MARITIME
SYSTEM
INNOVATION

# Virtual wires as a safety-enhancing concept

## Virtuella vajrar som säkerhetshöjande koncept

Ted Sjöblom, Rick Olsson, Carl Petersson, Roshni Pramanik, Martin Sanfridson, Fredrik Olsson, Joakim Lundman, Mattias Wallin, Thomas Elwinger, Fredrik Almlöv, Fredrik Skeppstedt, Susanne Stegberg, Håkan Burden

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# Abstract

This research project investigates the feasibility and potential benefits of implementing virtual guide wires as a safety enhancement measure for Swedish national waters, inspired by the Finnish Virtual Wire system developed by Finferries. The study focuses on cable ferry operations and functionalities, highlighting the variations in cable ferry and guide wire designs that are often influenced by specific route requirements.

A novel concept of a virtual wire system is proposed, mirroring the safety features of cable-driven ferries, guide wire ferries, and the Finnish virtual wire system, while incorporating an advanced safety features from automation system designed for self-driving ferries. Traditional guide wires, while aiding the own ships navigation, present challenges for others, such as obstructing maritime traffic, disturbing bottom sediments, limited use in ice conditions, and is restricted to routes with straight paths.

The project aims to enhance the safety and operational efficiency of both guide wire ferries and ferries. A significant driver for this research is the industry's difficulty in hiring qualified ferry operators, a trend expected to intensify in the future.

The Finnish virtual wire system, which is a digital navigation aid that provides real-time positional and directional information, was investigated. It utilizes GNSS data with RTK correction for accuracy and offers visual and audible feedback similar to a traditional guide wire. Cabel driven ferries operate very predictable and on a very limited geographical area. Advance automation system including auto docking, departure and position keeping along with traffic collision avoidance aid. A combination of listed functionalities are brought into the novel concept of a virtual wire system is proposed.

To assess the virtual wire's system, various risk assessment methods were challenging as the system influence the whole ferry operation and systems onboard and ashore. Following risk assessment methods was explored including RBAT, HAZID, Mitigation Analysis, D-FMEA, Fault Tree - Event Tree - Bow Tie Diagram, and What-if Analysis.

The project concludes that while virtual wire systems hold promise, comprehensive real-life testing and evaluation in the Swedish context are necessary. Factors such as operator training, system maintenance, regulatory framework, infrastructure integration, and public perception must be carefully considered for successful implementation.

**Key words:** Virtual wires, Cable-driven ferries, Maritime safety, Navigation aid, Maritime regulations

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# Sammanfattning

Forskningsstudien har undersökt möjligheterna och fördelar med införande av virtuella vajrar som ett säkerhetshöjande koncept för svensk inrikes sjöfart, inspirerad av det finska virtuella vajersystemet utvecklat av Finferries. Studien fokuserar på linfärjor med styrvajer, och belyser skillnaderna olika typer av linfärjor som ofta påverkas av specifika ruttkrav.

Ett nytt koncept av ett virtuellt vajersystem föreslås, som speglar säkerhetsfunktionerna hos kabeldrivna färjor, linfärjor och det finska virtuella vajersystemet, samtidigt som det använder avancerade säkerhetsfunktioner från automationssystem designade för självgående färjor. Traditionella styrlinor, medan de hjälper den egna fartygets navigering, medför utmaningar, såsom att hinder för passerande sjötrafik, rör upp bottensediment, begränsad användning i isförhållanden och är inskränkta till rutter med raka vägar.

Projektet syftade till att förbättra säkerheten och driftseffektiviteten för både linfärjor och färjor. En stor drivkraft för denna studie är svårigheten att anställa kvalificerade färjepersonal, en trend som förväntas förvärras framöver.

Det finska virtuella vajersystemet som varit inspirationen för studien är ett digitalt navigationshjälpmedel som tillhandahåller realtidspositionerings- och riktningsinformation. Det använder GNSS-data med RTK-korrigering för noggrann positionering och erbjuder audiovisuell feedback liknande en traditionell linfärjeled. Vajerdrivna färjor opererar mycket förutsägbart och på ett mycket begränsat geografiskt område. Avancerade automationssystem inkluderar automatisk dockning, avgång och positionshållning tillsammans med beslutsstöd för att hantera trafiksituationer. En kombination av listade funktioner införs i det nya konceptet av ett virtuellt vajersystem.

För att bedöma riskerna med ett nytt system har en kombination av olika riskbedömningsmetoder så som RBAT, HAZID, Mitigation Analysis, D-FMEA, Fault Tree - Event Tree - Bow Tie Diagram och What-if Analysis nyttjats. Utöver riskanalyser har RISE policylabb studerat de legala aspekterna och frågor lyfts med relevanta aktörer på workshops. Praktiska försök i Sverige och Finland med olika sensorer och tekniska lösningar har resulterat i ett förslag på koncept som behåller det enkla och rättframma med en traditionell linfärja, men med digitala stöd istället för fysisk vajer. Tillsammans med Zeabuz genomfördes en lyckad demonstration av konceptet på Riddarfjärden med färjan Estelle.

Virtuella vajrar i större skala har potential att öka effektiviteten, minska energiåtgången, underlätta rekrytering och kan sänka tröskeln i from av investeringar i infrastruktur för nya färjelinjer på platser som inte tidigare varit aktuella för linfärjor.

Projektet drar slutsatsen att även om virtuella systemsystem har potential, är omfattande tester och utvärdering i svensk kontext nödvändiga. Faktorer som operatörsutbildning, systemunderhåll, regelverk, infrastrukturintegration och allmänhetens uppfattning måste övervägas om implementeringen skall bli framgångsrik.

**Nyckelord**: linfärja, virtuell vajer, autonom sjöfart, sjösäkerhet, navigationsstöd

# Content

# List of abbreviations

- AD: Automated Driving
- ADAS: Advanced Driver Assistance Systems
- AIS: Automatic Identification System
- COLREG: International Regulations for Preventing Collisions at Sea
- ECDIS: Electronic Chart Display and Information System
- ETA: Event Tree Analysis
- FMEA: Failure Mode Effect Analysis
- FMCW: Frequency Modulated Continuous Wave
- FTA: Fault Tree Analysis
- FB VIII: License for navigator (Fartygsbefäl VIII)
- GNSS: Global Navigation Satellite System
- HAZID: Hazard Identification
- IMU: Inertial Measurement Unit
- LIDAR: Light Detection and Ranging
- LTE: Long-Term Evolution (a type of mobile network technology)
- MASS: Maritime Autonomous Surface Ships
- MOSCOW: MOSCOW principles based on prioritization categories, namely, Must Have, Should Have, Could Have and Will Not Have.
- RA: Risk Assessment
- RBAT: Risk Based Assessment Tool
- RTK: Real-Time Kinematic
- SAR: Search and Rescue
- STCW: Standards of Training, Certification, and Watchkeeping for Seafarers
- VHF: Very High Frequency

# 1 Introduction

## 1.1 Background

This report concludes the study regarding the use of virtual guide wires as a safety-enhancing measure for inland waterways. The concept originated from Finland and was developed by the company Finferries to increase safety and lower the environmental impact on their operated ferry routes. Finnish Maritime Authority created a technical regulation that covers the use of virtual wires. The Finnish concept was the foundation and the initial reason for starting this project to investigate how similar technical regulation and or use of similar technology could benefit the national sea transport. Unlike for the Swedish ferry network, in Finland the most common type of ferry operated by Finferries is the type that uses a wire for guidance, not for propulsion. This is the type of vessels that have been converted into using the virtual wire system in Finland.

Virtual wires are meant to be a digital system that provides a minimum equivalent function compared to a guide wire. In addition, the virtual wire has other advantages that contribute to higher maritime safety, reduced environmental impact and greater socio-economic benefits i.e. optimizing the number of voyages, routes and operational hours etc. The aim is to realize an uncomplicated and easy-to-use system for controlling the ferry. A cable-driven ship with cable pulling as propulsion should not be mistaken for a ferry guidance wire. The ship's propulsion type does not affect the guiding wire functionality. By digitizing today's guide wire, this alternative virtual wire solution is expected to be applicable to a larger number of ships and ferry routes due to reduced dependence on geographical restrictions on the route and through several safety-enhancing functions/features.

## 1.2 Project outset

The aim of the project was to explore virtual wires as safety-enhancing measures to strengthen national shipping for increased Swedish competitiveness. The schedule was set for 2023-01-09 to 2024-09-30 with total funding from the Swedish Transport Administration research portfolio for shipping of SEK 3 million.

**Project partners**

- Trafikverket Färjerederiet (Shipping operator)
- Zeabuz (System suppliers)
- RISE (Research Institutes of Sweden)

The project goals were set to contribute to the evaluation and production of documentation for future approval of virtual wires.

- Review policy and regulations to identify challenges and opportunities in deploying the application of virtual wires within national shipping.

- Analysis and evaluation of available technologies needed to enable virtual wires that allows for resilience and sufficient marine safety.
- Establish test facility for virtual wire on a ship.
- Estimate the effects of virtual wires on inland shipping.
- Documentation and dissemination

The study was divided into the following work packages:

1. Work Package 1: Description of the Virtual Wire System
   In this phase, a thorough environmental monitoring and insights from Finland's experiences. defining the requirements and provide a detailed description of the virtual wire system. Additionally, exploration of the impact of virtual wires on Swedish maritime operations and vessel management.

2. Work Package 2: Practical Testing and Evaluation
   practical implementation. plan and define tests, develop specialized testing equipment, and evaluate the functionality of virtual wires onboard vessels. Data collection, usability analyses, and risk assessments are integral parts of this stage.

3. Work Package 3: Policy Lab
   regulatory challenges and opportunities related to virtual wires. Drawing from Finland's best practices, policy hurdles were identified and how virtual wires can be applied effectively in Swedish waters was explored. Collaborative workshops with reference groups and industry stakeholders played a crucial role.

4. Work Package 4: Project Coordination and Disseminations.

## 1.3 Method

The project investigated what the current state of the virtual wire concept was in Finland and how the process had been laid out in Finland. RISE Policy lab concept was used to support the legislative investigation and evaluation of relevant regulations. This is described in 1.6 Policylab below.

Once this was outlined, the involved parties in the project did not deem it suitable for immediate use in the Swedish context, due to lack of connection between ships propulsion system and virtual wire system. As with a bit of increased automation on the ferries has the potential to operate in similar fashion as cable driven ferries and its redundancy and safety principals were preferable. There was also a desire from Färjerederiet that the resulting system suggestion from the study, can operate almost equivalent to ordinary cable driven ferry in the same manner as how they are operated today, meaning that it can be operated using only a lever that regulate the speed and nothing else.

Then the question arose regarding if there are any differences in the legislation regarding a cable ferry in Finland compared to how it is viewed in Sweden. There are differences, and in Sweden there are options to ask for applying foreign policy within Sweden but as the Finnish technical requirements for virtual wire system was repealed 2023-05-01 this is no longer an option.

In parallel documentation from reference group Marstrand municipality i.e. ferry LASSE-MAJA III was collected and reviewed to establish operating procedures, which was taken into consideration when defining the concept of operation.

The study has used several different methodologies concerning risk analysis and their pros and cons are described in detail under each individual risk analysis below in section 1.4 Risk considerations. A brief literature review regarding legislation concerning ferries have been conducted on the Finnish and Swedish legislation. A RISE-developed software, Crownest, was utilisied to make a mock-up of the setup for initial evaluation.

Additionally, information regarding processes onboard and system onboard have been gathered by onboard visits where crew have given a guided tour of how they operate their ships on a daily basis.

The above resulted in a Concept of Operations for Färjerederiets ferry service Isöleden and a field test setup including lidar at Lilla Varholmen to establish a suggested technical solution. This was demonstrated on Zeabuz passenger service across Riddarfjärden.

## 1.4 Risk considerations

The virtual cable system is designed and conceptualized to exceed the functionality given by the physical cable which is to give navigation guidance and limit how far the ferry can deviate from the route. The system design and its primary function can be referred to in section 3.1.4 Virtual Cable System Design. Since this is a new system in its design, concept and operation, therefore, to perform a holistic risk assessment with critical considerations of the virtual cable system are essential. This helps to better understand the system limitations and take mitigative actions wherever necessary. A combination of various risk assessment methods was used, namely:

- RBAT - Risk Based Assessment Tool
- HAZID - Hazard Identification
- Hazard Mitigation Analysis
- D-FMEA - Design Failure Mode And Effect Analysis
- Fault Tree Analysis - Event Tree Analysis - Bow Tie Diagram
- What if Analysis

***Assumptions:***

In relation to the risk considerations for the virtual cable system, the top risk scenarios are outlined to be of main interest. This means, events with catastrophic impact and severity of consequence are prioritized for risk considerations. Primarily, four modes of operation of the virtual cable system are investigated to limit the possible combinations of scenarios that are of scientific interest to the project. The four modes of operation of the vessel are namely; docked state, departure state, crossing state, docking state (See Figure 14 Flowchart showing the regular operation of the virtual wire system.).

### 1.4.1 Reflections on risk considerations

Selecting a single risk management approach that can be applied to identify, assess and evaluate risks, with corresponding mitigation measures, is complex. It is a complex task because in the newly conceptualized virtual cable system several parts of operation are based on concepts, tests and simulation only and the real time operation is yet to start. The complete picture of system functionality, goal definition, functional boundaries and operational interdependencies remains unknown. In other words, several questions are yet to be answered as the virtual cable system is still in its early concept development stage. The entire process from the virtual cable system ideation, conceptualization to design freeze and operation in real time has not been fully achieved. Therefore, to be able to fill in the gaps, inspiration and assumptions are also drawn from already operating physical cable driven ferry routes in Sweden. The virtual cable system is interpreted as a digital autonomous system on top of a physical cable driven ferry.

Given this background, the selection of risk approaches in this project and their respective rationale behind can be more accurately understood when interpreted as a risk consideration journey. More specifically, a multi-dimensional risk approach by applying a combination of various risk assessment methods that can fill in the gaps in the best way possible. This approach of using a combination of various risk assessment methods is also known as Dynamic Risk Assessment (DRA) which is well accepted and appreciated in system design and system engineering disciplines. DRA is clearly advantageous in the sense that it is better equipped to cover risk and critical considerations from various perspectives (Villa et al., 2016; Kalantarnia et al., 2009). Below, the risk management approaches is described in brief followed by the rationale behind selecting the approach.

### 1.4.2 Risk Based Assessment Tool

Risk Based Assessment Tool (RBAT) tool is a risk-based assessment tool developed by EMSA together with DNV-GL to identify top risk scenarios arising from functional failures at system, sub systems or system components level. The tool is aimed at creating an overview of functional interdependencies in relation to the risk scenarios. In operationalization of RBAT tool, risk, corresponding mitigation measures and severity are defined as follows:

"*Risk shall be evaluated as a function of consequences of the unwanted event and mitigating measures implemented to reduce consequences/recover a system to a safe-as-possible-state*".

*"Severity is understood as a degree of impact on safety (e.g., human safety and system degradation leading to an accident), while mitigation refers to how successful a response is at reducing consequences of unwanted event by preventing the impact or losses"*.

Overall, the RBAT tool aims at consequence/unwanted events arising from functional failures and corresponding mitigation measures that can be taken to reduce the impact of such failures. Due to this, the tool further undertakes functional goals and goal breakdown approach while identifying and assessing functional failures. Originally the tool was being developed to be able to compare the concept of operation (ConOps) for various types of ferries as test cases for the MASS concept (Maritime Autonomous

Surface Ships). The development, operational and motivational principles behind RBAT are still in progress by EMSA and DNV-GL (EMSA Report No.: 2021-1343, Chapter 3, 2021).

***Why RBAT?***

RBAT is the one of the most novel risk identification methods, especially introduced to be applied and evaluate the MASS concept test cases together by EMSA and DNV-GL. Therefore, it seemed to be a reasonable choice, given the autonomous digital interface design function conceptualized for the virtual wire project. The tool fit the purpose, context and intended application well. While on one hand, the design function breakdown can be captured well at various system and system component levels through RBAT, one the other hand, in this case capturing the desired level of risk interdependency by constantly zooming in and out at system and sub system levels turned out to be particularly challenging while using RBAT. More specifically, risk evaluation via some specific scenario determination seemed more reasonable way to proceed. Moreover, as RBAT is inherently structured to accommodate the comparison among various overall safety test cases of MASS concept ferries with high level functional breakdown, in this case of virtual cable system the context seemed to fit but not the scope of investigation that was desired neither the boundary conditions. Having said that, the RBAT method still applied to the extent possible that seemed to fit the scope and boundary conditions while taking the evaluation based on scenarios as an additional risk evaluation method to capture the dynamic nature of the risks that may arise in the virtual cable system.

### 1.4.3 HAZID

Hazard Identification (HAZID) is the first step in risk assessment according to the ISO 31000: 2018 Risk Management Guidelines. As the name suggests, HAZID involves identification of hazards and top risks. The top risks and hazards identified are further assessed and evaluated in the steps risk analysis and risk evaluation. These first three steps, namely, hazard and risk identification, risk analysis and risk evaluation, together make up risk assessment according to the ISO 31000: 2018 Risk Management Process (ISO 31000, 2018; Gjerdrum & Peter, 2011). Often these steps are confused and misinterpreted because of the closely related terms. Regardless of confusion among terminologies that are used or the chronology of risk methods, hazard identification followed by risk analysis and risk evaluation is well established practice and widely used across all disciplines, branches and industries. Hence, the introduction of the ISO 31000 Risk Management Guidelines which highlights the recommendations for best practice. Typically, a HAZID is followed by commonly identified mitigation measures which enables the stakeholders to prioritize actions (also called risk actions) and assess what more can be done in terms of mitigation and plan for contingencies. Mitigation measures can be taken either to prevent top risks from occurring or to reduce the severity of impact of the identified top risks. The mitigation measures are also classified under currently existing and potential, depending on evaluation of the currently existing mitigation measures (Deyle et al., 1998; Lacasse et al., 2012; Berke et al., 2012). A more detailed account of the mitigation measures and their assessment and evaluation is described in the following sections under mitigation analysis. The figure below describes the Risk Management Process according to the ISO 31000: 2018 Risk Management Guidelines. The orange rectangle in the figure depicts the risk assessment which consists of 3 stages as described above while the red rectangle depicts HAZID – risk identification, which is the first stage of the 3 stages in risk assessment according to the ISO 31000: 2018 Risk Management Process.

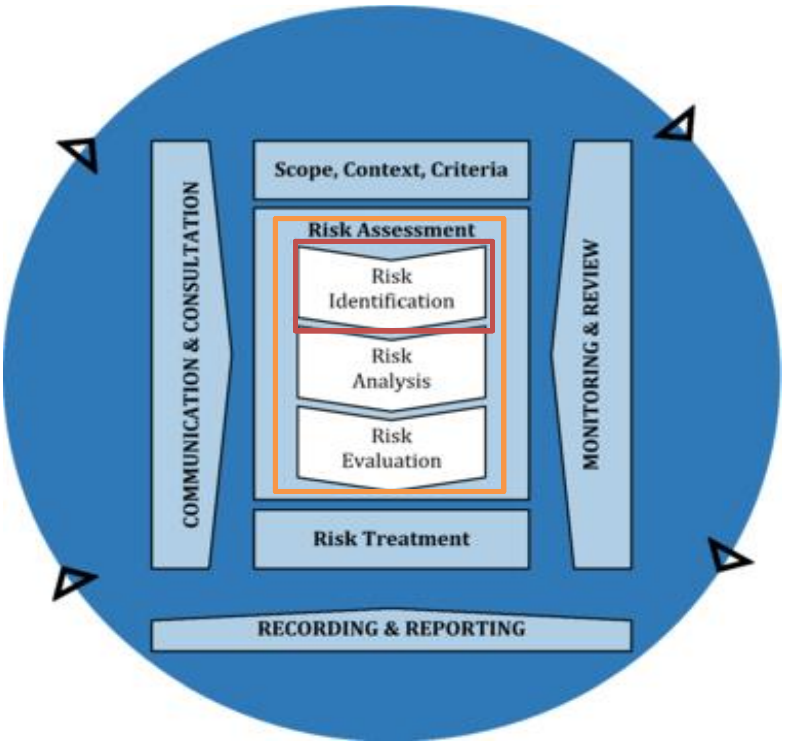



Figure 1 ISO 31000: 2018 Risk Management Process. Adapted from source: ISO 31000: 2018.

***Why HAZID?***

HAZID is a well-established method across various disciplines to identify top risks and hazards. The purpose suits the risk identification method for the virtual cable system. Furthermore, the HAZID method also accommodates in-depth assessment and evaluation of potential mitigation measures. With its scope and helicopter overview of various perspectives to weigh the risks, assign score, assess severity of impact with respect to risk identified, HAZID as a risk identification tool has a lot to offer to critically think, assess and evaluate. For several scientific and business innovation projects, HAZID has been widely used in various stages, right from conceptualization to launch.

## 1.4.4 Mitigation Analysis

Mitigation Analysis, better known as the Hazard Mitigation Analysis, is understood in context of Hazard Identification (HAZID) and mitigation measures taken or potential mitigation actions recommended corresponding to the hazards identified. According to the ISO 31000 Risk Management Framework (2018), hazard mitigation analysis is a step in risk management following the hazard identification (HAZID) (Olechowski et al., 2016; ISO 31000: 2018). Mitigation measures are categorized into existing mitigation measures corresponding to the hazards and potential mitigation actions which are not currently existing but must be developed considering the hazards identified and their overall impact.

***Why Hazard Mitigation Analysis?***

The hazard mitigation analysis in this case becomes a reasonable choice due to the scope of the method to capture the functional design mitigation actions in relation to corresponding risks. As already mentioned, the virtual cable system is designed as a digital system over the physical cable system. Therefore, the design thinking is based on, should there be any functional hazards or risks associated with the digital interface, it is mitigated by decoupling the digital interface from the physical drive system. In other words, mitigation measures are formulated as system fallback states with gate system. Each fallback state refers to corresponding gate that can be understood as various functional layers through which the complete decoupling occurs or can be achieved by separating the digital interface and giving full control or manual overrides.

### 1.4.5 FMEA

Failure Mode and Effect Analysis (FMEA) was first introduced by the US Military in 1940s and NASA used in 1963 for the Apollo Mission. In 1970s Ford Motor Company introduced it to the automotive industry. The failure identification method is based on heuristic context of failures in system, components, sub systems, product development and user cases where repair may be costly or even mean product recall or rollbacks from market or the industry in general. FMEA as a risk assessment method is widely accepted and used in aviation, aerospace & defense, automotive, and oil & gas industry among others. However, despite its wide popularity, the FMEA method is limited in its capacity to capture interdependency of failures, if the failure cascades from one system to another, or from one sub system to another. FMEA also does not consider human error (Breiing & Kunz 2002; Sharma & Srivastava 2018). In that sense FMEA must be limited to physical components, physical environment of the system and its primary functions.

***Why FMEA?***

As the virtual cable system and its concept of operation is still in its early design and conceptualization stages, a design (D-FMEA) seemed a reasonable choice to capture the design failures at the system level that might impair primary design functions. Instead of working through a fully developed D-FMEA with assigned RPN (risk priority numbers), in this case the D-FMEA structure, method and template are applied to identify the key design failures that might occur which might have catastrophic impact on system function.

## 1.4.6 Fault Tree - Event Tree- Bow Tie Diagram

FTA or Fault Tree Analysis is based on Boolean Logic structure capturing how a single failure often may ultimately lead to the top event or main event. The main idea is to identify causes of the failures and how they can contribute to the main event. Depending on the type of faults or failures each fault can either independently or concurrently be connected to each other replicating the branches of a tree. Hence the name, fault tree. The connections or branches are interpreted as failure nodes. The nature of the nodes meaning whether the failure nodes are independent or concurrent, is depicted by the Boolean Logic AND/OR gates. The fault tree with the nodes ultimately helps to constitute a bow tie model where the fault tree contributes to the main event or top event which results in consequent events or chain of events creating the bow tie. In other words, the left-hand side of the bowtie model depicts the fault tree which leads to the main event or the top event while the right-hand side of the top event or the main event depicts the consequence tree or chain of events. The right-hand side is also known as the event tree. The figure below shows a generic bowtie diagram with fault tree and event tree.

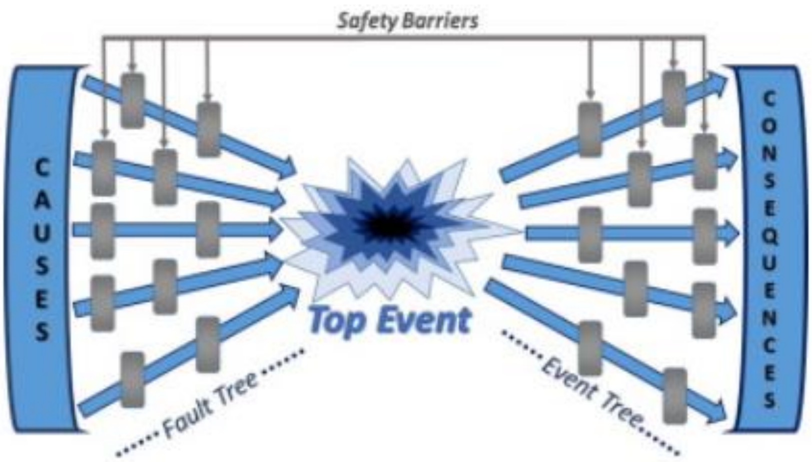



Figure 2 A generic Bow Tie Diagram consisting of Fault Tree and Event Tree. Adapted from source: Vila et al., 2016.

### *Why FTA/ETA- Bowtie?*

While the application of the FTA-ETA and bow tie diagram in this case, allowed to capture the top risk scenarios or top failure events or top faults on the left hand side of the bow tie, and at the same time constructing the right hand- side of the bowtie, which is the consequence tree or the event tree- (ET), sequence of events or consequences could not be captured due to the boundary conditions of our assumptions. To be more precise, the boundary condition and assumption for the virtual wire system is based on MOSCOW principle of prioritization (described below in the next section). This conscious choice has been made to delimit the top risk scenarios with catastrophic impact and consequence. The catastrophic impact and consequence are defined by potential loss of primary design function and/ or loss of life onboard. In other words, this means that the right-hand side of the bowtie diagram, which is the event tree, further analysis of other events which did not have catastrophic impact were consciously disregarded based on the boundary condition and assumption of the case.

## 1.4.7 What-if Analysis

The what-if analysis method enables to enumerate several scenarios of impact or consequence. It is commonly used in simulation, mathematical & computer based modelling and similar (Arsham & Kahn, 1990). The main purpose is to investigate specific scenarios of high impact and consequence based on several input parameters. What-if analysis is aimed to test the performance of a system, or system function through modelling and simulation. The scenarios of interest are built based on several input parameters. The selection of input parameters is not restricted or limited but commonly driven by business, project or scientific needs. The use of what if analysis is now extended to project management and contingency planning and similar.

***Why the What-if Analysis?***

The What if analysis seems particularly interesting in the case of virtual wire system because of the scope and the method that this tool accommodates. The main motivation behind using the What if analysis is to be able to identify the probable catastrophic scenarios and their impact in terms of severity, likelihood and mitigation measures. The selection of scenarios which were investigated was concluded by using the MOSCOW prioritization method. MOSCOW prioritization method is a novel technique widely used in software requirement gathering, and widely used in disciplines such as UI – User Interface requirement gathering, product launch market research, market research or requirement research prior to rolling out autonomous, AI, ML, digitalization features in products and similar. The MOSCOW principle is based on prioritization categories driven by functional requirements (Jahan et al., 2019; ProductPlan Glossary, n.d.) In this use case the first two categories, namely MUST HAVE-s and SHOULD HAVE-s were chosen. This is because these first two categories clearly have the most severe impact with the potential to impair the primary design functions of the virtual cable system, or even jeopardize lives on board and in the surrounding environment. Example subset of Virtual Wire - What if Analysis can be found in Appendix 1. Figure below depicts the MOSCOW prioritization principles based on prioritization categories.


Figure 3 MOSCOW prioritization principles based on categories. Adapted from source: https://www.productplan.com/glossary/moscow-prioritization/

## 1.5 Crowsnest user interface mockups

The Crowsnest is an open-specification research platform developed by RISE, accessible through any web browser and built on the React framework (https://react.dev/) for visualization of real-time data and using a microservice architecture where docker containers are used as connector or processor nodes. The purpose of the platform is to be able to easily design an own interface to connect sensors and process raw sensor data along with modular applying algorithms in whatever way is deemed suitable for the intended purpose.

This means that it has the benefit of being accessible from anywhere as long as there is an internet connection, local or over IP. One screen can show the user any number of different inputs from sensors.

Direct link to Github: https://github.com/MO-RISE/crowsnest

Mockups were used to explore concept development and potential audio alarms, based on discussion with project partners. It was found that the Zeabuz automation system included the components for the basic functionalities, therefore the need for separate development in Crowsnest was redundant. The project proceeded with an adapted branch of Zeabuz automation systems for practical demonstration of the virtual wire system functionalities.

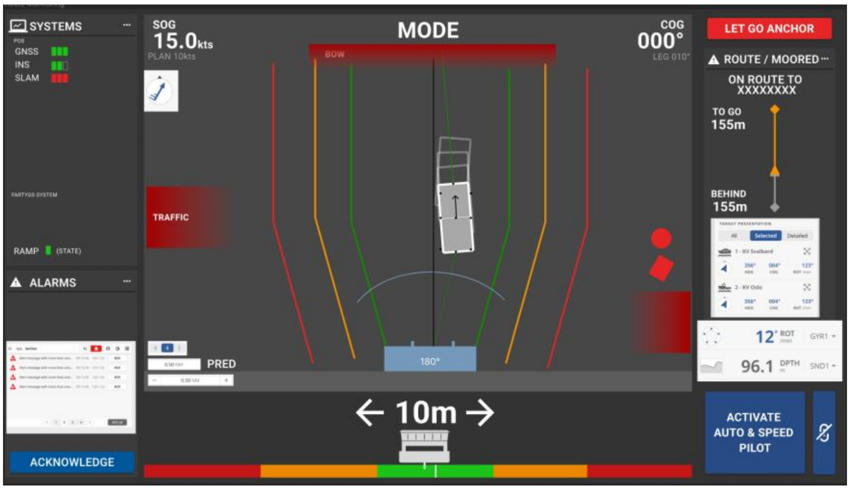



Figure 4 A Crowsnest mock-up of virtual wire operator display.

# 1.6 Policylab

The Policylab methodology involves a multidisciplinary exploration of obstacles and opportunities linked to policies. The method is used both in practical cases where there are regulations to comply with and in more visionary situations where few regulations exist. Actors participate with their cases and contribute with domain expertise. RISE participants offer competence in law, technology and design as well as experience from previous labs and process management. However, the participants do not solve the problems for the case owners, but together with them. The method is based on understanding needs, an iterative and multidisciplinary approach and prototyping with concrete tools or scenarios. In international comparisons, the policy lab has focused on actual cases rather than abstract concepts. Other labs have used artistic or design-based methods, but these are difficult to implement in digital meetings. Thanks to its legal and technical expertise, the policy lab has been able to immerse itself in legislation and identify challenges and opportunities.

The project started with workshop with all the involved parties in the project as well as the CEO of the Finish company FINNFERRIES and their technical supplier REWAKE. The reason for this was so that the latter could share their process towards the regulatory body in Finland regarding shipping called TRAFICOM. FINNFERRIES shared documents regarding the system that they have developed and now implemented and since September of 2022 is a ratified regulation in Finland.

The documentation provided between TRAFICOM and FINNFERRIES was written in Finnish, thus a process to translate these documents had to be started.

# 2 Context regarding cable ferries and autonomous ferries

The study identified several misconceptions regarding the operation and functionalities of cable ferries. It became evident that cable ferry and guide wire system designs vary significantly, often tailored to specific routes. Table 1 provides a summary of the Swedish cable ferry fleet, categorized into three main types.

**Swedish policy definition of cable ferry**

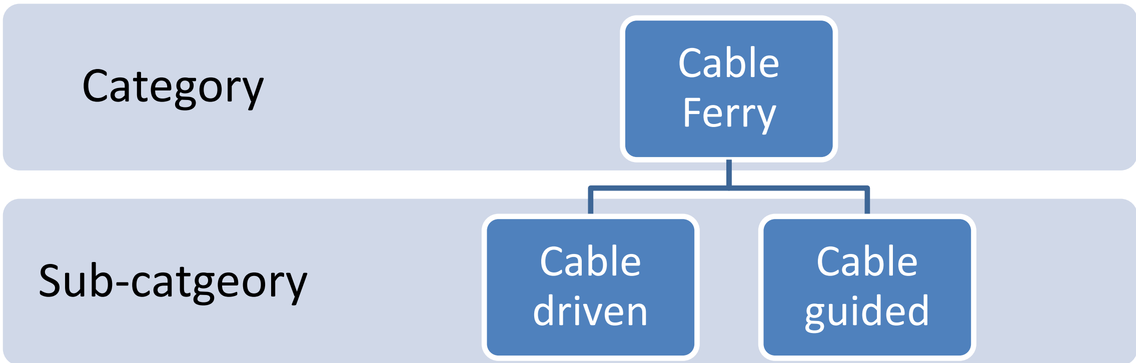
**TSFS: 2009:44**

7.16

Linfärja En linfärja ska framföras med hänsyn till den korsande trafikens möjlighet att undvika kollision med färjans lina, vajer eller kätting.

Bilaga 2

Definition linfärja: färja som drivs eller styrs med lina, vajer eller kätting



**Swedish fleet of ferries**

| Type | Quantity |
|---|---|
| **Cable ferry (Linfärja)**<br>Ferry driven or guided by cable, wire or chain | 21 |
| **Cable guided ferry**<br>Ferry that is guided by physical wire, all propulsion system except cable driven | 2 |
| **Cable driven ferry**<br>Cable Driven, guided by wire | 19 |
| **Ferry**<br>Ferry with conventional propulsion (No wires at all) | 47 |
| Färjerederiet total ferries | 68 (2022) |
| Ferry routes | 40 |

Table 1 Fleet quantities of main ferry categories (Trafikverket, 2023)

## 2.1 System description of cable driven ferries

The conventional propulsion system consists of two winches placed on one side of the ferry, in line longitudinally on a bed. These are driven by either hydraulic motors or electric motors via reduction gears. When operating the ship, the forward winch pulls in a wire that is attached to the opposite shore, while the aft winch pays out the wire attached to the shore the ferry is leaving. The paying-out winch has a braking torque of around 15% to keep the ferry on a straight course. The wire is routed via sheaves and rollers (pulley blocks) forward and aft on the ferry and into the winches, which are always located amidships on the starboard or port side. In general, there are two types of systems: electrical and hydraulic. The electrically driven winches have a "parking brake" in the electric motor that can be engaged when the ferry stops. The hydraulically-driven winches have a pawl that can press against a toothed wheel on one side of each winch drum to hold the drum(s) still (parking brake) during loading/unloading. On the opposite side of the vessel, a "steering wire" is laid out from one side of the fairway to the other. This wire passes over two or more wire guides (pulley blocks) forward and aft, and rollers along the side, with the purpose of keeping the ferry on the correct course through the weight of the cable itself. Depending on the sag (catenary) of the wire, the ferry cannot drift further from the center of the fairway than the wire's sag. The advantage of this system is that in ice, you can pull as much as the winch capacity without the wire slipping, which can occur with the other propulsion systems mentioned if the wire tension is insufficient, which would then obstruct passing traffic. On the steering wire side, there is often a "parking brake" that is activated (grips around the wire) when the ferry has settled in the berth, to prevent the ferry from drifting out of position during loading and unloading. Note that there is no brake to use while underway, other than shifting to neutral and letting the ferry stop on its own, which works a bit differently depending on the system driving the ferry. With conventional drive, you can pull the control lever back, which will pull in the paying-out wire, but this risks damaging the equipment. The disadvantages of this system are that it is difficult to get the wires to lay perfectly on the drums, leading to greater wire wear and a lot of work "tapping" the wires right from time to time, unless a spinner is installed. A spinner could work, but often the speed of the wire is often too high for it to work well in these compact installations. Additionally, two equal-length wires are required, unlike the other propulsion systems.

Figure 5. Conventional drive: Top left Exterior of wire drums, top right the wire drums, bottom left the winch bed and hydralic brakes visible drums, bottom right: the compact area of the whole winch system.

Omega drive, or friction drive, is a propulsion system where the ferry is pulled forward on a cable, either by cable fitted on one side or by on a cables one on each side of the ferry. The Omega systems are always driven by electric motors in combination with reduction gears on Färjerederiets ferries. The term "omega" comes from the fact that the towing cable is led up through the pulleys fitted at the end of the ferry then lead to the omega winch, which consists of three pulleys – a set of 3 three drive wheels, one large drive wheel often around 1.1 meters in diameter and two smaller (around 800 mm in diameter) tensioning wheels. The drive wheel is placed in the middle and the tensioning wheels are at the bottom, front and rear of the drive wheel, so that the cable which is tensioned under the front tensioning wheel goes up over the drive wheel and down under the rear tensioning wheel, forming the shape of the Greek letter omega. When the drive wheel is set in motion, the ferry is pulled forward by the friction between the drive wheel and the cable in the chosen direction. Some of the ferries have this drive on both sides and are then operated simultaneously. On longer routes, there is an "electric axle" as it was found that the axle started to pull unevenly after a certain distance and the splitted system with two drive units allows the systems to compensate for differences like wire slip etc that can occure over time . On the ferries with omega drive on one side, there is a "steering cable" on the other side with the same function as on the conventional drive. The brakes function largely the same as on all of the ferries.

Omega Drive

Brake on electric motor between hydraulic drive

"Moped-Brake"

Figure 6. Omega drive

In recent years, Färjerederiet have developed the omega drive into another variant where an idea from Canada was modified. In Canada they often drive the ferry via two larger pulleys (over 60 inches/1500mm diameter) placed in a row, with one of them angled slightly, and the cable is wound around both so that the cable lies against the outer half (front and rear) of the pulleys. The cable is tensioned and the ferry is pulled forward on the cable through the friction between the cable and the pulleys when they are set in rotation. Another similar winch system at a company that use it to hold back long cables with a smaller diameter when they were to be spooled onto drums for delivery to various customers, developed its system to suit the shipping company. It works on the same principle as the one from Canada, but the one used in Sweden have smaller diameter drums (around 600 mm in diameter) and the drum is much wider than the Canadian pulleys. The drums have removable "shells" (interchangeable) where 4-5 grooves have been turned for the cable to run in. The drums are placed as in conventional drive and the cable is wound around them, i.e. under the front drum, further under the rear drum and up and back down around the front drum, etc. until the grooves are filled, and the cable is drawn out under the rear drum and towards the pulley packs/pulleys.


Figure 7. Canada drive

Some cable ferries (6 in total) are today powered by electricity from the shore, by using an electrical cable that is wound up on a cable reel (the same technical solution used on many electric-powered cranes in ports) The reel is placed at the end of the ferry closest to the transformer station located on land. The cable is drawn out from the reel as the ferry leaves the shore, and then wound back in again as the ferry returns. The reel has a pre-set torque that allows it to retrieve the electrical cable at a suitable pace depending on the ferry's speed.

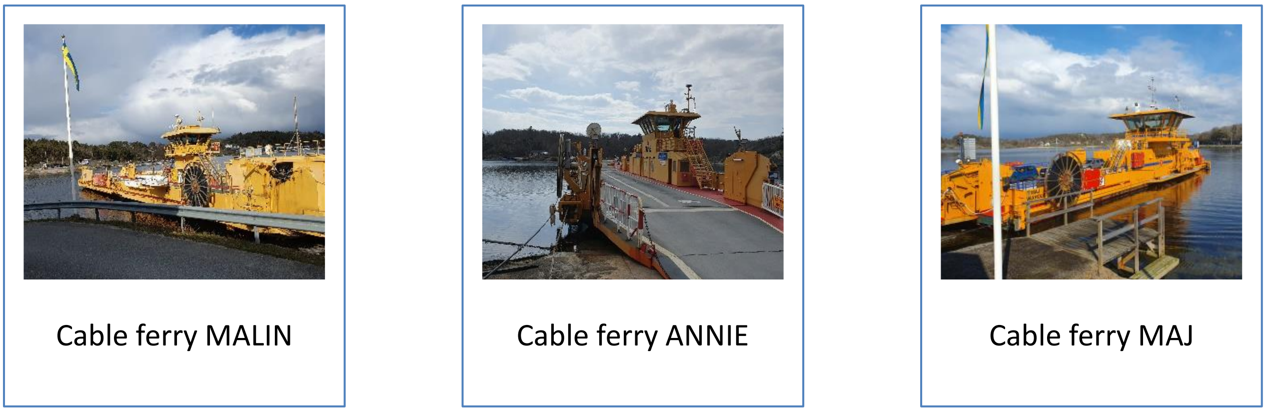



Figure 8. Electrified cable ferries with the reel for electric cable showing

These different kinds of systems can be used in different modes on cable ferries. In the examples listed below are some of the known setups used today.

- Dual command – cable drive P/S and S/B, allowing the operator to pull on each cable at their own command ie Kornhallsfärjan
- Single command Guide wire has brake capability (Sund-Jaren leden)
  One cable is for drive and one is only for guidance but the guidance side has a brake.
- Single command with Guide wire under tension that stretches out along entire route before departure which make the ferry align by only pulling in one cable. (Högsäterleden)

### 2.1.1 Operation of cable driven ferry

Operating a cable ferry is relatively straightforward - close the boom and lift the ramp when loading is finished, move the drive lever in the direction the ferry needs to go, and the ferry sets off. Arrival of a cable driven ferry can be challenging as there are more than one way to approach the dock. One method is to learn at what point one should completely release the lever and let the ferry glide in until it makes contact with the concrete landing. When the ferry has stopped, lower the ramp and open the boom. If the lever is released too early, one might need to drive forward again, which can cause the ferry to come in at a slight angle if it only has drive on one side. Although this may sound straight forward and easy to accomplish, in operational terms this requires lot of practice for the ship operator who also has to factor in the changes in wind and water currents and how that affects the ferry.

## 2.2 Guide wire function

The guide wire used on two ferries in Sweden today has only one purpose and that is to run alongside the ferries as a railing and by doing so, acts as a guide. As long as the ferry is maneuvered in a way that does not damage or break this guide wire, the ferry will reach its destination. Due to its small dimension this wire cannot be used for reducing speed of the ferry nor can it act as an extra mooring line and keep the ferry in position once it is alongside.

**Input from Finland " The guide wire does not work as a rail, a cable ferry does not run on rails. It's just a steering cable - if you steer the ferry off course, the cable breaks"** – (Fagerström, 2023)

It should be noted that the wire size can very between routes, according to Färjerederiet route Isöleden has stronger wire compared to guide wires usually found on Finnish installation.

**On cable driven ferry** in general the guide wire is expected to take external/weather forces and the weight of the wire is assisting the maneuvering. Example: this can be used for compensating wind gust as the ferry drifts from track, the wire stretches and the wire weight itself will pull back the ferry, almost like a pendulum swing.

**On cable ferry** the guide wire is not relied on in regular operation. The guide wire only assists if the ferry has moved past expected operation. Ex. Guide wire assisting to keep the ferry on rout in case of blackout.

The advantage of guided wire vessels is that under normal operation the ferry is restricted in deviation from route, decreasing the risk of navigational errors. The nautical requirements to be a captain on these kinds of vessel are generally lower than similar vessel sizes, and the amount of crew can be reduced according to the manning decision given to the operators of *Lasse-Maja III* by the Swedish transport agency.

Disadvantages of guide wire include the barriers that is created over waterways, posing a risk of collisions for passing traffic. Furthermore, cable ferries can currently only be installed where the route between the start and end points is completely straight (*Palvas, 2018).*

*"The increasing size of vessels diminishes the effectiveness of the steering wire , and the physical cable becomes an increasingly poor visual navigation aid as the distance between the captain/navigator and the cable increases with larger vessels. - Palvas, 2018"*

The key negative aspects of guide wire cables for ferries are:

1. Steering cables create a barrier over the waterway, requiring other maritime traffic to maintain a safe distance to avoid collisions. The cables quickly submerge but remain under tension, requiring traffic to wait until the ferry has crossed before passing.
2. The cables can disturb nearby ecosystems by stirring up sediments that may contain pollutants like heavy metals and environmental toxins. (Stockholms stad, 2018)
3. Seasonal ice formation limits the use of physical cables, due to the cable will run on top of the ice flow, and as the ice can move it risk tear the cable or potentially dragging the ferry along.
4. Requires straight routes limits which crossing points are suitable for guide wire. it is possible to rebuild some crossings, but it is very costly.

### 2.2.1 Cable ferry accidents

This section highlights a few cable ferry accidents from Transportstyrelsen that have occurred, and lessons learned from these accidents, impacted the designing of the virtual wire system that is suggested in section 4.

Färjerederiet: Since 2019, there has been an annual report on cable collision incidents.

Case number 8180: The cable ferry Gerd SFEP collided with a leisure boat. The cause was that the leisure boat's driver made an error in judgment while trying to pass the ferry. The leisure boat got entangled in Gerd's pulling cables.

Case number 8323: A leisure sailboat, that was making way under motor power, collided with the cable of the line ferry.

Case number 8411: When the Saga SIQM was about to dock on the Hamburgsö side, attention was drawn to a smaller boat that was supposed to pass. The boat operator on the smaller vessel was too eager and attempted to go behind the ferry before the cable had slackened. The boat disappeared before the Saga crew could determine whether there was contact with the cable and whether any damage had occurred

Case number 7675: The propulsion system of the Linfärjan ELVIRA consists of two 19 mm cables, each operated by its own winch. The ferry is steered by one 31 mm steering cable. At the relevant moment, the steering cable broke due to strong winds and wear. As ELVIRA was pushed sideways, one of the pulling cable also snapped. The captain managed to position the ferry using only one towing cable.

In 2016, there was a fatal accident in Norrbotten, where a man on a jet ski collided with a cable that drives a ferry." We operate 20 linfärjelder (cable ferries) throughout the country, and this is the first time an accident has occurred." You can find more information about this incident on SVT's website. https://www.svt.se/nyheter/lokalt/stockholm/farjerederiet

## 2.2.2 Crew requirements

A Transport Analysis report on the competence supply in shipping shows that in 2013, a total of 104 sea captains (Sjökaptensexamen) graduated in Sweden. In 2019, statistics showed that only 86 sea captains graduated in total from Linnaeus University and Chalmers University of Technology. This is a concerning trend, with approximately a 20% yearly decrease in sea captain graduates. The number of marine engineers who graduated also decreased by 30% during the same period. This negative trend will significantly complicate the ability to find maritime personnel with the appropriate qualifications (Transport Analysis, 2020).

Table 2 Table for limitation of service based on FB VIII- Inner waterways

| Gross Tonnage | Captain | Chief officer | Officer of the watch |
|---|---|---|---|
| <20 | X | X | X |
| 20-70 | X | X | X |
| 71-499 | | | X |

The table above showcase the limits based on "normal" vessels not Cable ferries

On most cable ferries today in Sweden the required certification is to have completed the course FB VIII – Inner waterways (no actual sea experience required) and then to undergo a familiarization on the specific vessel to be operated known as DoE.

In the examination for FB VIII - inner waterways there is no ECDIS (Electronic chart display and information system) requirement.

Cable driven ferries have existed for a very long time, traditional cable ferries have been operated with a solo crew member. The legislation and reasoning to have just a one-person crew as seen as adequately safe and the correlation to the use of a physical cable has not been found, most likely as cable ferries have been operated is such agreement for a long time, it is still the convention.

Similar vessels are not permitted to conduct to be operated single handedly.

In the past this was regulated by the "Sjöbefälskungörelsen" which was changed when STW (later STCW) and new training and command was implemented. The last Sjöbefälskungörelsen edition is from 1968 and was amended in a following memorandum in 1978.

There it was written: "Sjöbefälskungörelsen tillämpas enligt 1 paragrafen på alla handelsfartyg utom linfärjor och på fiskefartyg om minst 20 brt" (Sjöbefälskungörelsen, 1978)

Translated to "The maritime commander's announcement is applied according to paragraph 1 to all merchant vessels except cable ferries and to fishing vessels of less than 20 GRT".

The current regulation https://svenskforfattningssamling.se/doc/2024476.html (2011:1533) on authorization for sea personnel) does not retain the writing, but it is covered in the watchkeeping regulation. After that the “vakthållningsföreskriften” has the same scope in 2012:67 in the current consolidated edition. The only formal regulatory requirement for qualifications seems to be radio SRC (Short Range Certificate) if the cable ferry has VHF. Otherwise, according to the Swedish Transport Administration, the ferry company's own policy applies. In Swedish jurisdiction, the dangerous goods requirement seems to be missed, but probably covered by the Swedish Transport Administration's internal regulations/maritime safety system.

**TSFS 2012:67 Transportstyrelsens föreskrifter om vakthållning**

1 kap. Tillämpning och definitioner Tillämpningsområde

1 § **Dessa föreskrifter skall inte tillämpas på linfärjor.**

**-----------------------------------------------------------------------------------------**

**Translated**

TSFS 2012:67 The Swedish Transport Agency's regulations on guarding

1 ch. Application and definitions Scope

§ 1 These regulations shall not be applied to cable ferries.

### 2.2.3 Availability of qualified crew

The Swedish maritime industry is facing a severe shortage of qualified personnel. Over the next three years, the industry needs to recruit over 2,200 new employees. This shortage is already impacting the ability of companies to operate efficiently and is threatening Sweden's economic growth, which heavily relies on maritime transport (SVT, 2023).

The demand for maritime personnel far exceeds the supply, especially for deckhands, engineers, and officers. A shortage of qualified crew could significantly disrupt Sweden's sea transport both national and international, leading to economic consequences and decreases service offered i.e. number of ferry departures. Many experienced seafarers are nearing retirement age, exacerbating the shortage and there is a large need to attract younger people to seek a maritime career. Potentially better-tailored education programs and attractive work environment could assist. An improvement in the employer image of the maritime industry that can highlight the exciting and rewarding aspects of maritime careers is needed to attract young talent (Lighthouse, 2023).

## 2.3 Finlands Virtual Wire concept

In this segment, the report will refer to Finferries and Traficom, the Finnish equivalents of Trafikverkets Färjerederi and Transportstyrelsen in Sweden. In Finland, Finferries developed the concept of a virtual wire with Traficom as the governing agency. This development began already before 2018 to find a safer alternative to the guide wire (Olycksutredningscentralen, 2019)

In 1995, the Finnish "Vägverket" ordered an investigation into options for replacing the wire with another device. It was established that guide wire posed dangers to other maritime traffic passing and risks to collide with the wire. Additionally, the wires maintenance, infrastructure challenges, ferry geographical route and other incurred significant costs. It was also problematic that the ferry route needed to follow a straight line for the wire, and only one vessel at a time could be connected to the guide wire (Olycksutredningscentralen, 2019)

According to the investigation report of the cable ferry grounding on December 28, 2018, the primary function of a guide wire is to act as a visual steering aid, indicating the ferry's position relative to the passage track. While the wire can assist in maintaining direction to a limited extent, it is not designed to withstand continuous stress and can easily break under excessive force. Additionally, driving with a too steep angle against the wire should be avoided to prevent tearing. Therefore, operators must be careful to avoid overloading the wire. (Olycksutredningscentralen, 2019)

Ferry sizes has increased throughout the decades; therefore, the guide wire has lost it supporting function to assist steering (Åbo Underrättelser, 2022)

First test of the virtual cable system was tested on the Bergö ferry L-170 starting February 21, 2019. That route has significant challenges with the guide wire due to the rocky bottom topography. The cable could get stuck between the rocks, leading to either breaking the cable or causing significant wear and tear. This even increased the risk of the wire breaking and snapping back onto the deck. In ice condition the wire risks being stuck, laying on top of the ice and not sinking to the bottom after the ferry has passed and in such blocking the fairway. The guide wire also has a risk for negative impact on environment due to noise generation and wire lubrication along bottom sediment impact on nearby area (Rosin, 2023)

The functional principle of the virtual wire system is to be equivalent to a guide wire therefore the system is independent system from the ferry's other navigation system and steering control system, providing similar information as the guide wire did into a simpler and cleared digital form that is to be visualized on both the bridge and deck-mounted screens along with audio signal. The system is only an navigational aid for the operator. The operator maneuvers the ferry with a conventional steering control system, same as with a physical cable, there is no connection between the steering control and virtual wire system. The virtual wire system is fully automated and requires no interaction from the operator (Rosin, 2023)

### 2.3.1 Feed back from ferry operators

From the test on the finnish L-170 ferry, the feedback from ferry operators noted a simplicity and the system contributes to increased safety, especially under conditions with low visibility (Rosin, 2023)

The structures of ferry fleets of Sweden and Finland differ significantly. Sweden's largest ferry category is cable-driven ferries, while Finland's largest category is cable ferries with guide wires. In 2021, Finland's fleet had 33 cable ferries with guide wires (Åbo Underrättelser, 2022) compared to Sweden 2 ferries. Cable driven ferries are few in Finland but in Sweden it is the most common type of cable ferry.

It should be noted that the guide wire in Sweden is generally believed to be thicker compared to the Finnish guide wire (Färjerederiet, 2024).

Operator on Palvas expressed in the accident report that it is often easier and more efficient to drive a ferry with guide wire without a wire (Olycksutredningscentralen, 2019). The same comment was also noted during a visit on Marstrands ferry LASSE-MAJA III.

In discussions with Marstrands ferry LASSE-MAJA III operators expressed similar concerns and problematics with passing traffic and wire maintenance that have been noted in Finland. LASSE-MAJA III has also under an evaluation drill disembarked passenger to a pilot boat where the guide wire broke. The guide wire requires regular renewal as the wear and tear roughly on a yearly basis depending on the route.

### 2.3.2 FinnFerries virtual wire system

The virtual guide cable system developed by FinnFerries and Rewake, is a digital navigation aid designed to replace the traditional physical guide wire. This system is a stand alone and is not connected either to the ships steering or navigational systems. Instead, it supports the ferry operator by providing real-time positional and directional information relative to a predefined route.

The technology is largely based on the existing approved marine equipment commonly found on most ships, with additional functions based on geo-fencing and higher position redundancy in combination with a user-friendly visualization interface of the ship's relationship to the planned route.

The virtual guide wire system operates independently of the ferry's main navigation and steering systems. It automatically resets when the ferry reaches the end of its route or exceeding the pre-planned area ensuring continuous operation and never needs intervention from the operator. System changes can only be made by trained technicians when the ferry is docked. The system is isolated from external networks, minimizing the risk of interference or cyber-attacks.

The system overview can be seen in figure 5, it's components comprise of a GNSS (Global Navigation Satellite System), a central control unit, visualization screens both on the bridge and on the deck placed, and audible alarms. The deck screens are visible to both passengers and the navigator, replacing the physical cable that previously served as a visual aid. Below is a sketch of the system overview, consisting of antennas, receiver, Screens, speakers and to the far right is a depiction of LED-Displays that are placed out on the weather deck, visible for passengers and the navigator.

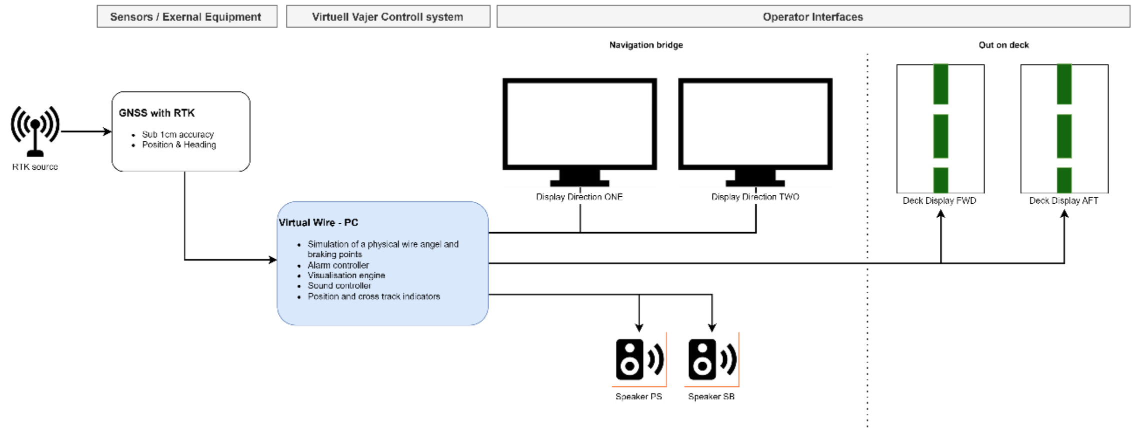



Figure 9. FinnFerry virtual wire system overview, consisting of antennas, receiver, Screens, speakers and to the far right is a depiction of LED-Displays that is placed out on the weather deck, visible for passengers and the navigator.

Virtual wire requires only position and heading data to operate and by using GNSS data, enhanced with RTK (Real-Time Kinematic) correction signals, the system achieves centimeter-level accuracy. The position and heading are then correlated to the pre-planned route and safety corridor indicating deviation from track.

It simulates the behavior of a physical guide cable by displaying the ferry's position in relation to the planned route and angle on the bridge and deck screens.

The system provides visual and auditory feedback, the visual feedback through a color-coded lane system displayed on screens. The lanes are numbered from -3 to +3, with the centerline at zero. Green indicates that the ferry is within the optimal lanes (-2 to +2), yellow indicates proximity to the route's edges (-3 and +3), and red warns of deviation from the route. Audible alarms complement these visuals, increasing in frequency and volume as the ferry nears the route's boundaries.

The ships operator will still maneuver the ship manually using the same levers, throttles etc. as usual. The difference is that in this setup the physical cable is removed and replaced with a screen out on deck that shows the vessel position in relation to the planned route and there is also the same information on the bridge for the operator to see and have audible alarms.

In case of blackout and propulsion loss, the system is configured to run on UPS. If the ferry drifts and with only environmental forces pushing, a conventional guide wire is expected to keep the ferry on route area. The equivalent solution would be an automatic emergency anchorage for the virtual wire system, this was deemed acceptable within the TRAFICOM/106399/03.04.01.00/2022.

The virtual guide wire system primary function is to provide the ferry operator with the same information about the ferry's position and heading that a physical guide cable would provide. The virtual system offers enhanced safety compared to physical cables, especially in adverse weather or ice conditions, where traditional cables might fail. It eliminates the mechanical risks associated with cable breakage and reduces the risk of accidents during cable maintenance and eliminates wire collision risk for marine traffic.

### 2.3.3 Finnish virtual wire policy development

Finland legislation adoption of alternative designs to guide wire inspired this project, and following is a summary of events and timeline related to adopting and removal.

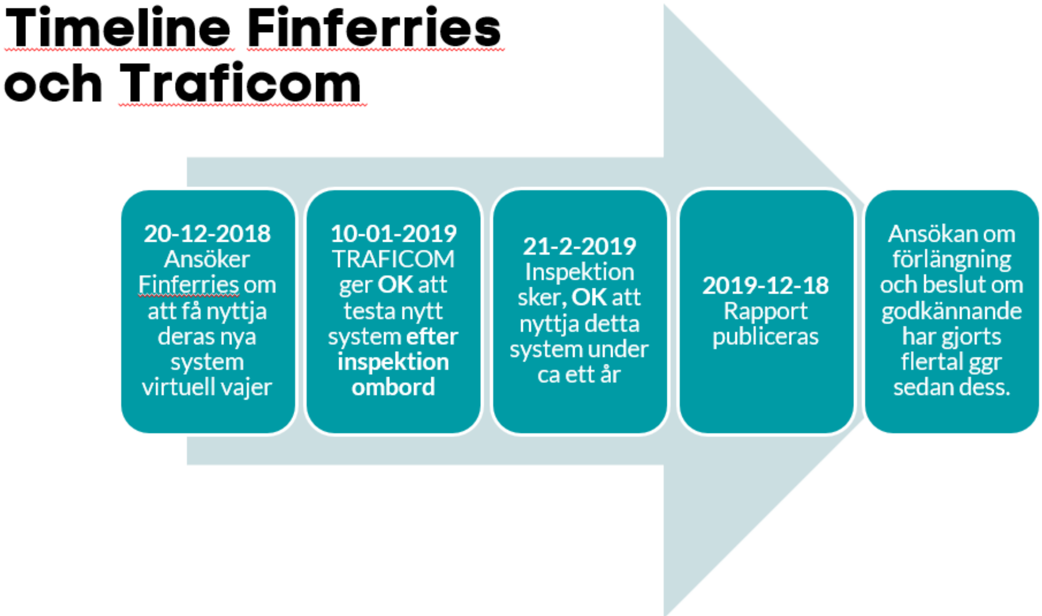



Figure 10. This picture showcases the milestones on a timeline of correspondence between FINFERRIES and TRAFICOM from left to right to get approval for the virtual wire concept onboard the route operated at Bergö in Finland.

**21.2.2019 - Virtual wire Commissioning control**

Inspection of the virtual wire system on the Bergö ferry route for final approval of commissioning.

**2021-05-03 – Extension application**

An application was made to extend the decisions (TRAFI/777482/05.01.08.12/2018 and TRAFICOM/579798/05.01.08.12/2019) to use the virtual wire on board the Bergö ferry.

**2022-06-08 - Approved an application for extension**

Approved an application for extension of continued use of virtual wire for test and development. On the grounds that during use of v**irtual wire system,** no such things have come to light that would prevent continued use of the system.

**2022-09-16 Finland, the authority had issued a technical regulation for virtual wire**

A sets functional requirement for a virtual wire system. On **September 16, 2022**, the regulation "Technical requirements for cable ferry steering cables and the procedure for approving such replacement devices - TRAFICOM/106399/03.04.01.00/2022", entered into force in Finland**.**

**2023-05-01 - Repeal of the regulation**

TRAFICOM found the regulation to be challenging in some aspects and revision needed to clarify technical requirements. TRAFICOM reached out to governmental agencies and industry for response on repealing the requirements, some of which;

**FinFerries** expressed support for the repeal. They believe that the repeal will allow for further development and testing of the alternative guide wire designs.

**The Centre for Economic Development, Transport and the Environment (ELY-Centre) of Southwest Finland** expressed its support for repealing the regulation. The equipment intended to replace the guide wire as required by the regulation differs significantly from the systems currently in use at some ferry crossings. Based on the experiences gathered, the ELY-Centre stated that the alternative equipment for virtual wire specified by the regulation is not suitable for short ferry routes. The ELY-Centre considers the system designed according to the regulation to be prone to malfunctions and noted that the regulation requires the equipment to provide significantly better and clearer audiovisual warnings about staying on the ferry route and the ferry's position relative to the route. Additionally, the ELY-Centre pointed out that the equipment intended to replace the guide wire, as built according to the regulation, disengages during evasive maneuvers, and in the ELY-Centre's view, it should automatically resume operation. The ELY-Centre deemed it necessary to repeal the current regulation and initiate a new regulation process that takes into account the appropriate functionalities, suitability for short ferry routes, and a sufficient level of automation. The ELY-Center also made general remarks about ferry traffic in the 2010s and commented on the problem points related to traffic with a traditional guide wire.

Sweden and Finland have differences in the regulatory structure, a comparison can be found in table below.

Table 3 Overveiw of regulatory structure in Finalnd and Sweden

| Nivå | Finland (backtrackat från Traficom 106399/2022) | | Sverige (baserat på Policy Labb Smarta Fartyg slutrapport) | | | |
|---|---|---|---|---|---|---|
| Parlament | Lag 1686/2009 Teknisk säkerhet och drift | Lag 503/2005 Trafiksystem och landsvägar | Väglag (1974:48) | Fartygsäkerhetslag (2003:364) | | |
| | 6kap. besiktning av färjor | 6§ Trafikfärja med kaj hör till landsväg, Traficom får föreskriva om vägfärjor | Färja med färjeläge ansluten till väg är väg | Betryggande säkerhet i relation till ändamål och användning | | |
| Regering med kansli | | Kommunikationsministeriet förordning om landsvägsfärjor (20/2006) | | Fartygsäkerhetsförordning (2203:438) | | |
| | | 1§ Definitioner | | 4 kap. §20 Tillräckligt med personal för att sköta evakuering (livbåtar mm)<br>4 kap §30 certifikat för personal | | |
| Myndighet | Traficom 106399/2022 Tekniska krav för vajerfärjor | | | TSFS (2017:26) Nationell sjöfart | TSFS (2016:81) Marin utrustning | TSFS (2009:1) Säkerhetsorganisation |
| | 1. Garantera säkerheten inom vajertrafik<br>2. Gäller ej frigående färjor<br>3. Vajerfärja kan styras med vajer eller annan av Traficom godkänd anordning<br>4.2 Hålla rutten oavsett väder (förankring ok), kunna förbikopplas, lämplig för omständigheterna, inte beroende av enskild elförsörjning | | | 1 kap §14 Sjösäkerhet Sammanhållet regelverk, riskanalys och empirisk data<br>10 kap § 1 och 2 Navigation (se även TSFS 2011:2 Navigation) | EU-fartyg | Ej bindande för statsfartyg, då gäller samråd med Transportstyrelsen |

In the Finnish concept, the cable ferries are equipped with a guide wire, which can be connected removed by decision of the company temporarily for up to 12 months. However, this does not affect the manning of the cable ferry, or the authorizations required of the driver. (Grounding Palvas, 2018)

In Sweden, if the guide wire is removed the manning level most be increased.

An innovative project with an electric cable ferry in Finland has been forced to stop after an administrative court ruled that the ferry cables pose a serious danger to maritime traffic. Although the project showed promising results in terms of energy efficiency and environmental impact, safety risks outweighed (Isabel Nordberg, 2022).

## 2.4 Norwegian Autonomous Ferrys

The Norwegian maritime sectors leading the path to Autonomous shipping, development is moving fast and with at least three vessels already in operation aiming toward remote controlled operations lessons can be learned even if a virtual wire system is not involving remote operation, but the technology underneath has potential to bring safety enhanced functions for manned ships.

The Norwegian company Asko is committed to achieving zero emissions in its operations and has invested in a pioneering, fully electric distribution solution for the region. A key component of this initiative is a new electric ferry line connecting Hortens and Moss across the Oslofjord. Asko's trailers are now transported on these low emission ferries, significantly reducing their carbon footprint.

The company aims to achieve its goal of zero carbon emissions from its logistics services by 2026. The electric ferry line plays a substantial role in realizing this vision.

While the current Asko vessels have a traditional bridge for manual operation with a crew on board, they also have the capability to connect to a shoreside operations centre. Once the autonomous technology is proven and receives necessary certifications, future vessels will be designed without a bridge, enabling fully autonomous operation. One of the largest obstacles to remote operation has been vessel connectivity "Seamless connectivity remains one of the key challenges for remote and autonomous operations, particularly in the open oceans" Pål André Eriksen (Maritime executive, 2024).

In June 2024, Kongsberg Maritime received approval in principle from DNV to enable the remote operation of Chief Engineer duties from a Remote Operations Center (ROC). The qualification processes followings the DNV's guidelines for Autonomous and Remotely Operated Ships (DNVGL-CG-0264) and Remote Engineering Monitoring and Control Systems (REMC) Kongsberg Maritime will continue to adhere to these standards during the qualification process to secure full approval (Kongsberg, 2024).

# 3 Färjerederiets Case for implementation of Virtual Wire at Isöleden

## 3.1 ConOps (Concept of Operation)

The physical cable on today's cable ferries drags on the seabed which does damage both to the cable and the ecosystem, and while also being a safety risk for for passing ships, boats and other vessels such as pleasure craft, kayaks, stand-up paddleboards (SUP) etc. Additionally, the cable limits the routes to a straight line between two berths. This reduces the number of suitable locations where a cable ferry can be used, and it might not be the best location from a transport logistic flow point of view either. The benefit of using a cable is that it aids with navigation, and it limits the ferry from drifting too far off the route if, for instance, the engine or rudder fails. This leads to reduced workload for the crew and increased safety.

The Virtual Wire system will reduce the need for maintenance as there is no physical cable to maintain as well as reduce the impact on the seabed. It will remove the risk of nearby ships sailing into the cable and enable cable ferries on non-straight routes and thus greatly increase the number of potential locations for cable ferries. The Virtual wire system will aid with navigation by ensuring the ferry is always on the correct track by controlling the heading of the ferry.

Färjerederiets cable ferry Fröja is used as a case study in the project. This ConOps will describe the operation of the proposed Virtual wire system on Fröja.

### 3.1.1 Organisation

The operation is organized with clear roles and responsibilities.

**Operator:** Färjerederiet is responsible for the safety management system and the ferry operation.

**Owner:** Färjerederiet is the owner of the ferry. Färjerederiet will be responsible for ferry maintenance under the safety management system.

**Virtual wire System:** Färjerederiet will own the virtual wire system and be supported by Zeabuz.

### 3.1.2 Traffic in the area of operation

The virtual wire system will notify the crew about traffic picked up by the systems sensors in the area of operation, also known as Operation Design Domain (ODD).

In the area of operation at Isö-leden it is common with smaller leisure crafts and vessels such as motorboats and sailboats but also smaller crafts such as kayaks, canoes and SUP’s This is typically restricted to Swedish summertime.

### 3.1.3 Ferry Design

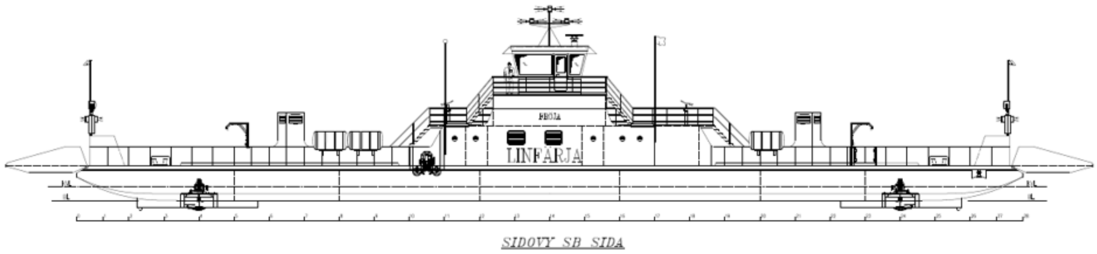



Figure 11 General drawing of Fröja from Trafikverket (Trafikverket, 2024)

Key design parameters for the ferry *Fröja*, based on its general arrangement drawing:

- Construction: Waplans Mekaniska Verkstad AB
- Cargo: 148 passengers and 42 cars
- Speed: Max 9 knots
- Propulsion: 2x pump jets
- Length: 63 meters
- Width: 13,7 meters

### 3.1.4 Virtual Cable System Design

The system is designed to exceed the functionality given by the physical cable, which is to give navigation guidance and limit how far the ferry can divert from the route. This is done by adding a software system which automatically steers the ferry along the planned route. With this system the navigator will only control the speed of the ferry while the system controls the heading.

This capability is based on an automatic system for motion planning and an automation system for actuation. The automation system comprises of the following functions:

- **Sensors,** including: radar, GNSS and AIS to keep track of own ship position and surrounding objects.
- **Object detection,** which processes sensor data and detects objects of interest for navigational decisions.
- **Situational awareness,** including sensor fusion and tracking algorithms that assess the most likely path for detected objects.
- **Motion planning,** includes modules for deciding heading based on current own ship position and the planned route. Motion planning also includes modules for docking and departure:

- ○ **Docking phase,** will ensure a smooth and safe docking of the ferry where the system steer the ferry, but the crew control the speed.
- ○ **Departure phase,** will release the ferry from the dock and allow for low manually controlled speeds, prior to commencing transit.

The automation system has the following functionality:

- **Automation system,** including positioning system and thruster allocation.
- **Actuator control,** including thruster and ramp control.
- **Traditional sensors & data sources,** provide additional data that is important for the automation systems.

The full system is illustrated in figure 8 below. Note that the figure shows the principle and not the actual implementation of functions in system modules. Blue boxes are the virtual wire system while the green boxes are other onboard systems. The illustration shows the complete system principle and interaction.

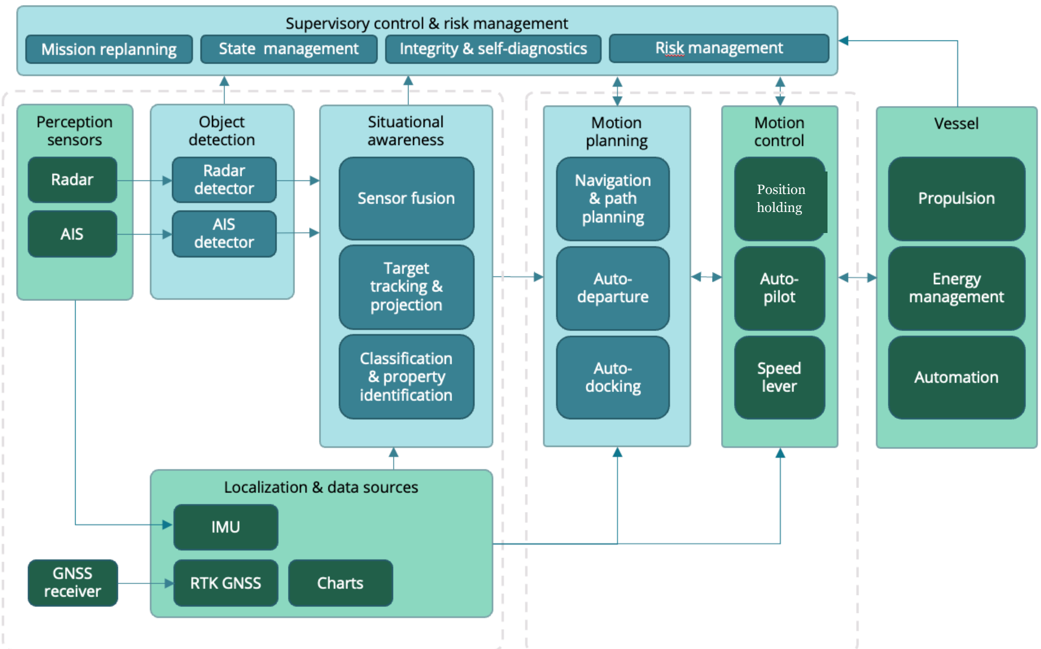



Figure 12 Virtual cable system illustration depicting the complete system principle and interaction with other existing onboard systems.

## 3.1.5 Operational area

The ferry operates between Norderön and Isön in lake Storsjön outside of Östersund, the crossing is approximately 1650 m long, and it takes approximately 11 minutes at normal service speed.

The environmental conditions in the area will be taken into consideration during normal operation. Under the winter months ice is expected yearly. During harsh weather, the ferry operation will be suspended.

This area of operation is considered as enclosed waters with very low traffic volume passing.


Figure 13 Area of operation between Norderön and Isön in Storsjön outside of Östersund.

## 3.1.6 Virtual wire operation

The virtual wire operation will have the same manning as a regular cable ferry has today which is a one-person operator. The navigator shall have the same competence and be supported by the same procedures as in regular operation in addition to the added procedures described in *abnormal situations*.

## 3.1.7 Normal Operation

During normal operation, where the system controls the heading, the navigator will have the following duties and responsibilities but not limited to:

- Responsible for safe navigation, look-out and ensuring that all systems are operational.
- Responsible for cargo and passenger handling. This includes limiting the number of passengers to max pax and ensuring that the ramp can be operated safely. It also includes ensuring smooth and safe embarkment and dis-embarkment.
- The first navigational action is to initiate the departure sequence, after ensuring that the correct number of passengers have boarded, that the area is clear such that the gate can be closed, ramp lifted and that there is no traffic in the vicinity. This is done by pressing the “departure” button which will activate the speed

lever. The ferry will now be navigated in low speeds to a point a few meters away from the quay.
- Once the ferry has reached this point it will automatically go into the crossing phase where the ferry can navigate at regular crossing speeds. During the crossing state the navigator controls the speed of the ferry with the lever while the system controls the heading. The navigator follows COLREGS by adjusting the speed to avoid traffic, just as a regular cable ferry.
- When the ferry reaches the docking zone outside of the quay the system automatically enters the docking phase which limits the speed to ensure a smooth docking. The system controls the heading all the way during the docking phase, but the navigator can take over full manual control of the ferry if needed.

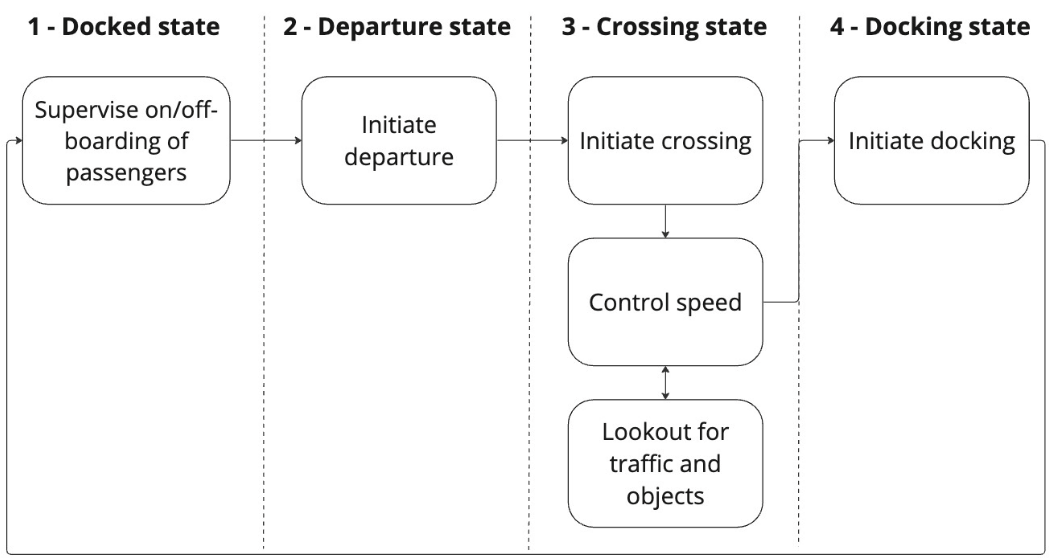



Figure 14 Flowchart showing the regular operation of the virtual wire system.

The navigator's primary means of control is a lever which can be moved forward to increase the speed or backwards to reverse, see figure 5. The navigator establishes situational awareness through his/her own senses, navigation instruments and through information from the automation system presented in separate touch panels, see figure 6. The touch panel also has buttons for "initiate departure", "initiate crossing", and "initiate docking", in addition to buttons to initiate each Fall Back State (FBS)

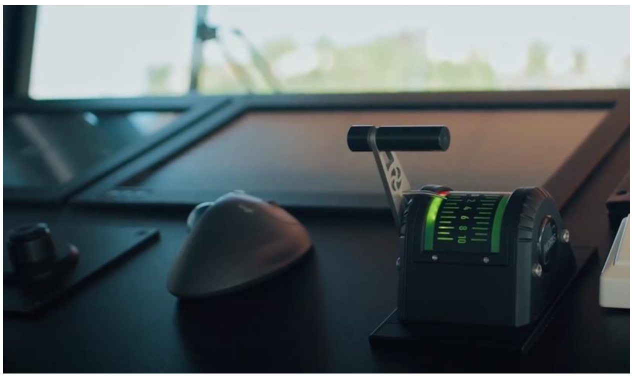


Figure 15 . Image of how the speed lever with two touch panels could look like on the bridge. (Source Zeabuz).

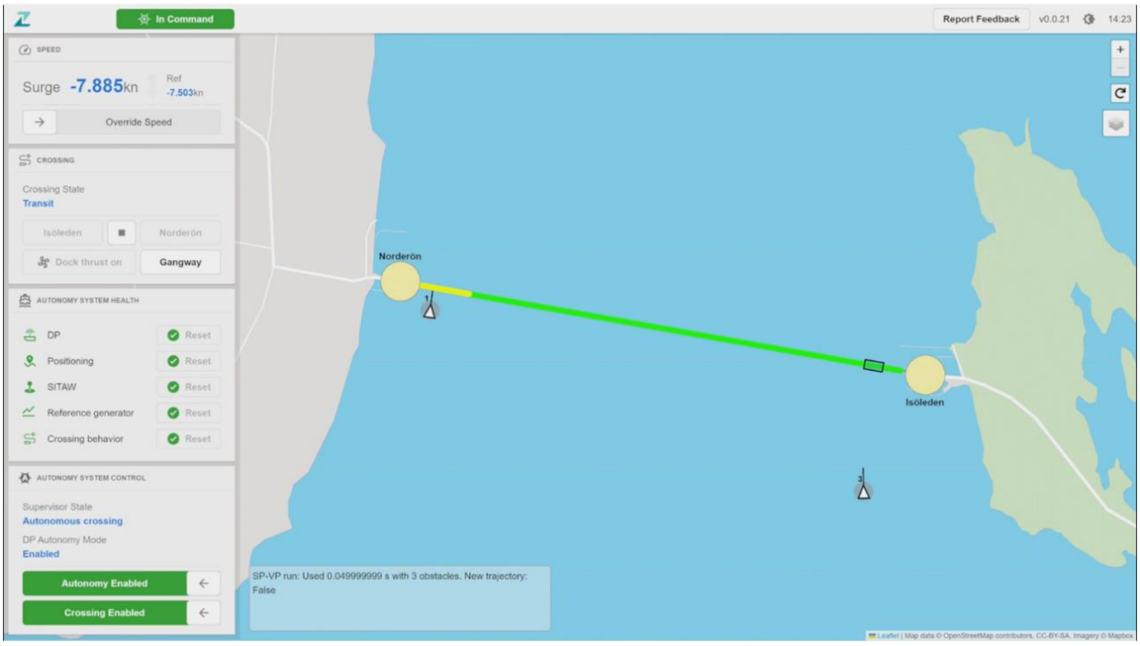



Figure 16 Suggestion of how the user interface of the Virtual wire System could look like. The color of the path indicates the reference speed during crossing state. The yellow circles indicate the departure and docking zones. The white triangles indicate the position and heading of surrounding traffic. A menu with control system information is displayed to the left. (Source Zeabuz)

### 3.1.8 Abnormal Situation

The navigator is responsible for detecting and handling operational situations where the virtual wire system fails, or when another abnormal situation occurs onboard. This includes, but is not limited to:

If safety appears compromised due to an apparent system failure, the navigator shall initiate Fall Back State:

- **FBS-I** disable the virtual wire system and transition to stay on location by motion control system only, similar today as stopping and hanging in the wire. After assessing the situation and ferry capabilities:
  - If deemed safe, re-initiate virtual wire system through the “initiate crossing” button and continue the crossing.
- **FBS-II** as today, operator take manual control using manual levers and controls. If needed reboot/resets system when docked.
- **FBS-III** as today, If it is not deemed safe to maneuver, stay on station-keeping, and contact emergency response according to established procedures.

All failures outside the scope of the system should be handled according to pre-existing company emergency procedures.

# 4 Practical tests

Practical tests using the Ouster OS2 lidar were performed at Lilla Varholmen ferry terminal, north of Gothenburg. Especially the potential use of existing reflective items, such as retroreflectors, to determine the direction of motion were of interest. The field test with lidar at Hönöleden shows that it is possible to track the motion of the ferry quite well.


Figure 17 Lidar setup on a foggy day and reflector setup on ferry and car ramp. In the top right picture, are two yellow retroreflectors encircled in red, placed on land on each side of the road.

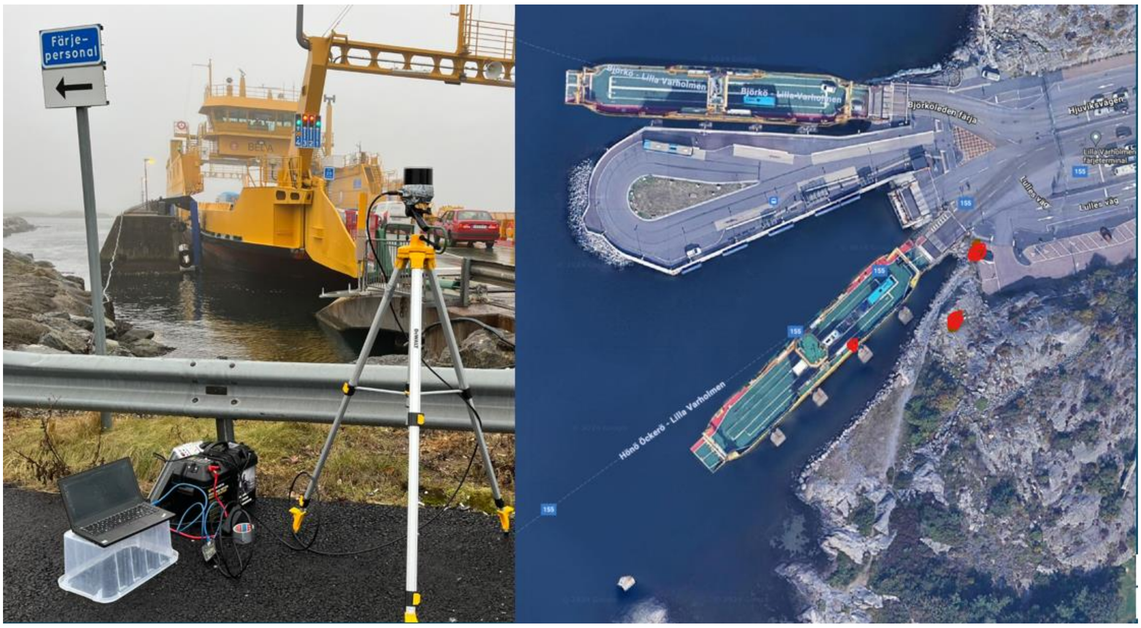



Figure 18 Portable LIDAR logging setup.

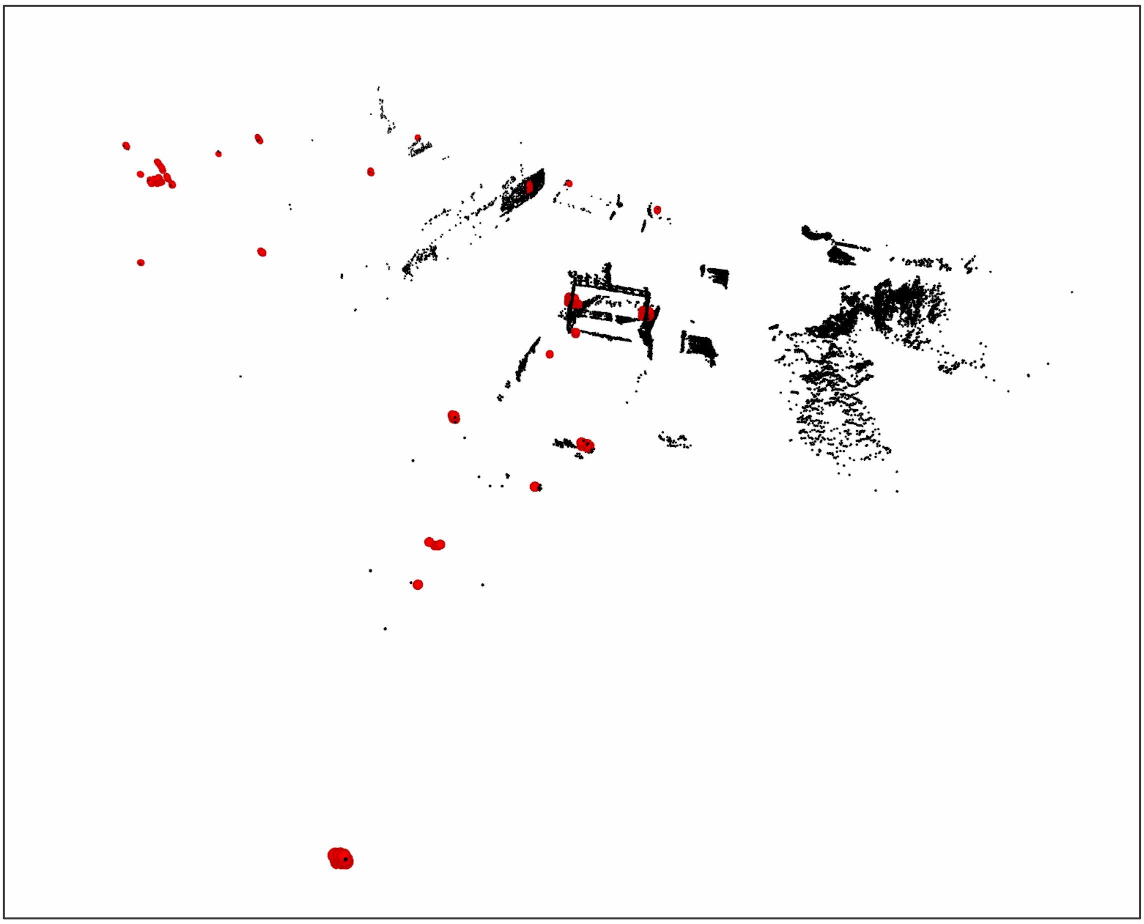


Figure 19 Point of view is from the ship at sea towards the lidar standing next to the ramp on shore. Red points are retroreflectors. Note for example the ones on either side of the gantry, in yellow close to land is clearly visible. The cylinders with retroreflective material on the bridge are also visible. There is also retroreflective material on vehicles aboard and on other signs or equipment.

Traffic signs such as the blue ones on either side of the ferry, guiding the embarking vehicles to their lanes has a reflective material. This means that a lot of intensity is returned from it back to the lidar, compared to more ordinary surfaces where light from the lidar reflects in all directions. The retroreflector is easy to find in the point cloud.

By tracking the retroreflectors, it is possible to determine the motion of the ship. This was tested and results from a straightforward tracker implementation using a Kalman filter is shown in the following figures. Two retroreflective objects on the ship have been selected: one of the blue lane marking signs near land and the other at the aft end of the ship, as far away as possible from the sensor. The distance between these two is constant. Both objects are visible in the point cloud shown above. The coordinate system used is the lidar sensor's own, which means that the origin (X=0, Y=0) is in the center of sensors lidar ranger. A trace of 25 consecutive points sampled during 2,5 seconds is shown. See the two figures below.

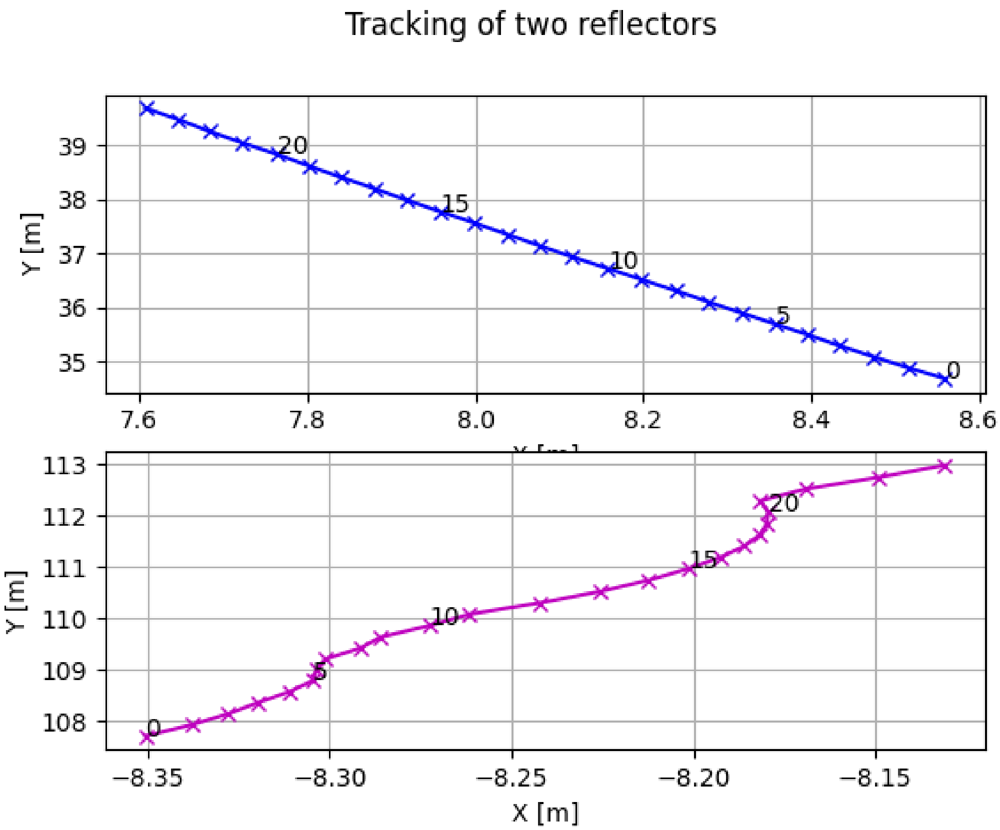



Figure 20 Tracking of two reflectors. One at each end of the ferry.

Two objects on the ship in planar coordinates (X,Y), where the sampling order is annotated along the line. The upper object is closer to the sensor. The X-positions vary in different directions, which means that the ship is turning slightly when it is leaving land. Note that the scales are different for all axes. The lower plot exposes the accuracy of the tracking result (filtered measurements) for a nearly constant X-value. The ship moves (and is accelerating) about 5 meters distance, for 2,5 seconds, which means that the speed is 4 knots.

The distance between the same two objects on the ship about 75 meters apart. During 25 samples, the measured (and filtered) distance varies within a decimeter.


Figure 21 Distance between reflectors.

The result that the relative distance between the two fixed objects on the ship, only varies within a decimeter, is promising for future usage of lidar technologies and more elaborate work on tracking record and report the motion of the ship close to land. In the future, lidars could provide higher precision than RTK GNSS and this is crucial during docking operations.

### 4.1.1 Brief comparison between guide wires and anchoring

The following are some simple calculations to compare the mechanical limitations between a guide wire and anchoring. The calculations are done with python and following sub chapters describe the mathematical formulas used and results. Numbers used might vary from reality and estimations are done for missing information, the answers are an approximation.

#### 4.1.1.1 Input data

**Ship information**

```
loa = 63                                 # m  (from GA)
beam = 11.7                              # m  (from GA)
draught = 0.8                            # m  (from GA)
displacement = 285                       # m3 (from GA)
anchor_weight = 200                      # kg (from email)
chain_length = 100                       # m  (from email)
mean_height_above_waterline = 3          # m (estimated from GA)
side_area = loa * mean_height_above_waterline        # m2 (estimated)
```

front_area = beam * mean_height_above_waterline *# m2 (estimated)*
Cd_x = 1.0 *# - (based on a similar ship shape in Brix Manoeuvring Handbook)*
Cd_y = 1.0 *# - (based on a similar ship shape in Brix Manoeuvring Handbook)*

**Guide wire information**
wire_mbl = 582_000 *# N (from email)*
assumed_wire_length = 1500 *# m (esimated, total length of wire is 1570m)*

**Route information**
start = (14.37900102293573, 63.138860268024423) # degrees *(estimated from map)*
end = (14.407126952066367, 63.136593198661444) # degrees *(estimated from map*

### 4.1.1.2 Calculating route length

wgs84 = nv.FrameE(name='WGS84')
start_p = nv.GeoPoint(longitude=start[0], latitude=start[1], degrees=True)
end_p = nv.GeoPoint(longitude=end[0], latitude=end[1], degrees=True)
route_length, _, _ = start_p.distance_and_azimuth( end_p )

Route length: 1441 m

### 4.1.1.3 Maximum movement sideways at route midpoint (geometrically)

**Envelope of guide wire**
max_deflection_at_midpoint = np.sqrt((0.5 * assumed_wire_length)**2 - (0.5 * route_length)**2)

Max deflection at route midpoint: 209 m

### 4.1.1.4 Limiting wind speed at route midpoint

Estimation of the limiting wind speed for the following condition:

- Vessel is stationary
- Wind coming from the side (vessel has largest wind area)
- Wire self-weight is disregarded

The limiting wind speed is found using the following steps:

1. Assuming max deflection to the side of the route (i.e using the result from the previous step), calculate the wire angles with regards to the straight-line route.
2. Use the MBL of the wire to find the maximum transverse holding force of the guide wire
3. Calculate the corresponding steady-state wind speed using the found maximum transverse holding force and the estimated side area and drag coefficient of the vessel.

***Initial check of wire structural integrity***
*At midpoint, with max deflection, will have the following angle deflection in comparison with the route line.*

angle_deflection = np.degrees(np.arccos((0.5 * route_length) / (0.5 * assumed_wire_length)))
transverse_mbl = np.sin(np.radians(angle_deflection)) * wire_mbl

*Which corresponds to the following wind steady-state wind-speed*

```
air_rho = 1.3
wind_speed = np.sqrt(transverse_mbl / (0.5 * air_rho * side_area * Cd_y))
print(f"Limiting wind speed: {wind_speed:.0f} m/s")
```

**Angular deflection of wire at base: 16 degrees**
**Maximum transverse holding force of wire (based on MBL): 162 kN**
**Limiting wind speed: 36 m/s**

#### 4.1.1.5 Anchor holding force estimates

The anchor holding force can be estimated using the formulas provided below. They differ depending on the bottom type.

In the following estimate, the limiting wind speed for the following condition:

- Vessel is stationary
- Wind comes head on
- Anchor chain self-weight is disregarded

The limiting wind speed is found using the following steps:

1. Calculating the maximum holding force for each bottom type
2. Calculate the corresponding steady-state wind speed using the found maximum holding force and the estimated front area and drag coefficient of the vessel

**Anchor holding force is estimated by**

$$F_{HF} = C_{HF} * m_{AN} * g$$

Where $m_{AN}$ is the mass of the anchor, g is the gravitational acceleration, and $C_{HF}$ is a non-dimensional constant accounting for the bottom condition and slope, assuming flat bottom, and using Saurwalt approximations for the different bottom condition (Saurwalt, 1975):

| Bottom type | Uneven rock | Solid mud | Sand | Water-mixed mud |
|---|---|---|---|---|
| $C_{HF}$ | 20 | 12 | 6 | 3 |

***Anchor holding forces for different bottom types***
*Here, the front area of the ship is used rather than the side area when calculating the limiting wind speed*

```
## Uneven rock
maximum_anchor_holding_force_uneven_rock = 20 * anchor_weight * 9.81
```

corresponding_wind_speed = np.sqrt(maximum_anchor_holding_force_uneven_rock / (0.5 * air_rho * front_area * Cd_y))

*## Solid mud*
maximum_anchor_holding_force_solid_mud = 12 * anchor_weight * 9.81
corresponding_wind_speed = np.sqrt(maximum_anchor_holding_force_solid_mud / (0.5 * air_rho * front_area * Cd_y))

*## Sand*
maximum_anchor_holding_force_sand = 6 * anchor_weight * 9.81
corresponding_wind_speed = np.sqrt(maximum_anchor_holding_force_sand / (0.5 * air_rho * front_area * Cd_y))

*## Water-mixed mud*
maximum_anchor_holding_force_water_mixed_mud = 3 * anchor_weight * 9.81
corresponding_wind_speed = np.sqrt(maximum_anchor_holding_force_water_mixed_mud / (0.5 * air_rho * front_area * Cd_y))

**Anchor holding force (Uneven rock): 39 kN which corresponds to a limiting wind speed of 41 m/s**
**Anchor holding force (Solid mud): 24 kN which corresponds to a limiting wind speed of 32 m/s**
**Anchor holding force (Sand): 12 kN which corresponds to a limiting wind speed of 23 m/s**
**Anchor holding force (Water-mixed mud): 6 kN which corresponds to a limiting wind speed of 16 m/s**

### 4.1.2 IACS equipment level

A tentative comparison with the International Association of Classification Societies (IACS) rules for sizing of equipment of vessels for unrestricted service.

- Estimate the Equipment Number (EN) for Fröja
- Compare with the expected level of equipment and the one found onboard

*# Comparing with IACS*
EN = displacement**(2/3) + 2 * (beam * 1.2 + 40) + side_area/10

Estimated IACS Equipment Number (EN): 170

**Table 1 Anchoring equipment**

| EN* | Stockless bower anchors | | Stud link chain cable for bower anchors | | | |
|---|---|---|---|---|---|---|
| | | | | Min. diameter | | |
| | No. | Mass per anchor (kg) | Total length (m) | Mild steel Gr. 1 (mm) | Special quality Gr. 2 (mm) | Extra special quality Gr. 3 (mm) |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 205-240 | 2 | 660 | 302.5 | 26 | 22 | 20.5 |
| 240-280 | 2 | 780 | 330 | 28 | 24 | 22 |
| 280-320 | 2 | 900 | 357.5 | 30 | 26 | 24 |
| 320-360 | 2 | 1020 | 357.5 | 32 | 28 | 24 |

Table source IACS Req. 1981/Rev.8 2023

| Ship chain proof and breaking loads | | | | | |
|---|---|---|---|---|---|
| Chain Diameter | Grades | | | | Min Weight (Kg per length of 27.5m) |
| | Proof Load, kN | | Breaking Load, kN | | |
| | $0.00981d^2$ (44-0.08d) | $0.01373d^2$ (44-0.08d) | $0.01373d^2$ (44-0.08d) | $0.01961d^2$ (44-0.08d) | |
| mm | Grade 2 | Grade 3 | Grade 2 | Grade 3 | Kg |
| 14 | 82 | 116 | 116 | 165 | 130 |
| 16 | 107 | 150 | 150 | 216 | 160 |
| 17.5 | 128 | 179 | 179 | 256 | 190 |
| 19 | 150 | 211 | 211 | 301 | 225 |
| 20.5 | 175 | 244 | 244 | 349 | 265 |
| 22 | 201 | 281 | 281 | 401 | 300 |
| 24 | 238 | 333 | 333 | 475 | 360 |
| 26 | 278 | 389 | 389 | 556 | 420 |
| 28 | 321 | 450 | 450 | 642 | 490 |

Based on the estimated IACS Equipment Number (EN): 170 the chain breaking load is som ewhere around 389kN which is well above estimated wind loads for this vessel, but the p roject do not have the information of actual chain used onboard Fröja.

#### 4.1.2.1 Stopping distances

When anchoring, the anchor might slide on the bottom for some distance before actually stopping the ship due to a combination of external environmental forces and vessel inertia. Below are some initial estimates for the "sliding distance" of the anchor before the vessel comes to a full stop due to inertia to give an idea about the magnitudes.

Based on the following assumptions:

- Initial speed when anchor chain is tightened is 6 knots
- Wind speed is 0 m/s

- Resistance of vessel is disregarded, account only for inertia

```
# Estimating stopping time and distance

def deaccelerate(initial_speed, holding_force):
  speed = initial_speed

  distance = time = 0

  while (speed > 0):
    acc = holding_force / (displacement * 1000)
    distance += speed
    time += 1
    speed -= acc

  return time, distance

## Uneven rock
time, distance = deaccelerate(3, maximum_anchor_holding_force_uneven_rock)

## Solid mud
time, distance = deaccelerate(3, maximum_anchor_holding_force_solid_mud)

## Sand
time, distance = deaccelerate(3, maximum_anchor_holding_force_sand)

## Water-mixed mud
time, distance = deaccelerate(3, maximum_anchor_holding_force_water_mixed_mud)
```

```
Emergency anchoring (Uneven rock). Time to full stop: 22 s, anchor sliding distance: 34 m
Emergency anchoring (Solid mud). Time to full stop: 37 s, anchor sliding distance: 56 m
Emergency anchoring (Solid mud). Time to full stop: 73 s, anchor sliding distance: 110 m
Emergency anchoring (Water-mixed mud). Time to full stop: 146 s, anchor sliding distance
: 219 m
```

### 4.1.3 Conclusions of wire comparison to anchorage

As the guide wire has a functionality of keeping the ferry within the designated route area, so should an equivalent system also function. The virtual wire concept exploring the use of emergency anchorage could be a sufficient equivalent system function.

As the load estimation are higher for anchorage then wire on the case of Isöleden, there appears to be an opportunity that anchorage could be equivalent. This is the belief that anchorage is equivalent safe to keep the vessel in its vicinity of it intended route in case of total loss of propulsion. At least on distances from shore where the anchor swing radius is not grater the position of the anchor location from shore. So outside docking/manuvering areas it is sufficiently equal.

Lessons learned from the Finish case with ferry L-317 that lost control just before (about 40 seconds) the jetty and collided first with the jetty (ferry-ramp) and then drifted away and collided with a second nearby jetty are considered. It is unknown whether an actual physical wire would have prevented or decreased the damage at least for the secondary collision, but with too many unknown factors it does not allow for any certain conclusions.

# 5 Results

The result brought forth by the project is to have a system that in all regards is similar to today´s operation of a ferry which makes way by pulling and is guided on a wire. The operator in this environment has a control lever on which the options are to either increase or decrease movement aftwards or forwards or simply hold still. With the automation system doing most of the work when it comes to maneuvering the vessel and keeping the vessel on track, it is allowing the operator to focus more on traffic and monitor the surrounding environment.

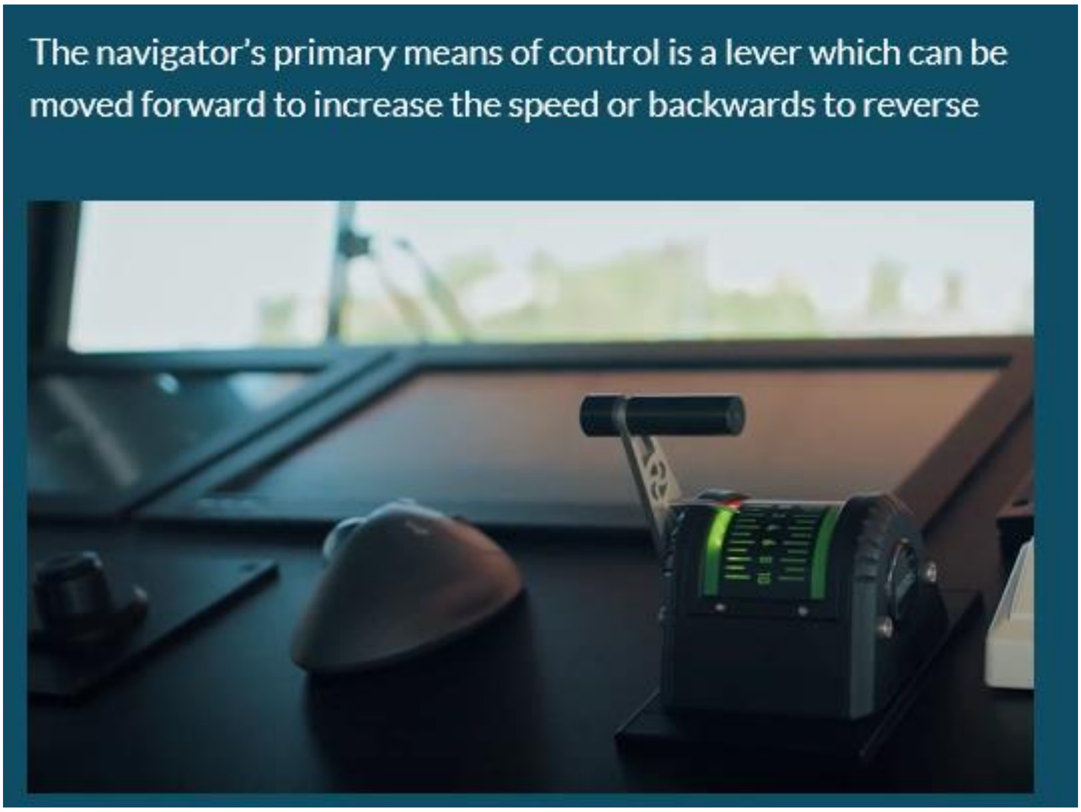



Figure 22 Main speed control lever. In total there are two speed control leavers, positioned so the operator has the lever in the line of traveling direction. (Source: Zeabuz, Estelle).

The operator can monitor the ship's state, position relative to track and traffic on a touch screen and is the primary way to interact with automation system. As this display is used as primary tool for navigation an ECDIS is not required or other electronic navigation system. As the interface is specifically designed for ferry crossing the system is much simpler to use compared to a ECDIS only necessary functions are included. Picture 20. displays the navigation exemplified for Isöleden.

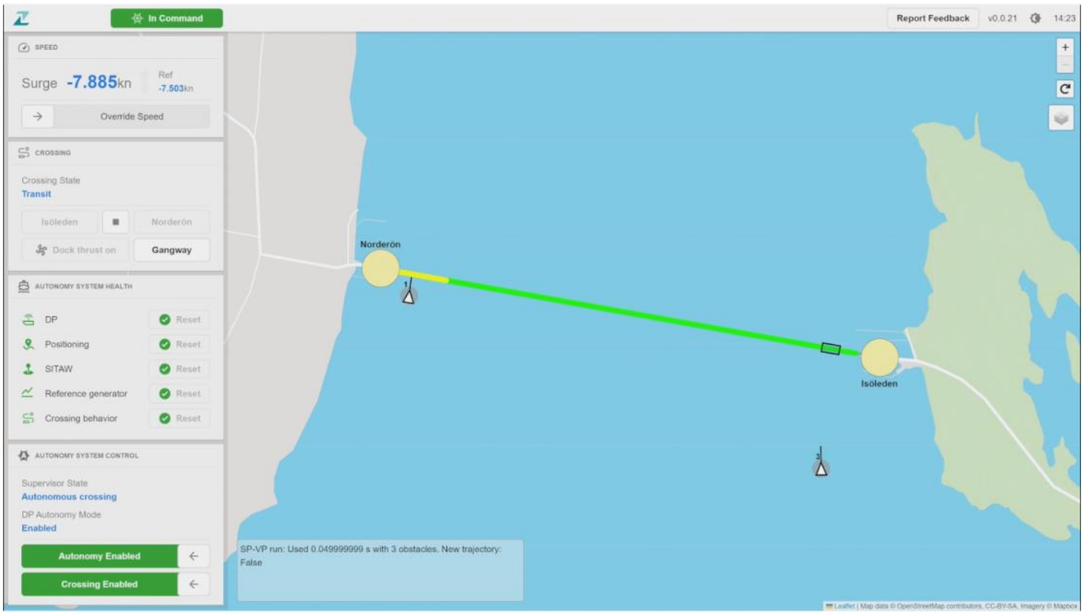



Figure 23 Showing the primary touchscreen display for the automation system (virtual wire).

## 5.1 Demonstration of concept

On May 27th 2024 the project demonstrated its concept on the ferry ESTELLE in Stockholm. The ferry is outfitted with a fully automated crossing capability, but by using a selected set of functionalities a virtual wire equivalent system was tested and demonstrated.

ESTELLE

Camera and LIDAR in each corner of vessel

Bridge overview


Ultrasonic parking sensors

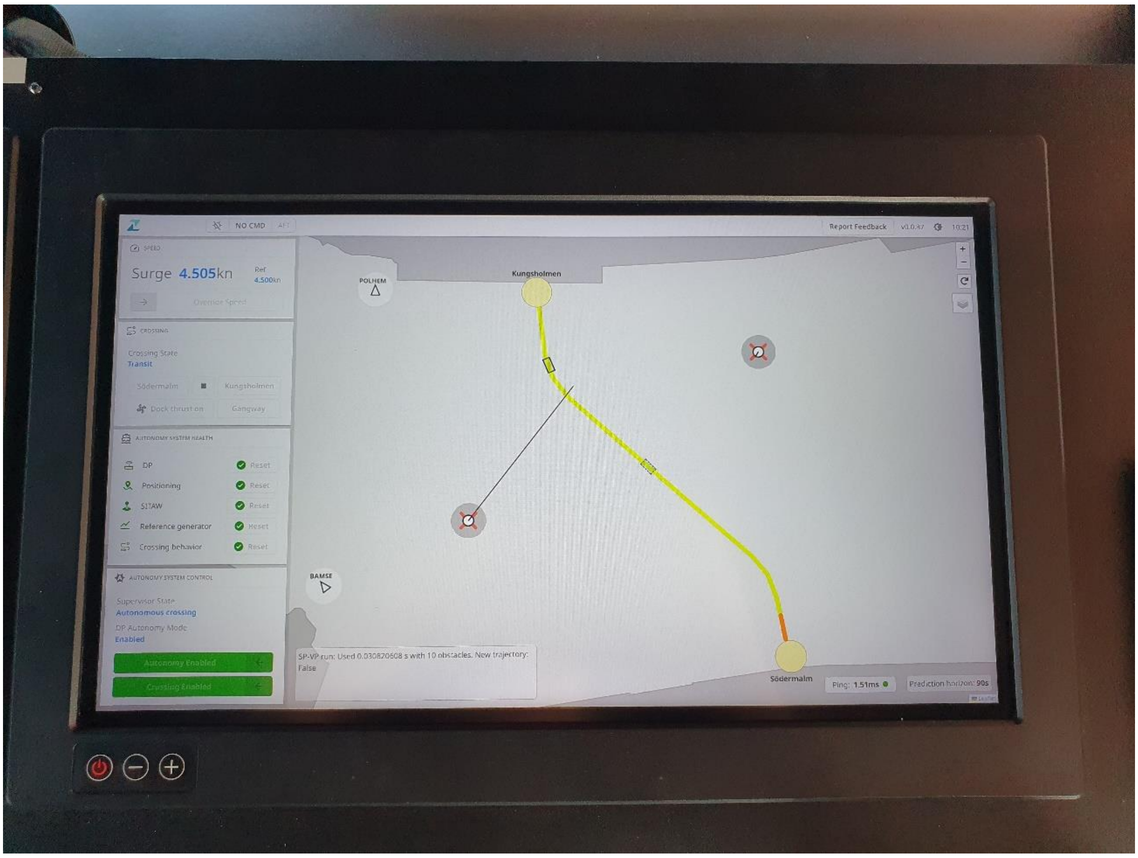



Figure 24 . Targets shown is either by AIS, RADAR or LIDAR symbols indicates which route in yellow. Orange is slow down zone as the ship approaches the jetty in the south. Monitoring of system status displayed to the left.

This is the ferry route across Riddarfjärden between Kungsholmen and Södermalm in Stockholm.

The demonstration consisted of multiple voyages across where the skipper only pushed a button that is shown on screen labeled either Kungsholmen or Södermalm depending on which destination is desired.

Once this button is pressed the vessel maneuvers out from the dock and once the vessel is cleared from the jetty (done automatically) the operator can set the desired speed by using the speed lever.

The vessel will now only follow the pre-set route, shown in the figure above. If the operator puts the lever in zero, the vessel holds its position on the route. If lever is set to negative knots the vessel will move aft wards along the route. This way the operator can follow the COLREG by use of speed/slow down/stop.

Once the vessel reaches the part of the route which is in orange, termed: Slow down zone, the vessel will adjust its speed automatically (set speed from the operator on the lever does not matter) down to a suitable speed for entering the auto-docking mode which is done totally automatic by the use of ultrasonic sensors similar to what the automotive industries uses on cars with the functionality of automated parallel park.

# 6 Conclusions

Based on the different activities within the project ranging from field studies in both Finland and Sweden, policy labs, workshops with stakeholders and practical tests of sensors and systems, the study not only gained knowledge but was also able to draw conclusions. There are many similarities between the Finnish concept and the goal for the actors on the Swedish side. And there are strengths and challenges with physical wires as well for systems without the physical wire.

## 6.1 The Finnish concept in a Swedish context

This study started with a comprehensive examination and mapping of the interaction between Traficom and Finferries, which resulted in the development of new legislation governing the use of the Finnish version of the "virtual wire." Extensive documentation was gathered and translated into Swedish, accompanied by a detailed explanation from the CEO of Finferries. This process is thoroughly outlined in the background chapter of this report, along with relevant appendices.

**Feasibility and Challenges**

The Swedish Transport Agency has a possibility to include the option of exploring foreign legislation for potential application in Sweden. However, this possibility has never been utilized, and since then, the Finnish technical legislation that covers over virtual guide has been revoked. No interest of further exploration of this alternative was expressed by Färjerederiet. Swedish stakeholders identified weaknesses in the Finnish version of the virtual wire and a more advanced system was deemed as necassary. The partners were not convinced that the Finnish solution could be directly implemented into the Swedish market without significant adaptations. However, if the goal is to only replace an existing guide wire with equivalent functionality the project could not find find any cause for not using the suggested FinnFerries virtual wire solution. As Färjerederiet had interest in enhancing the concept, FinnFerries virtual wire system was never tried on Sweden waters.

**Standardization and Education Challenges**

A review of Finnish accident reports (Vajerfärjan L-317:s kollision med bryggklaffen i Korpo) revealed a lack of clarity regarding the distinction between steering control systems, virtual wire systems, and autopilot systems. This ambiguity is prevalent both within the industry and among governmental agencies, likely due to a lack of standardized definitions within the marine sector when it comes to classifying automation systems onboard.

To address this issue, it is recommended that when discussing automation systems, a clear definition of the system's range of action, purpose, and relationship to co-existing systems is to be provided.

Furthermore, the project suggests that ferry operator education should not be limited to in-house training only. Transparency through third-party education and testing of operator knowledge should be encouraged to ensure a consistent and transparent approach.

## 6.2 Concluding Remarks

The results of the project highlight a system that closely resembles today's operation of a cable ferry, where the vessel makes way through water by pulling on a wire. In this environment, the operator has a control lever with options to increase or decrease movement backward or forward, or simply hold the vessel still. The automation system takes care of most of the manoeuvring and vessel tracking tasks, allowing the operator to focus on traffic monitoring and the situational awareness of the surrounding environment.

The current maritime digitalization maturity is considered sufficiently high to be able to replace the physical steering cable with a digital system as a safety-enhancing complement. In summary, the virtual wire equivalent system offers promising benefits for Swedish inner waterway transportation, but successful implementation requires addressing logistical challenges and ensuring a smooth transition for operators and passengers alike. The demonstration proved that the concept is valid and functional.

### 6.2.1 Impact on Swedish Transportation in Inner Waterways:

1. **Enhanced Safety:** By automating routine tasks, the system minimizes the risk of human error during navigation. Operators can concentrate on critical decision-making, improving safety for passengers and other vessels. By eliminating the physical wire all risks related to this have been mitigated. There is also the added benefit that since the vessel is not physically bound to the crossing, it can assist in emergency response in the vicinity should the situation call for it.

2. **Improved Efficiency:** The system's ability to follow a pre-set route accurately ensures efficient use of inner waterways. It reduces deviations and is a potential for reducing fuel consumption.

3. **Environmental Benefits:** Optimized and repeated navigation contributes to reduced emissions and environmental impact. By removing the physical wire, the interaction with bottom sediments can be reduced and limit the negative effect for the surrounding marine ecosystem. New routes could be established with a reduced impact on the environment.

4. **Increased Recruitment Base:** The adoption of such an automated system could allow the ferry to be operated with fewer crew members. With the vessel handling navigation assistance and manoeuvring tasks, leading to potential efficiency and decreased workload for the crew. Along with lowering the manning certification requirements, a larger set of available workforce have the potential to fill the need of seafarers.

5. **Enhanced transportation network scalability, flexibility and resilience:** Establishing a new route does not need a heavy investment in infrastructure or maintenance which expands the application area and

possibilities for "cable ferry" routes. The virtual wire can be used year-round, even during ice covered conditions without risk of a wire getting stuck in the ice. It even allows for using multiple ferries to use the same “wire” route and the route itself does not need to be in a straight line.

6. **Estelle demo and public relations:** A strong public relations strategy is crucial for the smooth integration of new technology like the virtual wire system. Just as the project has been demonstrated to partners, similar efforts can be made to engage the public through education campaigns, media outreach, and community programs. Public events, such as demonstrations, can showcase the technology and its benefits. Addressing concerns, promoting transparency, and building trust are key to ensuring widespread public acceptance and support.

### 6.2.2 Challenges and Considerations:

- **Maintenance and Reliability:** Ensuring the system's reliability and addressing technical issues are critical to its long-term success. Regular maintenance and continuous monitoring are essential for both hardware and software components to function optimally. Additionally, a comprehensive lifecycle plan is necessary to manage software updates, maintenance, and version control. This plan should account for ongoing improvements, security patches, and the adaptability of the system to evolving technological standards, ensuring sustained performance and operational efficiency throughout the system's lifespan.
- **Training & education of personnel to use the new system:** Comprehensive training and education are essential for the successful adoption and use of the new system. This process should include test runs, dry runs, use case simulations, and pilot runs to familiarize personnel with the system's functionalities in real-world scenarios. Equally important is creating user awareness about the system, ensuring that users are fully informed not only about its capabilities but also its limitations. Continuous education and hands-on training, combined with clear documentation and support, will empower personnel to effectively utilize the system and ensure its long-term success within the overall change management.
- **Legal and Regulatory Framework:** Finland initially developed specific technical regulations for virtual wire systems; however, these regulations were repealed in 2023 due to challenges in their implementation and concerns about their suitability in practical applications. This repeal has created a regulatory gap for virtual wire systems in both Finland and Sweden, highlighting the need for further regulatory development to establish standardized frameworks for their implementation. Despite this gap, current legal frameworks still allow the continued development and experimentation of virtual wire technology, though a cohesive regulatory approach will be essential to ensure widespread and standardized adoption.

- **Public Perception:** Public acceptance and trust in automated systems are critical for their successful implementation. Clear communication about safety measures, benefits, and reliability of the technology is essential to build confidence. Conducting thorough risk assessments and maintaining transparency in the system's performance, safety protocols, and potential risks will help address public concerns and foster greater trust.

- **Software validation and updates:** Managing software in an operational environment presents significant challenges, particularly in maintaining safety and security during updates. It is crucial to address the risk of introducing bugs or vulnerabilities during the update process. Ensuring that software updates continue to meet, or exceed, the required security standards over the system's entire lifecycle is vital. Effective strategies must be implemented to safeguard against potential issues while ensuring that software enhancements do not compromise the integrity or safety of the system.

# 7 Suggestions for future research

**Full-Scale Testing**: Conduct comprehensive testing and demonstrations to validate the concepts and operational models of virtual cable systems.

**Future profiles and competences:** Investigate the scientific rationale for crew requirements on virtual cable system-enabled ferries, focusing on decision-making related to staffing and task descriptions.

**Virtual Cable System Usability:** Investigate the feasibility and practical usability of virtual cable systems, including the potential conversion of existing routes to virtual cable routes, as well as testing on actual vessels recommended by ferry operators.

**Exploration of Extended Applications to Other Vessel Types:** Investigate the applicability of the proposed virtual wire concept and technical solutions to various types of national vessels.

**Development of a Safety Case Methodology for Complex Technology Systems:** Traditional risk assessment methods can be overly complex and resource-intensive, making them feasible only for large organizations with substantial resources. This complexity often stifles innovation and hinders the adoption of new technologies, particularly for smaller companies and startups that may lack the necessary expertise and funding. Object to simplification and accessibility, provides clear guidelines for implementation, fosters collaboration and knowledge sharing, and supports the integration of new technologies with effective feedback mechanisms.

**Investigate new ferry connections that can offload congested sections of highways and roads.** A ferry system without wires holds the potential to be deployed at new strategic locations that could effectivly offload the congested roads or allow new ferry connections that reduces the need for building bridges. In many cities and industrial areas, smart ferry solutions could allow new opportunities for sustainable growth.

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# 9 Appendix 1

| Ship State / System mode (Docked, Docking, Crossing) | External or Internal cause | High level / effects on multi level system: What If? Scenario / Event / Failure leading to service interruption or injury | Potential Consequences | Likelihood Once over ... | Severity (Safety injury or Unavailability) | Risk score (over 5 mitigation is needed) | Detectable | Barrier(s) / Fall back states (3 layers recommended ) | Sufficient mitigation |
|---|---|---|---|---|---|---|---|---|---|
| Crossing | Internal | System Loses position reference | loss of situational awareness, maneuvering system failure, unintended maneuver is triggered | 1 year | First aid / 1h | 5 | Yes, immediately | 1) 3 independent information sources cross checked and automatic switch over of primary source, warning is triggered for operator<br>2) All external references deemed unreliable or missing, system continues from last known position INS (Internal navigation System) in deadreconing, alarm level high triggered for the operator<br>3) FBS II | Yes |
| Crossing | External | Traffic colliding with physical cable Ex. Sailing boat | Collision and fatality, damage to wire and boat | 1 year | +2 Fatility / Rebuil... | 25 | Yes, under 5 min | Risk eliminated | Yes |
| Docked | External | External force pushing ship away or larger ship movement at jetty, this can be wind, current or other ship passing or collision | Damage to the ship and infrastructure, persons squeezed between ship and shore | 1 year | First aid / 1h | 5 | Yes, under 1 min | 1) Automation system trigger collision alarm or high wind alarm or position changed when moored to alert the operator<br>2) Operator monitoring weather and wind, in case of increased risk detected manually control is take and operator applies trusting force against the jetty (FBS-II)<br>3) FBS-III | Yes |
| Docked | External | Ramp damaged or debris (ice) preventing to complete docking, Automation system confused by unknown of miss information or wrong interpretation of actual ship states | Preventing automation system to complete auto docking | 1 year | First aid / 1h | 5 | Yes, under 1 min | 1) Automation system notice deviation under docking phase, stops and proceeds to position keeping or within 10m of jetty backing up to approach WP for position keeping<br>2) Operator triggers position keeping<br>3) Manual override | Yes |
| Docked & Crossing | External & Internal | Grounding, Fire, Leak/Flooding, Medical emergency | No major consequence change | 1 year | +2 Fatility / Rebuil... | 25 | Yes, under 5 min | Procedures as no change, automation system can assist if needed and selected by operator | Yes |
| Docked & Crossing | External | Weather negatively effect sensors performance | Loss of display function, wrong information displayed, ghost targets being displayed | 1 year | First aid / 1h | 5 | Yes, under 1 min | 1) Operator monitoring weather and crosscheck system with visual observation<br>2) FBS-II<br>3) FBS-III | Yes |

| | |
|---|---|
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