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Integrated Maritime Autonomous Transport Systems (IMAT)

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Abstract. There is an increasing focus on autonomous transport systems, and Norway has a technological and market advantage for such systems in the maritime segment. The national transport plan emphasizes that it is an objective to transfer more cargo onto keel. The MarOff, Maritim21, Hav21 programs and the political platform agrees, that autonomous vessels are an important part of this effort. Sea transport must be competitive with regard to price, efficiency and regularity, and should also have an environmental gain as well as a risk reduction.

Autonomous transport systems are one of the means of moving cargo tranport from truck to ship, but it must be documented that an autonomous transport operation can be carried out effectively, safely, and with enough barriers against errors. Land-based infrastructure will be important for the success of autonomous shipping. This paper will describe the IMAT project's objectives regarding definition, development and testing of land-based sensors, communication and control systems for support of an autonomous transport operation. The technological infrastructure will be able to give the transport system increased sensor redundancy and is integrated with shore control centres that will ensure safe and efficient operation. Land-based infrastructure is crucial for the safe implementation of autonomous maritime transport systems and has been given less focus compared to the autonomous vessel itself. This is what we will address within the IMAT project.

1. Introduction

The main project objective in IMAT, Integrated Maritime Transport Systems, will be to define, develop, adapt and test infrastructure that supports maritime autonomous transport systems and has the following focus areas:

- **Sensor and communication infrastructure:** The project will identify requirements for technology, test existing technology, develop and adapt solutions for use with autonomous transport systems.

• **Local Monitoring Centre (LMC):** This is a local traffic centre that is often operated by ports or by a local area responsible. The centre collects traffic information typically from VTS (Vessel Traffic Service), and from other existing infrastructure as well as dedicated infrastructure. The centre should be able to maintain local traffic safety. IMAT intends to define the new roles of the LMC regarding the introduction of autonomous maritime transport systems.

• **Shore Control Centre (SCC):** The IMAT project will identify the necessary infrastructure to establish an SCC. An SCC is normally operated by the shipping company or a dedicated company for the operation of one or more autonomous transport systems. An SCC will operate the vessel and will be able to send navigation instructions and / or remotely operate the vessel if necessary. The SCC is the point of contact for other SCCs. The project will focus on requirements of an SCC. In addition, it will be important to establish regulatory requirements for such a centre.

• **Collaboration:** For autonomous transport systems to succeed, it is important that the interaction between the different players is defined and regulated. In this activity, we want to look specifically at the regulations associated with autonomous transport systems such as; framework conditions, requirements for infrastructure and centres, information and message standards to be used, requirements and procedures for information dissemination. Further, the project will identify the best possible way to safeguard safety and security while optimizing the coexistence between autonomous and conventional transport operations.

The project will study how to introduce a maritime autonomous transport system; use and adapt existing technology and uncover the need for new technology through research. This has not previously been done in the scale we are now aiming for, especially for the land-based technology as support for autonomous vessels and their operations. This is essential for autonomous transport systems to succeed. Another crucial question is the relationship between the autonomous system and humans, how this is implemented safely and intuitively, as well as the degree of autonomy that is possible to achieve. Furthermore, the features and requirements of the elements of an autonomous transport system, the land-based infrastructure, the control centres, a vessel in different modes of operation such as transit or docking, and the characteristics associated with the various terminals being operated, will be described. Within each question lies the different technological maturity (TRL - Technical Readiness Level) as well as many unanswered research questions that need to be answered. These are the main research questions:

1. How vulnerable is an autonomous transport system and how can the land-based infrastructure help to make it more robust and secure?
    a. What are the minimum requirements for sensor information in order to operate safely?
    b. What is the consequence of system failures?
    c. Is there a need for redundancy of critical system components, or will the systems onboard and ashore cover for each other?
2. What are the requirements for the land-based communications infrastructure?
    a. What are the most critical aspects in regard to data security / cyber security (jamming / spoofing / hacking) and how to minimize the risk?
    b. How to document the integrity of the information?
3. What physical obstacles can be expected based on the land-based infrastructure?
    a. Does radar / camera / sensor failure occur so that vessels are not detected?
    b. Will the autonomous ship always have enough information to avoid collisions?
    c. Loss of communication.
4. How will the interaction between autonomous vessels and others work?
    a. What information should be exchanged and is there a need for standardization?

   b. How should the different control centres interact?
   c. How to create a comprehensive traffic image based on all traffic data?
   d. How can traffic data best be collected, analysed and disseminated?
5. Do different requirements have to be developed for the different vessel categories?
   a. Should the same requirements be valid for a small vessel as for a large vessel?
   b. What should and can be controlled by the various centres (LMC, SCC, VTS)?

2. Integrated Maritime Autonomous System

The main goal of the IMAT project is to define and describe the needed land-based infrastructure in order to conduct maritime autonomous transport operations safely and efficiently. That means that is not only about the vessel, it is about the transport system as a whole, including the ports, the traffic centers, the information exchange with other traffic centers and vessels, and not least the infrastructure used to navigate safely and to communicate properly. The phrase *"A smart vessel has nothing to do in a stupid port", by Alop Anatoli,* [7] is about the transport system, not only the vessel, and addresses the objectives within the IMAT project. A smart or autonomous vessel cannot benefit from its enhanced technology when entering a port that has no infrastructure to serve the vessel.

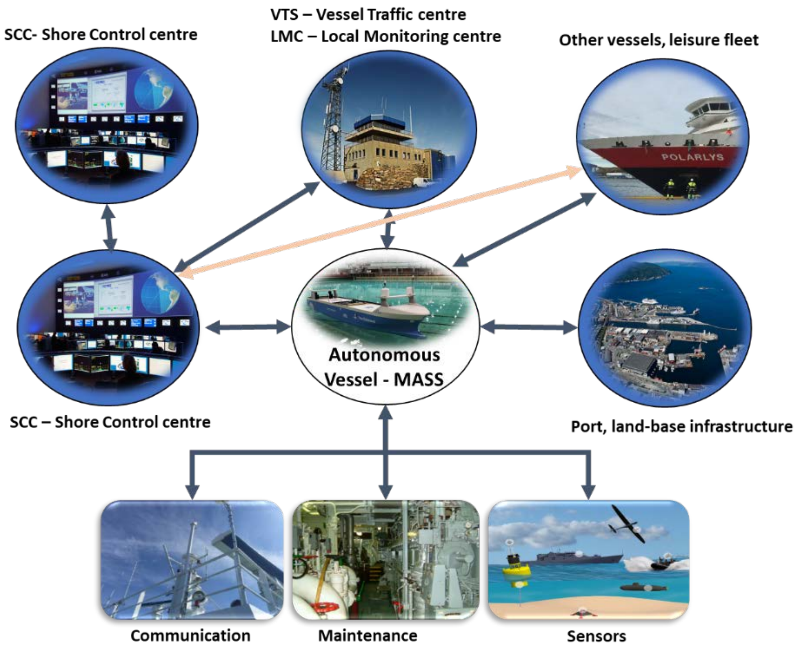

Figure 1 - Integrated Maritime Autonomous Transport system

Figure 1 describes the autonomous transport systems, where the focus not only is about the vessel but also the interaction between vessels and technology, as well as with other stakeholders [3][5]. A MASS vessel (Maritime Autonomous Surface Ship) needs a Shore Control Centre, SCC, to plan and to follow up the vessel. An SCC can remotely operate a vessel. An SCC needs to exchange information with a Local Monitoring Centre, LMC, that can be operated by the port or by local service providers and have better local information to be used for planning and follow-up by the SCC. In some areas an LMC solution can be autonomous or computer based itself, with no humans in the loop. An SCC will exchange information with other SCCs or a Vessel Traffic Service, VTS. An SCC will naturally also exchange information with conventional vessels, and with other users in an area where the MASS vessel is operating. A Maritime Transport System is to see all this integrated together.

One thought to be addressed in IMAT is to use land-based infrastructure to assist in the operation of a MASS. This will bring resilience into the system, where several technical systems and equipment, both on board a vessel and from the land-based infrastructure, can be used to build awareness to a MASS operation. There are many considerations to consider and good planning is probably even more important within autonomous operations than for conventional shipping.

Figure 2 describes the traditional communication channels from a vessel. The data can either be transmitted through satellites, from terrestrial solutions, or between radios such as VHF. The choice of communication channel must be done on an application level, where geographical position is an important input since there will be local differences concerning coverage and the available technology. Communication is vital when remote operation and instructions to a Maritime Autonomous Surface Ship (MASS) is established. Infrastructure is not only about communication, but also about positioning and object monitoring. Will the infrastructure need to provide GNSS corrections or other augmentations methods, so that a MASS safely can operate and be monitored in an area including the docking phase? Will there be useful to have a proximity zone surrounding the vessel that can identify position in relation to other objects/vessels? Are there need for additional sensors in this regard? What about the data integrity and the security level? There are many other vital questions to raise when developing a transport system used for MASS operations [5][6].

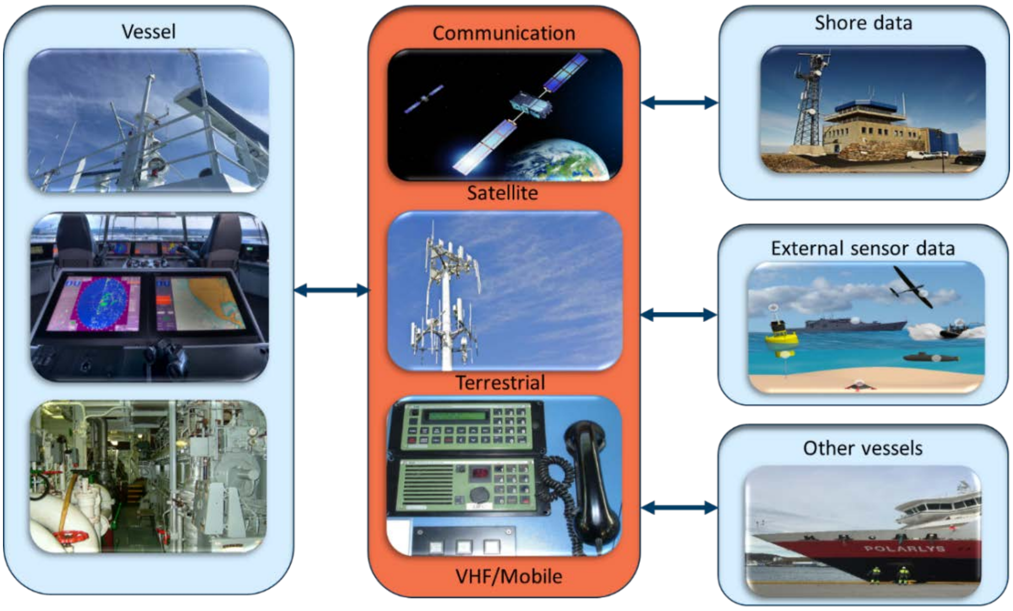

Figure 2 Different communication possibilities between vessel and other sites

This brings us to the CONOPS, Concept of Operation [2]. The main task of a CONOPS is to bring awareness to special situations, when and how such situations can happen, and how to prepare for them. A CONOPS will address the human factors in the MASS operation aspect, as well as the technical aspect [4]. The relation between automation and the human role is central. This affects the requirements to the infrastructure that provides the situational awareness in regard to man-machine-interface, MMI. A CONOPS is important when planning the implementation of a MASS operation, and in order to ensure sufficient system reliability and resilience so unexpected situations and potential failures can be handled properly.

3. Addressing the hazards and compare with sensor site infrastructure

We have identified the main factors from a list of hazards that distinguish an autonomous ship from a manned ship operation, where land-based infrastructure could assist in bringing awareness to the decision-making. With the identified causal and contributing factors that are critical with respect to hazard risk, we attempt to classify the level of contributions to MASS shipping [2].

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For each characteristic, a colour indicates to which degree this is contributing to the three risk types illustrated in following tables: Red means that it is hard to believe that land-based infrastructure can do a difference. Yellow is neutral impact. Green means that land-based infrastructure and sensor sites can contribute positively by bringing more awareness to the decisions. The list of Hazards is from the Bureau Veritas, Guidelines for Smart Shipping (draft), which was released in Aril 2019 [1].

The list is as follows:

A. Hazards for the voyage
B. Hazards for the navigation
C. Hazards for the detection
D. Hazards for the communication
E. Hazards for the ship integrity, machinery and systems
F. Hazards for the cargo and passenger management
G. Hazards for the remote control
H. Hazards for the security

In our work we have studied the hazards and have identified if we believe that land-based infrastructure could be used to lower the hazards.

A. Hazards for the voyage is very much related to the planning of an operation. It is about the interaction between an SCC and the MASS. There are many possible risks with regard to data exchange between an SCC and a MASS; what happen if some instructions are not received by the vessel, and do we have enough data from the sensors to be able to do a qualified planning? Also, if the position is incorrect, this can lead to a serious situation. The green colour in the table below means that land-based infrastructure can assist the operators with the planning based on data received from the sensor sites. It will be communicated either directly to the MASS or to an SCC/LMC. It means that the land-based infrastructure might be used for decision support by providing better situational awareness to the decision makers and computer systems.

		Sensor Site
Hazards for the voyage	Human error in input of voyage plan	
	Failure of updated information (nautical, weather, publications)	
	Failure in position fixing (due to e.g. GPS selective availability)	

Figure 3 - Hazards for the voyage

If a Shore Control Centre (SCC) is to have full remote control of a vessel, it needs to communicate commands for navigation and exchange of voyage plans, as well as to receive status and situational awareness from the vessel along the route. When building a voyage plan, it is an important to understand the general traffic picture in the area where a MASS should operate, for example based upon AIS data, as presented in Figure 4. Questions to be answered are: What kind of vessels and operations are in the area, what kind of fixed and mobile installations need to be planned for, what existing land-based infrastructure is available, what are the communication possibilities, and what kind of interaction with other maritime operators are likely, such as communication with conventional vessels and the leisure fleet?

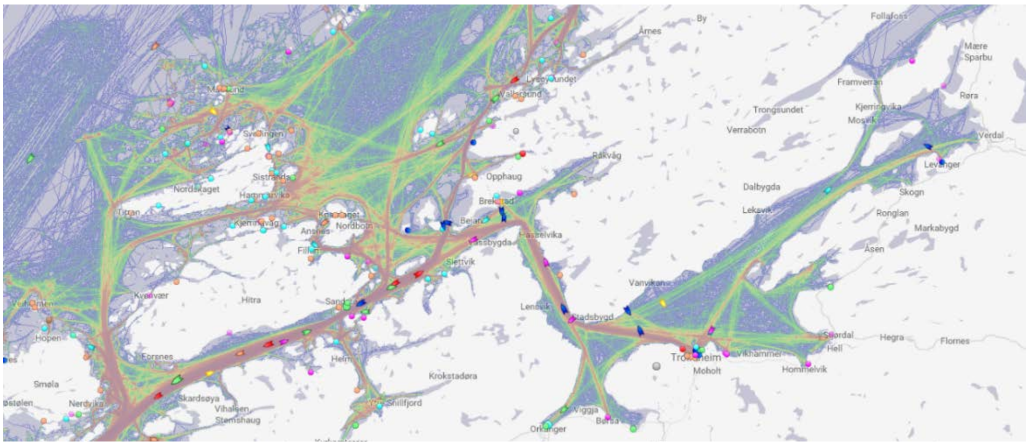

Figure 4 - Density map. Source: Marinetraffic.com

B. Hazards for the navigation is high on the priority list for a safe journey where sensor data from land-based infrastructure can be used to increase the safety of the system. It is likely that some of the sensors from a vessel can be assisted by land-based infrastructure, but this does not necessarily apply to all sensors installed onboard a MASS. One example is the cameras that will be used for collision avoidance with objects in the fairway. Simultaneously, if land-based infrastructure detects objects in a fairway, information can be sent to build awareness to the MASS navigation technology, either directly to the vessel or to the SCC. The green status marks where we believe land-based technology can assist, for example to identify the traffic picture, to forecast traffic prognoses, to build awareness to both an SCC and a MASS. Yellow boxes mean that it is neutral, and have a low impact, while red means that we do not believe land-based infrastructure can be used for the purpose.

Hazards for the navigation	Heavy traffic	
	Heavy weather or unforeseeable events (e.g. freak wave)	
	Low visibility	
	Collision with other ships or offshore infrastructures	
	Collision with floating objects	
	Collision with marine wildlife (e.g. whales, squids, carcasses)	
	Collision with onshore infrastructures or failure in mooring process	
	Loss of intact stability due to unfavorable ship responses (e.g. to waves)	
	Loss of intact stability due to icing	

Figure 5 - Hazards for the navigation

There might be several sources of data that can be used for safe navigation. One example is to use the historical traffic pictures, and if there are any anomalies in operations compared with historical data, this could be identified as a dangerous situation. For example, when using historical AIS data, and detecting that there are deviations from normal operation, there could be a status alarm. The data could also be used to identify areas of concern, where for example areas with crossing traffic. Historical data could also be used as input when planning an implementation of land-based infrastructure for a fairway, where cameras and radars could be used to improve awareness to areas of high concern.

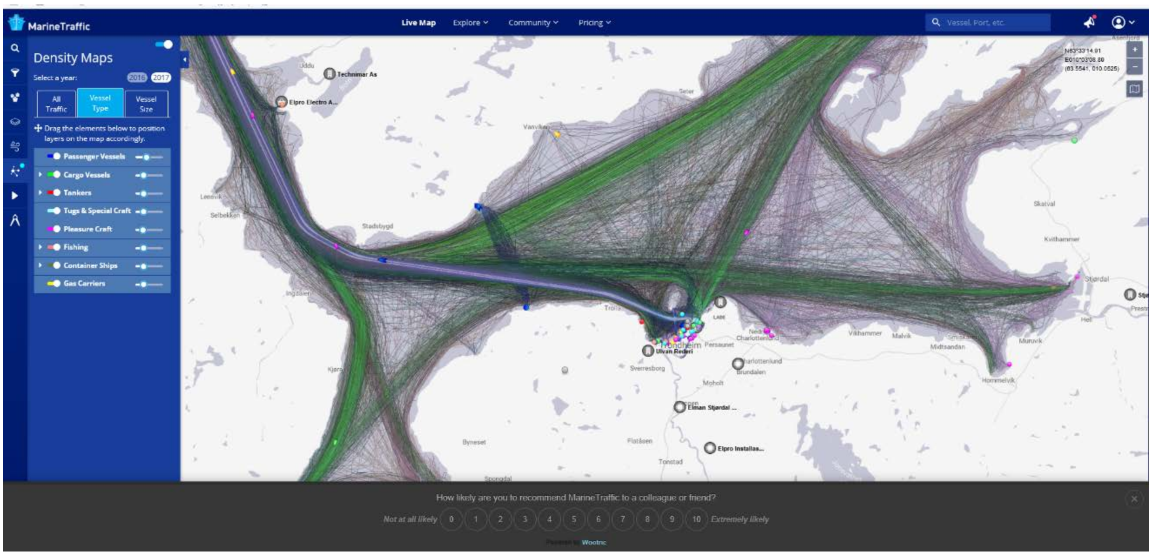

Figure 6 - AIS picture from Trondheimsfjorden. Source: Marinetraffic.com

C. Hazards for the detection These are hazards where it is extremely important to use several technical sources for identification and to build awareness, which is crucial for avoiding collisions with either objects or with obstacles in a fairway. Will it be possible to augment the MASS onboard technology decision systems with information from land-based infrastructure? Could information exchange be used to build better awareness? The table below summarises what we believe will be possible or not with regard to detection, where green means that land-based infrastructure can be used, while yellow is neutral and red means it will be hard to use land-based infrastructure for this purpose. Detection of slamming or high vibration will naturally be red since this hardly can be measured by land-based infrastructure. You need the sensors on board the MASS for vibration detection. This cannot be monitored from a land-based sensor.

Hazards for the detection	Failure in detection of small objects (wreckage)	
	Failure in detection of collision targets	
	Failure in detection of navigational marks	
	Failure in detection of ship lights, sounds or shapes	
	Failure in detection of semi-submerged towed or floating devices (e.g. seismic gauges, fishing	
	Failure in detection of discrepancy between charted and sounded water depth (e.g. wreckage)	
	Failure in detection of discrepancy between weather forecast and actual weather situation	
	Failure in detection of slamming or high vibration	

Figure 7 - Hazards for the detection

D. Hazards for the communication A communication failure means it will be difficult to remotely control and operate a MASS from a shore centre, as well as to accomplish data exchange between shore and MASS. If commands are sent from an SCC to a MASS, with signal failures/interference, degradation or low performance, would cause a MASS to either stay with its original plan or end up in a predefined safe mode. A safe mode could be if it is decided to stay in a safe position and remain passive until the communication link is re-established [5]. The communication failure with another ship in distress is marked yellow since this normally will be done from the SCC and not a MASS, which is important for the transport system and not only for the MASS itself. The identified hazards show that the infrastructure at shore can be used to improve the situation awareness and also provide a level of redundancy for the MASS on-board technology.

Hazards for the communication	Reduction of communication performance (e.g insufficient bandwidth)	
	Communication failure (e.g. with SCC, with relevant authorities, with ships in vicinity)	
	Communication failure with another ship in distress	
	Failure in data integrity (e.g. error in data transmission)	

Figure 8 - Hazards for the communication

E. Hazards for the ship integrity, machinery and systems This table shows most of the hazards marked as red, which means we do not believe that land-based technology can be used to detect or monitor these potential hazards. We need the sensors on-board the MASS. It will of course be important to bring the data from the vessel to the SCC, but that will be part of the hazards within the communication table. The only green box on the list will be the last hazard item; “Failure of anchoring devices when drifting”. The land-based infrastructure can be used to identify that the vessel is drifting and hence be a supplement to the MASS onboard sensors.

Hazards for the ship integrity, machinery and systems	Water flooding due to structural damage or watertightness device failure	
	Fire	
	Sensor or actuator failure	
	Temporary or permanent loss of electricity (e.g. due to black-out)	
	Propulsion or steering failure	
	Failure of ship's IT systems (e.g. due to bugs)	
	Failure of ship's IT infrastructure (e.g. due to fire in the server room)	
	Failure of anchoring devices when drifting	

Figure 9 - Hazards for the cargo and passenger management

F. **Hazards for the cargo and passenger management** is another group where the land-based infrastructure will play a minor role. The hazard item; “Too many cargo or passenger aboard”, is marked green because we believe land-based sensors can be used for passenger control. This must be a part of a gate control system in the ports. The item ”Passenger overboard”, is marked yellow because we believe a land-based camera could in some cases be able to identify such a situation. This will of course only be possible in areas where the land-based infrastructure is adequate, for example in a port area where advanced cameras can be used.

Hazards for the cargo and passenger management	Too many cargo or passenger aboard (overload)	
	Loss of intact stability due to shift and/or liquefaction of cargo or due to cargo overboard	
	Passenger overboard	
	Passenger illness	
	Passenger injured during arrival or departure	
	Passenger interfering in an aboard system	

Figure 10 - Hazards for the cargo and passenger management

G. **Hazards for the remote control** is a group where the SCC plays an important role. The technology itself can be used to verify human decisions, based upon for example machine learning or AI...

Hazards for the remote control	Unavailability of SCC (fire, environmental phenomenon...) or of operators (faitness, emergency situation, etc.)	
	Human error in remote monitoring and control (e.g. through situation unawareness,	
	Human error in remote maintenance	

Figure 11 - Hazards for the remote control

H. Hazards for the security All boxes are marked green, which means we believe technology ashore can be used in relation to decision making and security. Security hazards are, in this context, harmful acts by third parties, with the objective to damage or to unlawfully take control of a situation. The best protection for this crime will be to use multiple sensor sources, build redundancies, maintain high level of integrity and to provide enough information to identify or to take action in protecting the MASS. If the navigation system on board a MASS is hacked, the land-based infrastructure could be used to safely operate the MASS to a safe location, maybe by using another back-up communication channel.

Hazards for the security	Willful damage to ship structures by others (e.g. pirates, terrorists)	
	Attempt of unauthorised ship boarding (e.g. pirates, terrorists, stowaways, smugglers)	
	Jamming or spoofing of AIS or GPS signals	
	Jamming or spoofing of communications, hacker attack, also on RCC (e.g. in case of pirate or terrorist attack)	
	Failure in data confidentiality (e.g. data interception by unauthorized 3rd party)	

Figure 12 - Hazards for the security

4. Use Cases – Yara Birkeland and Trondheimsfjorden MASS Test Area

The autonomous transport operation planned for Yara Birkeland is the first real autonomous transport operation planned of this scale. This means that this project is in many ways ground-breaking, even though the stakeholders have long and solid experience from conventional maritime operations. It is of outmost importance that this project is accomplished without major incidents, since this would cause a serious set-back for the whole introduction of MASS globally.

For the Yara Birkeland transport operation, shore-based infrastructure will be implemented to ensure secure and robust communication to the MASS, and optimal monitoring of all movements in the operation area. Further, an operational service provider responsible for the overall transport operation will be appointed. In addition to the already existing VTS in the region, there will be another operational centre manned by the operational service provider. The implementation plan is based upon experience and earlier projects with similar requirements to operational efficiency and safety. For IMAT, a more scientific and systematic approach is chosen, but the Yara Birkeland use case will be monitored closely during the project. The first test period of Yara Birkeland is planned to the end of 2020.

Trondheimsfjorden MASS test area is used by industry, research institutes and the technical universities. The area needs to be properly rigged for safe and secure testing of novel MASS concepts, and this area will first and foremost be the focus area for IMAT. Based upon the earlier described methodology, an optimal infrastructure for maritime autonomous operations will be described, implemented and tested. Both operational (technical, security, safety and efficiency) as well as cost-benefit aspects, will be considered.

5. Summary

The main idea of the IMAT project is to define, develop and test the minimum land-based infrastructure in order to ensure a safe and effective maritime autonomous transport operation. Especially in this early phase of autonomous shipping, it is essential to build confidence in regard to safety. How can the current technology contribute? What will be the possibilities with emerging technologies, and which technologies will be essential to operate a MASS with the same, or a better safety and security level than conventional vessels? How can the interaction between vessels, with the leisure fleet, with the control centres, and with other stakeholders and sensors be achieved? Will it be possible to use land-based sensors to increase the situation awareness for the MASS operation as an extra information source to the technology installed at the MASS? Can land-based infrastructure be used to control and support the MASS operation?

Another question for the project to answer is the vulnerability regarding land-based sensor infrastructure for operational purposes. Firstly, the land-based infrastructure will be different from place to place, because of the technology available at different locations. It will also be differences because of types of traffic in the area and the governance of it. Secondly, it is likely that private actors will develop their own infrastructure, at least in parts of the fairway. This, if a MASS will be operating in a predefined area where it is possible to invest in own infrastructure. Thirdly, is how maritime autonomous transport operations are to be regulated by the competent authorities. IMAT aims to provide input to the minimum requirements for such regulations/standards on a national level with respect to the shore-based infrastructure. This project and the results can also be used when international regulations are to be developed and implemented.

New land-based technology to be used within the autonomous transport system development will increase the users' situational awareness, since the use of several information sources makes the system more robust. MASS operations mean more responsibility to land-based operators, to the SCCs, which again address different technological requirements for the planning and follow-up of a MASS operation. The IMAT project will work with vulnerability questions such as; What happens if a radar or communication infrastructure fails? Will it be possible to operate with other data available? Redundancies? How can a vessel also operate safely with other vessels in the area? There are many similar questions that must be reviewed to get an understanding of the land-based infrastructure role in an autonomous integrated transport system.

The first step has been to review the list of hazards from the Bureau Veritas [1], which shows that it is possible to use the land-based infrastructure more actively than today. For some of the hazards it is likely that new sensor sites give added value with regard to safety issues. The main goal of the IMAT project is to define and describe the needed land-based infrastructure in order to conduct maritime autonomous transport operations as safe and efficient as possible.

Acknowledgements

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