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Novel concepts for better positioning in port areas

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Abstract

As the maritime traffic gradually becomes more automated in the following years and decades, the shortage of human perception onboard must be compensated with alternative means. The signals from the environment must still be identified and interpreted, and the position of the vessel must be known both absolutely and in relation to its surroundings. When it comes to vessels with varying levels of autonomy, sensors and sensor fusion are the keys to build up situational awareness.

Today, the electronic positioning relies mostly on shipborne GPS receivers or DGPS and IALA radio beacon receivers. More advanced GNSS devices that utilize signals from, inter alia, GLONASS, Beidou, Galileo, and satellite-based augmentation systems (SBAS) such as EGNOS, are still quite rare. On short distances, the positioning bases primarily on optic navigation and the distances are measured with X or S band radar or are estimated by visual means, i.e., with eyes.

This study aims to address how the position of a vessel can be determined with modern sensor technology and sensor fusion in port environments with novel concepts in the maritime domain and shared further to the end-users. The data in this explorative research was collected with qualitative methods. An expert consortium was interviewed with semi-structured 1-on-1 interviews during the early summer of 2021.

In order to clarify the process of transferring the measurement data from the sensor to the end-user, the basic principles of the Finnish VTS system were explored and documented in the research as well.

The study suggests that the sensors that are able produce relative position information on short distances could enhance new flows of information, provide resilience for satellite-based positioning and facilitate new services as well as innovations in ports. However, the expected timeframe for the demand of any new possible services is hard to define. The sensors could be located both onboard the vessels and ashore on the ports.

Language: English
Key words: Positioning, Sensors, Situational Awareness, Remote Operation

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Secondly, my thesis supervisor Katarina Sandström from Novia University of Applied Sciences, deserves all appreciation for her academic advice and suggestions. Thank you a million times for the time you have invested in this project. Your input elevated the thesis to the next level.

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Last, but definitely not least, I would like to express my deepest gratitude to my beloved family for patience, support, encouragement and energy especially in the dark times when my father lost the fight against his long-term illness in March 2021. We all have different ways of coping - mine was to stay busy. Thank you for standing by my side and supporting me in my efforts no matter what.

In Playa Paraiso Tenerife, December 1st, 2021

Foreword

During my onboard years on Ro-Ro vessel Baltica (IMO 8813154), I felt stressed in the situations where the master manoeuvred in port areas and eventually took the vessel alongside a quay. My task as a deck officer was to assess the distances from the aft quarter to the fixed port structures and communicate the estimations further to the master via a handheld UHF-radio. When the vessel would reverse into its position in the port, I would be stating how many horizontal meters there were between the stern and the preferred position.

As the vessel made way through water, I gave out the meters: *"100, 90, 80, 70, 60, 50, 40, 30, 25, 20, 15, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1,5, 1, 0,5, 0,4, 0,3, 0,2 0,1"* - and finally – *"in position"*.

The master couldn't see the longitudinal distances from the bridge so he would base his decisions of engine commands on my subjective estimations. He could stand very little uncertainty or inaccuracies and wasn't shy to express his emotions. The task was undoubtedly essential, and the operation relied on my best-guesses on some level.

My coping mechanism was to think what a 25-meter swimming pool looked like and how many such pools would fit between the vessel and the preferred position. This was my original concept of understanding the relative position and the aspect of a vessel in port environments.

In this complex cognitive phenomenon, I fused the visual input data from my eyes with the psychological schemas that I had learnt before (the swimming pool analogy). The product of the process, i.e., the meters to the structure, were shared out verbally in auditive format to the end-user, who in this scenario was the master. The information was shared on the UHF band over radio frequencies between 151.94 - 154.57 MHz with 25 KHz bandwidth for Motorola RMM2050.

As automation and autonomy in seagoing traffic increase, practical issues in the physical world like determining the exact position and angle of a vessel can be resolved with modern sensor technology and novel concepts. The data can be collected and shared to the end-users without a human in the loop, which increases the safety and efficiency of the operations and enhances more lucrative working hours for the vessel crews.

List of Abbreviations

AI	Artificial Intelligence
AIS	Automatic Identification System
API	Application Programming Interface
ASM	Application Specific Messages
ASTERIX	All Purpose Structured Eurocontrol Radar Information Exchange
BAS	Berthing Aid System
DGNSS	Differential Global Navigation Satellite System
DGPS	Differential Global Positioning System
DTLS	Datagram Transport Layer Security
ECDIS	Electronic Chart Display and Information System
EGNOS	European Geostationary Navigation Overlay Service
EMSA	European Maritime Safety Agency
ENC	Electronic Navigational Chart
EOS	Electro Optical Sensor
EPFS	Electronic Position Fixing System
ESA	European Space Agency
FMCW	Frequency Modulated Continuous Wave
GLONASS	Globalnaja Navigatsionnaja Sputnikovaja Sistema
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
GBAS	Ground-based Augmentation System
IALA	International Association of Marine Aids to Navigation
IMU	Inertial Measurement Unit
IMO	International Maritime Organization
INS	Information Service (in VTS context)
INS	Inertial Navigation System
IP	Internet Protocol
IRNSS	Indian Regional Navigational Satellite System
JMAP	Joint Map (Product Name owned by Navielektro LP)
LASER	Light Amplification by Stimulated Emission of Radiation
LIDAR	Light Detection and Ranging

MASS	Maritime Autonomous Surface Ship
NAS	Navigational Assistance Service
NAVISP	Navigation Innovation and Support Programme by ESA
PNT	Position, Navigation and Timing
PTZ	Pan-Tilt-Zoom
PPP	Precise Point Positioning
QZSS	Quasi-Zenith Satellite System
RADAR	Radio Detection and Ranging
RADS	Radar Data Server
RF	Radio Frequency
RCC	Remote Control Center
RSIM	Reference Station and Integrity Monitor
RTK GPS	Real-Time Kinematic Global Positioning System
SBAS	Satellite-Based Augmentation System
SA	Situational Awareness
SOLAS	International Convention for the Safety of Life at Sea
TCP/IP	Transmission Control Protocol / Internet Protocol
TLS	Transport Layer Security
TOF	Time Of Flight
TOS	Traffic Organization Service
UHF	Ultra High Freq
UDP	User Datagram Protocol
VDES	VHF Data Exchange System
VHF	Very High Frequency
VTMIS	Vessel Traffic Management and Information System
VTS	Vessel Traffic Service
VHF	Very High Frequency
WAAS	Wide Area Augmentation System
QZSS	Quasi-Zenith Satellite System

1 Introduction

1.1 Background and purpose

Traditionally, the master who is in control of the vessel on the bridge wing, relies on his/her visual ability or the crew to see and estimate the distances from the vessel's fore and aft to the quay side. The difference in the distances of fore and aft gives out the vessel's angle relative to the fixed structure and further functions as the basis for the master's manoeuvring commands. Considering the Maritime Autonomous Surface Ships (MASS) gradually making their entrance in the commercial traffic, the onboard human resource will no longer be a fundamental element in the position determination process in the future.

Resilient PNT (Position, Navigation and Timing) has been identified as one of the core elements in the IMO's e-Navigation strategy (2018). Even though one can rely on satellite-based techniques impeccably most of the time, the vulnerability issues cannot be overlooked nor bypassed. Alternative reference sources are required for the sake of redundancy. The satellite-based positioning must be augmented in some way, and in addition, supplemented with alternative sensor technologies.

The sensors that are installed on vessels or in ports can assist in determining the position and compensate for the lack or reduction of shipborne human presence and eyesight. The positioning systems should adapt to the technological development to ensure the safety and efficiency of the operations. Once very relevant augmentation systems, such as DGPS, are coming to the end of their life cycles and are currently being replaced by new systems on a global level. All sensors and solutions, the type and role of which are dependent on the use case, have different strengths and weaknesses.

Further, whether the sensors are located onboard, ashore, or both, plays a significant role in the discussion. An onshore-based positioning system could provide redundancy for the vessel's own standalone systems and PNT determination capabilities. Nevertheless, MASS will undoubtedly be equipped with own sophisticated sensor systems regardless of the onshore installations. A novel augmentation service utilizing Real Time Kinematics (RTK) for GNSS can be seen as an interesting possibility in very accurate positioning in close distances.

The commissioner for this study, Fintraffic VTS Ltd, produces the radionavigation services for vessel traffic in Finland as per the standard described by International Association of Marine Aids to Navigation and Lighthouse Authorities' (IALA), hosts VHF/AIS base stations and maintains a land-based maritime surveillance radar network in the Finnish coastal areas. The radars, AIS and VHF radios form the basis for the situational awareness that is utilized in the Vessel Traffic Services.

Furthermore, in Finland the VTS situational picture is supplemented with live video feed from PTZ cameras and environmental information, such as water level, wave height and wind observations. The data from the different sources is gathered on electronic chart display on a Vessel Traffic Management and Information System (VTMIS) and portrayed to Vessel Traffic Service operators, who use the situational image as a reference data for their actions. What the operator sees, is a digital real-time model of the traffic and corresponding environmental circumstances in the Finnish VTS areas and waterways – under some definitions the image could even be referred to as *a digital twin* for the real physical traffic and environment.

The purpose of VTS, according to IALA's VTS Manual (2021) is to contribute to safety of life at sea, safety and efficiency of navigation and the protection of the environment within the VTS area by mitigating the development of unsafe situations through:

- Provision of timely and relevant information on factors that may influence the ship's movements and assist onboard decision making.
- Monitoring and management of ship traffic to ensure the safety and efficiency of ship movements.
- Responding to developing unsafe situations.

Vessel Traffic Services are recognized internationally as a *navigational safety measure* through the International Convention on the Safety of Life at Sea 74/78 (SOLAS) V/12. Guidance for the services is given in IMO Resolution A.857(20), which is currently being revised to accommodate emerging developments, such as the advent of MASS.

As the automation and autonomy take steps forward in the following years and decades, the VTSO's and other end-users of the position information should have access to even more accurate and exact data from the sensors that build up the situational picture. The better the dynamic factors are taken in consideration when making operational decisions, the better the VTSOs can contribute to the safety of the vessel traffic. Further, collaborative partnerships are also being established between Finnish ports and the Finnish VTS resulting in VTS taking more responsibility over the traffic management in port areas.

The upgraded situational picture would also be beneficial in recording the track histories from the VTS areas. The recordings are used e.g., for accident investigation purposes. The Safety Investigation Act (525/2011) defines the task and the mandate of the Safety Investigation Authority in Finland. The behavior of the remote-controlled vessels should be very carefully monitored and analyzed.

Fintraffic launched the eVäylä development project in November 2020, which aims to create a new digital situational picture and information exchange service for autonomous vessel traffic. One of the goals of the eVäylä project is to implement data exchange interfaces between vessel traffic services and remote pilots that are required for remote piloting. (Fintraffic Annual Report 2020). Such cloud-based data hubs are widely recognized as pivotal technologies to promote digitalization in shipping.

The purpose of this thesis is to examine operational aspects of different sensor solutions that provide the position of a vessel to the end-users. The data could be transferred via cellular networks or, for example, via VDES (Very High Frequency Data Exchange System). The possible end-users of the accurate position sensor data are expected to be the vessel operators, consisting of both shipborne and remote-control operators, VTS operators, pilots, port authorities or any applications of Artificial Intelligence (AI) technologies that would be able to control the vessel without human interaction. Eventually, the acquisition of accurate position data could be used for auto-docking functionalities with MASS.

1.2 Objective

Ensuring the integrity of Position, Navigation and Timing (PNT) information becomes more and more essential in the future as the number of autonomic and AI assisted functions on vessels and in ports increases. In full autonomy, the systems are fully independent of the human attendance. Fintraffic VTS Ltd oversees the safety of navigation in the VTS areas in Finland and the significance of receiving accurate and reliable information from the sensors into the VTS systems is a prerequisite for reliable vessel traffic services. Fintraffic VTS is also involved in several various research and development projects, the aim of which are to study, for example, how to affect the efficiency in port operations and services. Having access to a vessel's exact position information in real-time plays a significant role in the R&D projects.

Exact and secured position information is vital to be transferred to the VTS system without any undue delays, i.e., with minimum latency. The data is used by the VTS operators, who collect, analyze and share the information in order to prevent the development of dangerous maritime traffic situations and to provide for the safe and efficient movement of vessel traffic as per the Vessel Traffic Service Act (623/2005).

Moreover, Fintraffic VTS records vessel activity and movements in the VTS areas and the related VHF radio communications for future reference, i.e., to aid in accident investigation. Access to the records is subject to the provisions of the Act on the Openness of Government Activities (621/1999). The higher the quality of the recorded data is, the better the chains of traffic events can be analyzed and similar accidents in the future avoided.

The objective of this master's thesis is to examine concepts and solutions for better positioning in port areas, especially focusing on the multilateral use case of taking the vessel alongside. With novel sensor technology both conventional vessels and the vessels with varying levels of autonomy in the future can achieve better situational awareness in port areas. Rather than to make recommendations, the purpose of the thesis is to address relevant problem areas and function as advice for planning further studies (feasibility studies, site surveys, equipment trials etc.) and for professional discourse.

Previous research with a similar approach to the investigated matter was not identified during the thesis process. The 2021 workplan of ESA's (European Space Agency) NAVISP (Navigation Innovation and Support Programme), however, includes a proposed activity "055 - Attitude control of autonomous ships navigating in ports" to investigate different configurations of PNT sensors, i.e., GNSS + machine vision, infrared, lidar, and depth sensors, in conjunction with AI techniques. The NAVISP actions are implemented via competitive tenders by participating states and partners. (ESA NAVISP 2021).

One of the aims of the action 055 is to "develop and prove alternative PNT concepts for ship positioning and attitude in ports, assessing achievable level of performance" and to develop a prototype to be used in port scenarios. The main results for the proposed activity, for which planned tender issuing is Q4/2021 and the estimated price range 600.000€, will provide different alternative PNT concepts and technical solutions for present and future autonomous maritime vessels. (ESA NAVISP 2021).

1.2.1 Determining the position

Depending on the application, the requirements for the accuracy of the absolute position information of a vessel vary significantly. The position of a vessel making way in open sea areas needs only in very rare cases to be determined with higher accuracy than 10 meters, whereas the position and aspect in relation to the surroundings, must be exactly known and readily available when remotely executing manoeuvres or outsourcing the practice for AI in a harbor basin in order to effectively and safely control the vessel.

Table 1. IMO minimum maritime user requirements for general navigation, positioning and selected applications, Res. A.915(22)

Navigation phase / Operation	Horizontal accuracy (m)	Availability % per 30 days	Coverage	Fix interval (seconds)
Ocean / Coastal	10	99,8	Global	1
Port approach and restricted waters	10	99,8	Regional	1
Port navigation	1	99,8	Local	1
Automatic collision avoidance	10	99,8	Global	1
Automatic docking	0,1	99,8	Local	1
Local VTS in port operations	1	99,8	Local	1
Traffic management for ship-to-ship co-ordination	10	99,8	Global	1
Traffic management for ship-to-shore co-ordination	10	99,8	Regional	1
Casualty analysis in port approach and restricted waters	1	99,8	Regional	1

As a part of this study, solutions that produce position information, both absolute and relative, with an accuracy of less than 1 meter – preferably even 0,1 m as per automatic docking requirement (table 1) - in an environment of limited space, are examined.

Today or in the near term, in addition to the satellite-based positioning, some of the most significant alternative means are deployment of radars, lidars, terrestrial radio signals (R-Mode), compasses for cross-bearings, and acoustic methods, i.e., echo sounders in some special operations. The use of sextants has decreased in the previous decades, but the use is on the rise again. USCG has adopted the celestial navigation back to its training regime in order to provide redundancy against GPS related vulnerabilities as a cost-effective back-up solution (Brumfiel, 2016).

1.2.2 Fintraffic VTS

Fintraffic VTS aims to accelerate the development of automation and digitalization in the industry and has taken a stronger role as a provider of new, intelligent maritime information services and a strengthened situational picture through the eVäylä development project, which runs from 2020 to 2025. During that time, Fintraffic will be implementing digital information exchange services between vessel traffic services and port operators and creating a foundation for the digital management of evolving vessel traffic. (Fintraffic Annual Report 2020).

One of the objectives for the project is to develop and produce a service establishing efficient and real-time data transfer between vessels, Finnish ports, and variety of other port operators. The service will enable safer, smoother, and more efficient shipping, and the ability to link maritime transport to other modes of transport. Further, the eVäylä project will implement data exchange interfaces between vessel traffic services and remote pilots that are required for remote piloting. (Fintraffic Annual Report 2020).

During the year 2020 Fintraffic continued the development of vessel route and timetable data and reached the pilot stage in a project that is utilizing machine learning. A common interface service will improve both the common situational picture and the seamless usability of data, and this will have extensive impacts on the functionality of port logistics chains. (Fintraffic Annual Report 2020).

1.3 Problem formulation and the research question

Bearing in mind that determination of a vessel’s position cannot be based only on one singular system or sensor, alternative means must be deployed to offer redundancy and fault-tolerance. For the time being, the primary method to determine a vessel’s position in open sea areas is through satellite-based solutions, and when coming closer to coast, with the aid of maritime radars by referring to known fixed points and taking cross-bearings, or bearings with range, and transferring the acquired measurements on to navigational charts.

In traditional maritime operations, shorter distances and the relative position as well as the vessel’s aspect in relation to the surroundings are often determined visually by the crew. Considering the emerging technologies and the gradual advent of MASS, this study strives to find out which different sensors the position of a vessel can be determined with and what the operational differences between the most common technologies are. Sensors are needed to build the situational awareness and to compensate for the possible crew reduction or total absence at the ultimate end of the autonomous development spectrum.

If a vessel is remotely operated, the remote operator certainly wants to know the vessel’s exact position instead of rough estimates in port areas. The target of the study is to address which sensor technologies are feasible for determining the position of a vessel in port environments, ruling inexact terrestrial positioning possibilities, such as R-Mode, out of the question.

Further, the research investigates how the position data from the sensors can be transferred to the end-users reliably in real time (or as close as possible), and who the end-users could be. Studying the basic principles of the Finnish VTS system and its sensors promotes understanding the requirements and challenges related to data transfer. As an emerging new technology, the possible role of VDES, the so-called next generation AIS (Automatic Identification System) must be taken into consideration as well.

As the final topic in formulating the research scope is the question of costs: If this data from the sensors was transferred outside from the subject vessel, or out from the quay-side system in the event it was shore-based, should that data be free of charge or is there commercial potential in selling out the position information, and if so, which parties might be the customers. The problem formulation leads to the research question: How can the position of a vessel be determined with novel sensor solutions in port areas?

1.4 Delimitation

The study discusses the positioning of MASS, as defined in chapter 3.1, only in simplified port environments with distances of less than 200 meters on horizontal plane. The investigative focus is on the relative sensor systems, yet the indisputable role of satellite-based solutions in the position determination process is considered as well. Relative solutions refer to systems which measure the vessel's position in relation to any object, such as radars, lidars and base stations for correcting GNSS signals. When discussing fairways and remote operations, it should be emphasized that all informants have Finnish background, so the study's scope is very limited to a particular geographic area and infrastructure.

2 Theoretical part: MASS, positioning and sensors

2.1 Maritime Autonomous Surface Ships (MASS)

When it comes to automation, automation as itself is not the goal. The goal is to develop automation in order to increase safety, efficiency and sustainability of maritime operations. Improvements in these fields can potentially be achieved by developing autonomous systems. The ultimate optimization in the development could finally lead to an autonomous unmanned oceangoing ship (Figure 1).

Automated systems have existed in the maritime domain already over a century. Autopilots were invented 1907 – 1914 (Kellerman A., 2018) so the concept of executing navigational operations without human interaction is not anything new in this light. However, due to the latest breakthroughs that have led to the fourth industrial revolution, the prospects for evolution of the technology of autonomous vessels (Figure 1) have grown rapidly during the recent years.

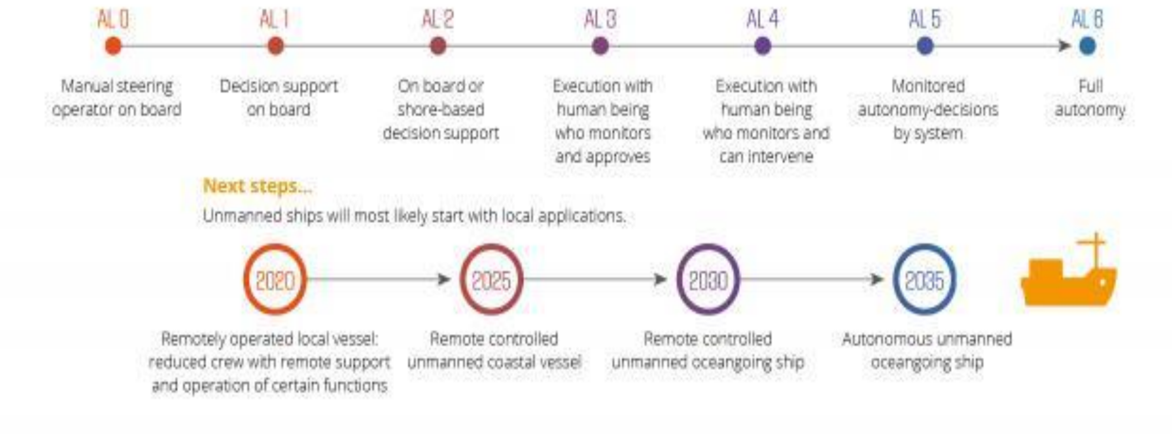


Figure 1: Vessel autonomy evolution prediction and Autonomy Levels (Lloyd's Register).

According to the British Cambridge Dictionary, the term "autonomous" refers to *"an autonomous machine or system that is able to operate without being controlled directly by humans".* Although in the definition the capability of the system to run without human presence is fundamental, it doesn't necessarily mean that the human wouldn't be involved in the operational loop at any stage. The role of humans can be monitoring or maintaining, for instance. All levels of automation require some level of attendance by a human except full autonomy. Consequently, it should be emphasized that the level of autonomy on a vessel doesn’t directly refer to the level of manning. Autonomous doesn’t equal unmanned.

The benefits of automation are eventually realized with savings in the operational expenses (OPEX) which can be addressed as the main driver for the market driven development. Another key driver is the international shortage of seafarers. While developing maritime autonomy, the safety of operations cannot be endangered at any stage and the legislative framework, international mandatory instruments and national and regional competent authorities have a definitive role in the progression.

In the maritime domain, the concept of autonomy can be divided into two subcategories: Operational and System autonomy (DIMECC One Sea, 2020). The International Maritime Organization (IMO) has laid down the foundation in identifying the different Operational levels of MASS in its Maritime Safety Committee’s 100th session in 2018 as follows:

Degree one: Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.

Degree two: Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.

Degree three: Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.

Degree four: Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself. (IMO 2021).

As interpreted from the table above, the operational autonomy stresses the role of seafarers, steering and/or watch-keeping, vessel features, back-up systems, and addresses the relevance of remote control, as well as composes a rudimentary liability framework. For the purpose of this study, it’s convenient to lay the primary investigative focus on degrees 1, 2 and 3. It’s not feasible to concentrate on degree 4 vessels yet, as apart from the accelerating pace of autonomous development, industry specialists believe this scenario is still many years ahead. In an optimal scenario, however, same positioning referencing techniques can be utilized irrespective of the MASS degree – the same solutions should work with all vessels, including conventional vessels as well.

System autonomy concentrates on the technical side. The degrees of system autonomy, as described by DIMECC One Sea (2020), are:

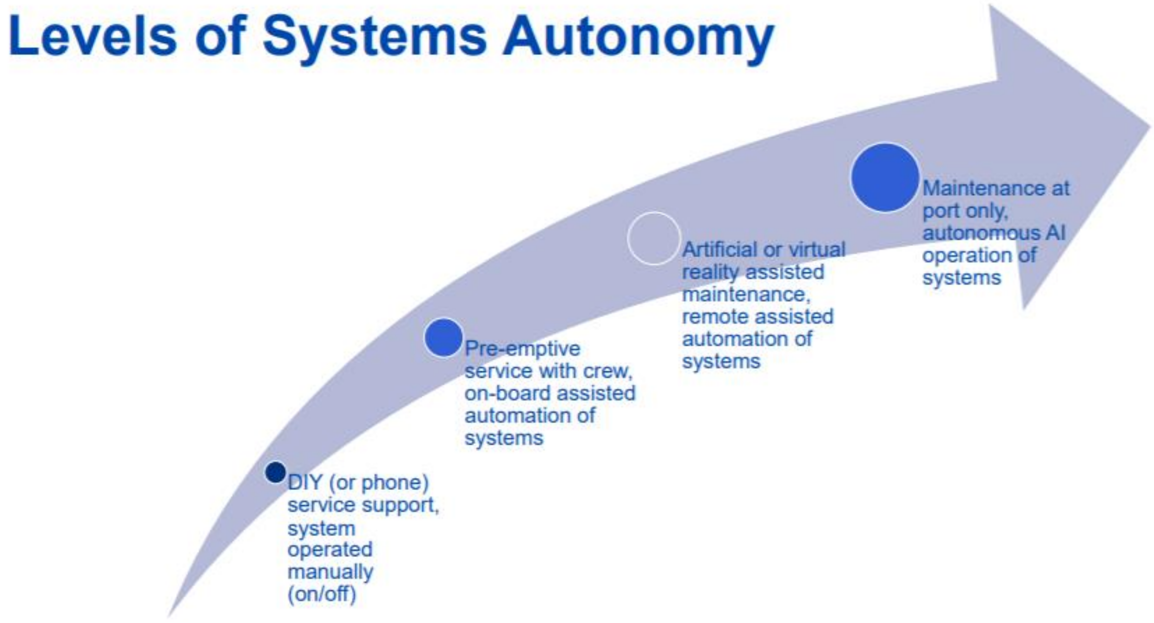


Figure 2: Levels of Systems Autonomy (DIMECC One Sea, 2020).

As can be seen in figure 2, the level of system autonomy increases from the lowest level, where systems are operated manually, to the highest level, where the systems rely totally on artificial intelligence and the maintenance is carried out only in ports due to non-existing onboard manpower. The system autonomy defines the framework for the type and place for the service, adopts a stand on the amount of automation during operation and in the systems architecture. (DIMECC One Sea, 2020).

As a conclusion, the concept autonomous is ambiguous. Although it doesn’t directly refer to the level of manning on the vessel, it can be summarized that as automation increases, the demand for manpower decreases. Humans can be operating, supervising, or alerted if needed, depending on the level of automation. Nevertheless, it doesn’t mean that a fully automated vessel couldn’t have any crew onboard in any instance. Figure 3 shows that MASS autonomy is a scalar phenomenon. The operation of a vessel can be manual even if it is totally unmanned, provided that it is remotely operated. On the contrast, the vessel could be periodically manned although the level of autonomy would be "full". In summary, it is reasonable to use the term "MASS" as an umbrella term for all vessels with varying levels of automation in the context of this work.

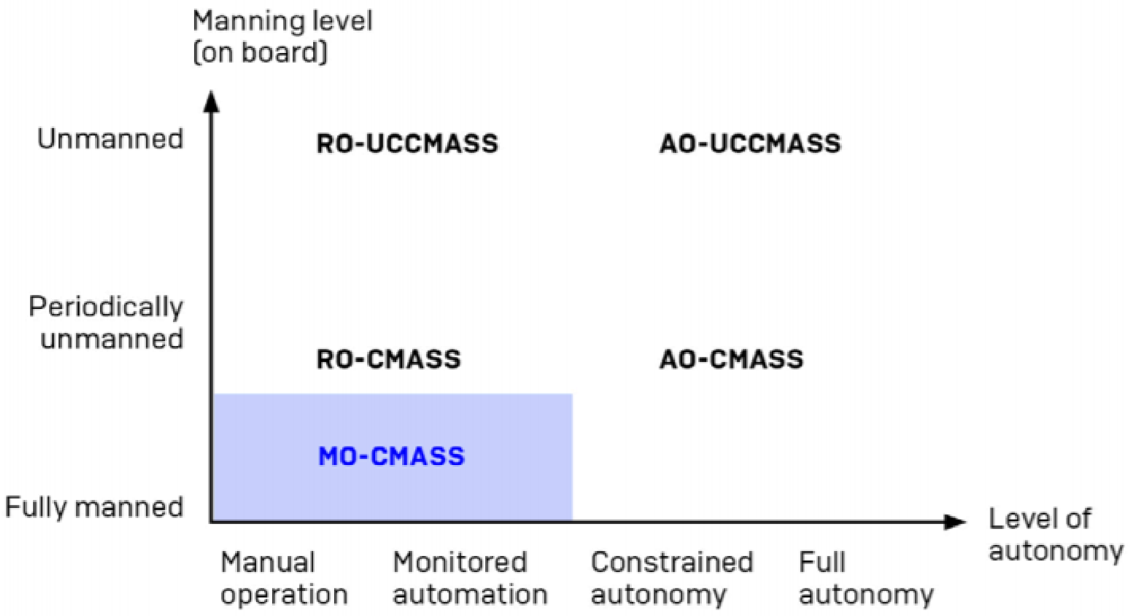


Figure 3. Separation of aspects of automation and indication of the nature of the legal challenge (Ringbom et al., 2019).

2.2 Positioning

Conforming to Zalewski (2020), the electronic positioning of vessels today relies largely on GPS or DGPS as well as IALA radio beacon receivers. More advanced GNSS devices that process GPS, GLONASS, Beidou, Galileo, IRNSS or QZSS satellite system signals or satellite-based augmentation systems (SBAS) such as EGNOS, WAAS, and SDCM, for example, haven't yet become very commonplace. Such multi-system receivers are presumed to become indispensable on MASS, and more common on the conventional vessels in the near term.

When integrated with gyro compasses, magnetometers, inertial and optical sensors, and with radars and lidars, the systems together will form the foundation for autonomous vessels (Zaleweski, P. 2020). Integrity of the novel sensors should be harmonized, standardized and further developed in order to be prepared for any error situations. The specifity of MASS and e-navigation safety should be taken in consideration in the development and standardization of such sensors, Zalewski argues (2020). Furthermore, according to Zalewski (2020), on all the autonomy levels, redundant multi-system receivers could act as the basis for absolute positioning, ensuring and securing the safety of MASS positioning. However, for the electronic position fixing systems (EPFS), such as GNSS or radar, no integrity measures have been adopted by IMO.

IMO and IALA have identified several technologies that enable e-Navigation on a wide scale. The technologies include e.g., ENCs (electronic navigational charts), as well as a robust and redundant electronic position, navigation and timing (PNT) system, and communications infrastructure between shore and ship. A prerequisite for robust PNT information is a core GNSS that is augmented with land or satellite-based service (DGNSS or SBAS) and, should the GNSS positioning fail, an adequate system for resilience (Hein, 2016).

The systems that could offer resilience for PNT, if made available for commercial use, include e.g., terrestrial eLoran or R-Mode navigation of which both approaches use radio signals that are not dependent on GNSS. Enhanced radar techniques could be used as well in the position determination process according to Hein (2016). However, the R-mode cannot reach port accuracy minimum user requirements on a back-up system (IALA R-129 based on IMO Resolution A.915 (22)), as the horizontal absolute accuracy requirement is 1 meter in port regions and the R-mode provides 10-meter accuracy level (R-Mode Baltic, 2019). As a conclusion, the back-up position must be measured with other means which can be onboard or ashore short distance sensors.

Also, such local error sources as interference, either unintentional or deliberate attacks, such as spoofing and jamming, or multipath events, can be ruled out with the use of backup PNT systems. The increased robustness, in conjunction with the GNSS and augmentation services, secures safe operations. In an event where single components in the system are affected by malfunction, the resilient PNT system enables positioning. In the development of the e-Navigation concept, the resilient PNT approach is being supported by IMO. (Hein, 2016).

2.3 GNSS navigation

Absolute positioning is the most popular method of positioning with satellite-based solutions. It is the simplest and most cost-effective way to find a position on Earth (Laurila, 2012). The GNSS (Global Navigation Satellites Systems) in use around the world are the United States owned GPS (Global Positioning System), GLONASS (Globalnaja Navigatsionnaja Sputnikovaja Sistema) operated by Russia, the Chinese BeiDou (Chinese: 北斗 Běidǒu, "Big Dipper"), Galileo in Europe and QZSS (Quasi-Zenith Satellite System) in Japan. Earth orbiting satellites form the basis for modern positioning as well as navigation and are widely used in various applications ranging from mobile phones to car navigation systems. The commercial maritime traffic today relies largely on GPS as well, but the amount of delivered GNSS units in the maritime market segment is expected to rise (European GNSS Agency). According to IMO Resolution A.915 (22) the use of GNSS in the maritime sector can be divided into two categories: general navigation and positioning applications.

The use of GNSS is based on the satellite transmitted information from several satellites simultaneously at a constant rate which allows measuring the distance between the satellites and results in determining the position of the receiver. Three satellites are needed for position triangulation (Figure 4) and a fourth one for determining the clock error (Cyber Security Course material 2018). The positioning process is not affected by the weather conditions. (Laurila, 2012).

Currently, when talking about GPS positioning, people usually refer to GNSS in general and the difference between the systems is not self-evident. GPS, more accurately GPS Navstar, is the most popular GNSS as it was the first GNSS launched by the U.S. Defense Forces in 1994 (Laurila, 2012) and partly due to its wide reliability with its 77 satellites, of which 27 were operational in June 2021 (NOOA, 2021). To reach an operational status for any GNSS 24 satellites are required (Laurila, 2012).

The development of GPS was initiated in the 1970's for military use with aims to provide positioning with a few meters accuracy, good tolerance against disturbances and ability to be used with only sending information to the recipient, meaning that the user devices only receive information from the satellites and don't send anything (Laurila, 2012). According to Laurila (2012), the requirements in the civil use development have been taken into account from the beginning regardless of the primary military use. Initially, for strategic reasons, the civil GPS was intentionally disturbed to reduce its accuracy. However, the selected availability was disabled in 2000 in GPS, which resulted in more accurate positioning in civil use (Laurila, 2012).

All GNSS include three segments: space, control and user. The space segment consists of the satellite constellation orbiting the Earth and transmitting GNSS signals to the user. The control segment acts as the core of the system. The purpose of the control segment is to monitor and control the integrity of the signals and the satellite status as well as to manage their orbital characteristics. Lastly, the user segment is formed by the receivers around Earth that obtain the Radio Frequency (RF) signals from the satellites. The number of satellites and monitor stations differ for the different GNSS. (Koivisto, M. 2019).

The GPS signals include a variety of information including satellite positions, the state of the internal clocks, and the health of the constellation. When measuring distances with satellites, either carrier waves or positioning codes can be utilized. The signals consist of the following parts in the GPS, but some principles apply on all GNSS:

1. The carrier waves of which the satellites have either two or three:

- L1, f = 1575.42 MHz, l = 19 cm
- L2, f = 1227.60 MHz, l = 24 cm
- L5, f = 1176.45 MHz, l = 26 cm

2. Positioning codes that include the raw data from which the GPS receivers derive their time and distance measurements

- P code (Precise) on L1 and L2 frequencies, intended for military use, period length = 29,3 m
- C/A code (Coarse Acquisition) or PRN (Pseudo-Random-Noise) on frequency L1, intended for civil use, on the newer satellites also on frequency L2, period length = 293 m. The chipping rate is 1.023 MHz.

3. Navigation message, the parts of which are:

- Time related information
- Orbit information from the satellites
- The health information of the satellites. (Laurila, 2012).

The user device receives information transmitted by several satellites simultaneously and the distances to the satellites are measured by the time the transfer takes. Each satellite emits its unique Pseudo-Random-Noise signal which identifies the satellite. As its period length and the speed of light (approx. 300 000 000 m/sec) are known, the distance can be calculated. When the same operation is executed with 4 different satellites, the result is an absolute position on Earth, also including the height information (Cyber security course material 2018).

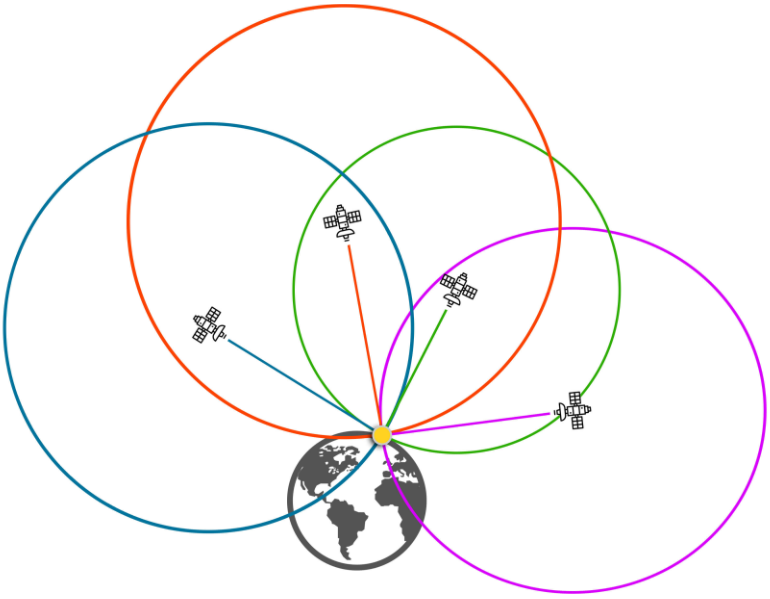


Figure 4: Triangulation / Trilateriation principle (Zarcycki 2019).

The signals that are received from the GPS don't involve any integrity information endangering the safety in maritime applications. Integrity information is vital, since without it, the user cannot know if the information broadcasted by the GPS is correct. As a response to the GNSS vulnerabilities, different augmentation solutions have been orchestrated to ensure robust positioning. Without any augmentation, the GNSS accuracy is within several meters. The GNSS position accuracy is affected by, for example, signal disturbances in the ionosphere and troposphere, satellite orbit and clock errors as well as multipath distortion. (Hesselbarth et. al., 2016).

2.4 GNSS augmentation systems

A variety of public and private GNSS augmentation systems and services have been developed to resolve the challenges associated with satellite-based positioning and to improve GNSS performance. According to NOOA, a GPS augmentation system is *"Any system that aids GPS by providing accuracy, integrity, availability, or any other improvement to positioning, navigation, and timing that is not inherently part of GPS itself."* The GNSS augmentation systems can be divided into Satellite-based Augmentation Systems (SBAS) and Ground-based Augmentation Systems (GBAS) or categorized by their range of operation into Local, Regional or Wide Area Augmentation Systems (WAAS) (Koivisto, M. 2019). This chapter introduces the augmentation solutions the informants referred to in the interviews in the Practical parts I and II in the research.

In a maritime context, the most popular solution to improve the GPS performance, until just recently, has been IALA Beacon DGNSS which is a public GBAS developed for maritime use in the 1990's. As a result of IALA's efforts in harmonization, the maritime sector could utilize the improved position accuracy and integrity in the position determination and navigational operations. However, the use of DGPS is coming to the end of its lifecycle. Intentional error in GPS position was removed in 2000 and for example Australia has declared that they have discontinued to send DGPS corrections as from July 2020 (AMSA, 2020) following the announcement from the United States Coast Guard in July 2020 to shut down its nationwide DGPS service (U.S. Department of Homeland Security, 2018). Some countries, including Finland, have not yet announced plans for replacing the DGPS service, but it is evident that the development of modern augmentation systems and progression in R-Mode positioning as a terrestrial substitute affect the provision of the service in the following years. As there is overlap on the Baltic Sea region on the DGPS coverage, any solutions made for future use should be uniform. DGPS is discussed further in chapter 4.3.

EGNOS (European Geostationary Navigation Overlay Service) is a public wide area SBAS operative in Europe (Figure 5). It is composed of 4 geostationary satellites, meaning that the satellites hold their relative position over Europe regardless of the rotation of the Earth. The satellites transmit integrity information and corrections for the GPS satellites in the L1 frequency band. Only one geostationary satellite in addition to the GPS satellites is required to benefit from the corrections resulting in very high level of redundancy. (ESA).

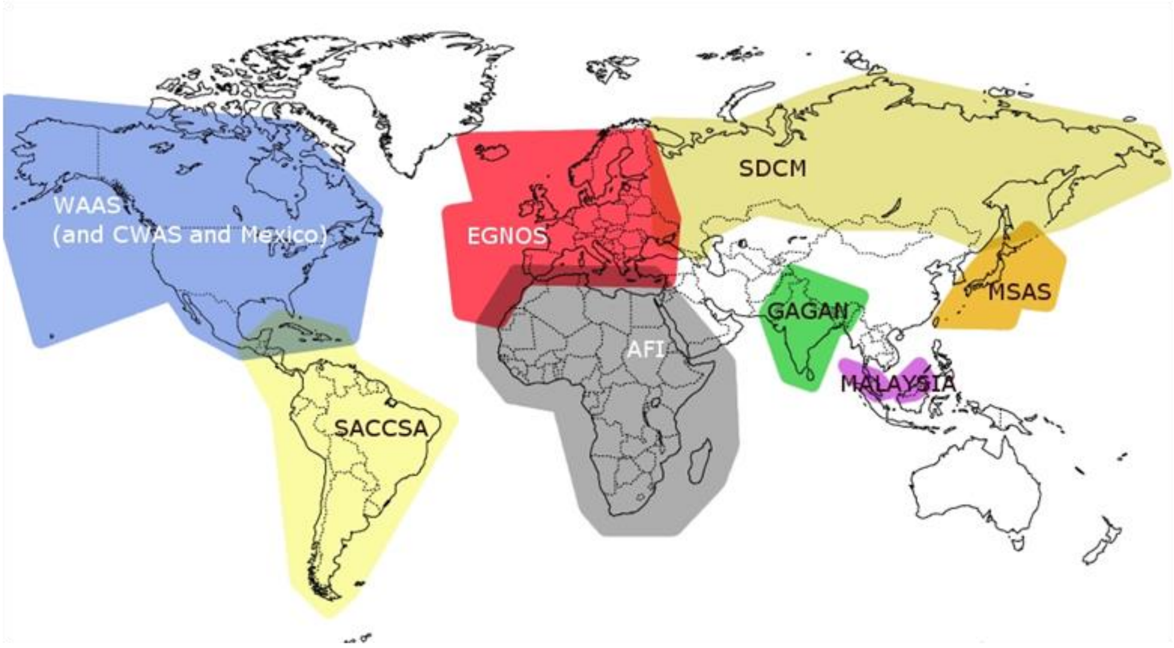


Figure 5: Public wide area Satellite-based Augmentation Systems (SBAS). (ESA).

According to the Conference paper “Comparison between IALA Beacon DGPS and EGNOS positioning performance in the transition area between Poland and Germany” by Hesselbarth et al. (2016) high quality performance of positioning with EGNOS corrections can be achieved in the investigated areas. The study also lists several opportunities to integrate EGNOS in the current maritime infrastructure, where IALA beacon has a significant role suggesting combinations are technically feasible. Bearing in mind the scope of this research, its noteworthy to be pointed out that the study (Hesselbarth et al., 2016) claims that the EGNOS-based positioning doesn’t meet the 0,1 m accuracy requirement for automatic docking as per IMO A.915 requirements discussed in chapter 1.2.1. but could facilitate primary position input for degree 1-3 MASS, at least in the investigated areas. Conforming to the measurement campaign conducted as a part of the study, the accuracy error for EGNOS is smaller than 0,9 m 95% of the time (Hesselbarth et al., 2016).

Even more accurate L-band corrections can be achieved by commercially provided augmentation. Fugro correction services are an example of a commercial SBAS (FTIA, 2021). Fugro’s products include such registered trademarks as Fugro Starfix, Fugro Seastar, Fugro Marinestar and Fugro Oceanstar. According to Fugro (2021), the horizontal accuracy range of their products is within 3-15 cm and they utilize PPP (Precise Point Positioning) techniques in combination with other systems.

Relative measurement techniques in satellite-based positioning are the most accurate, but in turn, the most challenging to implement (Laurila, 2012). According to Laurila (2012) relative correction systems require a base station and are commonly used, for instance, in surveying and machine control applications in earthwork processes with excavators. With RTK (Real Time Kinematics) accuracy on a 1 cm level position can be achieved (Laurila, 2012). Commercial GBAS services are provided by, for example, TrimNet RTK, HxGN SmartNet RTK and for research purposes only FINPOS Network RTK (FTIA, 2021).

RTK is a differential GNSS correction technique, the service area of which is, depending on the source, 2-10 km (Laurila, 2012) or 10-20 km (ESA) basing on the use of carrier measurements and the transmission of corrections from the base station to the user device which cancels out the errors that are associated with standalone positioning (ESA RTK). The upper limit in the working range is set by the disturbances in the ionosphere (Laurila, 2012). The size of the service area in the traditional RTK is also affected by the local obstacles, such as buildings, forests, and the topography in the measurement area, as well as multipath errors (Laurila, 2012).

The corrections are communicated in real-time from the base to the user, which requires a dedicated communication channel (ESA RTK). According to Gustafsson (2021) the corrections can be sent for example on the ISM band (Industrial, Scientific and Medical). In general, the connection can be established over radio modem or over cellular network (Laurila, 2012). VDES could potentially be utilized to transfer the corrections to the rovers in port areas (Koivisto, 2021). The technique is highly dependent on the number of available satellites. Conforming to Laurila (2012), the rover and the base station must track 5 common satellites, but in practice reliable measurements are achieved only when the number of common satellites is 6 or 7.

2.5 Radars

In terms of electromagnetic radiation, radio waves on different frequencies are everywhere around us. Considering the electromagnetic spectrum (Figure 6), radars work on the microwave range and their wavelength is less than one meter and bigger than one millimeter meaning that their operation frequency is between 300 MHz and 300 GHz (Briggs, J. 2004). “Radar” is an acronym for Radio Detection and Ranging. Maritime radars, which are undoubtedly one of the most essential tools for navigation, object detection, collision avoidance, measuring distances and position fixing, are operated at 3, 5 and 9 GHz frequency and their carriage requirements onboard merchant ships are laid down in SOLAS Chapter V. The technical characteristics of maritime radionavigation radars are described in ITU-R M.1313-1.

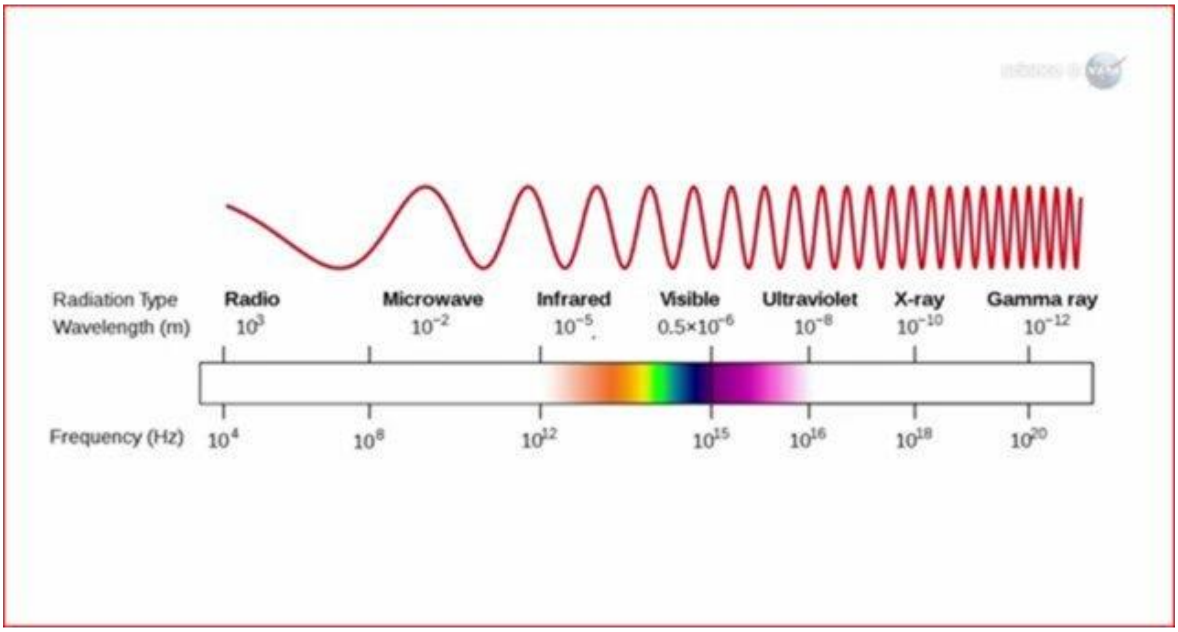


Figure 6: Electromagnetic spectrum (Patruno, J. 2014).

Wavelengths for the traditional maritime radars working on the X and S band are 3 cm and 10 cm, respectively (ITU). Due to shorter wavelength, X band radars are able to resolve between smaller objects and have higher resolution in the image, but their range is also shorter in comparison with S band radars because of the increased signal attenuation (loss of signal strength). Shorter pulse length reduces amplitude of received echoes. S band radars have greater range but on the other hand, require larger antennas. In electromagnetic radiation the frequency is inversely proportional to the wavelength as per the equation:

$$\lambda = \frac{c}{f}$$

where c is the speed of the wave in a vacuum, f is the frequency and λ is the wavelength. (Briggs, J. 2004).

The radar systems have transmitters that emit radio waves in predetermined directions. Through Time of Flight (TOF) calculation (d = ct / 2, where d = distance, c = speed of light, t = time), the relative positions of the targets can be resolved. The time is proportional to distance of the object. When the radar signals hit the targets, they scatter in various directions and also partly penetrate into the objects. Some of the transmitted signals reflect back to the radar receiver, and once the speed of the radio wave is known, the difference in time between the transmission and the reception, can be used to calculate the distance of the object in relation to the radar unit. (Briggs, J. 2004).

The signals from the pulse radars are short RF energy pulses and while they travel with the speed of light (approx. 300 000 km/s), the objects can be detected and ranged. Pulses are generated by magnetrons and radiated by rotating scanners. On the other hand, continuous wave radars, basing on frequency modulation, transmit uninterrupted electromagnetic signal instead of pulses. Conventional CW radars don’t measure the distance to the objects, but instead the rate-of-change in the range to the object by measuring the Doppler shift in the returned signal. Frequency modulated continuous wave (FMCW) radars can also give the distances by giving a unique “time stamp” for every transmitted wave. (Federation of American Scientists).

The maritime radars have become available for commercial use in their current form at the time of WW2. The basic working principle today is the same that it was more than 70 years ago, and radars are still very fit for purpose. What has changed during the time, is the thinking that radars are nowadays seen as a part of sophisticated integrated navigation-aid and situational awareness systems rather than standalone devices. Today, the radar picture can also be overlaid on ECDIS charts. (Briggs, J. 2004).

In the scope of this study, bearing in mind the port area use case for vessels with varying levels of automation, it’s interesting to focus on the radars that are operated on the higher frequencies and emit shorter pulses. They are more accurate on short distances, i.e., in port environments. The automotive industry has had the first experiments with use of shorter-range radars already in the late 50’s (Schneider, M. 2005). According to Schneider (2005), the development work on the car radars has primarily been focusing on at 17 GHz, 24 GHz, 35 GHz, 49 GHz, 60 GHz, and 77 GHz frequencies. The bands between 18-40 GHz can be called K bands, 40-75 V bands and 75-110 GHz W bands.

Similarly like in maritime traffic, collision avoidance has been an important driver for investigating the feasibility of radars for road traffic in the early days (Schneider, M. 2005). Today, on the automotive side, the sensor discussion is more broadly on the Advanced driver-assistance systems (ADAS) that aim to detect nearby obstacles or driver errors and respond to the developing situations accordingly. The downside with the higher frequency radars is their ability to function reliably in adverse weather. For example, S band radars are more robust in rain, since the signal attenuation increases as the frequency of the emitted radio wave increases. The automotive radars cannot endure a lot of snow, and therefore different ADAS systems, such as adaptive cruise controls, might not be available in less-than-optimal conditions. Since the range resolution and accuracy are inversely proportional to the sweep bandwidth, a 77 GHz radar sensor can achieve 20 times better performance in range resolution and accuracy compared to 24 GHz radar. The range resolution for 77 GHz is 4 cm when it is 75 cm for 24 GHz radar. According to recent market review, Guidance Marine, a Wärtsilä company, is the only product manufacturer with a 24 GHz maritime radar “RS24” in its product portfolio, but it is reasonable to expect more such appliances in the market in the coming years.

However, it should be addressed that the front-end techniques and antenna concepts between maritime and road traffic vary significantly. According to Schneider, M. (2005) in automotive use, the choice of sensor concepts is driven by functional requirements, limited space for the sensors’ mounting, regulatory issues, components’ costs and fabrication costs, and marketing schedules. The same thinking can be applied to maritime use as well. The carriage requirements for different sensors for MASS are not yet in place in SOLAS Chapter V, but it was noted in the IMO’s Regulatory Scoping Exercise, inter alia, that “additional performance standards for some navigational equipment of remotely controlled MASS most likely also need to be developed.”

Radars and their characteristics are discussed in more detail in the Practical parts I and II in the thesis.

2.6 Lidars

Lidars (acronym for LIght Detection And Ranging) are often called optical radars in the everyday speech. Fundamentally lidar’s working principle basing on TOF doesn’t differ from radars, but instead of microwaves, the lidars transmit and receive light signals. Referring to the Figure 6, lidars operate on the visible light, infrared or ultraviolet range in the electromagnetic spectrum. Since the wavelengths on these ranges in comparison with microwave range are much shorter, namely about 1 micrometer (0,001 millimeter), a much more detailed resolution can be achieved. On the contrary, lidars aren’t able to “see” trough fog and clouds. Due to very short pulse length, lidars can be used to produce very accurate 3D maps of environments (Figure 7) and, for example, to detect aerosol particles in the air. In low visibility conditions, it may be possible to adjust the scan frequency. (NOAA Lidar 101).

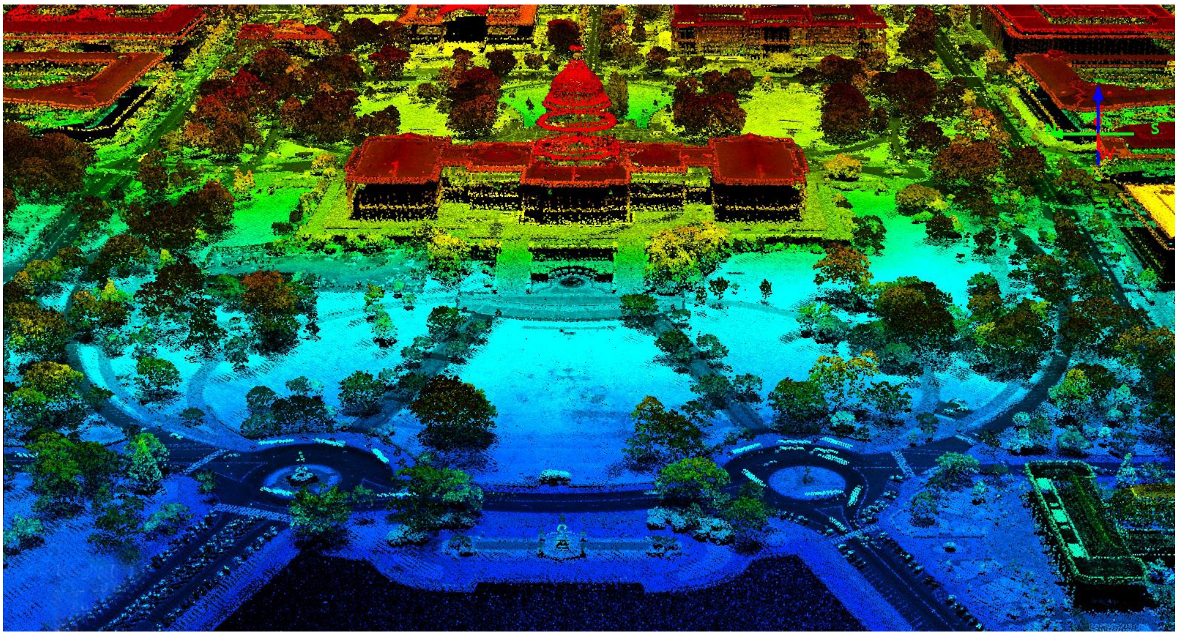


Figure 7. Lidar 3D point cloud. (GIS Geography, 2021).

Electro-optical sensors (EOS) in general refer to imaging systems such as daylight and night CCTV, and Infrared- and laser-illuminated cameras. Instead of utilizing the existing radiation, lidars produce their own. Therefore, lidars can be operated at night using near-infrared wavelengths whereas traditional cameras won't be able to see in the dark. In addition, traditional cameras without lasers cannot be used to measure distances without add-on features. Lidars and other laser-based sensing technology, can be seen as a sort of mixture of a camera and a radar (NOAA Lidar 101). With sensor fusion (Table 2), inputs from different sensors can be brought together to form a single model (Autonomous vessels – automation course material 2020).

Table 2. Sensor fusion. + = Strength, o = Capability, - = Weakness (Autonomous vessels – automation – Course material).

Attribute	Radar	Lidar	Camera	Fusion
Distance; accuracy	+	+	o	+
Distance; range	+	o	o	+
Object detection	+	+	o	+
Weather conditions	+	o	-	+
Lightning conditions	+	+	-	+
Velocity	+	o	o	+
Data density	-	o	+	+
Object classificication	-	o	+	+
Packaging	+	-	o	+

Lidars and their characteristics as well as sensor fusion are discussed in more detail in the Practical parts I and II in the thesis.

3 The research and the methods used

3.1 Study design

Bearing in mind the research objective and the conceptual character of the investigated niche, and further considering the available internal and external resources, the most feasible research approach to examine the study dilemma was deemed in the planning stage to be the acquisition of data via specialist interviews, which made the nature of the research process qualitative. Together with the commissioner of the research, it was discussed in the beginning of the process, who the potential informants could be and what is expected: They should be able to answer the questions in the interviews in a way that would help reach the aim of the research. The emphasized factors in the selection of the informants were their experience and knowledge in the investigated research area.

It was also reasoned in the beginning of the process that the interview data would eventually be analyzed with content analysis research method. Bengtsson (2016) argues that in the content analysis, the goal is to find meanings from the data and draw realistic conclusions based on it. The data is presented in words and themes. The composition of this study was designed on the basis of Bengtsson’s research article “How to plan and perform a qualitative study using content analysis” (2016). In the article Bengtsson suggests that qualitative concept analysis is not linked to any individual field of science although it has its origin in social research, and it provides a systematic and objective approach to describe a specific phenomenon of interest.

The research on this work consisted of four clearly identifiable stages: Planning, collection of data, analyzing data and writing the analysis, all of which divide into several smaller steps. Validity and reliability were considered to be of paramount of importance to the research in all its phases to achieve a credible level of trustworthiness. The biggest challenges in the research were to distance the researcher from the investigated area, to stay neutral in the interviews and avoid any predominant bias. The validity and the reliability of the research are discussed in the final chapter “Critical assessment of the work”.

According to Bengtsson (2016) there are five main issues to be considered when planning a study: aim, sample and unit of analysis, choice of data collection method, choice of analysis method and practical implications. In this study, the aim and the collection method were found very spontaneously in conjunction with the commissioner, but the remaining issues were solved gradually with a “step-by-step philosophy” during the process as decisions must have been made in order to make progress. The steps are described in the following chapters.

The results of the study consist of two entities: Practical Parts I and II. Different methods were applied in each part, and each part has its own purpose in the research. The aim of Practical Part I is to prepare the reader for understanding how the data from the sensors can be collected and shared using the Finnish VTS system as an example. In other words, the role of Part I is supportive. Practical Part II is the actual research to which the specialists were interviewed in terms described in detail in this chapter.

In summary, the practical research is divided into two parts:

Practical Part I: Preparative research. Helps to understand the main research.

Practical Part II: Main research. Includes the results of the specialist interviews and discussion.

3.2 Forming the sample

The number of informants in qualitative research is normally between 1 and 30 (Fridlund & Hildingh, 2000), but the available resources, such as research deadlines, as well as informational needs determine the applicable sample sizes. In this research, it was evaluated in the planning stage that the amount of available time would probably allow 8-10 interviews during the allocated time-window in the main research (Practical part II). In order to achieve as credible a sample as possible, it was decided during the mapping of potential respondents that also the respondents themselves could suggest potential respondents. The snowball sampling approach (Figure 8) provided an element of randomization in the sample and was also seen as an effective means to ease and partly outsource the selection process.

However, it was considered smart to choose the four first informants from different sectors to avoid too homogeneous background, which could cause unreliable results. All the informants who were asked to participate in the research accepted the invitation. Also, by agreeing the interviews with the first-round informants at early stage, an investment in research efficiency was made. This way a lot of time was saved as there were several interview requests pending simultaneously instead of only one at a time. The sample was not predefined, and it took shape dynamically during the process. Eventually one interviewed person recommended someone else to be interviewed.

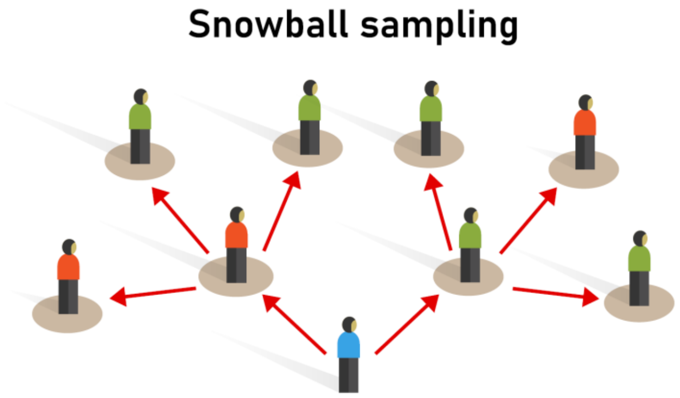


Figure 8. Snowball sampling. (Cutting Edge PR, 2020).

Although the snowball sampling method is particularly susceptible to sampling bias since it includes nonrandom selection procedures (Johnson 2014), a very niche expert consortium population was reached with its aid. By choosing the snowball sampling technique, higher detail and expertise in the researched matter can be reached, as the first round of specialist can use their expertise to deepen the level of research. According to Johnson (2014) Snowball sampling is widely used to find hidden populations.

3.3 Acquisition of the data

Bengtsson (2016) states that content analysis can be done on any type of written text. The choice of the data collection method, however, has its implications on the depth of the analysis. Conforming to Bengtsson (2016), interviews can provide very detailed answers, as the researcher has the opportunity to deepen the discussion with the respondents. If the data is collected from, for example, conference papers, then it is exactly what it is and there is no way to seek additional discussion in that format. Taking this into account, the data in this research was decided to be gathered via semi-structured interviews. The semi-structural form encouraged two-way communication in the discussions when something was found particularly significant in the answers or something required further explanation to be understood.

The questions (Appendices I and II) in the interviews were designed together with the commissioner of the work to address relevant challenges regarding the reviewed areas of interest. In the results chapter Practical Part II, the background for each question is introduced in the first paragraphs. After the introduction to the topic the respondent answers are presented in author’s own wording and categorization into themes, but citations used in case of direct quotations. Finally, conclusions basing on the answers are formed. As a summary, the main findings are also discussed in the chapter “Conclusions”.

The specialist interviews followed a semi-structured form and were executed in Finnish on Microsoft Teams. The structured set of questions that were asked from the respondents were the same in all the live interview sessions. An exception was made with one informant, who was interviewed in text format with customized questions as the last respondent. If the respondents had already given answers to upcoming questions in their previous answers, the respondents were not asked answer again on the subject, which caused a little variation in the actual asked questions.

The four first persons that were interviewed were selected co-operatively with the commissioner of the study. The first-round interviewees recommended 3 more persons in accordance with the snowball sampling philosophy, as per Figure 9.

The persons interviewed in the first round in the Practical Part II were:

- Olli Soininen, Program Manager, Fintraffic VTS
- Henri Suoniemi, System Responsible, Meyer Turku
- Miika Koivisto, Chief Engineer, Navielektro
- Johan Lilius, Professor of Embedded Systems and Data Technology, Åbo Akademi University

The persons interviewed in the second round in the Practical Part II were:

- Janne Lahtinen, Senior Lecturer, Satakunta University of Applied Sciences, recommended by Olli Soininen
- Karl-Erik Gustafsson, Hardware Systems Architect, Brighthouse Intelligence, recommended by Henri Suoniemi and Miika Koivisto
- Iiro Lindborg, Co-Founder and Vice President, Groke Technologies, recommended by Johan Lilius

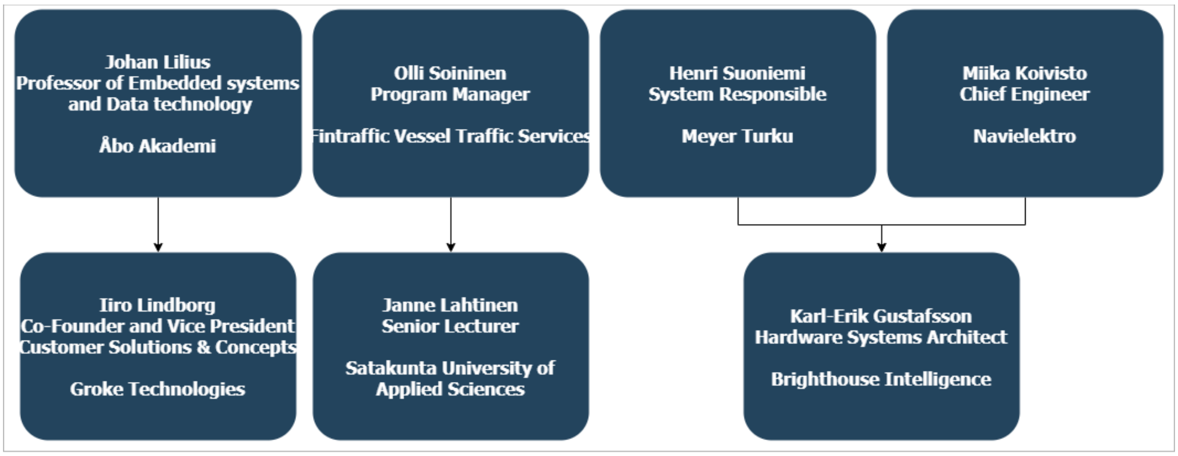


Figure 9. The interviewees and the recommendation chains.

Olli Soininen from Fintraffic and Miika Koivisto from Navielektro were also interviewed in the Practical Part I.

In practice, in certain questions nearly all respondents gave answers to more questions than were actually asked at that point, which made it unnecessary to present the following questions at a later stage. For instance, when asking question number 2, informants could already answer to questions 3, 4, and 5, since the questions handle similar themes. The list of questions is presented in the appendices. The respondents had the possibility to answer the interview questions as per their strengths and interest. Not all respondents answered all questions.

The interview process found its natural shape during the interviews. From the researcher’s point-of-view, it quickly became apparent that the answers of the respondents followed similar structures and there could have been more variation in the questions depending on the field of expertise from which the interviewed persons came from. Also, the importance of the themes of situational awareness and sensor fusion were recognized in the early interviews, and their significance was taken better into account in the later interviews.

Moreover, the Sea 4 Value project and its remote pilotage use case arose in many answers and were recognized to have a significant contact surface with the researched matter during the thesis process. The interview process was corrected by customizing the interviews as per the respondents’ specialization in the late stage and more freedom was taken in the expression of the questions, so that themes like situational awareness, sensor fusion and lessons learnt in Sea 4 Value were better brought forward.

Tailoring the questions for the respondents was identified as an effective method to bring depth to the answers and thus add value to the research. In addition, the snowball sampling philosophy was found a rewarding and handy approach to deepen the level of details in the study. The questions were designated to facilitate the ground for free association in the answers as the framework for the researched topics is wide, abstract and conceptual. No exact and explicit answers were expected from the respondents as there are no correct answers to the investigated matters.

3.4 Analysing the data and the writing process

Once the interviews had been finished, it was time to transcribe the material into written form as required in content analysis. In the transcribing process, what was irrelevant for the research's aim was left out. When transcribing semi-structured interviews that focus solely on certain subjects, only what is relevant for the research, can be picked forth from the interviews (Hirsjärvi & Hurme, 2008). Bengtson (2016) calls the excluded material *"dross"* and the included material *"content".*

When the recordings were turned into written content, it was split into *meaning units* directly. This saved a significant amount of work since the researcher didn't have to write down anything irrelevant from the audio. The next step was to identify codes from the meaning units to make it possible to categorize the themes later. The coding in this research was carried out by coloring the content that handled similar issues. The data was then organized by colors which enabled the producing of written text and categorizing the respondents' answers under certain themes.

In practice, the process was realized on Microsoft Excel by opening a new tab for each color and listing the data one upon another. For instance, all meaning units that described the content area of "Sensorien vaatimukset" (Sensor requirements) were coloured yellow and in the next step all the yellow lines of texts were compiled on the same tab, which was named "Sensorien vaatimukset". Later, the coded lines were, when applicable or found helpful, organized according to themes and sub-themes: For example, theme could have been "Toiminta sääolosuhteissa" (Performance in different weather conditions) and sub-theme "Lidar lumisateessa" (Lidar in snowfall). The English translation from the coded Finnish form was done directly to the thesis in the writing process.

During the writing process it was learnt that there are two ways to execute the data analysis in qualitative content analysis. The purpose of the manifest analysis is to use exact wording of the source data to avoid misunderstandings whereas in latent analysis, the aim is to find the underlying meanings in the text (Bengtsson, 2016). For the sake of simplicity, the manifest level was chosen. However, due to use of manifest analysis the written text might be more superficial and lack deeper analysis, as mostly the words are respondents' own to avoid misunderstandings in complex subjects. The manifest approach makes it possible to stay closer to the original content. In situations, where the respondents' answers are exactly same as in the interviews, and there are no author's own conclusions, citations are used within the text as separate paragraphs.

Finally, when the results had been written in English into the thesis from the coded form with the fundamentals of manifest analysis in mind, the texts were inspected to see if they were logical and flowing. The places of the chapters and individual phrases have been moved around countless times trying to make the texts more readable.

As the final check before publishing the research, the results went through respondent validation to confirm the outcome and strengthen the validity of the research. This was an effective way to increase the trustworthiness of the study. Some editorial and minor substantive corrections were applied to the texts in the Practical Parts I and II after the respondent validation phase.

4 Practical part I: Transferring the data from a sensor to a system and portrayal of the situational picture

4.1 Case VTS - Technical requirements derive from operational requirements

Considering the pragmatic nature of the work, it was deemed paramount to clarify the structure and the essence of the Finnish VTS system in the work's planning stage. Studying the basic principles on implementing sensor driven services and systems is beneficial for understanding the complex entity of sensor networks, maritime surveillance and building digital situational awareness.

The foundation for the technical requirements for the VTS systems has originally been laid down in IALA Operational and Technical Performance of VTS Systems (IALA V-128) in 2005. Later in 2015, the Annex of the former Recommendation has been changed to Guideline and revised to include additional considerations, new and emerging technologies in the IALA Guideline Preparation of Operational and Technical Performance Requirements for VTS Systems (IALA 1111).

Following the IALA normative provisions is obligatory, if a VTS authority claims to conform with the IALA standard S1040 "Vessel Traffic Services". V-128 Operational and Technical Performance of VTS Systems, the scope of which is Vessel Traffic Services technologies, is a normative IALA recommendation that shall be followed by the appropriate VTS authorities.

S1040 as well as other IALA standards are non-mandatory per se, but according to IALA, "*suitable for direct citation by States in the interest of an efficient and harmonized global delivery of VTS*". The principal idea of the standards is to achieve world-wide improvement and harmonization of Marine Aids to Navigation (AtoN) consisting of devices, systems or services that are external to vessels. In this context, the definition of AtoN includes Vessel Traffic Services.

The IALA Guideline 1111 presents a "*common source of information to assist Competent Authorities and VTS Authorities in the preparation and establishment of operational and technical performance requirements of standards and specifications for VTS system*".

However, the generic information of the guideline shall not be used as such to establish VTS systems since tailoring is required to capture the local performance requirements (IALA 1111).

The purpose of the IALA Guideline 1111 is to assist the VTS Authority in preparing, for example, establishment, operation or upgrades to a VTS system. The document presents system design, sensors, communications, processing and acceptance, of for example radars, electro-optical sensors and AIS, and addresses the relationship between Operational and Technical requirements as well as their importance to system design and sub-system requirements. The technical requirements for the VTS should derive from the basis of the operational requirements, which are:

- VTS area, sub-areas or sectors;
- type of service (INS, NAS, TOS);
- types and sizes of vessels;
- navigational hazards and traffic patterns;
- human factors;
- tasks to be performed by the system users;
- operational procedures, staffing level, and operating hours of the VTS;
- co-operation with external stakeholders;
- physical security of the VTS centers and remote sites;
- business continuity, availability, reliability and disaster recovery, and;
- legal framework. (IALA 1111).

The content for this first practical entity of the research was acquired during May and June in 2021 via specialist interviews, and from the Fintraffic's public website and Intranet. The specialists, Olli Soininen from Fintraffic VTS Ltd, and Miika Koivisto from Navielektro LP, have been strongly involved in the development of the radar and AIS networks and the VTS system in Finland and were therefore asked to share their much-appreciated knowledge for the study's benefit.

Furthermore, in this chapter the key principles of track fusion and displaying the data to the end-user in the electronic chart Tactical Display Framework (TDF) software “JMAP” by Navielektro LP, used by VTS operators and other situational picture end-users, are discussed.

4.2 The sensors

The technical maritime surveillance system consisting of several sub-systems, that is used to facilitate the Vessel Traffic Service in Finnish VTS areas, covers the Finnish coastline and Saimaa Lake area. Approximately 80% of the sensor network is owned by Fintraffic VTS, and the rest, about 20%, consists of sensor service, that is actualized in co-operation with METO-partners. *Merelliset toimijat* (METO) is a unique discipline of governmental maritime authorities and stakeholders, that has enhanced the development of a common situational picture system in a cost-effective manner.

4.2.1 Radars

The operational and functional requirements for radars in VTS systems are defined in IALA Guideline 1111 Chapter 2.

Finnish VTS centers receive radar picture from maritime X band radars and the last S band radars were removed from the system in 2017 (Koivisto, 2021). Currently, along the Finnish coast and in the archipelago, there are 101 radar units. The areas covered by the radars and the pictures they draw, have been defined taking in consideration the local environmental conditions for each location. There are three different types of antennas in the radars, and they function with one or two transmitters. All the radars are magnetron based and of similar type. According to Soininen (2021), the operational performance on radars is on the same level with all radar manufacturers and the differences between different manufacturers arise from the implementation of the maintenance services (Soininen, 2021).

Some of the radars are equipped with double transceivers enhancing frequency diversity. The devices have two different transceivers that work simultaneously on different frequencies. Thus, the movement of smaller objects is easier to detect (Soininen, 2021).

The radars are magnetron-based pulse radars and do not feature doppler processing (Koivisto, 2021).

The majority of the radars are owned by Fintraffic VTS. However, the situational picture is partly dependent on the radars owned by the Finnish Coast Guard and the Finnish Defense Forces. Technically the radars differ from one another depending on their owner and their local performance requirements. In turn, some of the radars owned by Fintraffic VTS share their image to the Finnish Defense Forces and to the Finnish Coast Guard. These radars are equipped with separate RDP units that are controlled by the Finnish Defense Forces and the Finnish Coast Guard. Put simply, other users cannot affect the control parameters of the scanners and pulses of the radars. (Soininen, 2021).

All radars owned by Fintraffic VTS are equipped with Radar Digital Processing (RDP) units (Soininen, 2021). Regardless of the area to be drawn, with the aid of the RDP units, better resolution for the radar image can be achieved in comparison with older processing techniques. The resolution of the radar scales automatically according to the level of zoom on the overviewed area on the electronic chart display. Compared to the older techniques, the possibilities to customize the radar image and the automation used to tune the radar image are more sophisticated with RDP units. RDP stands for Radar Digital Processor, and its purpose is to convert the analog radar image to the digital format that the VTS system uses. RDPs work on “analog in, ethernet out” principle.

RDPs also maintain the local target tracking and they are used to control the actual radar equipment as per VTS operator’s commands. The radar data is transferred from the radar site to the radar service (RADS server) where the images of individual radars are combined together and shared to the VTS workstations and to the VTS track recording service. The radar and the RDP unit together form the radar image that is seen on the VTS centers (Figure 10).

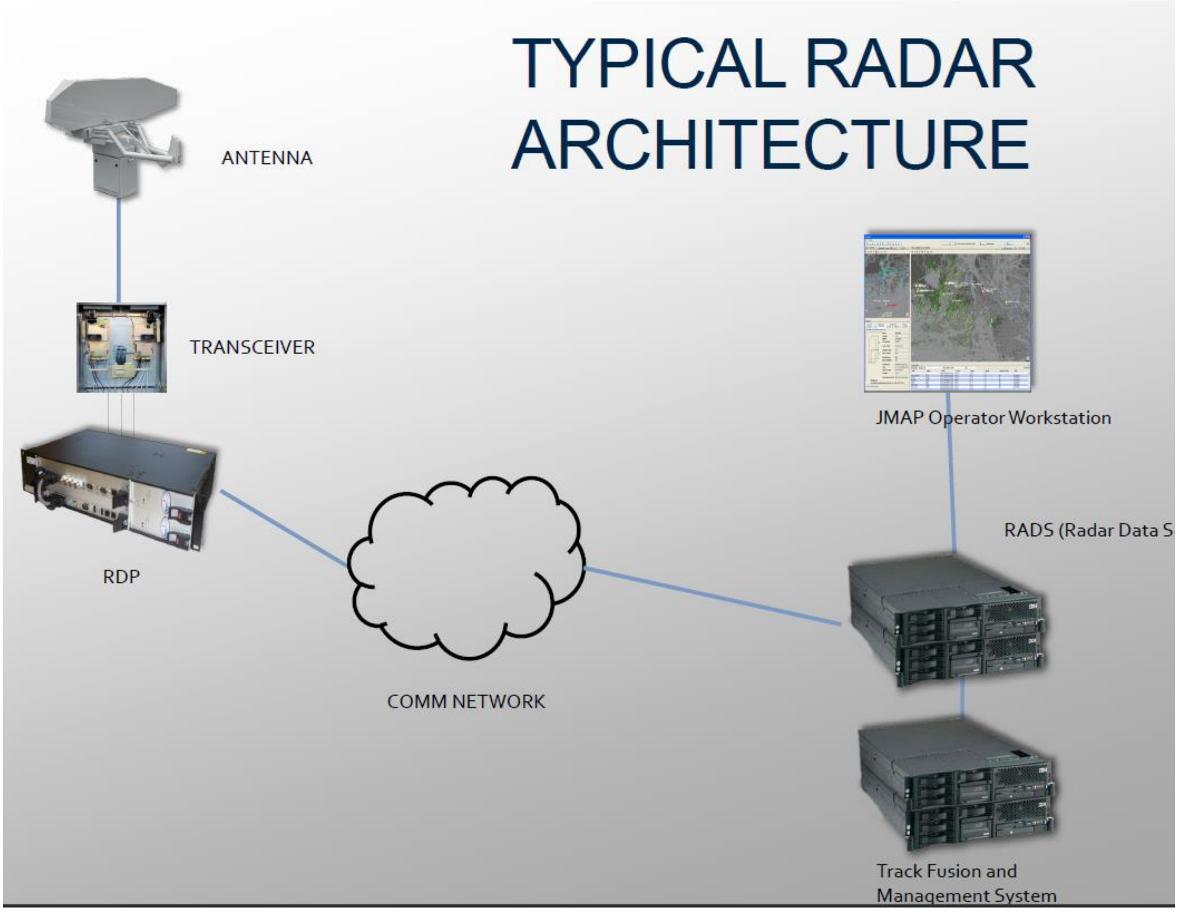


Figure 10. Typical radar architecture. (Navielektro).

The performance requirements for the radars originate from the IALA V-128 recommendation. While V-128 is a recommendation, it has been agreed in the *Decision to establish a VTS* that the technical systems of Fintraffic VTS centers and VTS areas conform to IALA's S1040 standard. The IALA recommendations cannot be explicitly followed, since the users might have on specific needs for the use of the radars. (Soininen, 2021).

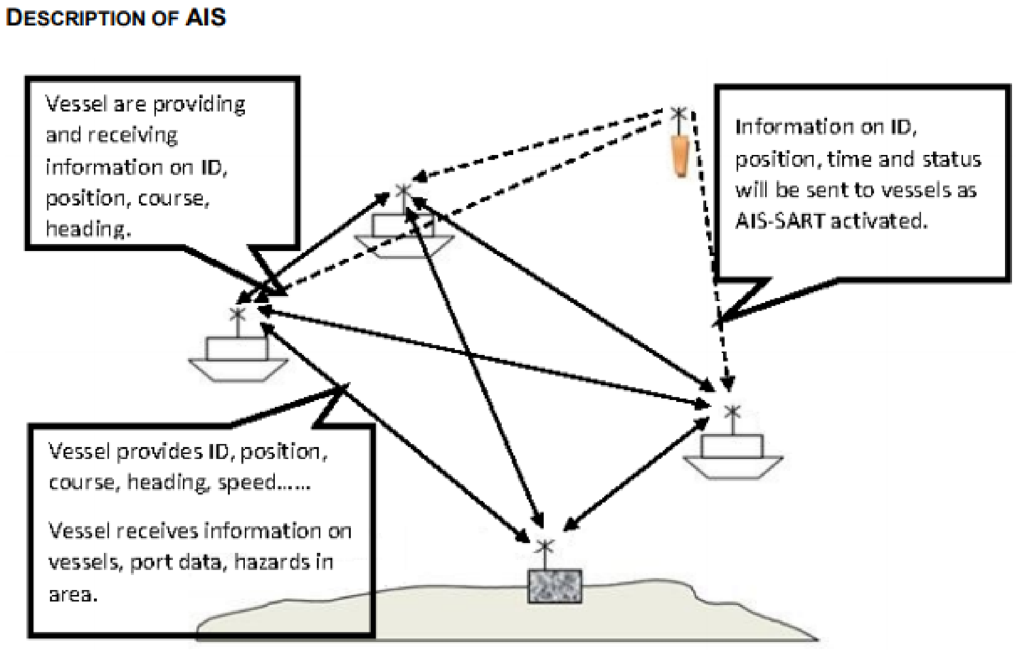
How a radar is able to perform and how it is utilized, is linked to the local environmental conditions and user needs. According to Soininen (2021) Fintraffic VTS doesn't have any own requirements for the radars, but in addition to the IALA guidelines, such factors as free-space path loss and the losses due to local infrastructure has been taken in consideration in the theoretical radar coverage calculations. With the radar and RDP technology, that the Finnish VTS system currently has in use, a fair overview of the surveilled areas on satisfactory resolution can be reached (Soininen, 2021).

The market prices for the radars vary between a lot, but in general they are in scope of a few hundred thousand euros per unit. The maintenance costs are normally 2% - 6% of the radar purchase price, and in practice they consist of replacing the magnetrons that are the consumable parts in the radars. The type of the magnetron can be either traditional or so-called diversity magnetron. The biggest costs regarding the maintenances consist of travel and access expenses to the remote locations of the radar sites. Unscheduled maintenance is hardly ever required. Typical problems are linked to data communication e.g., service operator level difficulties, or to challenges in power supply, which are quite normal in the archipelago environment. (Soininen, 2021).

4.2.2 Automatic Identification System (AIS) and VHF Data Exchange System (VDES)

The operational and functional requirements for AIS in VTS systems are described in IALA Guideline 1111 Chapter 3.

The AIS system hosted by Fintraffic VTS is based on a comprehensive land-based AIS network, which collects and shares the information sent by the vessels and reverts safety and supportive information back to the vessels, so that the information can be utilized in their navigational systems. Vessels transmit their data to other vessels and VTS stations and they receive data from other ships and VTS stations and other AIS stations, such as AIS-ATON and AIS-SART (IMO A29 Res. 1106).



DESCRIPTION OF AIS

Vessel are providing and receiving information on ID, position, course, heading.

Information on ID, position, time and status will be sent to vessels as AIS-SART activated.

Vessel provides ID, position, course, heading, speed……

Vessel receives information on vessels, port data, hazards in area.

Figure 11. Description of AIS (IMO A29 Res. 1106).

The AIS data collected by the land-based network is used by national authorities and, via international agreements, all the coastal states in the Baltic Sea region and EU member states. Moreover, Fintraffic VTS produces open, nearly real-time, AIS data for application development in Marine traffic APIs (Application Programming Interfaces) (Digitraffic 2021). AIS functions worldwide on VHF Maritime Mobile -band on frequencies 161,975 MHz (AIS 1 87B) and 162,025 MHz (AIS 2 88B) and the technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band are described in ITU's (International Telecommunication Union) recommendation ITU-R M.1371-5 (ITU).

Table 3. Update intervals of A Class AIS vessel (ITU-R M.1371-5).

Dynamic conditions of a ship equipped with A Class AIS	Nominal update interval
At anchor or moored, max 3 knots	3 min
At anchor or moored, more than 3 knots	10 s
0 - 14 knots	10 s
0 - 14 knots and changing course	3 1/3 s
14 - 23 knots	6 s
14 - 23 knots and changing course	2 s
More than 23 knots	2 s
More than 23 knots and changing course	2 s

As interpreted from the table, the nominal update intervals for the dynamic data are dependent on the vessels' speed and course alteration. For the static and voyage related information the update interval is 6 minutes or on request, when the data has been amended (ITU-R M.1371-5). The mandatory carriage requirements for AIS in certain size vessels derive from IMO regulations. According to EU directive 2002/59/EY all Member

States must monitor the vessel traffic in their sea areas with land-based AIS network. HELCOM collects AIS statistics in the Baltic Sea region (HELCOM).

VDES, the IALA supported successor for AIS, can be seen as an enabler for future maritime communications and e-navigation. VDES is an enabling technology that includes the traditional AIS and ASM (Application Specific Messages), but as a new addition, also the possibility for any kind of digital maritime communications is included, and it can be used via terrestrial components or satellite communications links (Lazaro et. al., 2018). Through effective utilization of the radio spectrum, additional channels and transmission mechanisms are introduced in VDES, and therefore the data rates are higher and able to answer to growing data exchange demands in e-navigation (Lazaro et. al., 2018).

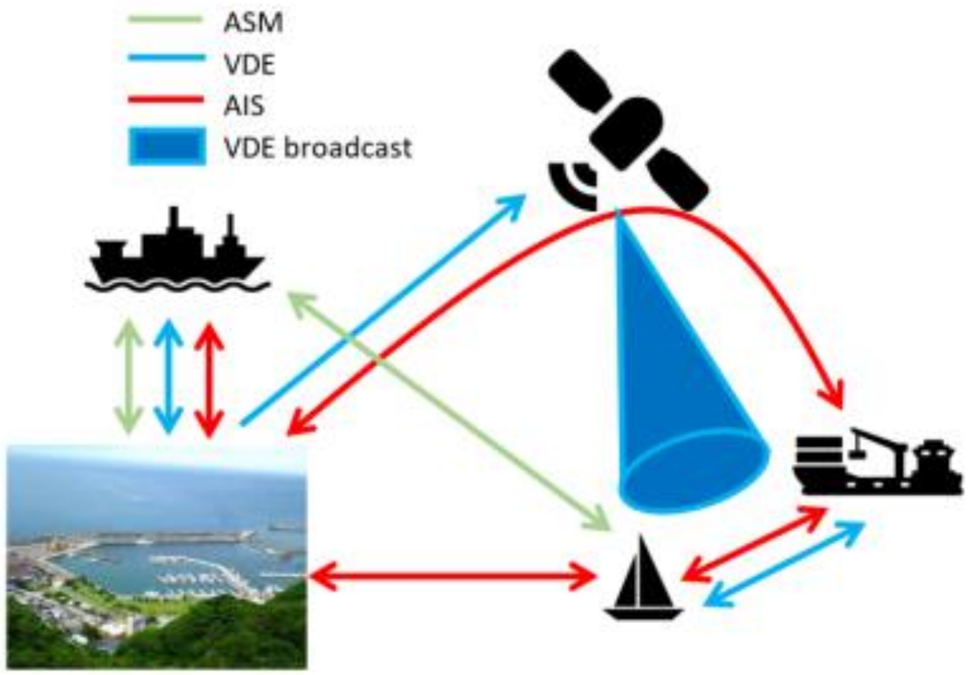


Figure 12. Possible VDES/AIS communication framework (Luglio. et. al., 2018).

Potential uses for VDES, according to IALA G1117 VHF Data Exchange System (VDES) Overview (2017), relate to SAR communications, Safety related information, ship reporting, Vessel Traffic Services – namely waterway monitoring, INS, NAS and TOS – chart updates, route exchange and logistic services. The technical recommendations for VDES derive from ITU M.2092 (2015). VDES will undoubtedly play a key role in future VTS digital communications and act as an empowering technology for any kind of new services requiring constant data transfer.

4.2.3 Cameras

The operational and functional requirements for electro-optical systems within VTS systems are defined in IALA Guideline 1111 Chapter 5.

The cameras in the VTS system consist of surveillance cameras (CCTV) and their management, control, and visual presentation services. Local conditions of the surveilled areas are considered in the performance requirements of the cameras, so the focal lengths, sensitivity and resolution of each camera unit vary case-specifically. Also, the means to control the cameras and record the image differ depending on their location. (Fintraffic VTS Intranet).

The cameras cover the Finnish fairway network only in selected fixed locations and the total coverage is relatively small. However, the selected locations are of significant importance from the aspect of traffic organization. These areas include, but are not limited to, pilot boarding positions, areas with higher risks, and some port areas. In addition to the cameras owned by Fintraffic VTS, some camera services offered by ports are utilized on a contractual basis. (Fintraffic VTS Intranet).

The primary use case of the cameras in the VTS system is to aid in exceptional circumstances by providing a strengthened situational picture. The VTS operators are able to control the cameras, and the cameras share their picture in real-time to the VTS centers in digital format. As an automated feature, the VTS operators can also lock some of the cameras on any moving targets (radar, AIS, fusion track etc.), which eliminates the need for manually operating the alignment of the camera. In this way, some of the cameras follow the vessels in the fairways without direct VTS operator interaction. (Koivisto, 2021).

Drones are not utilized in the operational VTS system as mobile cameras, but they are used as an aid to help in investigating fixed structures, such as radar towers, in the maintenance and upkeeping when applicable. However, the role of drones is expected to develop in the maritime surveillance in the following years (Personal communication, Mikkonen, 25.8.2021).

4.2.4 Weather sensors

The operational and functional requirements for environmental monitoring in VTS systems are described in IALA Guideline 1111 Chapter 4.

Weather information is vital for maritime traffic. An integral part of the VTS system is formed by weather sensors and mareographs, which are used to provide environmental information to secure the safety of navigation. The Finnish Meteorological Institute (FMI) manages the sensors that are used to receive data on wind direction and force, mean wind and peak measurements for 1- and 10-minute periods, air pressure, and air temperature. The mareographs are used to receive information about water levels in relation to the agreed datum. The data from the 13 mareographs along the Finnish coast is transferred to FMI in real-time and the VTS system receives it after it has been verified by FMI. The mareographs function automatically, and especially the reliability, cost-effectiveness, easiness of maintenance and system expandability have been underlined in the design of the system. (Fintraffic VTS Intranet).

Wave observation data is brought to the system from 4 different locations: Helsinki Suomenlinna, Northern Baltic, Sea of Bothnia, and from Bay of Bothnia. The data includes measurements on the significant wave height, highest individual waves, wave lengths and directions. The wave buoy information is available only when the seas are clear of ice. Different types of weather forecasts are also available in the VTS system. These consist of wind, wave and rain predictions that are delivered also delivered by FMI. The predictions are portrayed to the operators by using the simulation capability of the software. (Fintraffic VTS Intranet).

VTS operators share the weather information to ships when they report, at set intervals, whenever necessary or when a ship so requests. Meteorological reports by the Finnish Meteorological Institute are produced in accordance with Vessel Traffic Service Act 623/2005 5 §.

4.3 DGPS

Fintraffic VTS offers the DGPS service for the maritime traffic in the Finnish coastal waters and in the Saimaa deep channel. Following the IALA guidelines, the service is produced over

9 base-stations and 2 control stations. 7 of the reference stations are located on the coastal areas, and 2 in the Saimaa Lake area. In the Finnish territorial waters, correction signals also from 6 Swedish, 2 Estonian and a Russian reference stations, can be received to improve the accuracy of the position as well. The base stations (RSIM, Reference Station and Integrity Monitor) and the Control Stations (CS) are connected over TCP/IP and dial-up access. (Fintraffic VTS Intranet).

A marine radiobeacon DGPS is utilized to calculate improved position accuracy and integrity in the onboard marine receivers: The DGPS reference stations compare their known positions to the estimated positions of the GPS receivers locating on the vessels. The error sources are correlated between the land-based stations and the near-by users, which enables using the calculated position estimate and the true location to improve the accuracy of the positioning (IALA Table of DGNSS stations, 2018). The DGPS transmissions are done on approximately 300 kHz frequency and they follow recommendation ITU-R M.823-3.

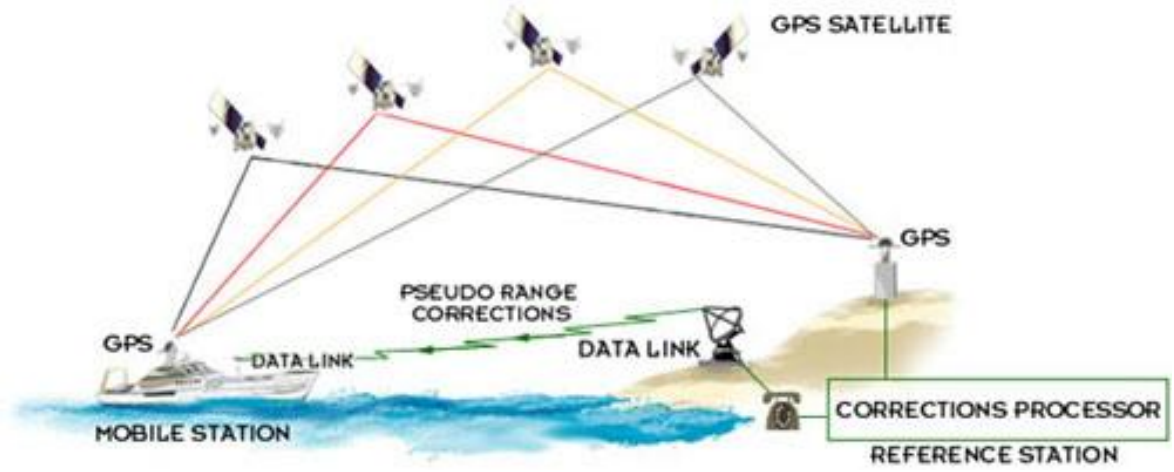


Figure 13. Description of DGPS (IALA PNT 2021)

The accuracy for the DGPS positioning has been specified < 10 meters 95% of the time, but in practice, the corrected position accuracy is 1 – 2 meters 95% of the time (Fintraffic VTS, 2021). The location of the RSIM plays a significant role in the accuracy of the correction signal. The closer the base station is to its user, the more accurate the correction is. Soininen (2021) considers that the error is approximately 70 cm in the estimated position per 100 km and the maximum operating distance is around 1000 km.

The signals from the GPS navigation satellites don’t include real-time integrity information, which is why the use of the correction data is unavoidable in merchant shipping. However, the use of DGPS will soon end totally and the position must be augmented with other means (Soininen, 2021).

According to Soininen (2021), there exists no receivers for the current MF band in the market anymore. As the DGPS signal is transmitted on the MF frequency, the modern vessels aren’t equipped to receive the differential correction information. Soininen (2021) estimates, that roughly 85% of the vessels aren’t able to receive the data, since they don’t have the MF receivers, that can bring the data to the GPS device, where the position is corrected. Today the modern DGNSS devices onboard vessels receive several different satellite sources and use them to fix each other. According to Soininen (2021), they can utilize EGNOS or some other satellite-based augmentation service (SBAS), but not DGPS.

Although the integrity information is provided by the modern SBAS, they are susceptible to spoofing and jamming as they use the same frequency band as GNSS (IALA Report of the workshop on the Future of Marine Radiobeacon DGPS/DGNSS, 2020).

4.4 Transferring the data onward from the sensor stations

Data processing and VTS data management in VTS systems is described in IALA Guideline 1111 Chapter 9.

Koivisto (2021) explains transferring the data from sensor to the end-user by taking radar as an example. Radar is an analog sensor and conforming to Koivisto (2021), the radar transceivers’ outputs indicate the response of the measured pulse (VIDEO signal), the timing of the received pulse (SYNC signal) and the direction of the pulse return (Antenna direction signals ACP = Azimuth Change Pulse, ARP = Azimuth Reset Pulse). ACP means that there are *n* pulses per revolution, whereas ARP means that there is only one pulse per revolution. This information is transferred to the RDP unit, that digitizes it and produces the image. At this point, depending on the accuracy of the digitizing, the bitstream is roughly about 300 Mbps per radar transceiver. In case of a frequency diversity radar, this is 2 x 300 Mbps. In practice, this size of bit-stream from 100 radars cannot be reasonably transferred to any processor center in real-time over vast geographical distances. The Finnish coastline is more than 1000 kilometers long. Therefore, in addition to the digitizing, the RDP tries to detect what is relevant in the image and compresses it. After that, the size of the image is less than 1Mb, which doesn’t cause any problems today in terms of data transfer. (Koivisto, 2021).

Next, the radar image is sent from the radar site over IP to the radar data server (RADS) that are located in VTS centers. For instance, in Western Finland VTS center in Turku, there are 4 such servers and they receive the image from all the radars from Örö to Tornio. The RADS produces a “bulk radar image” which is shared to different consumers. The user clients are, for example, JMAP (Product owned by Navielektro) window, e.g., the VTSO workstation and the poster (large screen display). The radar image can be shared to other users as well, for example to the Coast Guard, the Defense Forces or the neighbour VTS center. Also, the recording process is a consumer for the radar image. (Koivisto, 2021).

The recording server saves the video image on certain pace and resolution depending on how it is configured. In addition to the radar image, also plots and tracks, i.e., followed tracks and their vectors, are recorded to the server for later reference. However, they have their own path to the client, Koivisto (2021) states. So, put simply, depending on the configuration, the RDP units on the radar sites do the kinematic calculations and follow the tracks, and send the information about the tracks to the VTS center.

According to Soininen (2021), what is significant, is the resolution of the matrix – radars are processed in the video matrices - and also, the fact that the radars in the VTS system are doing only mono-tracking. Multi-tracking isn’t done at all, which means the system doesn’t utilize information from several radars to assemble the tracks (Soininen, 2021). The kinematic information is not connected to the tracks until the situational picture level wherein the track data is fused.

The AIS/VHF base station network in Finland is delivered by Navielektro. Data from the sites is transferred over IP to the AIS servers, that are located in the VTS centers. According to Koivisto (2021) the level of latency in the AIS data is in the fractures of a second. If there are cameras and radars in the same location, all data is transferred with the same connection. The total bandwidth for the connection is typically 10 Mb/s and most of the bandwidth is used by the cameras. However, normally the bandwidth is not fully used, and the actual use is less than 10 Mb/s. (Koivisto, 2021).

Removing duplicates takes place on the AIS server. The AIS base station network is built so densely, that the AIS signals from the same vessel can be received by 2 or 3 AIS receivers. In the output data there aren’t 2-3 same vessels, only one. When the data is shared out from the VTS center, there is more delay with the targets and their positions as the delays add up in every node. According to Koivisto (2021), the data that is shared by Fintraffic, is meant for building general situational picture, not for dynamic processes. The quality and timeliness may also have been reduced in order to keep the bitstreams on reasonable levels. (Koivisto, 2021).

Usually, the connectivity from the sensor sites is implemented with fixed-grade IP connections. These work with fiber-optic or fixed connections provided by the operators, which mainly are fiber-based solutions as well. In some cases, microwave links can also be utilized in data transfer. If there is no fiber connection in the location, the data is sent via the link to the closest node that has it. In certain key-locations, there are both link and fiber-optic network connections. In the Finnish coastline and archipelago, the types of IT connections and power supply systems are very variable and mixed. (Koivisto, 2021).

The sensor sites can also function over mobile connections. In fact, 20 4G modems were installed in the Western Finland VTS operating area between Kemi and Åland during 2020 and even more back-up connections have been installed during 2021. The back-up connections provide redundancy in selected locations. When a problem occurs, the connections shift to use the back-up systems. When considering operation using mobile technology 3G/4G/5G one needs to consider the reliability or usability of the mobile network. Koivisto (2021) gives an example: *“If one wishes to receive video from the Annansilmä camera during the Ruisrock, the outcome isn’t necessarily as good as possible.“*

4.5 Creating the situational picture and track fusion

Principles for tracking and data fusion in VTS systems are laid down in IALA Guideline 1111 Chapter 9.1 and the external information exchange in Chapter 12.

The measurements from the radars and the information received by AIS together form a fusion track in the VTS center. There is a process called “Tracker coordinator” that manages all the target information that is received in the system (Koivisto, 2021). Typically, a single target can be tracked, for instance, by 3 radars, a Finnish AIS base-station and an AIS station locating in the neighboring country. Conforming to Koivisto (2021), the task of the Tracker coordinator is to fuse the radar and AIS data into one target using different formulae to control the weighting of each individual component in the equation. What is weighted, is the reliability of the sensors and the real-timeliness of the measurement data. The actual position of the target is concluded from the basis of the measurement delay. (Koivisto, 2021).

For instance, if three radars plot one cargo vessel, and one of them is located directly ahead, one abeam and one astern of it, their ranging would give out different positions for the vessel due to the principles of radar technology, although the radars would be tuned to perfection. And, if the radar antennas rotate once per approx. 3 seconds, and the radars are not in synchronization with each other, they would “see” the vessel at different times. As a conclusion, no individual sensor can produce 100% reliable data, and that is why track fusion is an extremely important and quite complex subject. (Koivisto, 2021).

In the radars, the image resolution if affected by how far the radar is from the target and what is the pulse length and antenna beamwidth. These parameters define how accurately the radar can see the target in optimal circumstances. (Koivisto, 2021).

According to Soininen (2021), forming the fusion track is a sum of two elements. First, there are mathematical algorithms, that try to identify that certain mathematical factors are fulfilled ensuring that the target is the same. Secondly, there is a set of rules and conditions that must be met by the target. If the quality of the data from the sensor producing it decreases under the defined threshold, for example when the target reaches the edge of the radar’s range, the system may assume that it is a totally different target. The target drops outside the error ellipse when the system sees too much difference between the measurements. As a result, the system creates a new target. (Soininen, 2021).

This double-target effect can be managed by implementing rules. In the system, it is possible to affect the thresholds, so that track splitting wouldn’t occur. For example, in the Utö – Örö region tracks used to split regularly, since the AIS and the radar tracks were so far apart from each other due to the radar’s errors, Soininen (2021) demonstrates.

The AIS data is highly emphasized in creating the fusion target, as it is very accurate by default. Soininen (2021) explains:

> "The emphasis of AIS in the track fusion is more than half. AIS is given a fixed accuracy value since it presumably functions always on the same accuracy. For radars, however, the uncertainty factor can be calculated."

The values for the reliability of the radar data vary with the radar's own estimations about its accuracy. According to Koivisto (2021) the AIS data is very dominant in the equation and it is weighted significantly, except if it differs fundamentally from the position of the radar echoes.

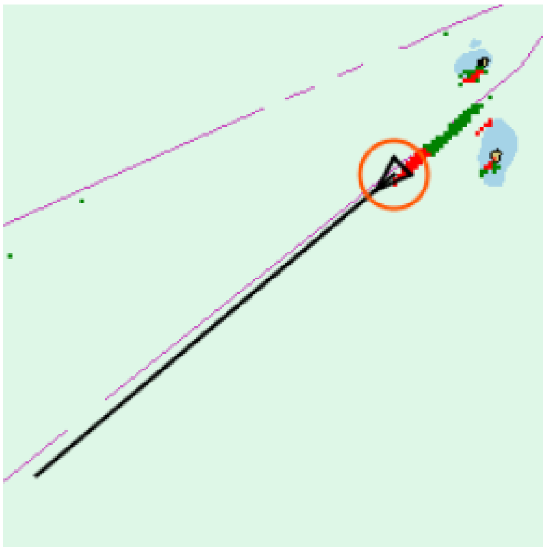


Figure 14. Navielektro JMAP track fusion (Navielektro).

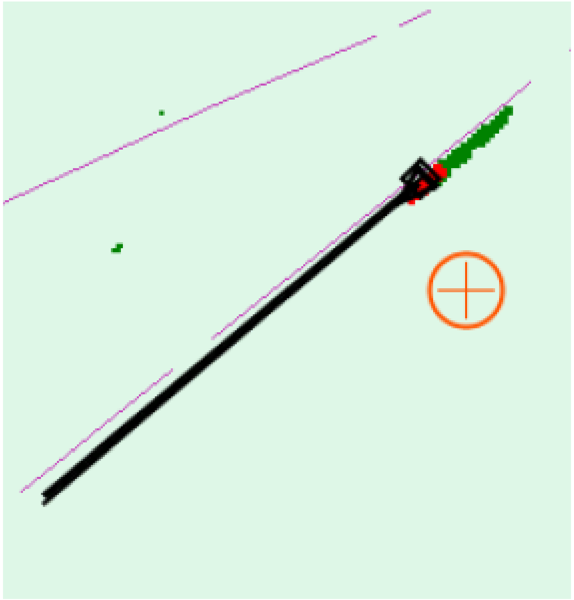
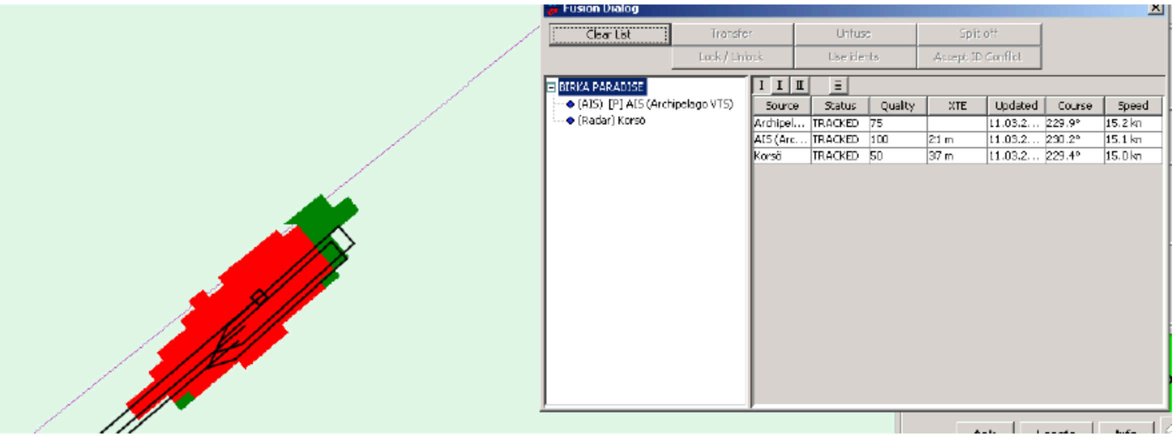


Figure 15. Navielektro JMAP track not fused (Navielektro).



Source	Status	Quality	XTE	Updated	Course	Speed
Archipel...	TRACKED	75		11.03.2...	229.9°	15.2 kn
AIS (Arc...	TRACKED	100	21 m	11.03.2...	230.2°	15.1 kn
Korsö	TRACKED	50	37 m	11.03.2...	229.4°	15.0 kn

Figure 16. Navielektro JMAP track not fused, all components (2 radars + AIS) visible (Navielektro).

The data is transferred in Navielektro's internal format from site to the server (Koivisto 2021). When the systems were developed, there existed no standardized formats for transferring the data. Today, there is "Eurocontrol" which governs the standards on the aviation radar use. Their Asterix standard describes the message structure in the data exchange. Asterix stands for All Purpose Structured Eurocontrol Radar Information Exchange. It describes how the tracks and plots are exchanged, but it doesn't standardize how the raw radar video is transferred, Koivisto (2021) explains and continues:

> "In a way, the Eurocontrol standard gives the possibility, but then again, leaves it totally open. It's like a barrel: you can put raw radar image in this bucket in approximately this format, but it is left totally open and free, which means that the ASTERIX-format from one manufacturer will definitely not work with another manufacturers' equipment. Therefore, Navielektro hasn't started to use it as it wouldn't offer us anything."

According to Koivisto (2021), basically any information could be brought to the VTS software, for instance lidar picture. There are no restrictions in the format in the Navielektro's JMAP product. Currently, the system already utilizes, for example, weather radars and satellite image data and are able to portray them on the software. Lidar data can be fused with AIS data on JMAP, but of course, in that case the amount of data would rise very high. *"Consider for example the amount of data, if all harbor basins in Helsinki were covered with lidars – it would be challenging to transfer the data, but it isn't impossible"*, Koivisto (2021) points out.

5 Practical part II: The results of the specialist interviews

5.1 Factors in sensor selection

The interview participants were asked what should be taken in consideration when choosing sensors that indicate a vessel's position. The respondents could associate freely on the wide topic as the frame was not defined or the question's presentation didn't adopt any stands on where the sensors would be located or, for example, on the level of autonomy on a subject vessel. The purpose of the question was to chart what type of factors should be weighted in the sensor selection process.

When choosing sensors for different applications, one could start narrowing down the options by the distance the sensors are expected to cover. If the sensors are used in port conditions, the distances are limited, and the sensors don't have to work over many mile distances (Suoniemi, 2021). On a more general approach, it is vital to understand that position indicating sensors can be roughly divided into two categories: absolute and relative (Lahtinen, 2021; Lilius 2021). Relative sensors give out the position in relation to some object, for instance to quay structures, whereas absolute position sensor systems, such as GPS, provide the actual position on Earth (Lahtinen, 2021).

Another way to categorize sensors is to address whether the sensor is independent on external reference objects, such as radar reflectors. If the sensors require counterparts on the objects, the operation is more contingent on the working environment. (Lahtinen, 2021). It is also of essential nature to understand, what the accuracy that is required from the sensors in the final systems is and what the use case is (Suoniemi, 2021). When it comes to the accuracy, the fact that the system must be weather-proof, i.e., it must work both in winter and summer conditions should be addressed (Soininen, 2021). The sensors' ability to see accurately cannot be dependent on the weather conditions.

Moreover, the costs and reliability were pointed out in the answers. One should consider such factors as expenses and maintenance. There should not be parts or structures, that require constant maintenance, as the systems must be able to function reliably 24/7 (Soininen, 2021). Further, if some actions are based on this type of sensors, there must also be overlap on the sensor coverage (Soininen, 2021). The sensors must be trustworthy and unfailing, and the actions cannot rely only on one sensor (Gustafsson, 2021). In practice, this means that the sensor systems are built redundant and fault tolerant (Gustafsson, 2021). In order to achieve fault tolerance, the positioning challenge should be resolved with two-or-three different methods (Lilius, 2021).

In many cases, the sensors work nicely in good weather conditions, but it should be an essential choosing criteria, that the sensors are be able to perform as well in challenging conditions – exactly in the demanding situations in which the aid from the sensors is required (Gustafsson, 2021). In bright daylight a human is able to observe the environment just fine, but when visibility is restricted due to weather, that is usually the time when one should be able to rely on sensors (Gustafsson, 2021). One instance of such conditions is snowfall, which sets limitations for the sensors (Suoniemi, 2021).

According to Suoniemi (2021), the local conditions and the infrastructure should also be stressed: If the sensor is land-based in a port area, where can it be installed and what requirements does the type of the sensor have for the installation? The position of such a sensor should be deemed so that the sensor wouldn't locate in the shades of other vessels or structures or in any blind spot sectors.

If the distance is measured from the hull of the vessel to the side of the quay, it would work on situations on which the vessel approaches the quay laterally, but if the vessel approaches its position longitudinally, that could be problematic. When vessels enter docks, they approach in same direction with the quay, i.e., longitudinally. (Suoniemi, 2021).

Considering the answers of the respondents, the factors that should be given value in the sensor selection process can be divided in practical considerations and performance requirements. In practical terms, such items as whether the sensor produces absolute or relative position information and whether it is independent or dependent on external assets were named. Also, the importance of taking into account the specific use case was highlighted: what is required from a sensor depends on the distance it is expected to work. The expenses of the sensor including maintenance requirements were stressed as well.

On the performance level, the informants suggest that accuracy, robustness, reliability and redundancy are some of the key qualities in the selection criteria. The sensor's ability to work flawlessly in all weather conditions was deemed as an essential element in the sensor selection process.

5.2 Sensor options

The participants were asked, what different sensor solutions there are for relative positioning in port areas and which sensors can achieve an accuracy of 0,1 m in about 200 m distance. Furthermore, in some interviews the question was supplemented with a follow-up question on what sensor the respondents would recommend in an application, in which the position of a vessel should be transferred to the end-user without undue delays, and the end-user (or system) could use this data as the basis for their operations. The follow-up question was only asked in case the previous answers of the respondent didn’t evaluate which sensor would be the most feasible for the purpose.

The answers of the respondents are in line with each other and there appears to prevail a common understanding of the suitable options. Some respondents also brought forth the abilities and challenges related to satellite-based positioning solutions.

The question itself was designed from the basis of the hypothesis, that in areas of limited spaces, e.g., port areas, the relative sensor systems could compensate for the lack of human eyesight. A satellite-based system doesn’t tell anything about possible obstacles in the way or about the inaccuracies of the chart material in the port, except if the obstacles are AIS-equipped. It’s also noteworthy, that relative positioning sensors could be located either on the vessel or ashore, but absolute positioning system rovers are always the vessels. Therefore, the compositions of the questions didn’t rule out the possibility that the sensors could also be land-based. The aim of the question was to see in practice, which type of sensors could meet the practical demands and performance requirements that were described in the chapter 5.1.

When discussing positioning in ports, one should probably start with maritime radars. Radars are one of the most reliable, robust, and weather-proof sensors there are (Gustafsson, 2021). The most feasible solutions for short distances in harbor basins could be radars that work on 30 – 70 GHz frequency range but then one should make compromises with the radars’ ability to see. The lower the frequency, the bigger the radars are, and the better they penetrate snow and rain (Koivisto, 2021).

The frequency of the radar affects the distance, of course, but for example radars that work on 22 – 77 GHz range could aid in formulating the aspect of the vessel in relation to the quay according to Lilius (2021). Radars of this type are used in cars, and the challenge is that they are modules, that can only see straight forward. Radars, that are used in cars, are applicable on short distances. In the context of automatic docking, there could be several of these radars one after another, and they could see the vessel's angle from the quay (Lilius, 2021). At the moment, different solution providers seem to favour solid state radars for port manoeuvring purposes (Lindborg, 2021). The radars, that are used in cars, have better visibility than lidars and they tolerate bad weather better (Lilius, 2021). Short range radars are the "strongest contenders" in the port use case, since they can endure at least a little ice, snow, and rain (Koivisto, 2021).

Then again, with microwave technology we can drastically improve the current radar image from what it is now on the 9 GHz frequency on the X band. And one must understand that the bit rate of the raw radar image, that is displayed on the VTS system, is compressed from 300 Mt to 1 Mt when sent from the radar site to the VTS center, so it is obvious that something is lost during that transition. However, the accuracy with the current radars wouldn't reach meter-level even if the picture was improved. (Koivisto, 2021).

Koivisto (2021) explains that the accuracy of an X-band VTS or navigational radar is limited by bandwidth or pulse length (range resolution) and antenna aperture (azimuth resolution) and the maximum obtainable resolution for X-band maritime radars is rather > 10 m than < 1 m. According to Koivisto (2021) it is important to understand that the resolution for any radar diminishes with range (azimuth resolution). Therefore, maritime radars and VTS radars are good for what they are planned for - navigation and collision avoidance. They are not intended for the resolution required for docking or other precise maneuvering. What is more, navigational radar and VTS radars also usually rely on a mechanically rotating radar antenna, which has a typical speed of 20 RPM (3 second). This means that the radar picture is usually 3 seconds old already for this reason alone. (Koivisto, 2021).

Making the resolution better doesn't automatically mean starting to use lidars. Naturally the high-frequency radars that are used in cars are also prone to rain and snow, but not as much as the laser-based solutions (Koivisto, 2021). In some scenarios, however, hiqh-quality lidars can operate in semi-challenging circumstances. They can filter out reflections, and they don't make conclusions from the first reflections that "this is the target" and they actually have the ability to penetrate disturbances on some level (Gustafsson, 2021). Lilius (2021) has some firsthand experience on the lidar performance in adverse conditions:

> “We have tested lidars in the Suomenlinna ferry a few years ago, and our experience was that it could give out distances behind the snowflakes from the actual targets, but it wasn’t reliable. The lidar pulses are very short, and when there is enough of them, some of them do penetrate the snowfall.”

In good weather, lidar is very good, but on the minus side, it’s quite expensive (Suoniemi, 2021). However, laser-based positioning is very common on offshore operations on the oilfields and lidars have great potential – especially if the lidars coming soon to the market cost less than $99 and have a range of 100 m, then it would be possible to install for example 10 such units on a ship and thus receive exact information about the distances and the objects around the ship (Lindborg, 2021).

According to Lindborg (2021), the use of lidars is still very limited and ABB might be the only company that utilizes lidar technology in docking operations. The challenge is the price in relation to the range. There are several different makes and models of lidars that work on approximately 100 m range, but in maritime use they are useful only in docking situations with distances of about 50 meters, when they can give out the exact measurements between the vessel and the quay. Longer range lidars, for example from Neptec, are too expensive, at least for now: The price is about 70 000€ and the range 1 200m, Lindborg (2021) states. One of lidars’ benefits is the ability to produce 3D maps of the operating environments if the chart material is deficient for GNSS use.

In port operations, one must rely on position references that are verified with land-based information, according to Lahtinen (2021). Currently, decimeter-accuracy can be reached with corrected GPS-signals, so the wheel doesn’t have to be re-invented in that sense, Lahtinen (2021) reasons. Instead, different types of verification and validation processes could be implemented for the position information from the aspect of interference and fault tolerance. According to Lahtinen (2021), the additional values for locating a vessel with alternative means are more on that side than in the need of better accuracy.

Different laser and radar-based relative reference systems, such as Radius, Radar Scan, CyScan and Fanbeam, are relatively cost-effective today. They each have their own stumbling-stones, like the weather conditions. Laser-based systems are most vulnerable during sunrise and sunset, when the solar elevation angle is small and the laser systems receive false reflection signals in their transceivers whereas the radar-based systems, like Radius, suffer from the same problems as the normal radars. (Lahtinen, 2021).

As responded by Koivisto (2021), relative positioning is justifiable and smart from many aspects, but it doesn't remove the need for absolute positioning. According to Koivisto (2021), operations cannot be based on the statement that *"Otherwise ok, but it's raining so you can't dock today".*

Distances can also be estimated with cameras, but the challenge is the measuring. There are, however, different solutions and techniques, and the implementation mostly a cost-related question according to Lindborg (2021). On general, these systems are called Berthing Aid Systems (BAS) and they are manufactured by, inter alia, Prosertek, Marimatech and Trelleborg. In Wärtsilä's Smart Quay (former Guidance Marine) solution, for example, the issue is resolved with a grid overlay, that can be used to estimate the distances (Lindborg, 2021).

MetaData - Stern
Fender Distance: ---m
Lateral Speed: ---kn
Heading: ---°
MetaData - Bow
Fender Distance: 31.40m
Lateral Speed: -0.12kn
Heading: -0.04°

Figure 17. Wärtsilä SmartQuay daylight- and infrared camera-based distance analysis system.

If one is ready to buy signal correction packages, for example from Fugro, very accurate GPS positions can be achieved (Lahtinen, 2021). The new cruise vessels, that are currently being built by Meyer Turku, are equipped with the satellite-based solution Fugro Ocean Star, that utilizes GPS, Glonass, and Beidou, and it uses 2, 3 or 5 antennas on the ship

(Suoniemi, 2021). Its benefits from the vessel's perspective are that the system gives out very accurate position and heading information, trim, list and hogging data, and if the vessel is also equipped with inertia sensors, the system can eliminate or reduce the movements caused by heavy seas (Suoniemi, 2021).

UTC: 2016-08-16 13:46:08
Latitude: 059° 55.116' N
Longitude: 010° 41.165' E
SOG: 0.1 Kn
COG: 354.7°
Quality: ●
RAIM: ● Safe
Accuracy of solution:
Position: 0.08 m
Height: 0.11 m
Corr. Age: 16.0 s
HDOP: 0.6

Selected berth: 44 Akerselva Quay, east

Figure 18. Fugro Ocean Star GPS + Glonass GNSS positioning system.

In spoofing situations using several antennas can tell from which direction the disturbance comes from, and the system generates an alarm on the bridge. However, from the shipyard perspective, especially relative position information would be very practical to have in situations where the new-buildings aren't yet equipped with satellite-based positioning systems, Suoniemi (2021) explains. The shipyards need the position of the vessel when it is moved in the docks. According to Suoniemi (2021) it would be useful to have the sensors ashore in this situation (Suoniemi, 2021).

RTK (Real Time Kinematic) GPS can also be used to receive a corrected position signal (Lindborg, 2021). RTK bases on same principles as DGPS, but the system's working mechanism differs. Already over 10 years ago, RTK technology was utilized in farming and land surveying applications, and the received positions were received on a 3-cm accuracy (Koivisto, 2021). RTK-based positioning systems work well in practice, when it is possible to place the RTK base stations in such locations that they are able to provide the corrected signals to the ports, i.e., in a few km proximities (Gustafsson, 2021). RTK systems could be feasible in port environments.

RTK can use the ISM-bands (Industrial, Scientific and Medical band) to send the correction signal to the GNSS device and, on the area that the signal covers, all stations that can receive the signal and summarize that correction to their own position, could utilize the improved accuracy. The system is not bound to one transmitter – receiver – pair. (Gustafsson, 2021). According to Koivisto (2021), other bands than ISM can be used as well, as the RTK doesn't care *how* the data is transferred. For example, the VDES could be used to send the corrections to the vessels in port areas in the future, as VDES, with all odds, will become a mandatory onboard instrument at some point. Other options are, e.g., data satellite, cellular network, or licensed radio (Koivisto, 2021).

On Brighthouse Intelligence the experience from RTK comes from the SVAN-project when road ferry Falco was operated remotely and also fully autonomously between Parainen and Nauvo in 2018. The positioning of Falco was built on good INS (Inertial Navigation System), IMU (Inertial Movement Unit) and GPS RTK. The set-up produced 1 cm accuracy and made it possible to bring the ferry to the desired position at the pier. (Gustafsson, 2021).

Figure 19. Rolls-Royce Remote Control Station on project SVAN. (Rolls-Royce 2018).

In SVAN the docking was based on a good situational picture and on predefined target positions at the piers. Since the piers the ferry uses are always the same, defining the target docking positions beforehand was the easiest method to execute the dockings. Also, in the FinFerries case, in the final positioning the situational picture was supplemented with cameras that were used to see if the ferry was within the pier side forks and what was the distance that was left. (Lindborg, 2021).

On extremely short distances, also ultrasound and magnetism-based sensors can provide position information. The selection of sensor type depends on what kind of systems one wants to create. If the distances are longer, proximity sensors can provide the position information on distances up to tens of meters and could work on the final approaches. These sensors work on the 70 – 80 GHz range and are currently being widely utilized in the adaptive cruise control systems on the car side. (Gustafsson, 2021).

There are also cost-effective options on the electro-optical range, Suoniemi (2021) points out. For example, distance measurement systems that base on infrared wave lengths have been installed on some Tallink Silja ferries. The limitation with this type of systems is, however, that they don’t draw any shape of the measured object and they’re also dependent on the weather. Using such systems could be a cost-effective solution in some cases, on the condition that the user would also receive the online AIS data from the vessel. The AIS data shared by the VTS is not exactly “online”, Suoniemi (2021) states and shares further firsthand experiences:

> “In our shipyard projects we have solved the issue by receiving the AIS and camera data via Transas pilotplug, and this information has been shared in-real time to the assisting tugboats. This implies, that the cheaper options could also be useful, provided that the vessel’s dynamic information, for example the heading, would be received from the vessel in real-time. In practice, this set-up would require some additional device, that would be inserted to the vessel’s pilotplug.”

The weather can be seen as the most significant challenge with relative positioning. At least the experiences with lidar prove that no critical outdoor operation can solely rely on weather-sensitive solutions. Lilius (2021) discusses what has been learnt about the electro-optical sensors:

> "All the options that we have researched in our projects, namely lidar and camera, work in certain circumstances but not in poor weather conditions. Same applies to infrared cameras. It would be interesting to evaluate the suitability of car radars next in our projects in Åbo Akademi University."

The answers of the respondents suggest that radars that function on higher frequency than what the maritime use has traditionally been, could aid in the relative positioning process in the ports. The higher the frequency of the radar is, the more accurately it works on the closer distances and the smaller the radars are by antenna size. However, such radars, that function on the higher frequencies, and are currently being utilized by road traffic and the car industry on a wide scale, are not as reliable on adverse weather than the traditional maritime radars. They are not able to penetrate the rain and snow as well and the operation of a sensor cannot be dependent on the weather conditions. When the weather challenges the vessel, that is usually the time the sensors would help the most in the operation.

Lidars, on the other hand, can be seen as a trending, emerging alternative for radars on short distances and could therefore be considered for some port positioning applications as their purchasing costs have settled in the recent years. Their strengths are linked to the high-resolution and accuracy as well as their ability to produce 3D maps of the operating environments and the ability to draw exact shape of the scanned objects. However, at this stage, it can be argued from the basis of the answers of the informants that they are not presumably compatible for day-to-day operations due to the lack of reliability in critical operations at times of rain of any type or, for example, when the laser systems receive false reflection signals from the sun. On the electro-optical range also some technologies basing on the infrared wave lengths could be feasible for distance measurements in ports. Such solutions combined with cameras should be closely monitored and addressed as strong alternatives in a supportive role in position determination.

Basing on the experiences of the respondents, satellite-based solutions, such as the Fugro Ocean Star, work reliably and accurately and can be utilized well in port areas as a primary means for position determination. An answer even suggests that the additional value for back-up relative positioning system doesn't derive from the accuracy at all, since on the satellite-based systems, when augmented with corrections, the accuracy is already on very high level. On the contrast, what should be weighted in consideration, are the themes of verification and validation as a resolution to the GPS interference and fault-tolerance questions.

In port applications also the RTK GPS was named as noteworthy technology worth consideration in some answers. With its aid centimeter level could be achieved in port areas. The strengths of the RTK GPS are related to very accurate and robust positioning available for all users who are able to receive the correction signals in the proximity of the port, whereas the weaknesses are the same as for GNSS in general. VDES could be used as an enabling technology to send the corrections to the vessels in local use. As a final conclusion, in optimal scenarios the positioning of a vessel would be built on several different types of technologies that could support and supplement each other and offer fault-tolerance and redundancy for the position determination and verification process, but it must be born in mind, that the requirements for the accuracy of the positioning derive from the level of autonomy.

5.3 Situational awareness in docking

The role of the sensors in creating the situational awareness by means of sensor fusion arose in many responses and was identified as a relevant topic during the research. Forming the situational picture shouldn’t be reliant only on any individual sensor. Although there were no exact questions in the interviews that were designed to gather comments on the situational awareness, except for Lindborg, its significance became apparent among other reviewed topics.

In situations when you need sensor redundancy the most, it is usually least available. This paradox makes the subject challenging but also interesting. One can call it redundancy, that there are several sensors of same type, but as well the sensors can be of different type with each other. This way some of the sensors work more optimally in certain circumstances than the others, and they can support each other. (Gustafsson, 2021).

Ideally there would also be a weighting system, by the help of which the sensors, that give out wrong or poor measurements in some conditions, can be left unquoted in the sensor fusion. By fusing different sensors with each other, the data is of better quality and more reliable. The reliability requirements for the data define the amount and type of the sensors. (Gustafsson, 2021).

According to Lindborg (2021), the situational picture can be either internal (the state of the machinery and the vessel) or external (what happens outside the vessel). Situational awareness means that the interpreter of the information understands which targets around the vessel pose possible risks. At simplest, one uses binoculars to produce the situational picture, and from this basis the Officer Of the Watch (OOW) identifies the targets around the vessel and interprets the possible associated risks. Situational picture systems based on data communicate the risks directly to the user and can also assess the severity of the targets (Lindborg, 2021).

Currently, the radar is the primary technological solution that is used to create the situational picture. Nonetheless, the delay from the observation to the user can be tens of seconds and it can be very challenging to identify fast boats, for example. This can be problematic especially for inexperienced seamen. Sensor fusion offers a solution to this by enhancing the tracking of non-AIS-vessels in real-time. (Lindborg, 2021).

Lindborg (2021) responded that greatest majority of the companies that work with sensor fusion utilize AIS signal and radar image in the data fusion (for example Sea Machines and Furuno), but these companies have informed that they will bring along machine vision and image recognition capability. At the moment, the most sophisticated commercial solution is produced by Orca.AI but Groke Technologies Ltd is releasing a similar fusion solution to the market during the year 2021 using machine vision, AIS signal and radar image. The position is taken from the vessel’s signals or via external GNSS sources. (Lindborg, 2021).

Noteworthy is the fact that in sensor fusion the measurement data from different sources is combined with each other and presented on the same platform. “Fusion” as a term cannot be used if the information is found on different systems. So far, the situational picture has its own interface in its applications, in part because manufacturers don’t want to turn SA systems into classified navigation systems. That means that AIS, camera, and radar data are brought to the SA solution interface. Currently, a few companies are considering the possibility of importing SA information and identified objects into the ECDIS map as “read only” data like how it is done with radar overlay. However, no companies are offering this commercially yet. (Lindborg, 2021).

Conforming to Lilius (2021), the information from different sources has not been presented on a specific SA interface in their projects:

> "In Åbo Akademi University projects with the test boat "Åbåt", we have used cameras and lidar as the base data. Furthermore, the dynamic information about the vessel movements is required as accurately as possible. At the moment, the system architecture on Åbåt is actualized in a way that all information is displayed on different panels. The use case is a city ferry, so the needs are very different in comparison with merchant shipping. Our sensor platform has been collecting data on Suomenlinna ferry and on Ruissalo's water bus."

According to Lilius (2021), it is remarkably complicated to take into consideration the speed and acceleration in sensor fusion after recognizing an object from machine vision and defining its position with lidar. Historical information must be considered in determining the acceleration and velocity of the targets. (Lilius, 2021).

According to Lilius (2021), relative positioning is interesting because of the fact that it is used as the basis for the decisions concerning what is done next. What makes it challenging, is that the absolute position is determined with GPS-type methods or INS-based solutions. This means that when you know the latest position exactly, and carefully record the movements of the vessel, it is possible to calculate the new absolute position. Relative positioning would be easier, if all the vessels communicated their exact position and movements to others, but while that is not possible, it must be done with other means. (Lilius, 2021).

The camera and the lidar also both require an image stabilizer to correct for the movements in the signal. Conforming to Lilius (2021) this is not a problem with Åbåt, since it cannot be operated in wavy conditions anyway. Mathematically it is significantly simpler to locate a vessel with GPS and INS methods than with cameras and lidars, Lilius (2021) states.

When it comes to satellite-based positioning, the accuracy in the different parts of the system must be on a similar level. GNSS does not indicate if there is something between the vessel and the quay or if the chart material is not up-to-date. From the basis of only GNSS information one cannot dock if, for instance, the quay is of a different shape in reality than what the chart material implies. Or if there are 1 meter-diameter-fenders attached to the quay, and their existence is not announced in the chart material, the foundation for the GNSS-reliant docking is already 1 meter incorrect. If one relies on the fact that the vessel should be manoeuvred into the position in which the quay is drawn on the chart, exact charting in the ports might be the starting point to resolve the issue. Otherwise one must make own charts or make corrections. (Gustafsson, 2021).

According to Suoniemi (2021), the Fugro's docking system could be useful in aforementioned circumstances. With the Fugro Ocean Star system and service, different vessels from the same shipping company can share information about the docking positions and manoeuvres with each other. If a sister vessel has already visited the same port, another similar vessel can be brought to that same position within the port with 10 cm accuracy. The system has been perceived handy from the aspect of cruise vessel crews (Suoniemi, 2021). However, the accuracy of the GNSS can change rapidly, if there are objects that reflect or block the signal. It is not self-evident that the accuracy always remains the same. (Gustafsson, 2021).

Fugro's solution, that starts by defining the reference position to which the vessel is manouvred with DP is pretty much the simplest way to execute auto-docking, according to Lindborg (2021). Even so, it is not very cost-effective since the prices for the DP systems are high due to high sensor and performance requirements that are related to the propulsion systems. Furthermore, if one wants to execute docking by using DP, the system operators must carry DP certificates that are in force, which then again requires a certain amount of DP operation hours, continuous education and so forth. For that reason, Royal Caribbean Cruise Lines has laid aside DP's use in docking. (Lindborg, 2021).

In project SVAN with Falco, the options were that it could be operated 1) From the bridge, 2) From the remote-control center or 3) Totally autonomously, when the ferry itself made the conclusions about its position and what it should do next. The role of other sensors than GPS was supportive, as the absolute position was determined with GPS. When the vessel was underway autonomously, only GNSS + RTK and precise IMU were needed to receive the accurate information about the movements and about the position. (Gustafsson, 2021).

In the big picture the easiest implementation of auto-docking is to utilize the autopilot for heading control and speed pilot for speed control, according to Lindborg (2021):

> "In principle, how the master docks in different circumstances must be modelled in a software and this data is replicated into automatic operation. At one time I had presented this technique to Mitsui O.S.K. Lines (MOL) and they, in fact, appear to have adopted this technique in their auto-docking a while ago."

The consensus of the answers is that building a high-quality situational picture for dynamic operations, such as docking, cannot be based on absolute or relative position information alone. In optimal circumstances, the GNSS data is supported with a set of different microwave and electro-optical sensors. Very precise satellite-based positioning can be achieved with RTK GPS technology, as it is augmented with land-based corrections.

The answers suggest that Inertial navigation systems, which use accelometers and gyroscopes to compute the position, orientation and velocity without external references, should be utilized on the side of satellite-based solutions to calculate the position, while radars and lidars "only" give the distances.

Sensor fusion is the key in building situational awareness. The sensor technologies that were appointed in the answers and associated with situational picture, were namely radar and cameras. Lidar is not yet widely in commercial use in sensor fusion solutions and the sophisticated systems today are based on the AIS data, radar video and machine vision (cameras).

5.4 Sensors onboard vs. ashore

The interview participants were asked, what they consider would be the associated benefits and deficits of the relative sensor systems locating either onboard the vessels or ashore in ports. The answers were scattered, and a great deal of different aspects were shared. The purpose of the question was not only to highlight the differences in the operational aspects, but also to promote the thinking that the maritime infrastructure can aid in implementing novel positioning strategies and progression towards autonomous maritime operations.

The answers of the respondents appear to be concurrent on the idea, that the future autonomous vessels will be equipped with their own sensor packages anyway, excluding autonomous road ferries that could manage by shore side sensors alone in some circumstances. Shore-side port sensors could provide additional value to the maritime traffic as a supplementary service by offering redundancy to the MASS but also facilitating new services for conventional vessels. The challenges of remote pilotage and remote control were also high-lighted in the answers.

A great number of the interview participants also discussed the Sea 4 Value remote pilotage solution, Brighthouse Intelligence's SmartBox application and its feasibility. The topic was recognized so relevant from the research's perspective, that the solution is discussed separately in more detail in chapter 5.7.

When discussing fully autonomous vessels, they will inevitably be equipped with a comprehensive set of different kinds of sensors. Even so, according to Lahtinen (2021), the development in maritime autonomy at the moment appears to favour "collecting the low-hanging fruits" meaning such solutions, that contribute to the safety of a wider user community than only the autonomous vessels, Lahtinen (2021) continues. This refers to applying the changes to the fairway infrastructure rather than on the vessels. The changes are advantageous to the processes of both conventional and future vessels when they appear in the fairway structures and in the subjects that surround the vessel. Lahtinen (2021) reasons:

> "If all the mechanisms and support systems would be located ashore on the pier, they could bring additional value also to the operators of the conventional vessels. Establishing such systems ashore would be remarkably more justifiable, since they would be beneficial for larger user community than only autonomous vessels. In that sense, I would keep the amount of the added technology to the vessel lower, which is justified from the commercial aspect."

Conforming to Lahtinen (2021), the threshold to utilize different intelligent solutions becomes lower, when the conventional vessels don't have to answer to any transformation expectations. In this thinking, the mechanisms and solutions locate outside the vessels. When equipping vessels and adding new technology, the ship owners want to know what's in it for them. If the commercial benefits aren't very clear, the equipment won't be added to the vessel, Lahtinen (2021) argues and gives an example from the remote pilotage framework:

> “In the context of remote pilotage, the thinking is exactly that. In principle a vessel could be remote-piloted tomorrow, but on the condition that a remarkable amount of technology would be added on the subject vessel. The shipowners rather choose the conventional pilot than pay millions for fitting the equipment on the vessels.”

Soininen (2021) sees that the reversed thinking is to build autonomous vessels on different levels, when they have very high transformation requirements in comparison with the current vessels. When the sensors are installed on the vessels, only radar or lidar reflectors and mirrors, or equivalent, are needed to be installed in port areas to act as geo-references. In this scenario all the vessels would locate themselves independently on their own behalf.

According to Soininen (2021), the conventional vessels today don’t require more accurate position information, since they are already taken alongside excellently with no damages: The pilots pilot the same vessels all the time, and the dockings are executed successfully in the same berths without any additional acccurate position information. Therefore, if an open API was developed for this, it would potentially be interesting only for some, but not for the great majority, Soininen (2021) argues. It would mean offering a solution that is not genuinely required.

On the other hand, if the autonomous maritime traffic or remote pilotage becomes reality, and the vessels must be taken all the way to the berth, the accuracy for the positioning must be achieved somehow. Soininen (2021) discusses:

> “The question is, do all the operators implement their own solutions, when we will have individual solutions by ships, ports, and shipping companies along the coast, or is it done coherently as a common service. Both options have similar likelihood of happening, but the latter option poses strategic approach. In this case, it must be chosen, that this will be executed in this way and it requires an investment decision.”

If the decision is made in Finland, that the government wants to support these functionalities and one of the infrastructural abilities is better positioning in the ports, then different commercial operators will not start building them. If this decision is not made, then all the operators are forced to make their own solutions. If it continues far enough, afterwards it’s hard to correct it in any direction. (Soininen, 2021).

Both approaches are probably just as good with each other according to Soininen (2021). But if it is chosen, that we want to be progressive in the development and make open APIs for several operators, and it becomes a critical ability for remote-piloting and remote-controlling, it can also be offered as a supplementary service for the conventional vessels, Soininen (2021) states. If all the operators implement the systems on their own behalf, they remain in their individual use and the implementation will take more variety and it will become more challenging to find a common API, on which the services would be available. Then it will not become a regional or national service, and the systems are solely companies' own berthing solutions. (Soininen, 2021).

Discussing the docking, the aiding system could, for example, measure the vessels distance, and with some type of traffic light system give guidance to the vessel how to move in relation to the quay and execute the berthing in a safe manner, Lahtinen (2021) suggests. The traffic light system could be a land-based visual indicator telling, for example, if the approaching speed is suitable and what is distance between the hull of the vessel and the quay. This type of visual indication could be beneficial in the process, in which a remote-controlled vessel is being docked with aid of cameras (Lahtinen, 2021). The indication systems that are currently being used, in e.g., oil terminals, consist of info screens that display the data from the land-based distance and weather sensors (Lindborg, 2021). The increased availability of sensing technology that have led to more appealing purchasing prices for customers is anticipated to make different BAS (Berthing Aid System) applications more commonplace in the future.

Figure 20. Prosertek BAS information display.

Considering the port use, Lindborg (2021) supports lidars as the “go-to technology” and shares his vision for building sensor systems both on and off vessels:

> “If I were to develop a land-based solution at the moment, I would begin with installing short range lidars on approximately 50 m distance from each other, when they can be used to create an exact image or 3D model of the harbor basin and its vessels. Then again if the need originated from shipping companies’ perspective, I would install tens of short range lidar units around the vessel, when a 3D “geofence” could be constructed on approximately 75 sectors around the vessel.”

If the sensors were land-based, they would operate best from high towers where they see the longest. However, in port scenarios, there can be cranes in the line of sight that can cause blind sectors and problems. The cranes are also problematic for satellite-based positioning. Taking this into account, the optimal location for the sensors could be closer to the quay edge. At easiest, the accurate positioning can be actualized rather onboard than ashore, but that cannot be required from all the vessels, so the systems could be totally located on the port side. According to Suoniemi (2021), when talking about unmanned vessels, the sensor sets can be totally onboard. However, in some circumstances, if the sensors were solely in the port, you would still receive the AIS data from the vessel and use a lidar-solution to draw the vessel’s shape – the best solution depends on the specific scenario. (Suoniemi, 2021).

On a general approach, the system could be shore-based, and at maximum one could presume that the vessels had some simple device onboard, like the one from Brighthouse Intelligence that is connected to a pilotplug, Suoniemi (2021) reasons. The device would send the conning data and dynamic data sets onward from the vessel. On most parts, the vessels are piloted to the Finnish ports, so the pilots could attach the device. Suoniemi (2021) admits, however, that it is a little questionable to require something like this from the ship, but if it was pilotage-related, it could work. In remote pilotage, the device would be delivered to the ship beforehand, and the crew could attach it for pilotage, harbour manoeuvring and docking purposes. If something like that was required from vessels entering Finnish areas, the device should be inexpensive and small. (Suoniemi, 2021).

If the vessels are remote-controlled, they can have their own ashore sensor sets in their destination ports. Remote-control operators have their own sensors on the ships anyway and the sensors’ role is to produce reference data. What differs from this, according to

Soininen (2021) is the remote pilotage: Most of the vessels that use the fairways on a regular basis, either have Pilot Licenses or Pilotage Exemption Certifications (PECs). The vessels, that are actually being piloted, are the ones that visit the ports irregularly or at infrequent intervals. Soininen (2021) addresses the problems related to any additional pilotplug devices:

> “If we wanted to attach something to the pilotplugs of the piloted vessels, who would deliver these devices to the vessels, and how can we know if the vessels already have the devices onboard, if they arrive to Finland for the first time? If they are the pilots, who deliver the devices to the vessels, why wouldn’t they just pilot the vessels conventionally, while they are there? If a vessel visits Finland two times in three years, are we going to share out some device just in case they happen to visit Finland again? That is not realistic. Moreover, would the vessels be in charge of the operation of the devices? If they are not mandatory navigational instruments or standardized as a part of ECDIS, the systems must locate outside the vessels. Consequently, if we only choose the vessels that require pilotage-services and they visit here often, the number of vessels is very low. If the technical solution is the device that is connected to the pilotplug, the solution cannot be applied to the irregular visitors.”

The device that facilitates remote pilotage test runs during autumn and winter 2021 is connected to the IEC61162-450 ethernet gateway, not to the pilotplug. It is called SmartBox and it is developed by Brighthouse Intelligence (Gustafsson, 2021). The philosophy of positioning in the Sea 4 Value remote pilotage tests is discussed separately in more detail in chapter 5.7.

According to Gustafsson (2021), it would be very beneficial, if the sensoring could be carried out from land so well, that the amount of data transferred from the vessels remained low. If the data was transferred from the ships, it would mean that all ships would need a device and data connections to the destination, where the data would be produced. But if the sensors were shore-based, and they were able to provide the position, movement and possible other data, on the basis of which it would be possible to determine the turning vectors, the speed information and other parameters that are used to calculate the trajectories of the vessels, it wouldn’t be so meaningful, where the data comes from. In these circumstances it could come outside the vessel. (Gustafsson, 2021).

If the data was gathered on shore, and it would be reliable, one wouldn’t be required to install any new sensor technology onboard the existing vessels. Thus, the system would support all vessels that are using the waterways and the ports as all the targets could be sensored. In this case, it would increase redundancy to have a set of several different type of sensors on the quay. They would be located in different positions, so if there were blind sectors from one direction, another sensor could fill in and patch the image. If more vessels arrive simultaneously, there should be more sensors on the other side of the harbor basin that could replace the other sensors. These sensors would create a 360-vision and this type of solution could be realistic in port conditions. (Gustafsson, 2021).

Moving further from the port environment, the prospects for installing such equipment differ significantly conforming to Gustafsson (2021):

> “Further away along the fairways it would be challenging to install such a number of sensors. It would hardly be cost-effective, but in the harbor environments it could be justifiable according to my estimation, if the accuracy was high and the vessels would actually be able to utilize the data.”

In certain circumstances the sensor package can be located ashore. In Trondheim, in the city ferry project milliAmpere, the sensor solution for the autonomous operation is land-based and it has many benefits, Lilius (2021) mentions. Computationally more challenging tasks can be executed onshore and, in practice, even though the sensors would be located onboard vessels, the processing is done ashore and the problem with high amounts of data is the connection bandwidth. Consequently, if the sensors are located onboard, also the computation must be executed onboard. Otherwise, it won’t work, according to Lilius (2021).

If for instance, there were cameras installed in ports, it would be possible to remote-control a vessel based on that data. A human can train himself to think and control matters from different perspectives. Fundamentally, there is no reason why a human couldn’t be able to learn to control vessels remotely from an outside perspective according to Lilius (2021). What Lilius sees as a bigger challenge, is the transfer of physical feeling via any technology:

> “In remote-control the problem is - without any thorough understanding of the matter - that when you are physically onboard the vessel, you have a gut feeling about its movements and what happens, when you use the controls. Then again, if one controls the object remotely, it resembles more like

> playing a car simulation with a computer: One doesn't receive any physical feedback about how the car reacts to the controls, and one relies only on their ability to see."

So – should, for example, the chair of the remote-controller or remote-pilot start to vibrate, so that this information could be transferred? According to Lilius (2021) it's very hard to estimate acceleration, for instance, by visual means only.

When a ship reverses to its position, a similar parking sensor that are used in cars, could be useful to assess distances. Conforming to Lilius (2021) it's a ship-building related issue: Basically, a sensor must be brought to the side of the vessel, it must be covered and fed with electric current and constructed in such a way, that the cabling and the sensor itself can be maintained. Lilius (2021) doesn't, according to his own wording, understand why it hasn't been done already as in the total cost of a vessel its part is very marginal. Such systems must be accepted and validated by officials, but Lilius (2021) doesn't believe it would be a difficult issue per se.

Soininen (2021) points out, that In Sea 4 Value remote pilotage has been discussed only in the aspects of what it could be, and which different factors affect it as a process. If remote pilotage was actually performed, it must be examined also from the Vessel Traffic Service's perspective as it affects its procedures.

According to Soininen (2021), same solutions must apply for all types of vessels in all operations. When discussing the positioning, one cannot examine only autonomous traffic, remote control, or remote pilotage separately. Positioning must be scaled to concern all these fields when it can become cost-effective and justified. In Finland the discussion on the autonomous maritime operations has an ecosystem approach rather than focusing solely on any specific operation.

The answers of the respondents clearly indicate a consensus that the status of sensors in future vessels with varying levels of automation will be extremely vital and the sensors will play a key role in observing the environment. However, sensor systems can also be located ashore but their existence doesn't rule out the need for onboard sensoring in traditional maritime operations. In turn, the lessons learnt from the milliAmpere project suggest, that the sensor solutions on autonomous ferries close-to shore can locate at least partly outside of the asset.

The answers from the informants imply, that shore-side systems could supplement the situational picture of the fairway users, which would also be a cost-effective solution, since that way the potential end-users would be all fairway users notwithstanding the degree of autonomy on the subject vessel. The answers of the informants also suggest that retrofitting new technology on the existing conventional vessels isn't seen ineffectual per se, it just isn't a cost-effective solution and is therefore not expected to become a wide-spread phenomenon. The shipowners won't probably add any new equipment on their fleet in case there aren't any obvious advantages on it.

Moreover, the threshold to utilize different autonomous systems is lower, when the solutions are mainly implemented in the infrastructure, as the existing vessels wouldn't meet such high transformation expectations in that scenario. However, it must be born in mind, that the operators of conventional vessels wouldn't probably need any more accurate position information, as there still are and will be onboard seafarers for a long time, who can rely on their visual ability to see and estimate distances. Another question is, how the establishment of such onboard systems would contribute to the level of manning on conventional vessels on the long term. Furthermore, it was pointed out in the answers that the data exchange can be arranged more practically and powerfully when the systems, at least on some level, locate ashore.

5.5 Loss of position information

The respondents were asked, what happens to a remote-controlled vessel without seafarers onboard or fully autonomous vessel, if it loses its position information. The purpose of the question was to examine redundancy strategies, the importance of resilience and to see in practice, what kind of solutions the informants would suggest. The position information could be lost, for example, in GNSS jamming or spoofing occasions, or when the vessels' own sensor systems for some reason don't produce reliable reference data.

As the question was very conceptual and the examples of such occurrences in the context of MASS are few, not all respondents speculated about possible outcomes or solutions. The hypothesis behind the question was, that a secondary system could assist to provide the position information should vessels' own sensors fail. For instance, the position reference could be provided from sensors that are located ashore.

According to Lahtinen (2021), it's an excellent question, what happens to a MASS when it loses its position information. There should be some type of back-up plan if the vessel loses its position information and must remain stationary. In practice, it could be electronic anchorage that is implemented with the aid of a DP system, but of course that is challenging as well, if the vessel is lacking the position information, Lahtinen (2021) discusses. The possibility for conventional anchoring exists as well, but the question is how it could be executed without onboard personnel. Lahtinen (2021) suggests that one solution could also be to transport a human or humans to the vessel. Anyway, the resiliency must be so high, that complete losing of the position information is virtually no option. In case it is possible, however, odds for it must be extremely low, so that it can be accepted as a risk (Lahtinen, 2021).

It would be useful to receive the position reference from ashore in a situation, in which the vessel loses its own position information, Lilius (2021) reasons. The question is, how the data can be shared with vessel, since if there is a fault state, one must consider the fact, that the information cannot necessarily be received from ashore either (Lilius, 2021). This might imply, that there should be back-up systems even for back-up systems.

According to Lilius (2021), the occlusion effect is a problematic phenomenon in this context: If something comes in between the receiver and the transmitter, the only way to handle the situation is to receive the position information from above. That basically rules out terrestrial data transfer. In general, there are a lot of different situations and they all required different solutions Lilius (2021) states and shares possible outcomes:

> "With our remote-control boat projects in Åbo Akademi University, we have reasoned that the vessel would stop making way (surge) and start turning around its vertical axis (yaw) or switch itself off and remain drifting. As with vessels in open sea areas, there is not so much one can do, should its engines shut down."

Regardless of the safety-case, it could be justifiable and rational to define the algorithms so that when the sea-going vessels arrive in port areas, in which the position information can be received safely, the vessels would systematically start to use shore-side position information instead of their own data, Lilius (2021) suggests. The position information from the shore could potentially be more reliable as it would be verified. If there are defects in the equipment, the detection is easier and resolving the issues is faster. It wouldn't necessarily be a bad idea to design the systems in this way from the beginning according to Lilius (2021).

Losing the position information is a very case-specific problem and doesn't affect the conventional vessels in the same manner. All situations are different, as the local conditions, the weather and the vessels vary. Suoniemi (2021) gives an example from the cruise vessels: They are being piloted anyway, so in case the position information was lost and even all the navigational displays were shut down, the pilots possess very high local knowledge, and the operation of the vessel can rely on optical navigation. Of course, the level of autonomy on the subject vessel even in this scenario has a pivotal significance, but the cruise vessels aren't presumably the first vessels to promote autonomy in navigation anyway.

For this respondent group the practical means for resolving a situation that includes the loss of position reference, or in the wider scale the situational awareness, are anchoring, remaining stationary, stopping making way and starting to rotate around vertical axis, or starting to drift. The answers imply that such a phenomenon should not occur in the first place, but in an event it does, the connection should be re-arranged in one way or another. If all connectivity was lost, transportation of humans was recognized as an opportunity.

5.6 Potential end-users

As the sharing of data and wider availability have been recognized and addressed as cornerstones in the digitalization of maritime traffic, the number of the future end-users will undoubtedly increase. The interview participants were asked, who they believe could be the potential end-users of the relative position information of the vessels in port areas. The aim of the question was to challenge the traditional thinking, that only the onboard master and bridge crew would be interested in the exact position of the vessel.

According to Lahtinen (2021) the position information could be valuable for pilots and crews of the vessels and possibly for VTS operators as they are also interested about the vessel movements. On the contrast, Lahtinen (2021) doesn't believe the exact position information would be essential for the operators within the port structure.

Lilius (2021) also believes the operators of the vessel, whether located onboard or at a remote destination, should know the accurate position of the vessels in the port, especially the ones that are moving. However, the position of the other vessels doesn't necessarily have to be as accurate as the position information of the own vessel. Further, Lilius (2021) recognizes that potential end-users are also the instances who oversee the operation of the vessels from the safety aspect, for example VTS and even the ports.

Gustafsson (2021) points out that the VTS has a thorough sensor network, consisting for example of radars and cameras. If that type of comprehensive situational picture could, in general, be shared to the vessels, so that their ability to interpret their environment wouldn't rely only on their radar image and AIS data, that could be beneficial, Gustafsson (2021) supposes. That sort of broader situational image could potentially by utilized by many waterway users both on the commercial and on the pleasure craft side (Gustafsson, 2021).

What is more, the software developers need the data to improve the autonomous functions. Conforming to Gustafsson (2021), the situation is probably the same as with cars: In order to make the cars move without human interaction, the requirements for the amounts of data are massive and there must be enough data to program their operation. Eventually the utilization of the sensor data could make fully autonomous vessels reality. According to Lilius (2021) this is what really brings value for the data. The algorithm and software developers would be interested in that data, so they could utilize it in training their AI algorithms.

Considering the answers of the respondents, the strong consensus is that the instance in charge of the vessel movement would be the end-user for the relative position information. Regardless if the user is an onboard person or a navigator in a remote location, they both were recognized as potential data consumers. Also, pilots were named to be potentially interested in the data, but in the answers no distinction was made whether it plays any role, if the pilotage process would be of traditional type or executed remotely. However, it can be reasonably presumed, that once the onboard human element is no longer a fundamental part of the position determination process, the sensor technology can compensate for the lack of eyesight as a building brick of situational awareness. Therefore, the need for any upgraded position references is probably higher in the remote operations.

Gustafsson (2021) also brought forward the VTS data hub approach and considered the future possibilities on a wider scale: If the position information was produced coherently as a service, possibly any waterway user could find ways to benefit from the data. Other answers suggest that also VTS operators could be the end-users for the data. The better the data quality and accuracy is in the VTMIS, the better readiness the VTS operators have to interact with the developing situations.

Finally, very essential potential consumers for the data were named as the software and algorithm developers, who need massive amounts of data to train their AI solutions. The data sets could be used as a basis for AI driven docking that could eventually improve the level of autonomy in shipping.

5.7 Transferring the data and the Sea 4 Value remote pilotage use case

The interview respondents were asked, how the data should be transferred onward from the sensor and what kind of requirements and factors are associated in the process. The purpose of the question was to study the themes related to connectivity and cyber security. The Sea 4 Value remote pilotage use case data transfer solution was discussed under this topic area, as it was recognized as a very relevant entity during the research. In general, the answers indicate that the suitable connectivity depends on the operating area, but cellular connections, especially 5G, is seen as very potential alternative as a data transfer protocol. Satellite connections come into question once the availability of the mobile networks degrades.

Mobile connections are considered sufficient for most applications. It is, of course, dependent on what is shared, and how much bandwidth is needed. For the moment, according to Lahtinen (2021), the thinking is that the data would be transferred via 5G cellular networks and data hubs, which are cloud-based services whereto the data is shared and downloaded from. The cloud services become sort of “buffets”, Lahtinen (2021) describes. The hubs incorporate certain amount of data from different sources. The end-users would pick the information they need at the time: Metaphorically they collect their own serving from the buffet to maintain their own situational awareness.

Sea 4 Value is a Business Finland -funded project that aims to develop and promote smart fairway structures and remote pilotage, and the data transfer questions have already one year ago been resolved by attaching the SmartBox device from Brighthouse Intelligence to the pilotplug of the vessel, according to Lahtinen (2021). With the aid of the device, the dynamic and some of the static data from the vessel are transferred, on relevant parts, to the remote pilots ashore. This solution enhances testing and demonstrating processes in the Sea 4 Value project, but if it is a final resolution leading to commercial use and up-scalability, that is another question according to Lahtinen (2021).

The Offshore SmartBox product will be utilized in the remote pilotage demonstrations in the Sea 4 Value project, and currently the aim is to do the first field trials during autumn and winter in 2021, Gustafsson (2021) confirms, and explains further:

> “We are not bringing any new sensors to the vessels in Sea 4 Value, and our intention is not to bring them to vessels later either. We rely totally on the existing onboard sensors and the measurement instruments, that are already found on the ships. Our experiment vessel is an escort tug located in Sköldvik, but the actual remote pilotage demo is meant to be carried out with Viikki (IMO 9797620) or Haaga (9797632). The navigational instruments between the vessels and the tug are basically on the same level. At the moment, we don’t adopt any stands on the question, whether the sensors produce as good data as it is possible or if there are any central barriers that prohibit the receiving of better-quality data. We are concentrating only on creating a system, that would utilize the same data that the onboard crew uses in their decision making.”

The system built by Brighthouse Intelligence transfer the data from the vessel to the cloud in real-time, and when the purpose is to execute remote pilotage, the remote pilot should be able to see the same measurement indication as onboard the vessel in real-time. The problem with this thinking is that if the data is incorrect at the vessel, it is also incorrect at the remote control center, wherein the pilot tries to use it. (Gustafsson, 2021).

The navigational appliances and equipment onboard Haaga and Viikki are traditional maritime instruments, which excludes for example camera vision. According to Gustafsson (2021) it is still open, what kind of camera or lidar systems could be installed on the vessels. Brighthouse Intelligence has the possibility to add appliances to the vessels and connect them with their systems, and further transfer that data outward from the vessel, but that is not the starting point or any fundamental principle in the project. It's not included in the scope of the project. According to Gustafsson (2021) Brighthouse Intelligence is not bringing any resolutions to that problem and doesn't intend to bring, for example, RTK GPS to this system as an addition to supplement the vessel's sensor data. The principal idea is to deliver as comprehensive measurement data set, plus radar and chart overview, from the vessel to the remote pilots as possible with current instruments.

Conforming to Gustafsson (2021), SmartBox platform has been developed to certain use applications through projects, and the Offshore SmartBox has primarily been customized for the Sea 4 Value on the basis of certain basic infrastructure: The processing platform, modem, data transfer, operation and antenna solutions are sort of umbrella structures for the SmartBoxes. If the Offshore SmartBox in the remote pilotage with Haaga or Viikki will be similar to the one in the experiment tug, or if there will be any changes, is still unclear. However, it will base on these umbrella structures taking into account the case-specifc needs (Gustafsson, 2021).

Gustafsson (2021) opens the data transfer:

> "In practice, we can manage with two modems, but our system is not limited to the thinking, that there must be exactly two cellular-radio-modems – we can have *n* units of those. The data transfer protocols can also differ: There can be, for instance, WLAN, proprietary, or satellite radios. The system is modular and customizable, and the elements are chosen on the basis of the needs of how much data is wanted to be transferred and by which method. On the experiment vessel our system is built so, that we are able to connect to the Furuno-based command bridge, which is the same on all three vessels. Furuno produces data for IEC 61162-450 ethernet gateway and we subscribe and collect the multicast sensor traffic into our systems. Part of that data updates several times per second, and another part updates once per second. Our thinking about timeliness is that the dataset would be transferred into the cloud once per second, so the data would be, at maximum, one second older than the data on the ship."

The SmartBox system re-samples the data from the gateway, and it can be sent to the cloud in the pace and amounts seen suitable. The system allows to subscribe to different datasets from the vessel. According to Gustafsson (2021), the data is currently transferred over two separate modems with two different operators. The data bands are aggregated into one individual tunnel in which the data is transferred out from the vessel, and simultaneously the aggregation system allocates the data to this tunnel on the background enabling the ability to maintain the real-timeliness, Gustafsson (2021) explains.

According to Gustafsson (2021) the data is transferred as secured UDP (User Datagram Protocol) from the vessel to the cloud which means that there is a secured tunnel from the application to the cloud's application, the proxy server, from where the data is sent further to the users. The idea is, that the end-users never strain the data link of the vessel, which works independently, and the end-users get their data from the cloud instead. This way the link can maintain real-timeliness and the bandwidth usage stays under control. Currently, the data from the vessel is not packed - only encrypted, Gustafsson (2021) states. It is DTLS (Datagram Transport Layer Security, TLS secured UDP) which means if someone gets their hands on the data, it is in unreadable form. The data is decrypted in the cloud and is normally readable again. (Gustafsson, 2021).

So far, the data is not compressed for sending. Gustafsson (2021) opens the bandwidth requirements:

> "The system is built on Elisa's and Telia's commercial 4G cellular networks, which means, that when the vessels diverge from the coastal areas, the bandwidths get narrower and their availability weakens. Our intention is to study, what it means in terms of data transfer. When we locally parser the sensor data from the vessel before it is sent further, we can evaluate if it is necessary to send it out at so frequent intervals, or if all the same data as in good circumstances, is needed to be sent out. The intention is to have 5G connectivity in the remote pilotage demonstration with Haaga or Viikki in Helsinki. With all odds, the 5G is available in proximity of the harbor basin, but what data could be transferred over it in this context, remains still open."

Also, in the SVAN project and in Svitzer Hermond's case the connectivity was resolved with mobile network connections, and in both instances, it performed well and were deemed sufficient for the purpose according to Lindborg (2021). On the other hand, one must consider the fact, that the mobile networks in Copenhagen and in the Archipelago of Turku are very good to start with. The recent studies by Groke Technologies in Japan indicate that the local mobile network is not suitable for remote operation purposes, but 5G networks might bring relief to this according to Lindborg (2021). Satellite-based communication is too expensive for remote operation use case, because the reservation of bandwidth raises the expense to 100 000 € per month price range. (Lindborg, 2021).

However, according to Lindborg (2021) the usage of the bandwidth can be optimized as it’s not rational to transfer video image over satellites. The satellites can still be utilized to produce a so-called object-map, and from its basis to create a virtual representation of the traffic situations, Lindborg (2021) points out. When it comes to controlling the vessel over satellites in areas where mobile networks aren’t available, Lindborg (2021) believes it will be conducted as a mission control rather than directly propeller and rudder control. In this scenario, only waypoint coordinates would be given to the vessel via satellites, and the vessel itself takes care of the process of controlling the power output and its course. (Lindborg, 2021).

In a shipyard environment, even private 5G networks would be interesting alternatives for data communication, Suoniemi (2021) states. Naturally private mobile networks work within ports also. According to Suoniemi (2021) the use of two operators, as they do in Brighthouse Intelligence with the 4G LTE connections, improves the redundancy of the connection. Suoniemi (2021) further shares his vision of data transfer:

> “Like we currently transfer the data from the cruise vessels to the tugs (AIS and camera data), it would be logical to also share data from ashore to the vessel in the same way. There could be a tab in the iPad application for the land-based data, and as the distances are so short in the port areas, the data can be transferred via mobile networks or even via WiFi-network in approaches and departures.”

Basing on the beliefs of the respondent group, mobile connections available today and in the near term, are seen as feasible data transfer enablers in operating environments near shore. Bearing in mind the redundancy strategies, cellular connectivity can promote data transfer in maritime context in selected applications. Cloud-based data hubs acting as proxies are collectively agreed as functional waypoints through which the data travels to the end-users. The use of satellite-based communication is also an option, albeit it is not necessarily as rational with possible high data rates. The specific maritime application and operating environment, including the existing infrastructure, define which systems are feasible or even possible in which circumstances. Not all solutions function practically in all applications.

The lessons learnt in the Sea 4 Value remote pilotage exercise and its data transfer solutions should be carefully monitored and assessed in the future discussion regarding the operational and performance requirements for increased maritime connectivity, taking in consideration also the aspects of cyber security in the next generation maritime remote operations. Such demonstrations and exercises promote innovation and, on the contrast, give guidance on what is practical and what is not. On paper it's possible to orchestrate sophisticated architectures, but the reality in the field trials might be something else. Projects like Sea 4 Value can push the whole maritime transport system forward.

5.8 Financing and costs

The interview respondents were asked, should the data be free of costs to the end-user, if the data from the sensors was shared openly on some level. Also, as a follow-up question, it was asked, which instance should finance the systems. Establishing sensor systems can be market driven, guided with public funding or any combination of the two. The questions were designed on the hypothesis, that the data was collected from either the ship's sensors or ashore sensors in a port area. If the sensors are only on the ships, they might require counterparts on the port structure.

The allocation of costs of using such data depends on where to the data is shared and who produces it (Lahtinen, 2021; Suoniemi, 2021). If the data is shared to the vessels as a back-up, somebody must pay at least for the data transfer fees. There could be a reasonable year or month-based fee, as it would be a service after all, Suoniemi (2021) reflects. Pilotage and port services are charged anyway, and the prices are, in fact, quite high according to Suoniemi (2021). The shipowners wouldn't probably pay for this type of service separately, but if, for example the pilotage fees arose respectively, they wouldn't necessarily defy it. In the VTS ecosystem and in governmental co-operation (Coast Guard, Defense Forces, Customs) the situation is different and the information, regardless of the type, should be shared free-of-charges so that it would be available if needed, even though it wouldn't be actively used, Suoniemi (2021) states.

Lahtinen (2021) points out that when we start talking about the commercial use and cost structures, and an intelligent fairway structure is produced for remote pilotage as an example, the question actually is how the current costs will change: What are the costs that incur for different actors, when the fairway and port structures are up-dated and new services provided? There must always be some incentive. Lahtinen (2021) explains:

> "The Finnish Transport Infrastructure Agency won't certainly develop the structures out of goodwill. Of course, the overall safety is always being increased, but when there are individual service providers and companies, that produce these technologies and maintain them in the fairway structures, it is essential to ask at some point, how the costs are divided and who pays for what. When discussing the systems in port areas, I find they would be beneficial for the operators of the conventional vessels as well, so paying and creating such systems would be significantly more justified, when they can be utilized by wider user community than just autonomous vessels."

According to Lilius (2021) there are different expenses in the maintenance of ports, and these are logically being covered with different port charges. If verification and augmentation of the vessel's position is a service produced by the society, positioning the vessel in port areas doesn't fundamentally differ from positioning the vessel anywhere else. In that sense, positioning in ports should be free-of-costs for the customers (Lilius, 2021).

From the commercial approach – when autonomy at some point emerge – there is probably some instance that defines, that this sort of technology must be found in every port, Lilius (2021) believes. However, according to Lilius (2021) it's hard to see, what additional value it would offer in comparison with other ports. If for example, Port of Turku had this type of service, in which way would it become more appealing to the customer?

Gustafsson (2021) believes that decisions on a strategic level should probably be made, whether the government should finance the services or should the progression be market-driven. Although it would be market-driven, if the data was available for free, the interest could be broader, and the development could take faster steps forward, if compared to a situation, in which the data would be chargeable and limited (Gustafsson, 2021). Availability of free data could promote autonomous shipping regardless of who pays for the systems.

The issue is two-sided. The investments aren't probably cost-effective in the beginning. Gustafsson (2021) wonders, would some instance do it out of goodwill and offer the data for free – these are tricky questions at the moment. According to Gustafsson (2021) it's very fortunate, that there are projects like Sea 4 Value, which are partly funded by governmental financing, and these matters can be promoted and brought into discussion.

The data wouldn't be, however, totally open for public in any scenario, Gustafsson (2021) believes. According to Gustafsson (2021) the problems in the field are very interesting: What should be available, in case something was available in the first place. There are necessarily no correct answers, what sensors are sufficient in which use, so it could be beneficial to find the solutions trying different set-ups (Gustafsson, 2021). It could be of benefit to include the sensor manufacturers in the process, so they could improve and develop the systems that work in certain conditions, and the systems would be targeted for these types of applications - However, some governmental support would presumably be needed in the background to facilitate it, Gustafsson (2021) presumes.

Soininen (2021) has a critical approach to government funding. According to Soininen (2021) only sensors, that are genuinely required, should be installed permanently. The sensors, that are "nice to have" cost significantly, and not the ports nor the state want to invest or have the ability to up-keep them, if they aren't significant. If the role of the sensors would be only supplementary, their demand must be very carefully evaluated. Such sensors always become expensive to maintain. According to Soininen (2021) the sensor systems always become costly, once the demonstrations and prototype testing phases are over. There will barely be any market or investor for them in the professional all-year-round use, Soininen (2021) assumes and brings forth relevant challenges:

> "If the role of the sensors is only supplementary, what are they supplementing, why should they be invested in, and why should one pay for it, if they aren't actually needed? And the data can hardly be sold anywhere, so there won't be any market for it. Who would pay for the data? If a remote operator transits, for example, between two ports, it would be more economical for them to install their own sensors."

According to Soininen (2021) it is essential to identify the path where the progression is leading on the international level: Where IMO (International Maritime Organizaton) directs the development and, after that, what requirements EMSA (European Maritime Safety Agency) sets for it. Soininen (2021) notifies that the in the maritime context the solutions should be harmonized:

> “Even though we had good 5G connections from Turku to Stockholm, we must understand, that maritime traffic is global. Same solutions must work with a Finnlines ferry transiting between Hanko and Rotterdam, and also on a Chinese vessel that only once during its lifecycle visits Finland. Although we wanted to be progressive, we cannot promote solutions, that are tailor-made only for Finnish conditions and don’t work anywhere else. Sure, we have a unique coastline etc., but the solutions must be globally verifiable. Only then we can assure, that wherever the vessel comes from, certain basics, like pilotage, AIS, and VTS phraseology, work with the vessel in the same way all over the world.”

Soininen (2021) points out that if the system in question is only a supplementary addition to the infrastructure, it must be associated with a very critical Business Impact Analysis taking into account its cost, the cost of the maintenance, what are its benefits, and is it worth it. According to Soininen (2021) we cannot be sure currently, that this is a critical technology for future vessels. It must truly be evaluated, that where the financing to this would come from, what else there is to be done on the field before it, and is this the project, to which 10 millions should be invested, or is it somewhere else, Soininen (2021) concludes.

The responses from the interview participants indicate that the financing for sensor driven systems could come from either the commercial market, when the solutions would be specific for each use instance, or from the government, when it would be more justified to build such systems as more customers would be able to utilize them. However, at this very early stage when autonomous vessels de facto aren’t an everyday phenomenon – rather a distant curiosity - it’s still very unclear to see any obvious benefits for such systems. Therefore, the time isn’t yet mature for the discussion on the allocation of costs given the complexity of the subject and the lack of international guidance, standards and uniform implementation.

Nonetheless, it is reasonable to presume that such systems, that could provide the exact position for the vessels in ports that have reduced onboard resources, at some point become more commonplace in ports as the situational awareness must be built one way or another with sensors. The information of the position of the vessel in relation to its surroundings, including fixed structures and moving objects, is the cornerstone for decision making, whether it is done onboard, remotely, or by AI.

If the sensor systems will be seen inevitable at some point, the shipowners and ports will start to implement their own solutions. Same has recently been observed with auto-mooring systems. When we go forward in time enough, there could be a mixed collection of different type of systems for each individual port user. On the other hand, if the positioning systems were established coherently by governmental guidance, they could be utilized by a larger user community and the openness of data could encourage the development in automation in wider spectrum.

However, until the systems aren't genuinely required as the onboard decision-making capability still today is a fundamental part in the maritime transportation, it's hard to see any benefits for building such systems at this time and age. It can also be interpreted as a strategical step to not impede in the natural market-driven progression. As a pure supplementary means, it isn't economically defensible to establish very accurate shoreside positioning systems with governmental financing as long as the position determination capability remains onboard the vessels in full, and the commercial operators won't probably build their own systems unless the potential in the business case becomes evident.

6 Conclusions

Accurate positioning systems enable connecting smart vessels to smart ports while increasing redundancy. If placed ashore, the systems can also improve the situational picture the conventional vessels have. This master’s thesis presented next generation alternatives for producing and sharing position and distance information as a part of situational picture to varying end-users. Relevant background theory, previous studies on alternative positioning and the basic principles of the Finnish VTS system were discussed in the thesis on the side of the actual research (Practical Part II) to which seven competent informants from various backgrounds took part.

Sophisticated sensing technology, formerly utilized only in specific maritime operations, i.e., in DP applications, as well as different augmentation services for satellite-based positioning, are becoming more and more common in the commercial traffic and can be considered as enablers for the advent of MASS. The modern transfer technologies, such as 5G and VDES, and the advances in the positioning and situational awareness systems increase the likelihood of MASS become reality rather sooner than later. The results of this research suggest, that notwithstanding the placement of the sensor system, the novel concepts in positioning could aid the onboard and remote operators in determining the vessel’s position in short distances, i.e., in port areas.

Eventually the accurate relative position information could be shared to the users as a service but at current market there are no clear drivers for it. The end-users can be the crews and pilots of the ships regardless of degree of automation, the fully autonomous ship itself, remote pilots and remote operators, VTS operators and hardware/software developers.

Critical thinking and realism were promoted in the study, while the operational differences between different systems and sensors were discussed highlighting the MASS context. According to the results, different waterway and position information users have different needs and interests, but in optimal circumstances, the same technical solutions enhancing improved situational awareness and accurate positioning would benefit as many users as possible. For example, if remote control operations require accurate position information, the same sensors could be used to offer the data for conventional vessels as well.

Choosing sensors for the systems and solutions is driven by what kind of systems one wants to create. The technological requirements derive from the operational needs. There might be potential to develop new innovative systems that produce position information in the ports as a part of intelligent fairway infrastructure and these systems could facilitate new services, but the timeframe for the demand of any new possible services is hard to define.

Future shipping will need accurate position information in remote operations in ports to compensate for the absence of onboard human visual observations. On the other hand, there are no evident incentives to offer accurate position information for conventional vessels in ports alone, although in some scenarios it could be useful. Cost-benefit analyses could be carried out to address the strengths and weaknesses of any supplementary systems. The information can be imported, for example, from AIS, radars, lidars, cameras or GNSS augmentation systems. Further, the inputs from multiple sensors should be fused so that the critical navigational operations wouldn't be dependent on any particular solution.

The future needs for accurate position information are case-specific and partly blurry for the time being. It is also problematic to refer to the "future" without any accurate definition for the timeframe. At the moment, there are no clear incentives to establish new shoreside systems, since at present the operation of the existing vessels rely on onboard manpower and MASS will undoubtedly be equipped with their own comprehensive sensor sets. Expensive systems should not be built ashore just because the technology is available - there must also be a genuine and obvious benefit. The development in the MASS framework should be closely monitored and continuously assessed both publicly and by the operators in the commercial market.

In summary, only when the positioning references are arranged in a manner that all waterway users, notwithstanding the level of automation, can utilize the same technical solutions implementing the systems can be cost-effective and justifiable on shoreside. Shoreside systems could supplement the sensors onboard MASS. The ability to accurately measure the position of a vessel in relation to its surroundings in port areas could be a critical capability once emerging practices, such as remote pilotage, become everyday operations. Accurate shoreside positioning systems could empower remote pilotage for conventional vessels. Accurate positioning services enhancing high-quality situational awareness in port areas could be key strategical abilities in the world where MASS meet traditional vessels in the same intelligent fairway and port structures.

The position information should be seen as a part of the situational picture, from the basis of which the situational awareness is built. The situational awareness is the prerequisite for effective decision-making, regardless, if the decision-maker is located onboard, at a remote location, or is a machine.

This research acts as a statement for further studies along the road towards autonomous seafaring. The following studies could be proofs-of-concepts, feasibility studies, site surveys, equipment comparisons and trials etc.

7 Critical assessment of the work

The purpose of this assessment is to analyze success in meeting the research’s purpose and aims as well as bring forward the challenges that were met during the process. The assessment allows the reader to address the actions that might have led to different interpretations in different circumstances. All studies must be open for criticism and evaluation.

The composition of the research question, how the position of a vessel can be determined with novel sensor solutions in port areas, was intentionally left abstract and wide. Given the conceptual nature of MASS as an emerging trend, it was learned in the early stages of the process that no time should be wasted in trying to find any specific or literal answers to the research question. The gap in the knowledge regarding different solutions, however, can be argued to be at least a little narrower after the study, which progressed through exploration and examples closely related to the research question. Rather than giving any explicit answers to the research question, the study carefully constructed a path towards a more thorough understanding of the investigated matter.

The objective of this master’s thesis was to examine concepts and solutions for better positioning in port areas and it was successfully achieved. A thorough general overview was executed on the present state of varying emerging technologies and solutions and it was achieved via specialist interviews. The snowball sampling philosophy brought depth to the research.

Some solutions discussed in the study are not new and revolutionary per se, but the idea to use them in an exceptional context makes the solutions novel. One such instance is the use of 24 GHz radars in the maritime domain. Some other solutions, on the contrast, such as the GBAS RTK GPS – a type of DGPS – present the state-of-the-art technology that has recently become available in the market.

One of the major challenges in the work was to stay within the scope of the research. Everything seems to be linked to something else important, or at least to something so interesting that it was hard to be left out. If I made the same thesis again from scratch, I would try to make it shorter and more oriented in the position determination process. I wouldn’t discuss, for example, the allocation of costs at this stage.

As there is still no clear consensus even on the international instruments regarding MASS, it is nearly impossible to stay definite in any particular question related to any pragmatic issues. It was very demanding, or abstract, to discuss the positioning of the MASS with experts, since there is no water-proof definition or common understanding for remote pilotage, for instance. The timing for this type of work might have been a little too early.

When it comes to reliability and validity, the thesis followed the principles of academic research. The results are reliable since the informants represent the sharpest knowledge in their fields and the interviews were carried out effectively and transcribed carefully. Further, the sample size was found sufficient for the purpose. The results are also valid, because only minor substantive corrections were applied into the texts after respondent validation. The conclusions drawn from the results are logical and in line with the answers of the respondents. The interview questions were carefully constructed with the commissioner of the work to address relevant challenges in the scope of the research.

The conclusions drawn from the results might diverge in different circumstances, but a high abstraction level approach was emphasized in order to avoid too specific interpretations. What might affect the results, however, is the fact that all informants were from Finland, all around same age, and all males. In other words, the respondent group was homogenous, but given their strong understanding in the investigated matter, their uniformity probably doesn’t harm the research. MASS is MASS regardless of the country of origin, but the investigation of the research topic was possibly a little too “Finland-oriented” which might mean that the results wouldn’t apply as such to any other geographical areas.

Considering the objectivity in the interviews, it must be brought forward that my role as a researcher was not the most scientific one. The interviews were mostly quite friendly and there were lots of laughs and little jokes in the discussions. The interviews were carried out on Microsoft Teams, and although I tried not to affect nor guide the answers of the informants, in some cases I probably didn’t succeed. This was because on Teams, it was hard to stay silent and keep myself distanced from the investigated matter, since I felt that I should somehow try to participate more actively in order to be polite and friendly. The digital Teams era, thanks to COVID-19, might therefore have affected the data acquisition. In most of the interviews, the tone was, however, quite professional and subject-oriented leading to sufficient quality in the material and further to solid, repeatable conclusions.

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Appendices

Appendix 1: Practical part II interview questions

1. Who are you and what is your task?
2. What should be taken in consideration when choosing position indicating sensors?
3. What different options are there to locate a vessel’s relative position in port areas?
4. With what kind of sensors 0,1 m accuracy can be reached in distances of approximately 200 meters?
5. What kind of sensor would you recommend for an application, in which the position of a vessel should be received as accurately as possible and shared without undue delays to the end-users or systems, that would use this data as the basis for their/its operation?
6. What are the benefits and deficits of such a sensor locating either onboard or ashore?
7. What happens to a remote-controlled or autonomous vessel if it loses its position information?
8. Who might need the relative position information of the vessels in port areas, i.e., who would be the potential end-users?
9. How could the data be shared to the end-users and what does it require?
10. If the data is shared, should it be free of costs?

Appendix 2: Practical part II interview questions for Iiro Lindborg

1. How can the relative position of a vessel be determined with maximum accuracy in ports and in docking operations?

2. How can the data be shared outside from the vessel for example, for remote pilotage and VTS purposes?

3. How do you define situational awareness and what does it consist of?

4. How was the situational picture built up in project SVAN, what elements it consisted of and was it found satisfactory?

5. What is the most developed form of sensor fusion at the moment, and can all the data be brought on the same panel/interface for the end-user?

6. Can the new solutions in sensor fusion, such as camera-based solutions, build better situational awareness than what it is in conventional vessels?

7. How can the position of a vessel be estimated with camera-based solutions and what is their role in the situational picture?

8. In case of conventional vessels, how can position information or distances from the quay to the vessel be shared from shore to the ship?