel thrusters[26], most likely to achieve the needed availability of these systems.
- The MEGURI2040 DFFAS project introduced a *Remote mechanical function* including an anomaly prediction system which enable a remote chief engineer to monitor and make decisions about the condition of the onboard machinery from the Fleet Operation Center.
- Several ships already operate with periodically unmanned engine rooms. For an Unattended Machinery Spaces (UMS) ship the crew typically work during normal/daylight hours, then they will rotate to be available on-demand (usually triggered by an alarm) during periods when the engine room is unmanned and under UMS operation.

One advantage of running a coastal ferry service over an ocean-crossing voyage, is the fact that the vessel remains reasonably close to shore. In the case of the Levanger – Ytterøy ferry, the vessel is never too far away from one of its home ports. However, the vessel carries passengers, meaning that the risk is high if the ship loses a critical system such as propulsion. In line with the expected need to perform digital condition

[25] https://www.rivieramm.com/opinion/opinion/breathing-life-into-iyara-birkelandi-54833
[26] https://www.kongsberg.com/no/maritime/support/themes/autonomous-ship-project-key-facts-about-yara-birkeland/

monitoring and fault detection of critical components, some type of Health Monitoring System will likely be required for unmanned operations. Relevant systems that are expected to be critical and should be monitored includes the engine/machinery, the fuel tanks (or battery system for electric vessels), the bilge system, the ballast system, the rudder, shafting and propeller system, windlass and mooring systems, lifesaving equipment, fire detection and fighting system. Suitable sensor types can support monitoring of temperature, pressure, vibrations, electrical current and (rotation) speeds.

Torghatten acknowledges the Ytterøy ferry's track record of reliable operation, considering its relatively recent construction in 2015. However, the ferry has only one engine in each end and is not built with redundance in mind. The ferry does not have any predictive maintenance systems but uses a maintenance tracking system called Premaster that e.g., generates an alarm when parts are due for replacement and that also requires manual signoff. Unplanned faults/maintenance is also reported in the maintenance tracking system.

High level acceptance criteria that are relevant for unmanned engine room operation are summarized in Table 4.

#	Operational phase(s)	Criteria for feasibility of unmanned engine room
Eng1	All	There should not be systems onboard that require frequent physical verifications or actions.
Eng2	All	The ferry should be able to operate in between defined maintenance intervals without downtime or need for unplanned repair/maintenance.
Eng3	All	A ship health monitoring system should be available and perform a predictive maintenance analysis for all critical systems and generate alarms and alerts as appropriate.
Eng4	All	System redundancy as required by an unmanned safety analysis should be installed.
Eng5	All	For all phases of operation, the ship should revert to a clearly defined Minimum Risk Condition (MRC) in the event of loss of propulsion or minimum maneuverability.

Table 4: High-level criteria for the feasibility of unmanned engine room

3.3.1 At Port

A critical system failure is not typically a safety issue if it occurs while the ferry is located at the port, with a critical failure of the bilge system as a notable exception. The type of operations that take place in port, is very dependent on the particular ferry service, the duration of the transit and the time spent in port. For M/F Ytterøy, there is currently an onboard chief engineer that performs the more continuous maintenance such as replacement of oil, filters and hydraulic fluids. The stay in port is typically very short and not suited for doing any major maintenance work that has to be performed at the dock. Valve adjustments are performed by the chief engineer, but external companies are used for larger maintenance work. If needed, the ferry will be taken out of service a few days and the backup ferry will be used.

3.3.2 Near Port

For unmanned docking to be an option, the critical systems that are involved must have the necessary reliability and/or redundancy. For M/F Ytterøy there is no automated docking solutions available currently. The engine control room is on the bridge, but due to the lack of fully redundant propulsion systems, the chief engineer is required to man the engine room during arrivals and departures. This ferry is sensitive to cargo handling and the placement of trailer-trucks is important. For the same reason, it is required that one thruster is rotated to point in the opposite direction when approaching port.

3.3.3 The Coastal Sailing Phase

In theory, by having a skilled machinist readily available at the next port, any detected failure can be repaired quickly but with a risk of the ferry incurring delays. Also, if a machinist must be dedicated to support the ferry operation anyhow, he might as well be on board the vessel and perform preventive maintenance. It is expected that all the autonomous ships that are currently in development will include some type of Ship Health Monitoring System that performs predictive maintenance assessments. Such a system will help to reduce the risk of unmanned navigation to an acceptable level and will also help to prioritize the (preventive) maintenance work for the ferry. After such a system has proven sufficiently reliable, operation without a machinist onboard at least for some periods can be considered. The recent trial voyage of Autonomous Ship Soleil successfully tested new systems that detect fuel leaks and remotely monitor the ship's engines and electric motors.

An alternative option is to consider implementing an artificial machinist, such as a robot, capable of handling tasks that are frequently attended to by the onboard mechanic. However, the development of such a system is not expected to be cost effective compared to redesigning the engine room systems to support more unmanned operation and at the same time transition to electric propulsion. Up until today, the manufacturers of these systems have not been challenged to produce systems that minimizes the frequency of repair and maintenance. If ship-owners and operators accept to pay a bit more for the systems to optimize them in this direction, much can be gained.

For M/F Ytterøy, the chief engineer performs various maintenance activities throughout the day, but Torghatten assesses that the chief engineers "are not extremely busy" but also has other duties (not related to the engine room). Torghatten reports that they have discussed the use of a "matmot" a combination of "matros" (Able seaman) and motor man for some of their ferry operations.

3.3.4 Summary of Unmanned Engine Room Feasibility for Levanger – Ytterøy

An unmanned engine room for the Levanger – Ytterøy ferry service would require a new ferry where the engine room systems were designed with unmanned operation in mind (including required redundance) and where a ship health monitoring system would monitor critical systems and plan predictive maintenance activities that could be performed at regularly scheduled intervals. A key requirement would be that the new systems should need considerably less maintenance than the systems in use today.

It is considered technically feasible to purposefully design and construct a ferry specifically for the Levanger – Ytterøy route, adhering to the criteria detailed in Table 4, in order to enable unmanned engine room operation. However, engine room systems that are optimized to minimize repair and maintenance are not yet available and would need to be developed (which is expected to be possible in the near future). The technical feasibility assessment is summarized in **Figure 5**. The yellow light indicates that unmanned operation is expected to be feasible in the near term (within the next five years) with targeted technology development and the green light indicates that the operation is feasible using today's available technology.

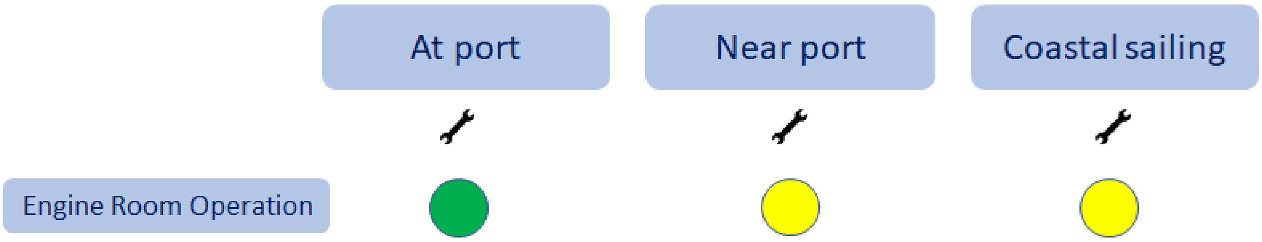


Figure 5: Technical feasibility assessment of unmanned engine room operation for the Levanger - Ytterøy ferry service.

3.4 Communication for Unmanned Ferry

The need for real-time communication with a Remote Operation Centre is highly dependent on the degree of autonomy of the unmanned vessel. A fully autonomous vessel should never rely on external actions, nor depend on any real-time communication beyond the inputs it receives from external navigation sensors/sources (e.g., GNSS). However, autonomous ships require a lot of communication between the relevant networked systems and the overall architecture can be quite complex. The connectivity architecture for autonomous ships is covered in some detail in [3], where the illustration reproduced in Figure 6 is presented.

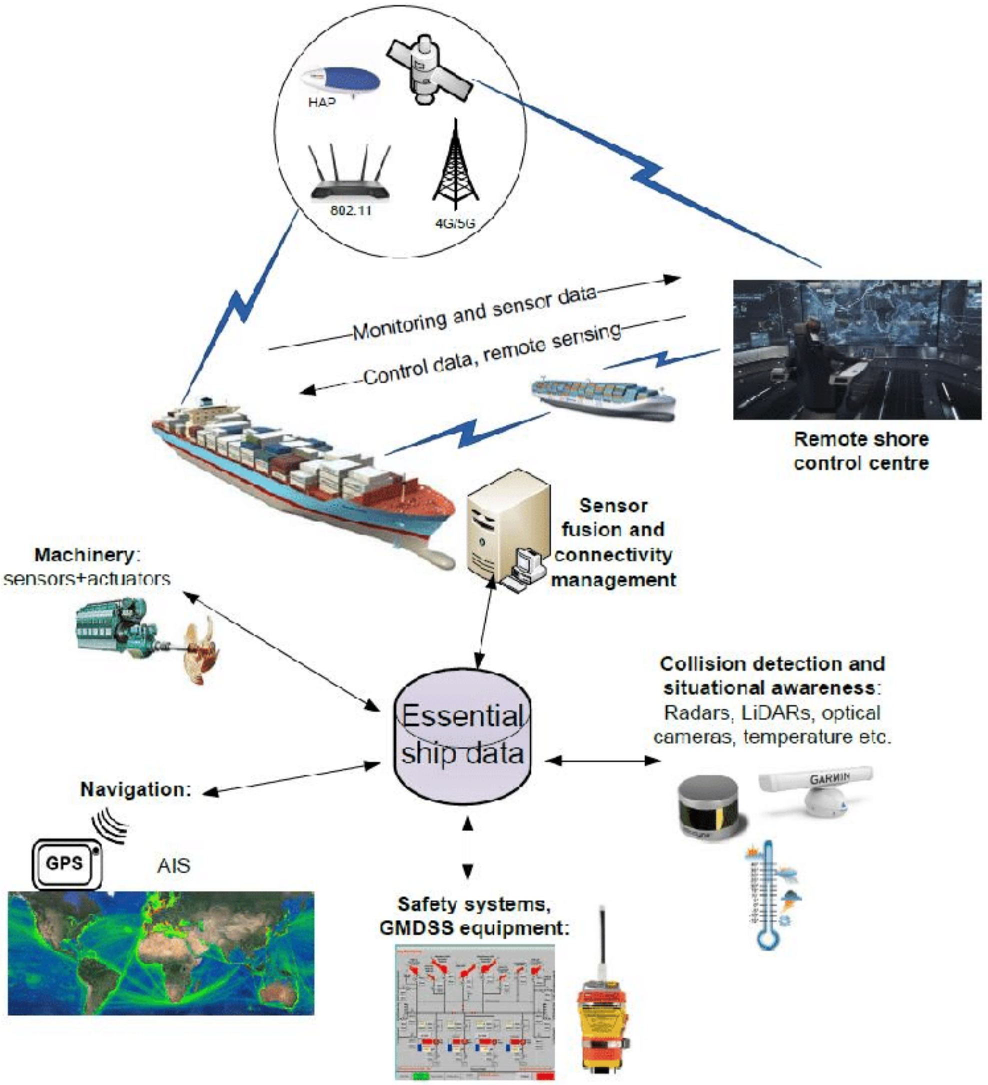


Figure 6: Connectivity architecture for autonomous ship reproduced from [3]

Essentially, the more an unmanned ship relies on the remote operator, the more data must be transmitted to shore real-time (minimal delay). This data includes live sensor feeds such as video. The following aspects should be noted regarding state-of-art ships and ongoing projects on autonomous ships:

- Onboard Yara Birkeland the current communication capabilities are based on Maritime Broadband Radio, Satellite Communications and GSM[27]. However, Yara and Telenor are collaborating to introduce 5G. One of the first industrial 5G network in Norway has been established at Yara Birkeland's homeport at Herøya[28]. Furthermore, Telenor and Yara are hoping to achieve ship-to-shore communication based on 5G, with response times close to 1 millisecond[29].
- For the MEGURI2040 DFFAS project ship-to-shore communications were performed using cellular LTE technology close to shore, while satellite-based technology (Sky Perfect JSAT) was used further from shore.

[27] https://www.kongsberg.com/no/maritime/support/themes/autonomous-ship-project-key-facts-about-yara-birkeland/
[28] https://telenor-no.mynewsdesk.com/pressreleases/yara-og-telenor-aapner-industriell-5g-paa-heroeya-3185320
[29] https://www.telenor.no/dekning/5g/suksesshistorier/

Potential benefits of the use of 5G for Maritime applications are summarized by Petersen et. al., [4]. They note that while 5G offer novel options that enables to dedicate capacity to certain assets and to have private local networks with reduced latency, use of 5G is only relevant for coastal operations as the connection relies on having many Radio Access Networks (RANs) that have a range of a few kilometres only.

Cyber security is a critical aspect to consider related to the communication solutions for increasingly autonomous ships as they will inherently require a higher degree of cyber-physical interaction than a traditional ship. Cyber-attacks can be directed directly at the onboard systems or by corrupting signals that the onboard systems rely on, such as AIS and/or GNSS data and/or critical commands from a Remote Operation Centre.

High level acceptance criteria that are relevant for the communication/connectivity of an unmanned ship are summarized in **Table 5**.

#	**Operational phase(s)**	**Criteria for feasibility of communication/connectivity with unmanned ship**
Com1	All	Data from the unmanned ship must be transmitted in a secure and real-time manner to the Remote Operation Center as needed to allow the operator to have the required situational awareness to allow safe operation of the unmanned ship.
Com2	All	Commands must be transmitted in a secure and real-time manner from the Remote Operation Center to the unmanned ship to allow safe remote control of the ship as needed.
Com3	Near port, Coastal sailing	The ship navigation system must have algorithms in place to detect manipulation of critical external inputs (such as GNSS signal).
Com4	Near port, Coastal sailing	The ship navigation system should be designed to detect and handle short dropouts of external navigation signals (such as GNSS signal).
Com5	All	The unmanned ship should be able to communicate with other ships and other external stakeholder in a similar manner to what the crew onboard manned ships do today. Note that Com5 implicitly requires fulfillment of Nav3 (acceptable situational awareness).
Com6	All	For all phases of operation, the ship should revert to a clearly defined Minimum Risk Condition (MRC) in the event of lengthy fallout of critical external inputs.

Table 5: High-level criteria for feasibility of communication/connectivity with unmanned ship

3.4.1 At Port

When the ship is docked at the port, communication activities primarily focus on ship loading, including addressing any issues related to the handling of non-standard cargo. Currently, for the M/F Ytterøy ferry, communication with shore-based entities, if required during any operational phase, is carried out using regular cell phones or VHF radio. However, according to Torghatten, there is usually minimal demand for such communication. For unmanned operation, the responsibility for this type of communication can be assumed by the Remote Operation Centre without major difficulties, e.g., by using Voice over Internet Protocol (VoPI) rather than VHF. However, the task of vehicle loading is currently planned and supervised by the onboard crew, who provide passengers with verbal and visual instructions during the process. To achieve fully unmanned operation at the port, the Remote Operation Centre would need to oversee the loading of cars and passengers. This would require the development of new electronic solutions specifically designed to optimize the loading process and guide vehicles to their designated positions on the deck. While the technology to support this is feasible to develop, there is no guarantee that all vehicles and passengers will strictly follow the instructions due to factors such as impaired hearing, distractions, or non-compliance. This could pose challenges if no crew is present on-site. Additionally, for unmanned operation, the Remote Operation Centre would need the capability to create and/or verify the planned route for the next crossing, but this should not be a significant obstacle given the availability of suitable digital tools.

3.4.2 Near Port

As the vessel departs from the port, effective communication with other vessels becomes crucial to avoid hazardous situations. Currently, VHF radio serves as the primary means of communication, and this responsibility would need to be transferred to the Remote Operation Centre for unmanned operation. It is essential that any incoming VHF communication directed to the vessel receives the prompt attention of the responsible remote operator. To ensure this, a visible and audible alert should be generated to notify the operator. Additionally, a Public Address (PA) system is necessary to communicate with passengers aboard M/F Ytterøy. In the case of an unmanned ferry, the PA system can play pre-recorded messages for regular passenger information, but the Remote Operation Centre must have the capability to broadcast important messages when required. However, similar to the previous section, the absence of onboard crew may pose challenges in handling unresponsive passengers or situations that require immediate human intervention.

The transmission of critical real-time data is of utmost importance for an unmanned vessel operating away from the port, as it enables the responsible remote operator to maintain the necessary situational awareness. Various technologies, including Maritime Broadband Radio, Maritime 5G, and satellite communication, can be utilized for this purpose. Depending on the risk analysis conducted for unmanned operation, redundant solutions may be necessary to ensure reliable data transmission. However, as the vessel approaches the port vicinity, existing communication technologies can effectively address this challenge.

3.4.3 The Coastal Sailing Phase

The coastal sailing phase closely resembles the near port situation, with the exception that there might be areas with limited coverage as the vessel moves further away from the port regions. Torghatten reports that they currently do not encounter such coverage gaps with the communication methods they employ. However, the main challenge lies in the lack of or limited coverage in the engine room. To address this issue, Torghatten has installed a 4G transmitter for receiving coverage in the engine room on the Horten-Moss route.

Due to the relatively short distance covered during the Levanger – Ytterøy service (9 km) and the proximity to the shore throughout the transit, it is anticipated that multiple communication systems will be available, provided they demonstrate sufficient security measures. Additionally, by incorporating onboard systems with a high degree of autonomy, it becomes feasible to establish an acceptable interval for data dropouts based on the risk analysis conducted for autonomous operations.

3.4.4 Summary of Unmanned Communication Feasibility for Levanger – Ytterøy

There are three primary areas of concern regarding the current state-of-the-art solutions for communication with unmanned ships that specifically relates to high-level acceptance criteria Com1, Com2 and Com5:

1. The loss of physical communication and interaction with passengers, which cannot be completely replaced.
2. The security aspects of the remote communication solutions are still being evaluated and not yet fully proven.
3. The reliability of transmitting large datasets with minimal delays has not been thoroughly tested and validated under real operating conditions.

Nevertheless, it is anticipated that these challenges can be addressed and resolved in the near future. The feasibility assessment for communication with unmanned ships is summarized in **Figure 7**. The yellow light indicates that unmanned operation is expected to be feasible in the near term (within the next five years) with targeted technology development.

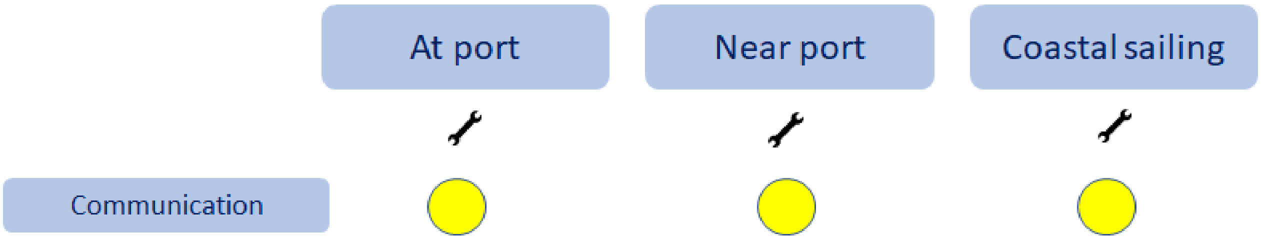


Figure 7: Technical feasibility assessment of unmanned ship communication for the Levanger - Ytterøy ferry service.

3.5 Unmanned Mooring

Several unmanned mooring systems have already entered the market or are about to be placed on the market. Notable solutions include:

- Systems for vacuum-based remotely-operated mooring are provided by Cavotec's MoorMaster[30] and Trelleborg's AutoMoor[31].
- AutoMooring Solutions[32] (spin-off from Mampaey Offshore Industries) offers several types of mooring systems that are suitable for unmanned operation, including a semi-automatic robotic arm with AI to recognize bollards over which it can automatically place the mooring rope (AMS Rope Picker Robot).
- The Yara Birkeland is equipped with a mooring system that operates without human intervention, developed by MacGregor[33]. The system consists of two 7-axis electrically powered robotic arms with 21 meters reach outfitted with sensors and a camera. One arm is mounted aft of the container ship, and one is mounted forward. The arms are designed to grab the mooring rope and place it over the bollard and traditional mooring winches are used to tighten the rope.

High level acceptance criteria that are relevant for unmanned mooring are summarized in **Table 6**.

#	Operational phase(s)	Criteria for feasibility of unmanned mooring
Mor1	At port	The vessel can moor without human assistance and without causing any material damage (to ship or port infrastructure) or person injuries.
Mor2	At port	The mooring system must be able to handle all foreseeable (combinations of) weather, draft and tidal changes that it is approved for.
Mor3	At port	The mooring system must be able to handle all foreseeable motions of the ship as the ships is loaded and unloaded.

[30] https://www.cavotec.com/en/your-applications/ports-maritime/automated-mooring
[31] https://www.trelleborg.com/en/marine-and-infrastructure/products-solutions-and-services/marine/docking-and-mooring/automated-mooring-systems/automoor
[32] https://automooringsolutions.com/
[33] https://gcenode.no/news/autonomous-ship-delivered-from-yard/

Mor4	At port	The mooring system should provide an alarm/alert to the (Remote) Operation Center in the event of any critical failures of the mooring system

Table 6: High-level criteria for feasibility of unmanned mooring

The only operational phase that is relevant for autonomous mooring is "At port". Currently, the mooring of M/F Ytterøy involves several manual steps. Upon arrival the gate/flap is manually lowered onto the car bridge and the "slisse" on the car bridge is locked into place on the ferry. While this fixes the front of the vessel in place, the rear end of the vessel can move a bit. Torghatten reports that they do not currently use mooring lines for a short turnaround, but that the Captain or responsible navigator applies thrust as needed to keep the vessel properly aligned. For longer durations (>30 minutes) they may use a mooring line ("trosse") and the same applies if they struggle to stay in position with use of a thruster.

The currently available unmanned mooring systems seem to possess the necessary flexibility to accommodate a vessel like M/F Ytterøy. However, the cost of these systems is expected to be a crucial factor to consider. In order to enable unmanned service for the Levanger – Ytterøy route, it is probable that a new vessel will be required, preferably equipped with an electric propulsion system. For proper alignment of an electric ferry, ensuring efficient charging, Torghatten utilizes the automatic mooring solution provided by Cavotec for other electrified ferry services such as Flakk – Rørvik.

Assuming a new ferry that is built with autonomy in mind, fully autonomous mooring is viewed as technically feasible with today's technology as reflected in Figure 8.

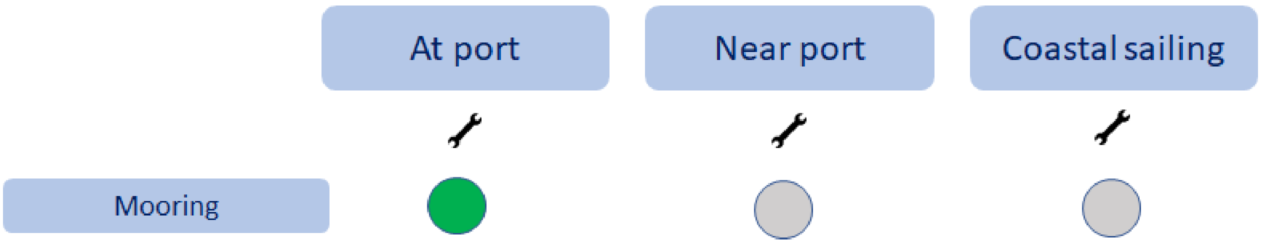


Figure 8: Technical feasibility assessment of unmanned mooring operation for the Levanger - Ytterøy ferry service.

3.6 Passenger and Vehicle Handling for an Unmanned Ferry

The sole purpose of a ferry is to transport persons and vehicles between two locations separated by a body of water, and it is critical to do so in a safe and efficient manner. High level acceptance criteria that are relevant for passenger and vehicle handling for an Unmanned Ferry are summarized in **Table 7**.

#	Operational phase(s)	Criteria for feasibility of unmanned passenger and vehicle handling
Pas1	At port	All the passengers and vehicles must be guided onto and off the ferry in a safe and efficient manner.
Pas2	At port	All passengers must be counted when boarding and off-boarding the ferry
Pas3	At port	The placement of vehicles onboard must consider relevant loading restrictions for the ferry, and also be secured in accordance with regulations and the current operational conditions.
Pas4	All phases	The safety of the passengers must always be upheld, even in the event of unexpected incidents or accidents. This necessitates maintaining a safety record

		(measured by the number of injuries and fatalities) that is at least as good as the current standards observed on manned ferries.

Table 7: High-level criteria for feasibility of passenger and vehicle handling for an Unmanned Ferry

3.6.1 At Port

In addition to the challenges that remote communication offer, that were discussed under Section 3.4.1, there are other tasks that the crew performs associated with the loading of the ferry that are difficult to replace with automated solutions. Such as lashing down e.g., motorcycles to the deck in challenging conditions.

3.6.2 Near Port

During a normal transit there is likely not a lot of work associated with care of the passengers. However, in the event of a system failure or accident, the situation is very different. Currently, each passenger vessel carries a minimum safety crew that is specially trained to handle different accident scenarios such as fires onboard, collisions, loss of propulsion etc. Most of the onboard safety equipment requires correct operation by humans. While early technology developers have started to work on autonomous safety solutions for unmanned ships (e.g., autonomous lifeboats) this work is in a very early phase. It is unlikely that sufficiently robust solutions that can replace the emergency response actions performed by the onboard crew today will be available within the next 5 years.

3.6.3 The Coastal Sailing Phase

The same argumentation applies as for "Near port" operation. Farther from port the ferry is less likely to be in range of other vessels that can come to the rescue, and also has a longer way to travel to get to shore, which is expected to be a Minimum Risk Condition (i.e., "safe state" for a vessel as defined Section 2 in [2]) that will be used in the Risk Analysis for unmanned operation.

3.6.4 Summary of Unmanned Passenger and Vehicle Handling Feasibility for Levanger – Ytterøy

Keeping the passengers at least as safe as onboard a manned ship today is expected to be the most challenging part about a transition to a fully unmanned ferry. While more autonomous safety equipment will enter the market, human crewmembers are expected to be better at handling the unforeseen events at least for the next 5 years. To ease the passenger and vehicle handling, the ship design should be revisited to look for ways to reduce the risk of events such as groundings/collisions and onboard fire. Fully autonomous car and passenger handling is not viewed as technically feasible in the near term as reflected in **Figure 9**.

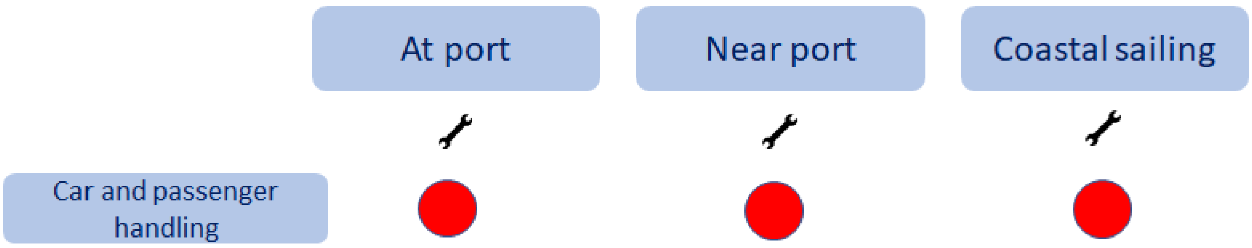


Figure 9: Technical feasibility assessment of unmanned car and passenger handling for the Levanger - Ytterøy ferry service.

3.7 Overall Summary of Technical Feasibility of Autonomous Levanger - Ytterøy

Currently, M/F Ytterøy is not well-suited for autonomous operation. While it is possible to retrofit the ferry with certain systems that will reduce crew workloads, the number of crewmembers is not expected to change. To have a meaningful impact on crew numbers, it would be necessary to replace the existing ferry with a purpose-built vessel designed specifically for autonomous operation, taking into account the need for minimal maintenance. By doing so, the role of the "dagmann" would likely be eliminated, which could also allow for the consolidation of positions such as Chief Engineer and Able Seaman.

The technical feasibility assessment for autonomous operation, encompassing all defined functions across all three operational phases, is summarized in **Figure 10**. Red light indicates that unmanned operation is unfeasible for the foreseeable future, yellow light indicates that unmanned operation is expected to be feasible in the near term (less than 5 years from now) assuming targeted technology development, green light indicates that the operation is feasible with technology that is available today, and grey light indicates that the option is not relevant.

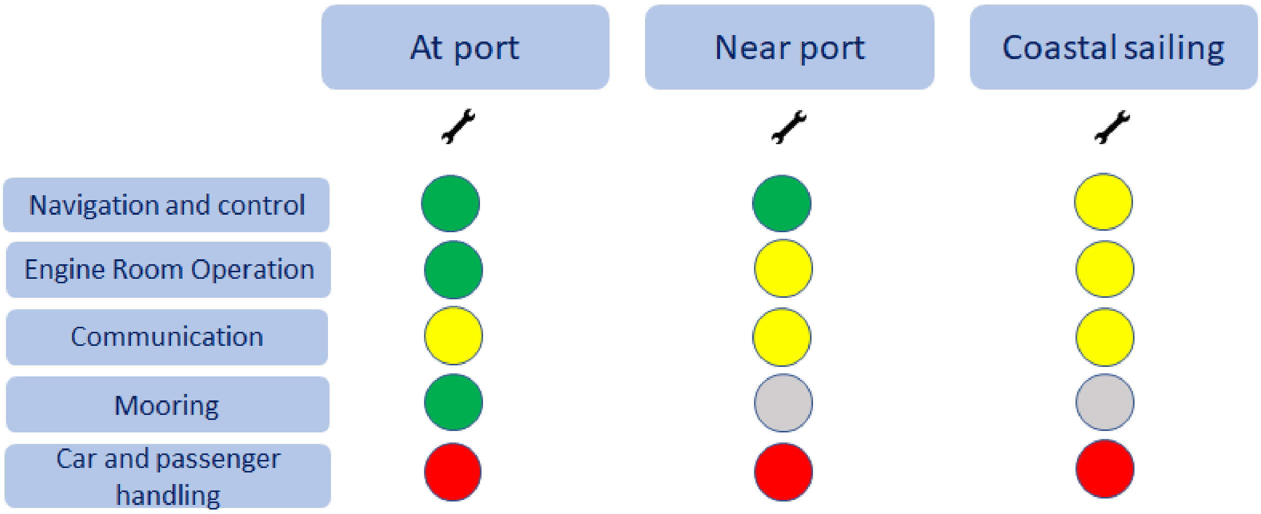


Figure 10: The technical feasibility assessment for autonomous operation of the Levanger – Ytterøy ferry

4 Regulatory Feasibility of Increased Autonomy and/or Reduced Manning

While conducting a comprehensive analysis of all regulations and guidelines relevant to the operation of autonomous ships is outside the scope of this report, this section offers a brief summary of key regulations. Additionally, it provides an overview of recently published hazard and risk analyses pertaining to autonomous passenger ships, as well as important viewpoints and assessments gathered during workshops with the Norwegian Maritime Authority, DNV, and the Norwegian Coastal Administration. This valuable input will be utilized to assess the regulatory feasibility of each operation type in alignment with the technical feasibility assessment conducted earlier.

4.1 International Regulation of Autonomous Ships

The work to develop regulations addressing autonomous or partly autonomous ships is ongoing. The **International Maritime Organization (IMO)** has started to investigate them and tries to move relatively quickly because they realize that the technology is quickly surpassing the regulations [5]. The Maritime Safety Committee (MSC) has released several circulars with relevant guidance for Maritime Autonomous Ships (MASS), the most notable ones are briefly summarized in Table 8.

Circular number (Date of release)	**Title**	**Brief Highlights**
MSC.1/Circ.1455 (24 June 2013)	Guidelines for the Approval of Alternatives and Equivalents as provided for in various IMO Instruments	The Guidelines outline a methodology for the analysis and approval process for an alternative and/or equivalent design. NMA uses this circular to ensure that autonomous or remotely operated ships have the same safety levels as conventional ships due to the lack of specific regulations that address autonomous or remotely operated ships.
MSC.1/Circ.1604 (14 June 2019)	Interim Guidelines for MASS trials	The guidelines specify that "Trials should be conducted in a manner that provides at least the same degree of safety, security and protection of the environment as provided by the relevant instruments", and that measures should be put in place "to reduce the risk to as low as reasonably practicable and acceptable".
MSC.1/Circ.1638 (03 June 2021)	Outcome of the Regulatory Scoping Exercise for the use of Maritime Autonomous Surface Ships (MASS)	A key assumption made in this document is that "passenger transports without seafarers on board cannot be performed". Identifies common potential gaps that must be addressed for MASS operations, including: • The role of the remote operator as a seafarer (qualifications and responsibilities) • Provisions requiring actions by personnel (Fire, Spillage Cargo Management, onboard maintenance, etc.) • Connectivity, cybersecurity • Watchkeeping • Implications of MASS to Search And Rescue (SAR) Additional noteworthy statement:

		• "Taking into account the above potential gaps and/or themes identified, for the carriage of cargoes by ships without persons on board during sailing, one of the important issues to be considered is how to establish the procedures for ensuring safety of cargoes in normal conditions."

Table 8: Overview of IMO circulars with particular relevance for MASS

According to Norwegian Maritime Authority that is involved with this work, the new MASS code under development should initially cover cargo ships. The possibility of autonomous operation of passenger ships should be assessed for incorporation at a later time. Hence cargo ships are the main focus for the current work in IMO.

4.2 Autonomous or partially unmanned operations in Norwegian waters

Norwegian Maritime Authority (NMA) has published Circular RSV 12-2020 *Guidance in connection with the construction or installation of automated functionality aimed at performing unmanned or partially unmanned operations*, that apply to autonomous as well as fully/partially remotely controlled ships. Specifically, the standard states that it applies "to all ships with a level of autonomy equal to levels three to five that will be engaged on Norwegian domestic voyages", where Level Of Autonomy (LOA) is per the Norwegian Forum for Autonomous Ships (NFAS) definition that is provided in Table 1.

Autonomy Level	Description
1	**Decision Support**: Decision support and advice to crew, but the crew is in direct command of ship operations. This will normally involve various types of autonomous operation carried out by a computer, such as maintaining the course and speed (auto pilot). It may also involve various types of alarms, e.g. when there is a risk of collision (ARPA – Automatic Radar Plotting Aid).
2	**Autonomous:** Autonomous under constant surveillance with the option to take control of the vessel (advanced or enhanced "track pilot"). This may also involve alarms to operators on detection of dangers. This is a further developed stage where the entire or part of the voyage is automated, such as a fjord crossing by a car ferry or autonomous berthing and mooring.
3	**Periodically Unmanned:** At night in good weather and with little traffic, or unmanned for days, but with crew on board or in an escort vessel to handle the berthing or more complex tasks. Here, the operator will be alerted or the crew be awakened if situations arise that the system is unable to handle.
4	**Unmanned:** Completely unmanned, but with an option of direct or indirect remote operation from a shorebased control centre to handle complex operations. It is then assumed that there is no crew on board for any part of the voyage and that a continuously manned control room is monitoring the ship. Also in this case, an alarm system is required to alert operators in situations that the system is unable to handle.
5	**Fully Autonomous:** Completely unmanned and without monitoring from shore. This is of little or no relevance for ships, and particularly for ships engaged on international voyages. This is both due to complexity and safety, but also to meet the requirement that the ship must be under the control of a responsible person at all times, and that Coastal States must be able to call up the ship.

Table 9: Autonomy Levels for Ships (based on NFAS definitions) referenced in NMA Circular RSV 12-2020

The circular states that the legislation that applies to the specific type of ship, in this case a passenger ferry, always apply to the (partly) autonomous/remotely operated vessel, and that the ship additionally will be assessed based on the degree of autonomy or remote operation. A few key points to note from the Circular that is of particular relevance to this feasibility study:

- A detailed Concept of Operations (CONOPS) must be developed that includes a clear description of:
  - intended degree of autonomy
  - which operations that are performed by humans and which that are carried out without human intervention
  - the Human Machine Interface (HMI)
  - when human interaction is required/necessary
- A HazID-based risk analysis is required that is based on the intended operation of the ship as well as the specific geographic area for the operation.
- A Safety Philosophy must be developed that includes a description of:
  - how an equal safety level is met during unmanned and autonomous operation
  - how at least 2 Minimum Risk Conditions (MRC) that are available in normal situations
  - which MRC should be available at any time during the operation
  - how at least one MRC is available at all times after a fire or the filling of a fire zone or a watertight compartment, in case of blackout or loss of communication with any Remote Control Station
- Specification of critical components, systems and equipment that must be functional in order for the MRC to be operative as well as documentation of the reliability of the functions.
- Description of compliance with the Norwegian Rules of the Road at Sea including ability to handle complex traffic situations such as when other traffic does not comply with the Rules of the Road at Sea.
- A Design Philosophy that includes:
  - any limitation in the various integrated systems relative to the function they are to replace or automate
  - fail-to-safe mode in case of system and equipment errors
  - principles for segregation, redundancy and robustness

A more detailed discussion of the general regulations relevant for autonomous ships has been included in the *Feasibility Study for an Unmanned Deep-Sea Bulk Ship and Short-Sea Container Ship* [6] that was written in parallel with this report. The rest of this chapter will focus specifically on the autonomous passenger ship use case.

4.3 Manning Regulations

For passenger ships operating in Norwegian waters today the NMA formally determined the safety manning based on an application from the ship owner. The safety manning should cover all operations and tasks that are relevant for the safe operation of the ship. Factors that must be considered include number of passengers, the propulsion system, the technical condition of the ship, type and size of the ship, operational speeds, evacuation analysis and available safety equipment. Ultimately it is the ship owner's responsibility to assess if the safety manning is appropriate and to keep NMA updated on relevant operational changes. If the onboard crew is reduced or removed, the safety functions described in the third section in §8 section 3 of the "Bemanningsforskriften" (i.e. Norwegian Manning Regulations, FOR-2009-06-18-666) and part 3 of the " Forskrift om vakthold på passasjer- og lasteskip" (i.e. Norwegian Watchkeeping regulations, FOR-1999-04-27-537) will have to be replaced by equivalent solutions.

4.4 Review of relevant Hazard and Risk Analysis Work for Autonomous Ferries

The growing interest in the operational testing of autonomous ships, undertaken by various initiatives worldwide, is accompanied by a parallel focus on conducting HazID-based risk analyses. These analyses, which are referenced in the current guidelines and commonly employed for assessing other automated/autonomous systems in different sectors, have garnered increased attention. In this section we will review recent publications on this topic and derive the key experiences and lessons learned that can help us form an opinion of the feasibility of unmanned operation of the Levanger – Ytterøy ferry.

In [6], the authors apply a safety assessment framework based on "what-if" analysis to a hundred maritime accident reports in an attempt to test, and to provide some early insights into, the theory that the navigational safety can be improved by making ships more autonomous. The main argument for the safety improvement would be that an increased level of autonomy will reduce the number of human errors. The analysis aimed to determine if the accident would have happened if the ship had been unmanned and if so, whether the consequences of the accident would have been different. The first part of the analysis, determining if an autonomous ship would have reduced the probability of the events to develop into an accident, favoured use of autonomous ships. The likelihood of the accident happening if the ship was unmanned was lower for 47% of the cases investigated (mostly due to elimination of human error), and higher for 16% of the cases (due lack of situational awareness on the bridge or inadequate maintenance or supervision of mechanisms). The second part of the analysis show that the consequences, particularly of non-navigational accidents such as fires and structural failures, are expected to be greater due to the fact that there will be nobody present to immediately counteract the damage. The authors thus recommend that the unmanned ship should be designed to prevent a single failure from propagating rapidly and to pursue robust designs that can withstand some damage to critical components such as hull, machinery and control system.

A publication from 2019, authored by Thieme et al. [8], presents a comprehensive hazard and risk analysis based on the work conducted in the Autoferry project. The analysis focuses on operating the Milliampere, a small automated harbor ferry designed for up to 12 passengers, in sheltered waters of Norway. The paper aims to provide some early guidance for how to perform such analysis for autonomous ferries. Through this risk analysis, the authors identified recommended mitigating actions to enhance the reliability and redundancy of critical onboard systems, such as the battery system, sensors, and communication system. Additionally, the paper suggests utilizing emergency measures like dropping the anchor to bring the ferry to a predetermined safe state. Furthermore, some risk mitigating actions focused on designing the ferry to be easy to escape from, and at the same time preventing the passengers from inadvertently falling overboard.

A subsequent study builds upon the findings of the hazard and risk analysis to conduct a comprehensive risk assessment specifically focused on collision risks associated with the Milliampere ferry [9]. The study entailed identifying safety barriers aimed at preventing collisions and the corresponding failure modes. Two key safety barriers considered were remote control and autonomous control, both of which would need to fail simultaneously to result in a loss of navigational control for the ferry. Additionally, the propulsion system of the ferry consists of two thruster packs, ensuring normal operation even in the event of one pack's failure. The design incorporates backup linear actuators and battery banks to enhance system reliability. The authors highlight that one of the major challenges in performing a quantitative risk assessment for autonomous ships is the scarcity of specific failure data. As a result, expert estimations and best guesses were utilized in the study to address this limitation.

Experiences of hazard-analysis and risk analysis of automated passenger ferries are presented for two specific automated passenger ferry cases as part of the AutoSafe project funded by the Research Council of Norway [10]. The first use case involves a small ferry with maximum 25 passengers operating close to shore while the second use case involves a fjord crossing with a larger and faster ferry that can carry maximum 130 passengers. The goal of the first use case is to go from 1 crew member to remote operation (via a ROC) only, while the goal for the second use case is to go from 3 crew members to 2 or 1. The approach used is based on the IMO Functional Safety Assessment (FSA) framework where a HazID is performed to identify potential hazards and threats. While some hazards can be mitigated by going to a failsafe condition or minimum risk condition, other hazard involve "non-failsafe" conditions that has to be handled by urgent human intervention, such as fire onboard or capsizing.

4.5 Viewpoints and Assessments from Workshops with Key Stakeholders

As part of this study, workshops were organized with key SFI Autoship partners that each have a role to fill in the regulatory landscape as described in Table 10.

Agency/company	Description of role related to regulation of autonomous ships
Norwegian Maritime Authority	The administrative and supervisory authority in matters related to safety of life, health, material assets and the environment on vessels flying the Norwegian flag and foreign ships in Norwegian waters.
DNV	An independent expert in assurance and risk management. One of the world's leading classification societies and a recognized advisor for the maritime industry.
Norwegian Coastal Administration (NMA)	Ensures safe and efficient traffic along the Norwegian coast and into ports, and is responsible for the national emergency preparedness against acute pollution

Table 10: Agencies/Companies that participated in workshops focusing on regulatory aspects for autonomous ships.

The goal of the discussions was to collect information on the current status of these agencies' work with autonomous ships in general and to find out what they see as the key remaining challenges. The key findings from the discussions related to operation of autonomous passenger ferries are outlined in the following subsections. It should be noted that only a few individuals from the Agencies/Companies in Table 10 participated in the interviews/workshops, and thus, their viewpoints may not necessarily align with those of all their colleagues.

4.5.1 Discussions tied to the Lack of Regulations for Autonomous Ships

Regulatory bodies like the Norwegian Maritime Authority (NMA) express their concern that setting requirements too early in the development of autonomous ships could lead to excessive conservatism and potentially stifle innovation. However, they acknowledge that there are certain areas, such as establishing "hard" requirements for Minimum Risk Conditions, where clear guidelines can still be applied without impeding progress. In general, NMA has taken on a collaborative role with the ongoing Norwegian projects that are aiming to develop and operate autonomous ships. While the Bastø ferries servicing Horten – Moss have a lot of autonomous functionality onboard, there is no associated regulatory work ongoing that is aimed at reducing the size of the crew. NMA emphasizes that passenger safety is of utmost importance in ferry operations, highlighting the criticality of equipment required for evacuation and firefighting. In the context of ferry connections involving multiple ferries operating concurrently, it is intriguing to explore collaborative measures in case of emergencies. For instance, the time it takes for another ferry to provide assistance becomes a relevant consideration. One alternative approach could be to maintain a readily available tugboat as a standby option. A notable example of innovative readiness can be seen in the case of Yara Birkeland, where a remote towline is pre-installed on the bow, enhancing operational preparedness.

In the absence of international regulations, projects aiming for unmanned operations in the near future will undergo individual risk-based evaluations that require approval from national regulatory bodies such as the

Norwegian Maritime Authority (NMA) for operations within national waters. Currently, all planned unmanned operations involve straightforward transportation of goods between two designated ports. DNV (Det Norske Veritas) acknowledges their involvement in case-by-case technical assessments within countries that are receptive to autonomous operations. They collaborate directly with regulatory bodies and have the potential to provide third-party approvals.

4.5.2 Discussions tied to the Lack of Humans filling the classical roles onboard the ship

There is an agreement that a major regulatory challenge stems from the fact that the current regulation was never written with an unmanned ship in mind, hence there is a lengthy list of formulations that refers to specific persons performing specific tasks. Examples are the manning regulations and the watchkeeping regulations. Also, a question like whether the Master has to be onboard the ship is still open and subject to discussion internationally.

4.5.3 Discussions tied to Collision Avoidance and COLREGs

DNV views the autonomous collision detection and resulting COLREG-compliant avoidance manoeuvre as one of the biggest remaining challenges to solve for the unmanned ship. One major consideration is the selection of appropriate algorithms for autonomous path re-planning. Establishing a common understanding and potentially creating a shared open-source implementation for such algorithms are potential solutions worth exploring. A particular challenge with COLREGs is the existence of certain regions or areas where alternative rules that diverge from COLREGs are commonly adopted by the majority of ships navigating those waters. These deviations may be a result of challenging geography, currents, or other factors that make adhering to COLREGs difficult. Adapting algorithms to accommodate non-conforming practices would pose a considerable challenge. Another possibility that was discussed was the use of external radars, at least for coastal areas with a lot of traffic.

NMA emphasized their opinion that modifying the COLREGs to accommodate autonomous vessels is not preferable. Instead, they highlighted the importance of designing autonomous ships to behave similarly to manned ships.

4.5.4 Discussions tied to the Requirements that should apply to Remote Operation Centres

NMA stated that one of the challenging aspects tied to ROCs is to decide if the operational responsibility belongs to the remote operator(s) or the autonomous system onboard. The solutions that allow the ROC operator to take control of the vessel is expected to be very important in this regard. It may be acceptable to sporadically lose connection, but the maximum allowed duration of the dropout and the corresponding MRC, must be covered in the risk analysis. For ROC-assisted operations internationally, additional legal and jurisdictional challenges arise if one considers that the ROC could be based in a different country than what the unmanned ship currently operates in. All these discussions are in the early phases and must be resolved before wide-spread use of autonomous ships worldwide can be realized.

DNV highlights that the scope of the Remote Operation Centre (ROC) extends beyond remote control functions, encompassing fleet management as well. They stress the importance of establishing agreed-upon terminology and using it consistently. To address this, they have adopted the term "connectivity" to refer to the communication required for remote control. While there are existing regulations for communication methods like radio, no specific requirements have been defined for connectivity. Some stakeholders believe that high-quality connectivity and communication will be provided as a service that can be procured. When transferring part of the navigational responsibility onshore, it is crucial to consider additional risks, such as how to handle incidents that could disrupt ROC operations, including scenarios involving fire alarms and actual fires on the premises.

4.5.5 Discussions tied to the Verification of the Autonomous Ship and Associated Infrastructure

A key question is on what basis e.g., NMA can judge that the autonomous systems are good enough? In order to determine if they are at least as safe and reliable as existing manned solutions, it would be necessary to do a lot of testing over several years. NMA expects that there will have to be some type of acceptance testing prior to approval that demonstrates the performance of the autonomous systems during certain types of scenarios and that a key element will be to ensure acceptable MRC under all circumstances.

DNV states that the current concept for unmanned ships has become part of a distributed system, and they refer to the vessel with all the automated systems as an Autoremote system. There is consensus among most stakeholders as well as the available regulations that the Autoremote solutions should be "at least as safe as conventional ship solutions". As stated above, this would take years to demonstrate, hence there is a need to break the Autoremote system into key functions and apply the equivalence principle to the lower levels. DNV expects to use simulators to be able to verify the performance of the different critical systems and algorithms for a sufficiently wide range of conditions. This can include consideration of individual as well as combinations of COLREG rules that DNV defines and has ownership to, potentially through a type of Monte Carlo analysis. DNV also state that functionality that is moved from the ship to a ROC still has to be covered by the classification societies.

DNV also notes that the equivalence principle is not easily applied for all rules, with notable examples being the following:

- SOLAS Ch. II-1/49.4 → Local control of all safety essential machinery should be possible.
- SOLAS Ch. II-1/31.2.3 → Emergency stopping device on the bridge that is independent of the control system.
- STCW VIII/2 2.1 → Officer of the watch on the bridge shall be physically present on the bridge.
- COLREG #5 → Every vessel shall at all times maintain a proper look-out by sight and hearing.

4.6 Overall summary of Regulatory Feasibility of Autonomous Levanger - Ytterøy

The regulatory activities for autonomous ships are still in their early stages, and it is unlikely that autonomous operations of passenger ships servicing Levanger – Ytterøy will be feasible in the near term. International passenger transport, in particular, is not expected to be possible within the next five years. However, if a new ferry specifically designed for autonomous operation is developed, it would help reduce the crew's workload and potentially decrease their numbers by one. This would also enable the collection of valuable experiences with the systems, making them nearly autonomous-ready when regulations and supporting infrastructures become available. It is worth noting that there is an expectation that operational approval may be granted for smaller and less complex ferry operations in the near term, such as those without a superstructure, vehicles, or covering short distances. These pioneering implementations will serve as valuable learning platforms for more complex operations in the future.

During the "At port" operational phase, a ship is generally considered to be in a relatively safe state, resulting in fewer regulations that directly impact this phase. For an autonomous ship, the engines are not expected to serve any critical functions while at port, and there are no ongoing navigation and control activities that would significantly impact regulatory aspects. Autonomous mooring systems are already in use today, and with proper electronic monitoring and alarm generation, this function should not pose any regulatory challenges. However, when it comes to communication, connectivity, as well as car and passenger handling, there are significant differences in operating procedures compared to the current practices, and these aspects are crucial for ensuring passenger safety. With a Levanger – Ytterøy ferry built specifically for unmanned operation it seems probable with a ship design and onboard systems where the risk analysis allows unmanned loading/unloading within the next 5 years.

During the "Near port" and "Coastal sailing" operational phases, the ship is no longer in a reasonably safe state, and any critical loss of propulsion or navigational control can immediately endanger the passengers onboard (depending on the immediate surroundings of the ferry). It is considered unlikely, even for a new ship specifically designed for autonomy, that sufficiently mature autonomous emergency equipment will be available in the near term to ensure an acceptable risk analysis for potential grounding, collision, or onboard fire incidents. Furthermore, it is deemed economically unfeasible to have a tugboat or dedicated rescue boat on standby solely for the Levanger - Ytterøy ferry service. However, in areas with a higher prevalence of autonomous operations, such an arrangement may be more practical and economically viable.

Based on the current assessment, achieving autonomous car and passenger handling in the near term is not considered feasible. However, the realization of an unmanned engine room is within reach for a purpose-built ferry designed with optimized machinery for minimal maintenance. This can be accompanied by the implementation of a predictive maintenance system to effectively plan and prioritize maintenance tasks during longer port stays, potentially including overnight periods.

Similarly, state-of-the-art navigation, control, communication, and connectivity systems are expected to support remote operation after an extensive test phase with the crew still onboard. This phase would involve collecting data to serve as the basis for the risk analysis associated with unmanned operation. While it is anticipated that this process may exceed the timeframe of 5 years, if given a high priority and sufficient resources, achieving such capabilities within the mentioned timeframe is considered feasible.

The technical feasibility assessment for autonomous operation of all the defined functions across all three operational phases is summarized in Figure **11**. Red light indicates that unmanned operation is unfeasible for the foreseeable future, yellow light indicates that unmanned operation is expected to be feasible in the near term (less than 5 years from now) assuming targeted technology development, green light indicates that the operation is feasible with technology that is available today, and grey light indicates that the option is not relevant.

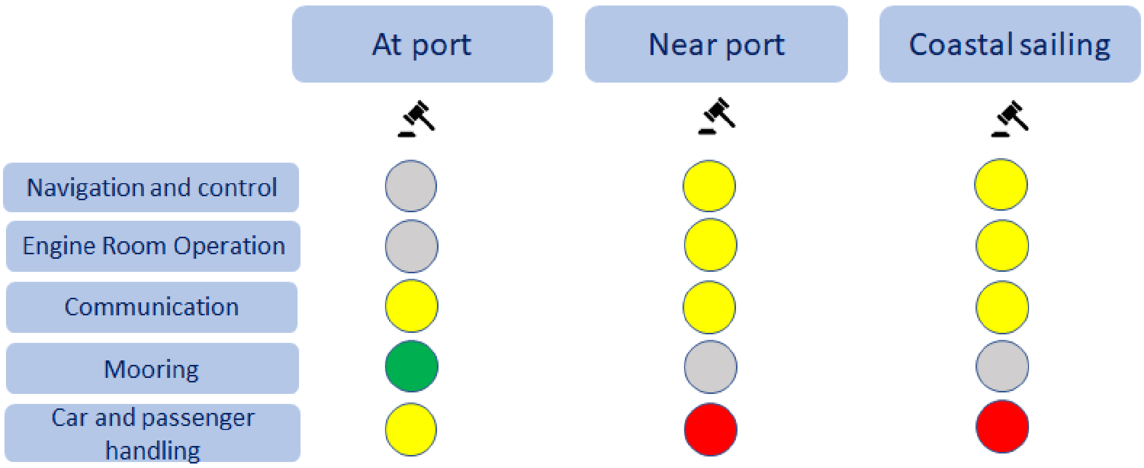


Figure 11: The regulatory feasibility assessment for autonomous operation of the Levanger – Ytterøy ferry

5 Conclusions and Recommendations for Further Work

This study has examined the technical and regulatory feasibility of unmanned operation of passenger ferries, by specifically considering the Levanger - Ytterøy service. The feasibility analysis is summarized in the traffic-light figure below, where **red light** indicates that unmanned operation is unfeasible for the foreseeable future, **yellow light** indicates that unmanned operation is expected to be feasible in the near term (less than 5 years from now) assuming targeted technology development, **green light** indicates that the operation is feasible with technology that is available today, and **grey light** indicates that the option is not relevant. The feasibility is evaluated from a technical (🔧) and regulatory (⚖) viewpoint. The commercial viewpoint is clearly of major interest but was too complex to address within the confines of the study. However, due to the importance of this perspective the table includes a commercial ($) viewpoint where the traffic lights are left blank, to indicate they have not been assessed. Each of the crew tasks are evaluated for each applicable operational phase.

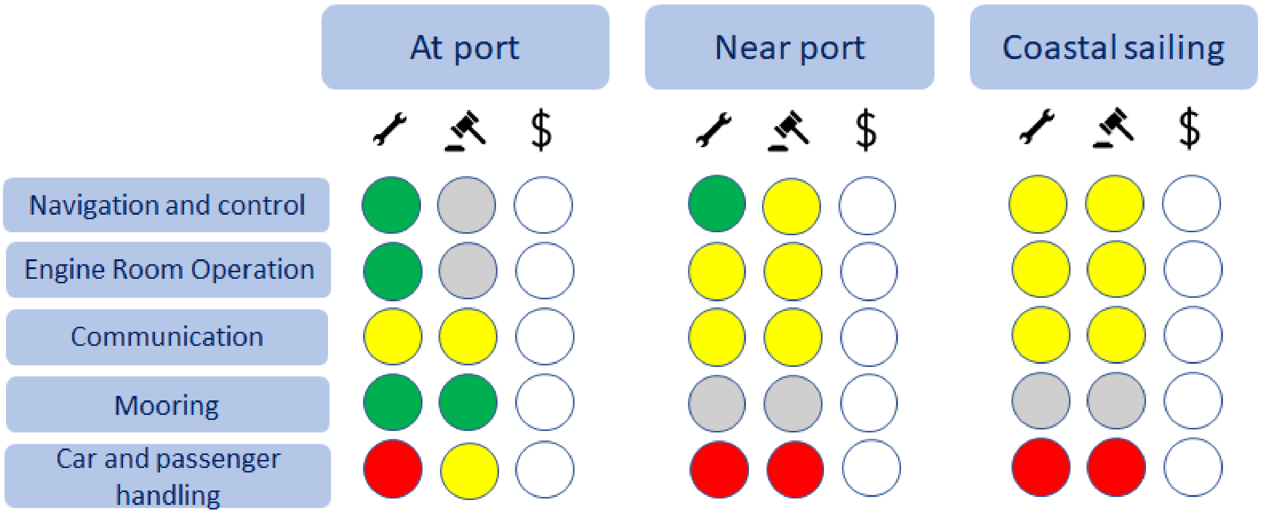


Figure 12: Summary of technical and regulatory feasibility assessment for autonomous operation of the Levanger – Ytterøy ferry

There exists a potential to automate certain functions onboard the existing ferry, but to remove some or all crew from the vessel, a purposely designed new vessel is needed.

Specific technological gaps that need to be addressed include:

- Implementation of operationally proven collision avoidance algorithms that comply with COLREGs (International Regulations for Preventing Collisions at Sea).
- Demonstration of an acceptable level of security in the transmission of commands and data between the ship and the Remote Control Center (RCC).
- Development of a safe mechanism and interface for transferring control to the Remote Control Center in challenging situations, especially when ships do not comply with COLREGs.
- Revisiting ship design, particularly the engine room, to minimize the frequency of repair and maintenance requirements.
- Integration of diagnostic systems to improve planning of repair and maintenance activities and minimize unexpected critical faults.
- Development of new digital solutions that can replace physical handling of passengers and vehicles.

It is important to note that the detailed interface between the unmanned ship and the Remote Control Center, which enables effective supervision, needs to be carefully designed. Efforts should focus on:

- Defining the information that should be available to the remote operator and how it should be displayed.
- Reducing complexity for "at-a-glance" comprehension while maintaining easy access to additional information if needed.
- Engaging in standardization activities to promote international acceptance of such solutions.

Unmanned systems require a lengthy demonstration phase to prove that they are equally safe and capable as traditional manual solutions. By strategically planning for a gradual integration of unmanned solutions, we can adopt a low-risk approach towards achieving fully manual operations. This approach allows us to accumulate valuable experience with these systems while the crew remains on board, readily available to handle any unforeseen events. Another effective strategy for gaining experience with unmanned passenger vessel operations at an acceptable risk involves the implementation of small passenger ferries that navigate short and sheltered passages.

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