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1. INTRODUCTION

When solving complex urban logistic and mobility challenges, innovation, smart, and green technology and automation are important key words. The plan for promoting intelligent automatisation, completed in the autumn of 2015, describes a vision of the importance of this sector in Finland. According to the vision there are world leading centres-of expertise in traffic related intelligent automation, in Finland. Robots moving on the ground, at sea, and in the air, are commonplace. They solve many challenges related to the service design of traffic in urban as well as rural areas. ¹

The open-minded utilisation of digitalisation has been put forward as one of the key factors for improving Finland’s competitiveness by the Sipilä Government. It is reasoned that the forerunners of the digitalisation development will benefit most from it. This is also why being a forerunner in the field is worth striving actively for. Finland has an excellent opportunity to be one of the leading countries in the development. ¹

Presently there is an opportunity to develop intelligent automation more widely in ferry traffic, e.g. as the average age of ferries and public transport vessels operating in the Finnish archipelago is high and the need for renewal in the next few years is significant². The Ministry of Transport and Communications encourages research and pilot projects on unmanned waterborne transport. The ministry hopes for agile renewal through them. In the trials, risks can be taken and mistakes must be accepted since it otherwise is difficult to embrace new solutions. In addition, the Sipilä government encourages to this. ¹

The Smart City Ferries project was designed to respond to the above-mentioned needs and to boldly develop intelligent, unmanned and eco-efficient waterborne transport; businesses, universities, cities and public authorities all together. One concrete objective of the project was to prepare and to contribute to developing and bringing into use an autonomous passenger ferry in the near future. The project clarified questions relevant to the realisation and operation of such a ferry. Practical solutions were also studied and tested.

The idea with this information package is to give the reader an overall picture about intelligent waterborne traffic, about the state of present R&D as well as challenges concerning it, and to spread information about experiences from the project. Some topics are described in more detail in separate reports, offering the reader more and deeper insights. The first part of this information package focuses on safety and technical solutions on autonomous vessels. In the latter part the smart pier concept and intelligent waterborne service design are presented.

1.1 AUTONOMOUS VESSELS

Traditionally vessels have been operated by a crew, using a various amount of technical aids for support. Humans have made the necessary decisions for manoeuvring and other operations of vessels. The decisions have been based on available information, own observations and own experience. Machinery and equipment have been maintained and monitored on site.

Autonomous vessels and their working principles, differ significantly from the above. Fully autonomous vessels are able to operate and make decisions independently and without human support, using technical systems and artificial intelligence. Technical systems on autonomous vessels are planned to diagnose and monitor their own status and to function without maintenance for as long as possible. Safety is ensured e.g. by duplicating critical equipment. Autonomous vessels will, at least to begin with, operate together with Remote Operations Centres (ROCs). The ROCs will, depending on the situation or chosen working mode, monitor the navigation of the vessel or interfere with it, when necessary.

The degree of autonomy is described through autonomy levels. There are no internationally agreed standards on this issue, so the different scales in use show small variations. The classification society Lloyd’s defines autonomy with a seven-step scale. Level AL 0 is a vessel almost completely operated manually by humans. At level AL 6, at the upper end of the scale, vessels are fully autonomous, capable to make all decisions independently and to execute them, without human monitoring. Different types of remotely controlled operations are performed on almost all levels of autonomy. Higher up in the scale, remotely controlled operations typically are reduced and the vessels do most operations independently.

Apart from autonomous vessels, also unmanned vessels are talked about. The terms autonomous and unmanned are often used as synonyms, thus confusing readers. Unmanned vessels have no crew onboard. In practice, unmanned vessels are thus always autonomous. Autonomous vessels are not necessarily unmanned. Onboard autonomous vessels there may be permanent crew, or crew from time to time, depending on the situation. Remotely controlled operations can be done on both unmanned and autonomous vessels.

All information from the Smart City Ferries project and the information in this info package can be applied and utilised on all levels of autonomy, regardless of crew size.

1.2 WHY ARE AUTONOMOUS VESSELS NEEDED?
New technology and its use is in itself not a reason to move away from the current operating practices. The goal, in the whole of society, is to achieve clear measurable benefits through remote operating and autonomous means of transport. The improvements - in comparison with the present situation - concern safety, efficiency and reliability. Currently all major car manufacturers develop cars that operate independently of the driver’s operations. The same development work has now started in waterborne transport.

Waterborne transport is developing all the time. In coastal towns and towns close to inland waterways, water has now been seen as a resource in the pursuit of sustainable growth. Improving the service offered by waterborne transport supports all travel routes. The aim is to develop cost efficient and flexible solutions, utilising autonomous waterborne transport, for cities’ changing needs. Autonomous vessels can e.g. be used in places where bridges cannot be built, or as a temporary means of transportation for neighbourhoods close to waterways.

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3 Lloyd’s Register, Cyber-enabled ships, ShipRight procedure – autonomous ships, 2016.
http://info.lr.org/l/12702/2016-07-07/32rrek
1.3 THE DEVELOPMENT OF AUTONOMOUS VESSELS

The development of autonomous and remote-controlled means of transport has accelerated only in the current decade. In the case of waterborne transport, R & D is done in many countries. The projects range from oceangoing freight vessels, to small commercial vessels utilised in urban transport. Many of the solutions that are developed are, by their very nature, such that they can be applied or modified for a wide variety of solutions. It is possible to apply parts of the information in this information package also in other contexts than in the context of urban passenger ships, as it is generic in its nature.

Competition is fierce in the R & D field and many actors try to get their products to market first. Estimates have been made that in the next few years, in coastal areas, at least some small autonomous vessels will operate. In the next ten years, autonomous vessels are expected to navigate also in open sea areas. Coastal areas are subject to their own national legislation in each country. This enables testing and even a fast introducing of autonomous vessels in national waters, without having to take slower international legislation work into consideration.

The most important R&D areas concerning autonomous vessels right now are e.g. detection technology for vessel surroundings, reliable data transfer solutions between vessels and Remote Operations Centres, fusion of sensor data, development of control algorithms and artificial intelligence, development of remote monitoring and diagnostics of technical systems and development of ROCs. The R&D activities, however, are not merely technical. Meeting different user needs, developing different services and improving user experience are fields to which different solutions are developed utilising service- and concept design.
2. SAFETY OF AUTONOMOUS VESSELS

The safety of autonomous vessels is an issue that has been the subject of much debate. This is understandable, since it is a question of a new way to operate in waterborne traffic and since there is relatively little information available on it. It is wise to consider the present situation and safety level as a starting point when studying the safety of autonomous vessels. How does introducing autonomous solutions change the situation and how can the accepted safety level be preserved and maybe even improved? We need cooperation between actors in the field, ways to produce safety related information and concrete know how in order to go forward.

2.1 TOOLS FOR ANALYSING AUTONOMOUS VESSEL SAFETY

The Smart City Ferries project developed a tool for analysing safety that would be suitable especially for autonomous vessels. The goal was to develop a process that could be used for analysing risks and risk mitigation methods as early as possible in the design process of vessels. This way it is possible to influence on vessels' structural design, systems and solutions, without additional expenses. The result was a systematic method, based on the existing STAMP (Systems-Theoretic Accident Modelling and Processes) and STPA (System Theoretic Process Analysis) methods, which aims at overall safety, rather than on correcting specific shortcomings.

The method of analysis was tested on two scenarios together with a broad group of experts. The scenarios were set in the city of Turku, or more exactly, on the river Aura. In the early stages of the five-step process the most likely accident types which could face the vessels in the tested scenarios were identified. In addition, the hazards associated with the accidents were noted. After that, mitigation actions transformed into actual safety controls for the hazards were established. These were developed into an initial safety management strategy. The result of the process was a clear picture of risks that the vessels in the scenarios could face. Further, the suitability of the safety controls and their operational principles in different situations was visualised.

The analysis of the vessels in the scenarios covers all the most probable emergency situations. These are collisions, groundings, sinking, fires, man over board situations and medical emergencies. Also the hazards leading to the accidents were analysed. The established safety controls clearly focus on preventive measures. The focus is on eliminating hazards and preventing them from developing into accidents. Only a small part of the safety controls focuses on minimising the effects of accidents.

Based on the analysis it can be said that the safety controls for managing technical risks mostly are based on choosing the right and suitable equipment, monitoring their functions and on the existence of redundancies. Careful planning, installing and testing are also important.

In managing passenger behaviour, the vessels' structural design plays an important part. If the vessel structure in itself, through the design, makes e.g. falling over board difficult, or directs passengers to behave safely and correct, many unnecessary hazards can be avoided. Another important issue is a more modern and developed way of guiding passengers in different situations. The clarity, unambiguity and understandability of the instructions is necessary. On top of that, the information should be made interesting so that passengers pay attention to it. Traditional safety guidance in writing can be completed with videos and mobile applications. For unmanned vessels, two-way communication needs to be considered for emergency situations. The role of Remote Operations Centres as instruction givers was recognised as important. In this study, however, the actual ROC functions were excluded from the analysis.
From the point of view of processes and operations, the analyses highlighted the need for more thorough planning. Currently, processes in ships, especially in exceptional situations, are often based on human situation-specific decisions, which are only loosely directed by processes and instructions. The operating models and processes of autonomous vessels must be more thoroughly planned in advance and also cover exceptional situations.

The results of the analysis cannot be directly applied on other vessels than the ones used as examples in the scenarios. The results are based on the views of the participating experts. However, they can be used as basic knowledge of the safety of autonomous city ferries and as an example of applying the method. See the English report “Hazard Analysis Process for Autonomous Vessels” on the analysing tool as well as for complete analyses.

2.2 THE PASSENGERS' ROLE IN AUTONOMOUS VESSELS

Along with technical solutions, it is important to consider the role of the passengers and possible changes in it. In addition, in the future, passengers should be able to travel safely and easily regardless of the degree of autonomy and the number of crew members. The keys to reaching this goal are, among other things, development of automation of life-saving appliances and fire-fighting equipment, even more intelligent sensors and communication systems, and effective monitoring and guidance. Structural solutions, aimed at preventing the need to evacuate vessels in the event of emergencies, simplify operating models.

Intelligent systems make it possible to reach a situation where the role of the passenger is not much changed and no greater participation is expected from him. If the emergency measures required are as automatic as possible, covering detection of situations, alarms and necessary operations, the passengers are only obliged to follow instructions and to be able to use personal life-saving appliances.

In the Smart City Ferries project, a study, made for a Bachelor's Thesis, focuses on the topic of managing exceptional and emergency situations on two city ferries, through four different scenarios set in Turku. The two vessels, as well as the routes, in the scenario, were the same as those used in the testing of the autonomous vessels' safety analysis tool. Mari Junkkari’s thesis (in Finnish only) "Emergency Management aboard Unmanned City Ferries – A New Role for the Passenger?" describes the topic in further detail.

2.3 ASSURING SAFETY OF NEW TECHNICAL SOLUTIONS

The role of classification societies and of the Finnish Transport Safety Agency is to ensure a sufficient safety level for vessels’ technical solutions. The development of autonomous vessels creates a pressure on these organisations to develop their own processes and to prepare for approving, inspecting and certifying a new type of vessels. Present regulation and procedures form a good basis for future classification rules for autonomous vessels, but they need to be developed in areas where there are differences compared to present day vessels, or in areas where there are no regulation or procedures.

The Smart City Ferries project facilitated workshops for Lloyd's Register and technology industry representatives. The workshops focused on three themes that were identified as important development targets. The groups have discussed the redundancy requirements of autonomous vessels' equipment and systems, the requirements of the autonomous vessel state monitoring systems, and the contingency plans required for emergency and exceptional situations.
The traditional prescriptive classification rules have accurately defined the requirements that must be met by the subject to be classified. In addition to this approach, a goal-based approach has emerged in recent years, better enabling development of technology and systems. In the case of autonomous vessels, the two methods will most likely be combined. With a goal-based approach, the importance of safety assessments in verifying selected solutions is emphasised because the same thing can be acceptably realised in many different ways.

The vessel’s traffic area, vessel type and degree of autonomy have been identified as being the most relevant factors affecting the level of requisite standards. For example, a small freighter, operating in a small area near the coast, is unlikely to require the same high level of system redundancy as passenger vessels performing longer or alternating routes.

In the development of equipment and systems it is possible to at least partly utilise present day, existing equipment, if their reliability is sufficient. New systems are however required. For example, new sensor technology needs to be developed to compensate for the present practise of human observation of the surroundings, done from the bridge of a ship.

Doubled or tripled systems are generally presented as the safety solution for faults. Thoughtless requirements in this area, however, easily lead to a situation where the systems become so complex and expensive that the operation of vessels is no longer economically viable. Instead of multiple assurance, considerate doubling of critical systems and choosing well-designed equipment are probably the most sensible overall solution. Instead of acquiring two identical devices that are both vulnerable to a single external cause of the problem, it makes sense to acquire two devices that operate in a different way, but produce the same information.

You can learn more about the topic and the work done by Lloyd’s Register and the technology industry representatives in the report, “Development of Classification Procedures for Autonomous Ships”.
3. ENERGY SOLUTIONS FOR AUTONOMOUS VESSELS

The use of autonomous city ferries will increase as one part of urban transport. Waterborne traffic makes it possible to utilise new routes and can easily be combined with functional mobility, walking and cycling, favoured in urban transport planning.

City ferries must be non-polluting and silent; they are also expected to be reliable and safe. In addition to the investment costs, operating costs of the vessels are at the centre of attention when considering offering new types of transport services for city residents. Autonomous unmanned vessels decrease manning costs and by choosing the right means of propulsion, the fuel costs can be reduced significantly. Long service intervals of the propulsion machinery facilitate scheduled operation of ferries, especially when replacement vessels are not available.

3.1 STUDIED VESSELS

The Smart City Ferries project studied energy solutions on ferries operating in the vicinity of Turku. The aim was to look for savings in energy consumption and in the environmental load. Study objects were the chain-operated "Föri" ferry, crossing the Aura river, and a city ferry, which is still at the planning stage (Figures 1 and 2). For the Föri the energy consumption of the original diesel engine was compared to the new electric battery based machinery installed in the modernisation of the ferry. For the city ferry four options were considered: a renewable fuel diesel engine; a biogas powered internal combustion engine with spark ignition; an electric hybrid engine as well as a battery powered machinery. Features to be investigated were environmental load, safety and reliability, investment- and operating costs.

Figure 1. The Föri ferry (Photo: Jari Lahtinen).
3.2 ENERGY CONSUMPTION

For the Föri, energy consumption was estimated on the basis of measured fuel consumption data. The electricity consumption of the Föri could be estimated with the readings of the consumption meter connected to the battery-charger. The results showed that the annual fuel consumption of the original Föri was an average of 7.4 m$^3$, which is equivalent to 76 MWh of energy. The amount of energy used by the electric Föri for propulsion was 46% lower. If the electricity is produced in a clean way, e.g. by means of nuclear power, wind or solar power, the environmental load of the electric ferry, when it comes to emissions, can be assumed to be zero. The energy consumption (117 MWh per year) of the second studied vessel, the city ferry, was calculated for a scenario in which the vessel operates at two destinations; Ruissalo and Satava (Figure 3).
3.3 ENVIRONMENTAL LOAD

The environmental load was calculated so that the vessel equipped with a diesel engine was the reference to which the three other engine options were compared. Environmental release types that were not affected by the engine selection (wave-formation, antifouling paints, etc.) or that were not generated at all (waste water discharges) were not taken into the calculations.

Electric hybrid vessels as well as electric ferries use batteries, which are utilised in hybrid implementations to achieve optimum use of the diesel engine. This results in reduced fuel consumption. In the study, batteries were also used to compensate for power produced by diesel engines at low speeds. Stopped diesel engines reduced fuel costs and, at the same time, exhaust emissions and noise. According to the study, hybrid vessels can achieve at best 10% fuel savings and emissions will correspondingly decrease by 10%.

Both the hybrid and the electric vessel cases were studied also with assumed installed solar panels on roofs and walls in addition to the batteries. The energy generated by the solar power system is used in the city ferry to rotate propulsion machinery and, in case of overproduction, the excess energy can be used to charge the batteries. The study showed that implementing such a system can achieve a maximum of 26% annual fuel savings. The advantage gained depends on the power of the solar power system to be installed and the annual weather conditions. The reduction of exhaust emissions from electric hybrid vessels was likewise 26%. Totally electric-powered city ferries do not produce any emissions, if the electricity used is produced without emissions.

Vessels with gas and diesel engines consumed about the same amount (mass) of fuel. Gas engines were found to be superior to diesel engines with respect to greenhouse gases, if the gas is made of waste. Considering undesirable emissions, the exhaust gas from the gas engine contained more sulphur and methane than the diesel engine exhaust gas.

City ferries are not in use at night, when the noise limits are stricter than in the daytime. In urban areas, noise from the city ferry is unlikely to differ from other traffic because it moves slowly due to
speed limitations and the engine power is thus low. The strictest noise limit is in the Ruissalo Nature Reserve area, which is located close to the ferry route, but the effect of the vessel on average noise levels can be expected to be negligible due to only periodic visits there. Electric-powered vessels are probably the quietest, as there is no exhaust system noise. Noise from electric hybrid vessels is also low in slow steaming when the diesel engines are stopped and driving is done using batteries.

3.4 SAFETY AND RELIABILITY
If gas-powered vessels are built in accordance with international shipbuilding standards, they must be as safe as diesel-powered vessels. This leads to a need for paying extra particular attention to prevention and detection of potential gas leaks. Safe filling of the gas tanks may require the vessel to move off the Aura river for bunkering. The safety of an electric-powered ship is enhanced by the possibility of realising a low voltage electrical system of 400 volts, in which there are no safety risks caused by higher intermediate voltage. Battery safety must however always be carefully considered in electrically powered vessels.

All engine solutions are functionally reliable because they have two separate independent propeller machineries. Problems can occur if there is a fire in the engine room or if, for some reason, the engine room is flooded. Gas engines have not been installed on small vessels very often, but this technology is well-known and widely used for example in city buses.

3.5 COSTS
From the point of view of cost, investments in gas vessels are higher than in conventional diesel engine powered vessels. If, on the other hand, electric hybrid vessels are purchased, the costs will increase significantly. The battery capacity required for hybrid implementations depends entirely on the use of the vessels. If the batteries are used only for the optimisation of the diesel engine usage, it can save up to 60-70% on the ship's battery investment. The use of electric power-driven vessels is advantageous, but the achieved savings do not make the investments economically viable, if the building costs for the charging stations are high. Operating costs of gas vessels are higher, because of the fuel price, than the operating costs of diesel engine powered vessels. There is also a need to invest ashore, i.e. in the vessel's gas bunkering systems.

3.6 RECOMMENDATIONS
The renovated electric powered Föri is a good example of how new technical solutions will be introduced in small vessels. The technology of autonomous vessels will develop fast and traditional energy solutions will be replaced.

Based on this study, it can be stated that a battery powered vessel is the most environmentally friendly option. The price of a battery powered vessel is about at the same level as the price for a vessel with a diesel engine. A gas powered vessel is more expensive than the two previously mentioned, but in environmental friendliness it comes between diesel and gas vessels. A hybrid vessel is more expensive than a diesel vessel, but its emissions are smaller than those of a diesel vessel. Granting public support to promote new types of engine solutions for various types of smaller vessels in future acquisitions should be considered. Without this support, the shift towards higher-quality autonomous water transport is slow.

More information on the topic can be found in the "A study on energy solutions for city ferries" report (only in Finnish).
4. VESSEL REMOTE OPERATIONS

Regardless of the degree of autonomy, autonomous vessels will need to be paired with Remote Operations Centres (ROCs) which, depending on the situation and the chosen mode of operation, monitor or control the vessels and carry out other necessary operations from the shore. Future ROCs will likely provide a broad spectrum of other services related to or supporting the operation of vessels. It is believed that the roles of maritime stakeholders will be significantly changed in the transition to autonomous maritime transport.

Monitoring vessel traffic and remote monitoring of the machineries are already commonplace within the maritime industry. Vessel Traffic Service centres follow vessel traffic and monitor the maritime surveillance picture. They also contact vessels in problematic situations to ensure safety. The passage of own vessels is also monitored in shipping companies. The operation and maintenance needs of the machinery are often monitored centrally by the system manufacturers’ own centres. The Remote Operations Centres may handle some of these monitoring functions in the future.

Existing technology would allow vessels to be manoeuvred remotely already at present. Existing vessels have however been designed to be operated by an onboard crew and their remote operation would not be safe or economical. Autonomous ships will be designed from different starting points, e.g. taking remote manoeuvring into account.

4.1 REMOTE OPERATIONS

Remote operation means operating of any technical system or machine from its outside. Nikola Tesla created the first principles for remote operation in a patent he acquired 120 years ago. Without any remote control possibilities, e.g. use of nuclear power plants would be practically impossible.

The shift from man-made activities to remote operation and the time of autonomous devices will take place in small steps and through several intermediate steps. It is thus a natural development in the society. In waterborne traffic, autonomous functions and technology that enables remote operations will be initially seen in manned vessels where it will support crew operations and increase safety. At the same time, user experience about the devices can be gathered and the devices can be further developed under supervision. The first systems that increase situational awareness are already on the market and are expected to become more common on vessels quickly.

One assumption is that, when technology reaches an adequate level, the number of crew on board will begin to decline and new similar jobs will emerge ashore. Before moving on to totally unmanned vessels it may be that a kind of caretaker will remain onboard who, with virtual reality tools and remote support, can repair nearly everything that can be repaired at sea. However, some vessels will go directly to full autonomy, totally without crew. These scenarios, as well as everything possible between the extremes, will likely be seen in the future.

4.2 REMOTE OPERATIONS CENTRE (ROC)

The first Vessel Traffic Service centre (VTS), which supervises vessel traffic, was established in Finland in 1996. In the maritime field, VTS Centres are the closest benchmark when considering future ROCs. Also air traffic control and control stations for nuclear power plants can be used for benchmarking.
The operational environment and needs of ROCs however, differ from any of the above. In the planning of ROCs, it is essential to begin with a clean slate and take the activities to be carried out as starting points and to consider the best possible technical solutions and work processes for performing them. Best practices and experiences gathered elsewhere, such as work processes, should be utilised, but so-called outside-the-box-thinking is also needed for achieving good results.

Remote Operations Centres have the opportunity to look at things from completely new perspectives without the technical constraints of a navigating bridge on a vessel. Presented visions are e.g. a visual 360° view on which augmented reality information about detected and identified subjects could be added. The operation of the various parts of the engine could be illustrated with 3D holograms. Panel displays would follow the black panel-ideology, where deviations or situations otherwise requiring reactions are emphasised. Using haptic systems that utilise human sensory observations, it would be possible for an operator to sense changes in situations without burdening the working memory. Touchscreens, holographic functions, and voice control are new technologies that are expected to replace key commands, at least partly.

Language and speech technology could also be utilised in a more versatile way than for voice control alone. It also makes it possible to enhance information production, such as dictating for the logbook or for a maintenance report or to facilitate and automate information searches. The Smart City Ferries project together with Lingsoft Ltd, tested speech recognition and the use of speech synthesis tools in a full mission simulator in the marine simulator Centre at Aboa Mare in Turku (Figure 4). The video in which the operator controls the vessel with the autopilot using voice commands is viewable at https://youtu.be/unrTp5BQcgg.

Figure 4. Operator steering the vessel using voice commands (Photo: Juha Kesti).

Different functions in the Remote Operations Centres require different information. When monitoring vessels navigating at open sea, a broad and comprehensive picture of the situation is the starting
point. That information can then be complemented with information on specific vessels or with information on the environmental conditions. When vessels are in fairways, the area to be monitored is generally smaller and the information on vessel state, fairway and the navigation of the vessel is the most important. When manoeuvring the vessel from the ROC, perceiving the vessel’s own movements is crucial. In exceptional or fault situations, the operator, after stabilising the situation, primarily tries to resolve or correct the problem in a way that compromises safety as little as possible and that minimises additional costs. In such cases e.g. detailed technical information on the vessel’s systems and their condition, as well as analyses and forecasts about the development of the situation might be needed.

All in all, in the planning of ROCs, the optimisation of operations to be as functional as possible is in focus. This can be achieved by combining the functions to be performed with the appropriate technology and information. Reporting and documenting, as well as storing data, are also routine for operators. In the future these operations will probably be executed in accordance with predetermined routines, mainly automatically.

4.3 REMOTE OPERATORS
In addition to the need to think about the design of the ROC’s technology, people and processes must be considered. What kind of person is suitable for working in an ROC? And what kind of training does the work require?

The Vessel Traffic Service (VTS) operators currently employed in the VTS Centres are seafarers (watchkeeping officers) who have completed the Vessel Traffic Operator training, including on-the-job training. The training program has been prepared by the International Association of Lighthouse Authorities (IALA) and approved by the International Maritime Organization (IMO). The training of vessel traffic operators focuses on e.g. knowledge about the used equipment and its possible faults as well as on knowing local conditions.

Official training requirements for personnel of Remote Operations Centres have not yet been established. In the Smart City Ferries project, the question was approached in collaboration with Rolls-Royce through a practical test in a simulator environment (Figure 5). In the test, a number of watchkeeping officers and captains with varying experience were instructed to steer a vessel from open sea, into the port of Vuosaari. The steering was done from a Remote Operation Centre, in this case a bridge simulator. During the test, connection problems between the vessel and the Remote Operations Centre were simulated. As the test progressed, the amount of information, received from the vessel and available for the operator, decreased.

The test showed that maintaining situational awareness and perceiving the vessel’s motions in a Remote Operation Centre, equipped like a present-day navigating bridge, is particularly challenging in exceptional situations. New visual tools and a more supportive environment for maintaining situational awareness are therefore required for Remote Operation Centres.

The most significant observation in the test was the rapid increase in workload in the event of a problem. As problems were piling up, the participants would have needed another operator to share the workload. Designing work processes is a major issue in order to be able to handle situations smoothly and safely, for example when switching from monitoring to remote control or when a problem occurs. The test also showed that the test persons could not, or did not want to, use the
external help and information that was available. This weakened their performance. In remote operations, vessel operations must be perceived in a new way and the operators need to be trained to work more as members of a team, utilising information provided by others.

![Image](image.png)

Figure 5. *In the remote operation test, connection problems between vessel and ROC were simulated (Photo: Sirpa Kannos).*

No reliable or generalizable conclusions could be drawn on whether the test results correlated with the background and experience of the test persons. However, it would seem that a positive attitude towards new technology, the ability to use navigation equipment diversely, and to rely on the information they provide, as well as adequate maritime experience, are factors that give the person a good basis for Remote Operation centre work. These are all areas that will certainly be taken into account when considering future training and qualification requirements.

4.4 TECHNOLOGY FOR OBSERVING VESSEL SURROUNDING

In order to avoid collisions and groundings, vessels must monitor their vicinity and other vessels. Current maritime radars are able to detect objects further away from the vessel very well. Small and low targets within a couple of hundred meters from the vessel often remain undetected by the radar. Seeing them is based on human observation. Replacing the human eye in the observation of the vicinity of vessels has become one of the important research topics in the development of autonomous vessels.

So far, no single device can replace the human eye. Around the world, a variety of equipment combinations are currently being tested in order to find combinations that will enable reliable object detection in the vicinity of vessels. In addition to detection, it should also be possible to identify the objects. The amount of data generated by several devices easily grows big, causing problems e.g. in situations where information must be transferred between vessels and ROCs. Processing and compressing collected data as well as artificial intelligence solutions related to identification, are research fields closely related to sensor technology research.
Various video and stereo cameras, thermal cameras, laser scanners, and close proximity scanners used in automotive technology are examples of devices that produce information on the vessel-vicinity, suitable for autonomous vessels. All the aforementioned devices have weak points, e.g. the laser scanner is disturbed by rain and fog. The Smart City Ferries project studied features of a laser scanner and a thermal camera together with video recorded reference material. Results from the tests can be read in the report “Specifics of using Lidar and IR-camera for detecting obstacles on maritime vessels”.

4.5 DEVELOPING CONTROL ALGORITHMS FOR STEERING
The developing of control algorithms for steering is based on the International Regulations for Preventing Collisions at Sea, or, "the ColRegs". While the ColRegs are in themselves clear, their interpretation can be quite challenging in complex traffic situations. Rules are often also violated, either intentionally or unintentionally. Sometimes, for example, the vessel's safety may require violations of the rules.

The starting point for the development of algorithms is therefore complicated. Today the officer on the bridge makes steering decisions based on equipment information, rules, experience and own situational awareness and judgements. Rules and judgments of situations are relatively easy to record in the form of algorithms. The computer’s judgement of a situation is likely to be more qualified than a human’s, if it has the necessary information. This is because the computer is able to make reliable calculations of different alternatives in seconds. Experience-based tacit knowledge is, however, an area where transferring it to the form of algorithms or teaching it to artificial intelligence applications, require a lot of work.

The development of an algorithm based on artificial intelligence requires enough examples to teach the system. Teaching is based on that a sufficient number of classified examples, from which it learns the structure of the problem, can be given to the system. The image recognition algorithms imported into consumer products have been possible to implement since there is a very wide classified image material database (http://www.image-net.org/) that can be used to teach algorithms.

The developer of autonomous vessel traffic algorithms is here challenged with the same problem as the developer of autonomous car control algorithms. There are no appropriate databanks. Currently, many car manufacturers use their self-developed traffic simulators to create a data bank. The approach has challenges from a safety aspect: The RAND corporation in the United States has calculated that it is necessary to simulate billions of kilometres of driving to ensure a sufficiently low risk of accidents for the control algorithm 4. There is a debate from time to time, to create a common database for and by maritime actors, but so far nobody has taken the lead in bringing the project forward. A shared data bank would speed up the collection of data needed for the development of autonomous vessels compared to the situation where each actor collects its own data bank.

So far not much has been published on autonomous vessels’ steering algorithms. It was not possible to study the topic in the Smart City Ferries project, due to limited time. It is possible to gain a basic

idea about the steering algorithms and their structure for example in the following article: *Perception, Planning, Control, and Coordination for Autonomous Vehicles*. 5 [https://doi.org/10.3390/machines5010000](https://doi.org/10.3390/machines5010000). Although the issue in the article is addressed from an autonomous car perspective, similar principles also serve as a starting point for vessel traffic algorithms.

### 4.6 Remote Monitoring, Diagnosis and Maintenance of Technical Systems

At present, remote monitoring and remote support are already widely used in ship maintenance. It is possible to automate controls and measurements, which enables proactive maintenance and fault analysis. Devices can be changed at just the right time before they break, thus avoiding possibly even high indirect costs. In maintenance and repair operations, the entire business culture has experienced a revolution. Thick paper manuals are becoming history when important information can be found on a handheld computer significantly faster. With the help of augmented reality tools, the crew alone under remote guidance can handle even more difficult work tasks locally.

In the future, remote monitoring solutions will probably be more widespread on vessels. Decision support systems will be available in real-time, resulting in an increased number of customised analyses and forecasts. With remote monitoring a continuous description of the autonomous vessels' state is aimed for. In the design phase of the remote monitoring system it is essential to consider what is wanted with the system: reliability, economy or efficient operation? Only thus the system can meet the desired needs. Only then, based on the needs, the sensors needed for producing information are selected. The selected sensors then produce reliable data, suitable for the purpose. Data analysis is based on e.g. statistical models, machine learning, simulation, prediction, optimisation, and virtual enrichment of existing knowledge.

Even if the remote monitoring and diagnostic tools are in order, vessel power production and other systems must be suitable for remote operations and long maintenance intervals. Generally speaking, the technology required also for this already exists, but its price has so far limited wider usage of it. It has been more profitable to put cheaper technology in manned vessels. Practical examples of system development objects include among others: increasing the number of alarm and measurement points, selecting more reliable equipment, remote control of valves and observing piping valves and connection points. The modularity utilised in air transport is considered to be one of the future trends in maritime maintenance work as well. In this case, larger "packaged" sets of equipment could be left ashore for maintenance after indications from the remote monitoring. The corresponding set of equipment would then be installed during the same port visit.

Who then carries out a necessary repair work on an unmanned ship, work that must be done immediately in order for the vessel to be able to continue its operation? In principle, such situations are to be anticipated and prevented at the design stage, for example by duplicating critical devices. Industrial manipulators, so-called robot handles, can be utilised for remote repair work, if the vessel's engine room is designed for manipulator repairs. Corresponding technology is used, for example, for underwater construction work, where the remote operated vehicle (ROV) - pilot controls the robot handles with own hand movements. As a last resort, you have towing the vessel ashore, just as it is today.

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5. AUTONOMOUS VESSEL INFORMATION TRANSFER AND DATA SECURITY

The need to monitor vessels and possibly to control them remotely, requires a lot from the data transfer. For this communication, there are many necessary boundary conditions, which must be met for operations to succeed. Steering instructions in narrow channels, for example, require both a sufficiently fast and reliable data transfer.

Since there is no global, fast, reliable and reasonably priced 4G-quality network for data transfer, other solutions that are technically feasible must be taken advantage of. In addition to satellite connections, various radio technologies can be used. The problem with all of these technologies is that the greater the capacity of the transfer technology, the shorter the range of the radio signal gets. In practice, the data transfer must therefore be split into parts, depending on the extent of bandwidth the data requires, and on how long a latency is allowed in the data transfer. Simultaneous use of a variety of communication technologies also provides the necessary redundancy if one communication link fails.

In data transfer, as known, it is not enough that the connection is technically functional. It must also be assured that the sender of information is exactly the actor that the message appears to be coming from. In addition, it must be ensured that no one has been able to change the transferred data at any stage. Data transfer should also be successful whenever it is needed. A denial of service attack in this environment means as big a problem as e.g. an engine room blackout. Technical verification alone is not yet sufficient for the whole. It must also be possible to ensure that all users of the data network actually are who they claim to be. On top of that it must be ensured that all used software is running with the correct version, which does not allow back doors or cause malfunctioning as a side effect.

The design of the autonomous vessel's cyber security must cover the whole life cycle of the vessel. It is not enough to think about data security at the beginning of the procurement process or e.g. once a year during operation. The process must be continuous and the whole concept must be internalised by all parties involved in planning and operation. Cooperation should cover software designers and technical systems designers, as well as operators and the authorities.

5.1 DIFFERENT DATA TRANSFER TECHNOLOGIES

Currently, ships communicate with their surroundings mainly on different radio channels, either via fixed land stations or through satellites. The high frequency HF signal carries thousands of miles, but the bandwidth is very low: the transfer of an ordinary 2MB photo, for example, takes more than a minute. In addition, the signal quality varies greatly with time of the day, season and the rhythm of the sun’s spots. The VHF frequency that carries less than one hundred kilometres has been found to be reliable in sea conditions. Although the data transfer capacity of a single VHF channel is not significantly higher than that of the HF signal’s even thousands of VHF channels can be used in parallel. The VHF signal also passes through the upper atmospheric ionosphere, so it is also utilised between satellites and earth.

In the maritime sector UHF frequencies have - for the time being - mainly been used in onboard communication. In the Smart City Ferries project, wireless data transfer was tested using IP (Internet Protocol) routers for radio communication in the 400 MHz frequency band in the Turku archipelago. Similar technology is currently being internationally used in the control and supervision of diverse security critical facilities ashore. Such facilities are e.g. electricity and water distribution networks.
With the method, a range of tens of kilometres can be achieved. Using repeaters can further lengthen the range. The advantages of the method are reliability, a short and in advance known response time, and a reasonable cost level. The low transfer rate, for example compared to data transmitted over the cellular network, can be seen as a restriction. UHF data transfer is excellent for transferring telematics data, but, for example, for video transmission the bandwidth is not sufficient. For more information on the test carried out by the Smart City Ferries project, with Satel Oy and the Åbo Akademi University, see the test report "Building and operating a UHF-band test network for providing mission critical marine communication in the Turku archipelago".

The 4G networks of commercial operators operate with microwave frequencies and directional antennas. Their range is up to 70 km and the data transmission capacity is multiple compared to the radio frequencies mentioned earlier. This mobile communication network is also rapidly evolving towards a "Network as a Service" type block network, where multiple blocks serve different user groups. The Internet of Things (IoT) also brings a significant number of new areas of use and opportunities with it. In port areas and in the immediate vicinity of fairways, 5G technology can also be utilised in the next few years. Farther from the coast, the use of 5G has limitations because the signal range is only a few hundred meters.

Real-time control of vessels via commercial mobile networks alone is not considered recommendable, even if it, as a connection form, can be used. Experts in the field are surprisingly unanimous about this. One of the keys to the development of intelligent automation is fast and direct inter-ship connections. In other words; in the future, vessels would act as base stations for other units at sea. Also buoys, islands and lighthouses can be equipped with IoT sensors and they can function as parts of future intelligent routes. All in all, the data transfer solutions for autonomous vessels depend very strongly on the area in which the vessel operates in. At the same time, the amount of data required for situational awareness varies significantly between wide oceans and congested fairways into ports.

The commercial competition between various actors in satellite communications keeps the price level tolerable. Such actors are e.g. FBB, VSAT, Iridium and Inmarsat C. A particular problem with current, geostationary satellites is that their range does not extend to Arctic waters. Another, geographically wider, problem is that the amount of data to be transferred worldwide doubles in about half a year, and new satellites are not launched at the same pace.

Figure 6 depicts a system that utilises several of the above presented data transfer technologies.
5.2 DATA SECURITY OF THE DATA TRANSFER

In practice, all radio communication between vessels and their surroundings is wireless and thus also public: outsiders can detect signals and signal transmission points can be located. Data transfer can be listened to and interfered with or it can be captured if these possibilities are not technically blocked. The most difficult and, at the same time, the most critical issue to be tackled is interference with data transmission; without contact, remote operations cannot work. Also for this reason, the simultaneous use of technologically different types of radio technologies is highly justified, and the transition to backup connections should be designed to be automatic and as timely as possible.

The basic principle in data security is to ensure that the data transferring traffic is always heavily encrypted. This can be accomplished by commonly used techniques and standards using a long enough encryption key. In terms of reliability of the encryption, the critical part is encryption key management. Encryption will not fail, even if the attacker has all the encrypted messages and information about how they are encrypted. However, leaking of the secret keys makes all the efforts meaningless. For this reason, an encryption key management plan should be developed. The plan should, for example, cover the creation, safe storage, distribution and validity of keys. The second most important thing is to allow only data traffic routines that are justifiable, considering the system and in terms of work tasks. There is a constant need to stay up to date about various connection methods, as well as about potential security weaknesses in cryptographic algorithms, so that deficient methods can be replaced when necessary. For example, TLS (Transport Layer Security, formerly known as SSL) and VPN (Virtual Private Network) are widely used encryption protocols.
Blocking unauthorised communications is done with a firewall. A firewall is a system that prevents unauthorised access from one network to another, for example from the public Internet to an autonomous vessel’s local area network. The firewall should be configured to allow only proper data traffic to the services in use. It should be noted that the firewall only filters the communications that pass through it. An attacker can also access the organisation’s network via other means, for example by using the wireless LAN’s base stations or by physically entering the organisation’s premises. Wireless local area network must always be protected with a sufficiently long password, which is not available to any third parties. If the wireless network is not completely isolated from the critical functionality of the system, one must never allow devices that may not be properly data secured to connect with it. This applies especially to the own mobile devices and laptops of the operating personnel.

For more information on the data and cyber security of autonomous vessels, see the report "Cyber Security and Securing Data Transfer in the Development and Operation of Autonomous Vessels" (in Finnish only). The report was commissioned by the Smart City Ferries project.

5.3 CYBER SECURITY - THE MINDSET UNDERLYING OPERATIONS

Cyber security means creating IT security for an environment consisting of its users, telecommunications networks, hardware, software, processes, stored and transmitted data, applications, services and, in general, all systems directly or indirectly connected to that environment. The objectives of information security are confidentiality, integrity and availability. These form the so-called CIA-triangle (Figure 7). Confidentiality means that the user of any part of the functionality has permission for that purpose. Integrity is realised when the content of all activities remains as it has been intended, without intentional or unintentional modification. Availability means that all functions are available when needed.

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**Figure 7. Confidentiality, Integrity and Availability (Source: Kalle Rindell)**
These concepts are complemented by another three essential concepts: Identification, verifiability and indisputability. Identification is a procedure in which users are identified individually. Verification reinforces identification; giving a password is the most commonly used example. Verification can also be based on, for example, a key card, or even a fingerprint. Security can be enhanced by two- or multi-step verification, using multiple verification methods. Indisputability means that it in retrospect can be determined, for all activities performed, who has done what and when.

Cyber security threats can either be intentional or unintentional. The latter may still be divided into targeted and un-targeted. Unintentional are, for example, software errors or incorrect security settings. The motives of intentional attacks vary from the pursuit of economic interest to terrorism. Other common causes include military intelligence, industrial espionage, revenge, activism, and vandalism. The attacks can be carried out either from the inside or from the outside of organisations. Shipping, as a strategic and critical activity to society, is a potential target to all these threats. The threats may apply to the vessel itself, its cargo, passengers, crew and operators, shipping company, owners, the environment or even the associated states.

Already in the design phase of an autonomous vessel, it is justified to appoint a security manager who is ultimately responsible for all security processes and, for example, the timeliness and availability of security instructions. For his support there should be a data-security expert, taking care of classification and processing of data at different stages of its life cycle, and of the implementation and effectiveness of data security practices.

A security plan, defined at three levels, needs to be made for security implementation and management (Figure 8). The strategic level describes the organisation's security functions and is the basis of risk management, linked to business objectives. The tactical level describes project and procurement plans, budgeting and subsidies. It clarifies the strategy and presents practical ways to reach goals. The operational level defines implementation, personnel-, training- and implementation plans as well as all practical processes.

Figure 8. Data security management levels (Source: Kalle Rindell)
Security risk assessment includes risk identification, analysis and criticality classification. Once risks requiring measures have been identified, appropriate risk management tools are defined for them. All risk management tools together form a risk management strategy, which must be supported with practical implementation arrangements. The database formed by all this data, must be kept up to date by repeating the same process periodically, in connection with system updates or changes in the operating environment. Risk management models and practices include, for example, Process Hazard Analysis (PHA) and Failure Modes and Effects Analysis (FMEA) and are governed by the ISO 31000 Series Standards.

5.4 DATA SECURITY FOR SOFTWARE DEVELOPMENT
As autonomy is based on software, security of software systems is naturally one of the key security issues. Security requirements must be taken into account in the development of critical systems, beginning with the definition phase. The confidentiality, integrity and availability of the system as well as the data contained therein - the three basic objectives of security - must be ensured throughout the life cycle. Information system development is often a continuous process.

When developing information systems, a sufficient level of knowledge in data security is a prerequisite for a successful project and achievement of the goals. Strict timetables and scarce human resources will only lead to short-term cost savings. Shorting in the development phase and ignoring the security requirements may later be followed by extensive maintenance and remedial measures. Security is never a worry of "someone else’s", and the consequences of neglecting it affect everyone.

Taking data security into the system development combines the organisation's business goals, risk management and security requirements. The qualitative and security-enhancing improvements in the development phase make it easier to maintain the system, increase its fault tolerance and make the system easier to recover after disturbances. As a customer of software development, it is often profitable to supplement own knowhow by using an impartial security expert to ensure the security and acceptability of the system. Critical systems may also be imposed by a requirement, by the authorities, for information security certification.
6. SMART PIER

6.1 WATER AS PART OF SUSTAINABLE GROWTH
In recent decades, we have seen the development of many technology-based road transport solutions for providing information and services to road users. It is only recently that waterways have also been recognised as valuable resources, though there are some aspects of water-based transportation that have seen little to no development in centuries, with the solutions developed focusing solely on vessel control and the identifiability of the operating environment. Waterborne traffic is, however, constantly developing, and water is now recognised as a resource that can drive sustainable growth in both coastal cities and inland areas. Increasing the service level of waterborne traffic supports all transport chains. One key aspect of this development is the connection of land-based functions to water-based transportation.

Water systems and their accessibility have an impact not only on business operations related to the sea, but on the attractiveness of housing, recreation and tourism as well. The digital transformation provides opportunities for entirely new kinds of services and solutions. With the help of collected and produced data, the quayside can serve as an interface between land-based and waterborne traffic, enabling more active utilisation of shores and water areas.

6.2 THE PIER AS AN IMPLEMENTATION PLATFORM
In the ÄlyVESI - Smart City Ferries project, the idea of the smart pier has been imagined as a pier concept that can accommodate autonomous passenger ferries while also serving as an implementation platform for a range of other smart waterborne traffic services in cities. One of the earliest stages of the project was the definition of elements that should be taken into consideration in the planning of the pier. These included the purchasing of tickets, passenger access control, accessibility and safety issues, the possibility of charging passenger ferries, boats and other vehicles, other service opportunities and the design of the pier itself. The premise was that similar piers for supporting waterborne traffic could be implemented not only in river environments, but in the city’s outer islands or uninhabited areas as well.

The Smart City Ferries project has also commissioned an idea plan for the specifications of a potential pier concept. In accordance with the prepared plan, the smart pier is smart, modular, adaptable and scalable. These characteristics are described in greater detail below.

6.3 SMART SOLUTIONS
The smart pier supports and utilises the new solutions and infrastructure created as a result of digitalisation. The pier’s functions are remote-controlled, so that its services as well as payments and the distribution of electricity, for example, can be provided via an online remote reservation system.

If the pier is used in public transport, it can be equipped with gates operated by motion sensors or a QR code. The gates can also be connected to a video surveillance and character recognition system, which can allow people in wheelchairs or those with a pushcart, for example, to enter the quayside/vessel free of charge. The video surveillance system can also be utilised in other ways, such as to monitor streams of people. With the help of so-called heat mapping, the pier’s various functions, such as the illuminated guidance system, can be adjusted automatically to keep the flow of people going smoothly during the busiest hours.
Since the pier is designed to function independently in uninhabited islands/areas as well, it can also be equipped with various alarm systems. In addition to alarm systems protecting against theft and vandalism, the pier’s camera system can be integrated with an alarm system based on heat sensors for detecting people who fall into the water.

Smart features that have been identified as important for users and tourists in particular include the possibility of creating a comprehensive guidance system for the piers with the help of information screens (Figure 9). These information screens can be used to display up-to-date information about vessel timetables and land connections as well as share city information or advertise local services. Access to and from the pier and to and from the vessel is designed based around an illuminated smart guidance system. The illuminated markers or accessways can be controlled and adjusted according to the situation, in addition to which the lighting of the entire pier is programmable. The pier can be kept fully lit up during operating times, with only the outline marker lights kept on when it is closed. The colour of the lighting can also be adjusted based on different themes.

The pier also offers free Wi-Fi to customers in its vicinity.

Figure 9: Smart guidance system and accessibility (Figure: Remotec Ltd; design Lauri Jaala).

6.4 MODULARITY AND SCALABILITY
The purpose of the pier is dependent on its location, while on the other hand the location also affects the pier’s dimensions. Because of this, the pier was designed as a modular solution, which also ensures that the piers are recognisable entities with a uniform appearance. Depending on the location, the pier can serve solely as a place for attaching a connecting vessel, but it can also be scaled up to an extensive guest harbour that offers a range of services. One such modular assembly that could be used as a guest boat harbour, for example, is shown in figure 10. The pier is equipped with pavilion buildings that function as service platforms as well as canopies that collect solar energy.
The smart pier creates opportunities for the construction of ecological and smart urban infrastructure. In urban environments, the pier can serve as a new and pleasant meeting place and event venue, introducing additional services to areas where providing them has not been possible before. The pier can also accommodate light-structured buildings that can serve as pop-up facilities for companies, seasonal service points and even as accommodation. On the other hand, the pier can also serve as a low-threshold bridge for archipelago tourism, providing services to boaters in archipelago locations. As a unique solution, the pier is easily recognisable and it can be used to easily create a distinct brand, with the piers themselves already creating an impression of the area’s functions.

The modular solution provides the opportunity to adapt the pier according to growing needs. Expanding the quayside is easy with the installation of additional modules, while the range of services offered can be expanded by simply adding more buildings. The piers’ smart solutions will be also expanded further as development continues and new opportunities arise in the future. In other words, the pier will be constantly adapted according to needs and the opportunities arising from new technologies.

One of the main themes of the City of Turku strategy programme ‘Competitiveness and Sustainable Growth’ is ‘Turku under construction and the environment’. The theme’s list of sub-objectives includes the following:

- Measures directed at city residents, tourists and companies shall emphasise the attractiveness stemming from water.
- Objectives related to the Aura River and the sea shall be actively promoted.
- Opportunities for seaside living will be developed through architecturally ambitious plans and implementations.
- Tourism infrastructure will be comprehensively developed in riverside and seaside areas while promoting the accessibility of the archipelago.
- The City will work towards enabling the active use of beaches that are freed up.

The smart pier “Åby” has been designed to primarily serve waterborne traffic in the Aura River and supplement the service level of the shore area. However, the concept has been designed to be expandable to anywhere in the world. Explore the concept from the report “Smart pier concept ÅBy”.
7. CONCEPT DESIGNING IN THE ÄLYVESI - SMART CITY FERRIES PROJECT

The concept design of the opportunities open to smart urban waterborne transport based on design began with linking urban waterborne transport and, more generally, smart urban traffic with a perspective on the future including, among other things, mega trends, trends and the various signals. Various future possibilities were given a specific expression in the form of product and service concepts.

At the second phase, the special target comprising various people – users and user groups – whose needs, desires, dreams and different fears were surveyed using user-centred information seeking methods (including user personas, user situation scenarios and user probes).

Alongside, and after such phases, the tools for creating new ideas and developing work included experiments through prototyping, and concepts also were prototyped for presentation. The project was showcased at the Stockholm Design Week at a fair stand dedicated to design concepts related to the smart ferry environment in February 2018. In this development and work for concept design, an approach based on a design thinking was used, and, at the same time, it was further refined towards a clear and easily understandable model. This 4DT - Design Thinking Parallel model will be presented in more detail in the next chapter.

7.1 4DT - DESIGN THINKING PARALLEL MODEL

Design thinking is a concept that emerged strongly in the 2000s and has become fairly widespread even outside the design business. Design thinking can be regarded as a kind of umbrella concept for traditional product and service design under which problems can be well or fairly well delimited and the assumed end results are products, services and service combinations. As a general rule, the overarching target of design thinking is the perception of wholes (organizations, enterprises, social and global challenges) and that of the understanding (sense making). In other words, the target of design is to seek understanding about the world without preconceptions of the end results or end productions. As understanding grows, the needs for change and development can be addressed, and more suitable solution models and methods can be sought in order to achieve a desired development.

In the following, the 4DT Model (Figure 11) will be elaborated on, creating an understanding on the target through progressively overlapping interactive processes. The concept design section of the Smart City Ferries project will be presented with this 4DT Model.

Figure 11. 4DT - Design Thinking Parallel Model (Figure: Tarmo Karhu).
**Holistic View** – Connections between people, things and systems, the variation of the examination of the distances, precision and viewpoints.

Things and activities always take place linked to their environment and a larger context. The impacts and their mechanisms should be viewed from the perspective of the whole (context), details (people as seen as individuals, products, etc.) as well as from the details towards the whole. The more diverse the issue is, the more diverse are also the various linkages and mechanisms of action between things. Clarifying the multi-faceted nature and making it understandable, several different viewpoints are required in relation to, among other things, time, social structures, the environment, technology, the economy and different people and groups of people. Using, among other things, the PESTE analysis, this multifaceted nature and its drivers of change can be divided into various parts. The abbreviation PESTE is derived from words “Political”, “Ecological”, “Sociological”, “Technological” and “Economic”. In other words, the aim is to make the perception of the whole simpler and, on the other hand, to find and to accept the diversity of details.

**Human View** – The understanding of experiences and feelings, and finding the real needs.

At the core of design thinking is the human being and the methods of information seeking and the problem solving of user-centred design. In this, the key is the sense of empathy and the involvement of the various parties in the processes of shared understanding and design. While the sense of empathy is required in all kinds of human activates in order to enable human coexistence and collaboration, in design it is highlighted, for example, in information seeking and in the creation of credible user personas and scenarios. User scenarios are simple situational descriptions (verbal, the series of images, played situations, etc.) in the life of the target person, in which a person’s viewpoint a particular situation in a particular environment is shown. Examples of the increase in the participating of human understanding including design probes and various sessions of shared work, such as the workshops of ideating, prototyping and concept designing, hackathons, jams and camps. Not all development takes place using the methods of information acquisition and in such experimental sessions; instead, they are more long-term and continuous development processes. However, at best, they provide essential grounds and give some approximate indication of the development.

**Experiment** – Swift practical experimentation (prototyping). User-centredness, speed and effectivity

The term “experiment” refers to the methods of development where, at the various phases of development, thoughts, ideas and concepts are experimented from various perspectives: simulating various user viewpoints in a cost-effective way, by involving real users in experiments and by seeking to direct experiments to produce essential experience-based information. Even the first thoughts and ideas can be illustrated and experimented, for example, with the aid of with paper or cardboard prototypes or by experimenting with the ideas and acting out the situations (quick & dirty). Early experimentation may help detect various deficiencies which are hard to put into words, and to build shared understanding between users and developers about the issue under experimentation.

**Concept Design** – Concepts create concrete content for alternative developments and opportunities.

As a basis for the creation of different and often alternative concepts, the perception of the Holistic View, the understanding of the Experiences and the picture brought by Experimentation of the possibilities in a particular context and in a whole and on a particular time scale are used. Such concepts can show things of the kind that are possible by different developments, and they also go to show
why they could be something to be needed or wanted from the viewpoint of users selected as targets.

4DT – Holistic View, Human View, Experimentation and Concept Design taken as a whole

Iterations of the design thinking under the 4DT Model are carried out on different scales: within the various subareas, there will be smaller scale and rapid 4DT work, while larger scale and longer term development projects will also be carried out, and work even beyond them. Although in the 4DT Model the four subareas are differed due to clarity and perception, in reality they are mixed, and can be freely overlapped as needed. For example, in various experimentations, user experience and the surrounding whole are always present as starting points. Conversely, experimentations bring about viewpoints for the understanding of the whole and experiences. Concept design combines all subareas together in alternative or interconnected examples.

7.2 HOLISTIC VIEW
Social targets and global and local outlook for smart traffic.

The background for the project is provided, among other things, by a publication issue by the Ministry of Transport and Communication from 2013, entitled “Kohti uutta liikennepoliitikkaa, Älyä liikenteeseen ja viisautta liikkujiille, Toisen sukupolven älystrategia liikenteelle” ("Towards a new traffic policy; Smart traffic and wiser travellers. A second generation strategy for traffic"). In it, the focus areas of the smart strategy for traffic are defined to be efficiency, safety, environmental friendliness, user-friendliness and implementation. These reflect the larger megatrends related to the population growth, the development of smart technology, the climate change, the human well-being and the global economy. The above-mentioned issues will bring about various opportunities and set requirements for smart traffic in water, on land and in the air. These factors determining the general whole were addressed by PESTE analyses, user scenarios and through visioning concept design. A good example of visioning concept design is provided by the Agorà ferry and service concept in Figure 12 (on the right) and by the link https://vimeo.com/266644735.

Figure 12. Smart urban water traffic is born in relation to the surrounding world and people (Figure: Tarmo Karhu).
Near waterways (Turku, Espoo and Helsinki), the ease of travel by water in the urban areas and also to the residential and recreational areas near urban areas may bring significant added value both to residents and visitors alike and, naturally, to residents of the archipelago. Safety, user-friendliness and efficiency can only be achieved if we understand the general life and the various individual needs and feelings sufficiently profoundly. This kind of understanding is needed in coordinating the various forms of the public transportation and, at the same time, the associated details, such as service meetings between people and devices. A good experience is born out of functional basics and out of small gratifying details to be observed. More about experiences will be presented in the next chapter.

7.3 EXPERIENCE
The needs and feelings of human travel in traffic.

Human needs can be recognized, and feelings can be understood, but direct questions such as “What do you need?” or “What do you want?” will not take you very long. More indirect methods are needed. Such examples include various forms of participatory brainstorming and development, such as, e.g. user probes, scenario tools and shared prototyping (Figure 13.).

![Figure 13. The levels of user information and experience (Convivial Toolbox: Generative Research for the Front End of Design, 2013, figure: Tarmo Karhu).](image)

The need and feelings associated with smart urban waterborne transport were clarified, among other things, with the aid of user probes and scenarios. The design user probe is a package designated for target users, containing various tasks easy to implement and store tasks related to the theme to be probed in the daily life. In other words, a person carries the probe, storing momentary feelings and experiences on it. The probe is not an enquiry but an opener of senses, observations, thinking and, in many cases, routine activities, seeking a deeper understanding. Using the probe, information on everyday activities and the formation of feelings, in other ways easily missed, can be obtained and, at the same time, the self-knowledge of the users can be added.

In the implemented user probes, in experiential observations and in user scenarios, various desires and fears related to autonomous vessels emerged. With regard to the desires, the ease and availability of services were highlighted, in particular. Fears about autonomy are largely related to the

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feeling of insecurity, if the vessel is not staffed and you cannot select your company. The experience of security can be affected by the design of the vessel’s use environment, such as spacious and accessible environments, their good visibility both indoors and outdoors, sufficient non-glare lighting, clear multi-channel and multi-sense guidance and the placement of safety devices’ visible but unemphasized placement (Figure 14).

![Figure 14](https://example.com/image14.png)

**Figure 14. How does smart urban water traffic feel? (Figure: Tarmo Karhu).**

**7.4 EXPERIMENTATION**

**Developing prototyping; development through experimentation**

Through experimentation, we have gained experiential information on both on the existing and on the thought-up possibilities of the surrounding environment from the viewpoint of the users of products and services.

Various experiential visualizations were performed to create a basis for the services of the smart urban traffic. With potential users, mood boards were gathered, in which images on various user groups and on various situations and conditions in waterborne transport. This aimed to make visible the possible users of waterborne transport and the various requirements that the different user groups may have regarding, above all, the various needs of the users of water traffic regarding age, gender and intersects, etc. Using the mood boards on conditions and associated feelings, it is possible to discuss the change of conditions on water in which connection the seasons, the times of the day and the changing weather conditions emerged as factors, including the changes they brought in the experiences in the travelling by water.

On the basis of the above, a kind of user scenario was drafted with the users were encouraged to get into character with various user groups. For the procreated user personas, possible situations on unmanned smart ferries for the passengers to move onto the ferry and from the ferry and travelling on the ferry under various weather conditions and at various hours, various situations were created. The users spoke out the experiences of their own role, which among other things brought forward the matters that affect the feeling of the safety. Setting oneself into the predefined role brought up things that affect to the formation of experiences, such as changes in sounds, lighting and window sizes. Such experiments showed that, the lighting, sounds and the window sizes etc.
have the situation related limit values, and exceeding them may shake the feeling of security. With the aid of these scenarios, cut as short films, it was possible to experience and show various issues related to the opportunities and threats of the feeling of security, usability and community orientation.

Example of scenario films on the left (Figure 15) and at https://vimeo.com/217163402.

7.5 CONCEPT DESIGN
Different alternative design concepts for smart traffic

Design concepts combining experiential knowledge obtained via opportunities and experiments emerging from the whole were conducted during the entire duration of the project. Concept design began as a visioning the opportunities of the whole and the future. The issue was approached by first taking up all possible existing solutions for water travel. In the PESTE analysis, the change factors for the future smart urban water traffic and people’s everyday life, among other thing, ecology, the possibility to combine work and leisure, sharing economy and the transferring services to people emerged. On the basis of these, future product and service needs were outlined. On the basis of the found needs, concepts were envisioned for various possibilities and possible targets of urban waterborne transport, sometimes clearly exceeding the current realities (Figure 16.).

With regard to a more distant future, the focus was returned closer to the present: the feasible and user-centred product and service concepts and concrete models that can be experimented with resulting from concept design and prototyping may be the foundation of commercial products, product development and setting target for development.

Service design is based on user profiling and understanding the various interest groups. The service blueprint is a tool, which describes the service process and path from the viewpoint of the different parties. The key is the forming of the user experience and, in the case of the smart ferry, boarding the ferry, being on the ferry and debarking the ferry. For the service blueprint, a user’s path will be gathered and, alongside with it, all the other action visible and invisible to the user. Also the concrete objects related to the phases of the path, such as tickets, rescue equipment, first-aid equipment and information signs, will be brought forward.
In service design, also the advance services must be taken into account, whereby the service is seen as beginning when the user gets an idea of the trip. Service paths were observed, experimented with and drafted, among others, with Föri and other ferries. By observing the user path and interviewing users on boarding a ferry, on being on board and on debarking, the researchers were able to pinpoint the sore points associated with the path – in other words, possible obstacles to the success of the service experience. Through the perception of the entire experience path, it was possible to focus various points requiring development. For example, the provision of safety guidance and getting familiar with the safety equipment should take place before boarding the ferry. This realization led to a game-based concept of the provision of guidance to the use of safety equipment. The ease of finding and visibility of the services also emerged in the construction of the service paths. These observations, among other things, resulted in the concept of lighting as a service (Figure 16).

Figure 16. Design Concepts are commonly understandable examples of various possibilities (Figure: Tarmo Karhu).

7.6 RESULTS OF THE CONCEPT DESIGN
The result was a great number of product and service concepts. The realization of the different limit values with regard to the optimization of the formation of the feeling of safety was deemed to be worth further study. Informative videos on lighting as a service and the accessibility in urban transport were made. During the process, the 4DT model clarifying the design thinking concept itself was also developed further.

Examples of the product and service concepts produced during the project:

**Services or the Smart Quay:** Research study on integrable services in the new movable Smart Quay. Master’s Thesis made by Ove Sundkvist in Turku University of Applied Sciences is available at [http://urn.fi/URN:NBN:fi:amk-2017101015920](http://urn.fi/URN:NBN:fi:amk-2017101015920).

**The Life Preserver concept:** Under the project, a safer and smarter life preserver was developed, the features of which included better visibility, better localization at sea and improved safety. Various colours and material of the life preserver were also investigated, including finding the easiest manufacturing method. The life preserver was tested with professionals, and the development process will be continues after the project. The concept is developed in Turku University of Applied Sciences by Sofia Nieminen and Kalle Tuominen.
**Smart Föri concept.** This concept takes account of the accessibility and amenities from the viewpoint of different users. The concept is developed in Turku University of Applied Sciences by Nicola Mäkilä, Zurisadai Hands, Niina Salmi and Veera Ketonen.

Figures 17 and 18. *Different users of the smart urban ferry and the ferry in the lower reaches of river Aura (Figures: left Henna Sandell, right Jaana Pitkänen and Henna Sandell).*

**Kipparikaveri - a game-based safety application**, with which the passenger can learn how to act and use the rescue equipment in dangerous situation on an autonomous unmanned vessel. The idea is that the passenger can gain familiarity with and learn to use the rescue equipment before boarding the ferry. The further development of the safety solution has been negotiated with the City of Turku. The concept is developed in Turku University of Applied Sciences by Markus Pulli, Laura Höglund, Airi Katajamäki and Emilia Kulma.

Composite of Figures 19. *Kipparikaveri safety application (Figures: Markus Pulli, Laura Höglund, Airi Katajamäki and Emilia Kulma).*
Info application for the provision of information on the archipelago. The purpose of this application is enable those with no boat but who wish to visit the archipelago to find the providers of both public and private water transport services, including the schedules and routes. The concept is developed in Turku University of Applied Sciences by Jaana Pitkänen and Henna Sandell.

Figures 20 and 21. Example views of the Info application (Figures: Jaana Pitkänen and Henna Sandell).

Urban Waterborne Transit service concept, which combines digital services with the ferry concept. The example of this include archipelago cards that can be loaded in advance, whereby the information on the island that is the destination of the trip will be stored on a smart device, also when no network connection is available. The concept is developed in Aalto University by Juho Kruskopf.

Figures 22 and 23. On the left, a view of the network service concept, on the right, an autonomous ferry concept (Figures: Juho Kruskopf).
**Lighting as a Service concept**, which provides guidance and creates a feeling of safety. The concept is developed in Turku University of Applied Sciences by Miska Harjamäki, Janne Juuse and Doris Välikangas.

![Lighting as a Service concept](image)

Figures 24 and 25. Among other things, light can be used to create understandability and accessibility (Figures: Miska Harjamäki, Janne Juuse and Doris Välikangas).

**Poijju concept**: floating recreational platform (for example for a sauna) that can be rented and that can be moved. The concept is developed in Aalto University by Liina Pölönen and Mikko Hakulinen. More information at contact@poijju.fi

![Poijju concept](image)

Figures 26 and 27. On the left, the user interface of the Poijju service, on the right, the Poijju ferry concept (Figures: Liina Pölönen and Mikko Hakulinen).

**Agorà ferry concept**: a place for meeting people, spending time, doing shopping and travelling between the city and the archipelago. The concept is developed in Turku University of Applied Sciences by Chiara Parise, Cristian Garcia Cebollada, Toni Heino, Milja Kokko and Debora Schwarzbach. [https://vimeo.com/266644735](https://vimeo.com/266644735)

![Agorà ferry concept](image)

Figures 28 and 29. The appearance and interior of the Agorà ferry concept (Figures: Chiara Parise).
**Wavelet** - a configurable bench projecting live light onto the floor, which projects light, creating a soothing atmosphere. The concept is developed in Turku University of Applied Sciences by Jaana Pitkänen. [http://innave.tuas.fi](http://innave.tuas.fi)

Figures 30 and 31. *Soothing light by the Wavelet seat concept (Photos: left Zurisadai Hands, right Tarmo Karhu).*

**Ror** - a lamp concept producing indirect light, under which lamps can be assembled to delineate space or, using different attachment methods, they can be used singly. Negotiations with a Danish lamp manufacturer are underway. The concept is developed in Turku University of Applied Sciences by Janne Juuse. [http://innave.tuas.fi](http://innave.tuas.fi)

Figures 32 and 33. *The Ror lamp concept in a natural concept and at a fair in Stockholm (Photos: left Janne Juuse, right Tarmo Karhu).*
**mushROOM seat and weather protecting cover concept** for waiting for a ferry on a smart quay. The concept is developed in Turku University of Applied Sciences by Giorgia Gallesio. [http://innave.tuas.fi](http://innave.tuas.fi)

Figures 34 and 35. A mushROOM cover and a seat (Figures: Giorgia Gallesio).

**BeBalance - a balancing seat concept** to counteract nausea during travel; the seat will remain aligned with the horizon even if the ferry was rolling. This concept makes use of a technology patented in another connection. The concept is developed in Turku University of Applied Sciences by Zurisadai Hands. [http://innave.tuas.fi](http://innave.tuas.fi)

Figures 36-38. BeBalance seat keeps you always in a horizontal position (Figures: Zurisadai Hands).
The Dock seat concept, under which your baggage will remain neat under the seat and your mobile devices will be charged over a wireless connection. The concept is developed in Turku University of Applied Sciences by Henna Sandell. [http://innave.tuas.fi](http://innave.tuas.fi)


Enabling Waterborne Public Transportation with Automated Service Piers - Human-Centred Service Design for Automated Maritime Travel within the Urban Archipelago. The concept is developed in Aalto University by David Bradley Mullen. [http://aboamare.fi/ÄlyVESI-Results](http://aboamare.fi/ÄlyVESI-Results)

Figures 41 and 42. Pier proposal and a view from the service storyboard. Images by David Bradley Mullen.

Figure 43. A service path on a ferry to the archipelago, with adventurous trippers as an example group (Figure: Sanna-Mari Jalonen).

The guiding videos for the design of accessibility, safety feeling and functional lighting can be found here:

https://www.youtube.com/watch?v=B6SxAOVF1E&list=PLng1TfzRr_2491fnp-8Gde1J-6DLW0JGS

For more information on the above mentioned concepts, click the links next to this and, if necessary, contact the Tarmo Karhu, responsible for the training and research in design at Turku University of Applied Sciences ([tarmo.karhu@turkuamk.fi](mailto:tarmo.karhu@turkuamk.fi)).
8. AFTERWORD

The development of smart urban waterborne traffic and autonomous vessels in Finland is still in the early stages. Sharing information and networking between companies, universities and cities are important prerequisites for the development. One of the aims of the Smart City Ferries project was to promote and support this cooperation. A large number of companies and other stakeholders participated in the project, and brought their knowledge capital to the project. The co-operation was realised e.g. in practical tests, expert workshops, seminars and student work. The content of this information package summarises the results of the cooperation and we hope it will benefit as many as possible.

Warm thanks to all the people, businesses and organisations that participated in the project!

Smart City Ferries, the ÄlyVESI project, was a conceptualisation, product development and innovation project realised by cities, businesses and universities 1.10.2016 – 31.5.2018. The project explored, developed and tested new technologies and intelligent urban waterborne traffic solutions and services. Novia University of Applied Sciences, Turku University of Applied Sciences, Aalto University and the City of Turku carried out the project in co-operation. The project was funded by the 6Aika-program of the European Regional Development Fund. In addition, the project was funded by the Finnish Transport Safety Agency and the cities of Helsinki and Espoo. More information about the ÄlyVESI project and the results of the project: http://www.aboamare.fi/ÄlyVESI-Results