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Successful autonomous transport – The need for coordination and integration of strategical and operational management

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The rapid pace of technological and societal changes creates a strong need for competence, standards and regulations that allows for exploiting the benefits of new technology, without operating at an unacceptable risk level. To be successful, resilience perspectives may be used to identify future functionality and adaption requirements, including flexibility of operation and interrelations between actors. This includes identifying principles for handling both normal operations and anomalies.
The Norwegian Research funded project MARMAN (Maritime Resilience Management of an Integrated Transport System) emphasises system challenges and requirements faced with increased automation and connectivity, including implementation of MASS (Maritime Autonomous Surface Ships). Particular attention is on integrated planning at different management levels (from government to operational practise) and the interrelations between the levels.
The purpose of this paper is to examine how a future Maritime Transport System (MTS) can prepare for successful implementation of MASS in an increasingly automated transport system. This includes to identify hazards, risks, operational procedures and challenges, collaboration within the MTS, deviation management, standardisation, in addition to planning capabilities to cope with them.
The paper describes automation of the maritime transport system, related risks and integrated planning. Further, the paper discusses main challenges for successful implementation of MASS and management at strategical and operational level to handle these. This includes resilience perspectives e.g. potential resources in case of procedure deviations and emergency preparedness.

Keywords: Transport, autonomy, automation, resilience, management, integrated planning, procedures, standards.

1. Introduction

The maritime sector is increasingly automated in both infrastructure (e.g. ports and terminals) and vessels (Fjørtoft et al, 2023). In addition, it is expected that less use of energy with more automated vessels will reduce the climate footprint and environmental impact. However, new challenges emerge with automation, as increased complexity, interrelations, and dependencies. The rapid pace of technological and societal changes creates a strong need for collaboration, competence, standards, and regulations that allows for exploiting the benefits of new technology, without operating at an unacceptable risk level. It will be a balance between technological investments and operations. To be successful, resilience perspectives may be used to identify future functionality and adaption requirements.

2. The Maritime Transport System

Increased automation of the Maritime transport systems (MTS) includes both infrastructures, vessels and related networks. The development implies a gradually transition from conventional vessels to more automated, and with a stepwise introduction of autonomy.

2.1. *Maritime transport chains*

MARMAN emphasises system challenges and requirements faced with increased automation and connectivity, including implementation of MASS. In addition to sea operation, this paper is limited to the sea – ports/terminals, nodes in a MTS.

Future shipping based on MASS must understand how the system is organised, e.g. navigational and operational information exchange with stakeholders and ICT systems (Stene, Fjørtoft & Holte, 2022). Rødseth et al. (2020) present a framework describing the autonomous ship systems, operations, and context. The ship system description includes all physical components and roles to ensure monitoring and control of the autonomous ship. The context describes the boundaries between the autonomous ship system and its environment illustrated in Figure 1.

Fig. 1. The physical context of the autonomous ship (Rødseth, et al., 2020).

The MTS constitutes five main categories:

1. *The Maritime autonomous Ship System* (MASS): physical system including information and data exchange with remote operations centres (ROC) or a Vessel Traffic Service (VTS).

2. *Traffic control centre:* VTS provides operational support and coordination of maritime activity for the operational area in question. Local Monitoring Centre (LMC) has an explicit focus on the local port and service providers. (b) *Other ships (Conventional and autonomous)* require operational standards and protocols for safe and predicable navigation, and include onboard ship systems, crew depending on degree of automation, ship management organisation.

3. *Port and fairway services*: Supports navigation and manoeuvring, including shipmaster, maritime pilot, tug master and VTS operator.

4. *Port and land-based infrastructure*– as cameras, radars and sensors along the fairway - are intended to ensure situational awareness for resilient operation of MASS.

5. *Context actors* represent a variety of stakeholders including organisations affecting decisions, e.g. the International Maritime Organisation (IMO), Flag States, Classification societies, and shipowners.

3. How to design Resilient Transport Chains?

3.1. *Strategical and operational management*

The framework illustrated in Figure 1 is relevant for resilience analysis, covering stakeholders at the operational level. Note that this include both manually and automated operations.

Resilience Engineering addresses the gap and distance between planning levels; strategic and tactical levels WAI (Work-as-Imagined) and the operational level WAD (Work-as-actually-Done). WAI represents the governmental level and includes laws, regulations, and standards. Stakeholders at the operational level may involve traffic management (control centre), network users (including MASS and conventional vessels), fleet operators, and service providers. In addition, stakeholders at the strategical level may represent the Authority, Regulator, Strategic planning management, Traffic management, Network management, and Emergency management.

The *Authority* is responsible for overall decisions on actions to be taken, monitoring and inspections of aspects of interest in the transport domain, and eventually interventions and sanctions. The *Regulator* is responsible for legislative issues (European and national) or regulations (national and local). A *Strategic planning manager* is responsible for the long-term planning, where contexts will be on cost intensive investments and the infrastructure, that will be part of the MTS. This also includes coordination between networks or modes at local, regional, national or international level. This includes plans and strategies for automated vs. manual measures, investments, access control, priorities, etc. *Traffic management* should be in accordance with the strategical directions as well as operational laws and regulations, e.g. safety, resource management, and coordination towards other networks or modes. A *Network manager* plans and operates a transport network and includes the physical infrastructure enabling the movement of transport means as well as equipment and the connected

infrastructures linked to the network. An *Emergency manager* is responsible for emergency preparedness, capability and response related to transport at a national, regional or local level.

Increased automation is expected to imply new ways of working and planning. There is a need for coordination between the stakeholders at all levels of the MTS organisation. One aspect is to adjust accompanying regulations and ensure that this is in accordance with operational practice. Thus, there is a need for coordination and integration of strategical and operational management – between governance, regulations, company actors, and operational practice (Stene & Fjørtoft, 2020).

3.2. *Increased autonomy challenge governance and integrated planning*

In the MARMAN project particular attention is on integrated planning between transport modes at different management levels (from government to operational practise), work practices in the sharp and blunt end, and the interrelations between the levels.

3.2.1. *Regulations and standards*

Guidelines for autonomous shipping was presented in 2019 (see Bureau Veritas, 2019) and includes issues as safety and security conditions, and rules and regulations. Rules and regulations are mainly outlined by the International Maritime Organization (IMO) and are classified as Society rules, SOLAS convention (safety of life at sea), MARPOL convention (prevention of pollution from ships), COLREG convention (international regulations for preventing collisions at sea), ISM code (safety management), ISPS code (ship and port facility security code), STCW convention (standards of training, certification and watchkeeping for seafarers), Maritime Labour Convention (MLC), and EU Ship Recycling Regulation (EU SRR).

Further, the guidelines states that there should be a responsible party defined at all times and in all circumstances for all operations of any ship covered by the guidance, even if that person is not on the ship. Thus, clarification of responsibility of both management and operation should be considered along the implementation of an even more automated maritime systems.

3.2.2. *Planning across planning levels*

Compared to traditional planning, the concept of Integrated Planning and Logistics (IPL) is particularly useful when focusing on the entire operational system, especially the interfaces and interdependencies of activities and resources across boundaries. The IPL aim is to avoid "silo planning" resulting in unsafe operations, loss of efficiency, and increased cost for the operational system. IPL was developed for the offshore petroleum industry to make better decisions and execution by using principles of integrating people, work processes, and technology. In addition to collaborative techniques and real-time data, measure include sharing of expertise across disciplines, organizations, and geographical locations (Ramstad et al., 2013).

3.2.3. *Integrated Planning for Autonomous transport operations (IPA)*

Autonomy is likely to change transport operation and the way of planning. Fjørtoft et al (2023) introduce Integrated Planning for Autonomous transport operations (IPA) as a framework towards successful implementation of autonomy into the transport system. The procedures for conventional planning must be changed so collaboration between humans and technology become stronger.

The IPA includes two key capabilities (1) human and cultural (2) enabling (structural factors), and the emphasis has been on the former. Incorporate of resilience perspectives are emphasised for successful implementation: What capabilities are needed for the system to be resilient? Resilient needs and new issues related to automated shipping are incorporated in each of the four capabilities (4Cs) defined in IPA: Competence, Commitment, Collaboration and Continuous learning.

4. Hazards, Resilient Functionality and Planning Capabilities

Øyen, Fiskvik and Øren (2021) present a guide for estimating the resilience level in critical infrastructure. After defining the area of interest and critical infrastructure, they suggest starting to consider risks, threats and/or events. What are the expected hazards the system might face, and the capacities/capabilities needed to address any

stresses or shocks caused by those hazards are questions for the automated transport chains. To make more informed decisions, planners and decisionmakers must be aware of the hazards that are most likely to cause stress or shock.

Bureau Veritas (2019) presents guidelines to enhance autonomous shipping including the main recommendations for the design or the operation of systems. One central part is to identify hazards to prepare for potentially contributing and undesirable events or accidents leading to e.g. collision, sinking, grounding or loss of location. In the list below from Bureau Veritas, we have added natural disasters of eight hazard groups that autonomous ship systems can face, and we have added a new group, called Natural disasters, that should be included when identifying hazards to MASS operations. Within each of the categories below some possible hazards to be considered with potential consequences are listed.

Øyen, Fiskvik and Øren (2021) describe the resilient curve in five functional phases: 1) Understand risks 2) Anticipate/ prepare, 3) Absorb/ withstand, 4) Respond/ recover, and 5) Adapt/ learn. They suggest considering risks in each phase. Below hazards are specified in accordance with the resilient functional phases. IPA is a framework for more resilient plans that may support significant decision making. Resilient needs and new issues related to automated shipping are incorporated in each of the four capabilities (4Cs) defined in IPA.

1.Hazards for the voyage	
Examples: Human error in input of voyage plan, Update failure (nautical data, weather forecast), Failure in position fixing (GPS etc.)	
Understand risks	• Error in or not updated voyage plan • Changes due to external factors (e.g. natural disasters, weather, terminal locations, etc)
Anticipate/ predict	• Simulate changes (decision making tools/charts, updated competence and training etc) • Control of ship progress and potential deviations
Absorb/ withstand	• Understand available capabilities and resources, ICT decisions and automated control
Respond/ recover	• Recognise deviations, warnings and alarms, and consequences by changing plans • Competence needed for control
Adapt/ learn	• Machine learning • Management and operator learning
IPA	• *Competence*: Planners should understand hazards, vessel capabilities, infrastructures and cultural understanding. Navigational and technical competence. • *Commitment*: Stick to the plans, change of plans is negative. Follow regulations, ColReg, laws and enforcement. • *Collaboration*: ROC-ICT-External. Voyage planning, change management, conflict management. • *Continuous learning*: Learn capabilities, change management, consequences, ICT, External traffic.

2.Hazards for the navigation	
Examples: Heavy traffic, Heavy weather or unforeseeable events, Low visibility, Collision with ships or offshore infrastructures, Collision with floating objects, marine wildlife, or onshore infrastructures or failure in mooring process, Loss of intact stability due to unfavourable ship responses (e.g. to waves), Loss of intact stability due to icing	
Understand risks	• Technical errors (navigation or positioning) • Consequences by change in plans • Operations with conventional traffic
Anticipate/ predict	• Deviations in positions/ speed and early warnings, redundant infrastructure and technology • Fall-back procedures
Absorb/ withstand	• Operational envelope • Fall-back procedures
Respond/ recover	• Redundant technology, infrastructure or network, call for assistance, resources and supervision • Change or stop procedures
Adapt/ learn	• Exchange of navigation data/plans • Machine learning • Management and operator learning • Operational Envelopes
IPA	• *Competence*: ROC operations, autonomous technology. Ability to effectively manage risk that might arise during operation including hand-over between ICT-ROC. • *Commitment*: Shared awareness between terminal and MASS operations. • *Collaboration*: ROC-MASS, ROC-

	terminals, ROC-other traffic. • *Continuous learning*: Learn navigational capabilities, change management, consequences, object detection

3.Hazards for the detection	
Examples*:* Failure in detection of; small objects (wreckage), collision targets, navigational marks, ship lights, sounds or shapes, semi-submerged towed or floating devices (e.g. seismic gauges, fishing trawls), discrepancy between charted and sounded water depth (e.g. wreckage), discrepancy between weather forecast and actual weather situation, slamming or high vibration	
Understand risks	• Technical error in navigation or external sensors, Degradation of signal and technological capabilities
Anticipate/ predict	• Weather forecast • Reports on planned maintenance • Local awareness
Absorb/ withstand	• Technological failures (e.g. manoeuvring and stability), redundancy of critical systems • Awareness from external sources/technology
Respond/ recover	• Inform influenced and related stakeholders, identify appropriate measures to be taken, call for assistance, resources and supervision • Change of procedures, go to fall-back/ safe mode
Adapt/ learn	• Machine learning (object library) • Management and operator learning • Consider changes of technology, regulations, standards and procedures
IPA	• *Competence*: Understand limitations and vulnerability. • *Commitment*: Between traffic centres and ROC/MASS in case of technological failure in infrastructure. • *Collaboration*: Close collaboration between ROC-Terminal-Traffic centres- and other traffic. • *Continuous learning*: Understand consequences in degradation of navigational support, and local constraint parameters.

4.Hazards for the communication	
Examples: Reduction of communication performance (e.g. insufficient bandwidth), Communication failure (e.g. with RCC, with relevant authorities, with ships in vicinity), Communication failure with another ship in distress (e.g. message reception, relay, acknowledgment), Failure in data integrity (e.g. data transmission)	
Understand risks	• Update on digital and technological development • Technical error in systems or sensors • Degradation of signal
Anticipate/ predict	• Forecast potential signal failure • Reports on planned maintenance • Detect communication quality problems
Absorb/ withstand	• Plan for a redundant communication channel
Respond/ recover	• Situational awareness; swich to back-up system/ communication channels • Data from alternative, external sources/ systems • Change of procedures, eventually go to fall-back if communication is disturbed
Adapt/ learn	• Update communication requirements, data integrity, recovery from loss • Training and simulation of changes in technology, procedures or requirements
IPA	• Competence: ROC-operators should understand the different systems and applications demands for communication. Some requires high bandwidth, others only limited. It should also be easy to swap communication channel, redundancy should be identified and tested. • Commitment: All involved stakeholders • Collaboration: All involved stakeholders • Continuous learning: A map showing coverage should be built. Coverage should then be mapped with bandwidth application demands

5.Hazards for the ship integrity, machinery, systems:	
Examples: 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), Failure of anchoring devices when drifting	
Understand risks	• The risk picture for both own vessel as well as external vessels and terminals to be visited • Machinery automation system control • The fighting technological capacities

	• Emergency procedures and resources
Anticipate/ predict	• Data in real time from sensors at the vessel • Machinery automation system condition • Predictive actions defined
Absorb/ withstand	• Automatic identify deviations, and activate alarm system • Adequate control actions defined • A clear maintenance program in place
Respond/ recover	• Redundant systems, automatic activate means to safe recover • Procedures for handover of control • Emergency or evacuation procedures • Call for assistance, resources and supervision
Adapt/ learn	• Debrief of involved stakeholders • Update technology, procedures, and regulations, dynamically updates of training program for handling hazards and events, regularly learning of digital developments and related management requirements
IPA	• *Competence*: Understand vessels capacities and limitations, and how to recover from a top event. • *Commitment*: To external service providers located close to operation, that can assist in case of accidents. • *Collaboration*: Between authorities, ROC, external providers, and with external traffic. • *Continuous learning*: Training of accidents should be done regularly, also involving externals

6.Hazards for the cargo and passenger management:

Examples*:* Overload of cargo or passengers aboard, Loss of intact stability due to shift and/or liquefaction of cargo or due to cargo overboard, Passenger overboard, illness, injured during arrival or departure, Passenger interfering in an aboard system

Understand risks	• Loading and unloading operations • Risk of passengers having unwanted tensions • Operational limitations • ROC manned with qualified, certified and medically fit personnel • Emergency means and procedures
Anticipate/ predict	• Data in real time from vessel sensors • Cargo management automation system for monitoring cargo • Passenger management system to prevent overload or injury • Simulations, sensors measuring values and deviations
Absorb/ withstand	• Build barriers to avoid unwanted loads or injuries • Requirements and procedures for direct and remote control (incl. automated information to ROC for identifying operational abnormalities, threats and errors)
Respond/ recover	• Alarm system to issue warning or alert (automatically and manually by emergency push button) • Monitoring of vessel functionality status (e.g. temperature, pressure, gas, water incoming) • Means for automatically control (e.g. heating, cooling, ventilation or pumping) • Support or rescue from ROC or other external resources (e.g. information display/dashboard, communication, decision making facilitation)
Adapt/ learn	• Validate management automation systems for control, understand vessel stability calculations • Update risk picture, procedures for warning or alert to crew, operators, and managers • Update means, procedures and standards for monitoring, control and rescue • Simulator training for practising operators and supervisors
IPA	• *Competence*: Understand limitations and follow vessel certificates, including weight, types of cargo, number of passengers, need for external support etc. • *Commitment*: Understand service providers role and capacities in loading and unloading. • Collaboration: ROC-MASS, ROC-terminal service providers, ROC-passengers, ROC-ICT • Continuous learning: Passenger behaviours, as well as experiences in cargo management.

7.Hazards for the remote control

Examples*:* Unavailability of RCC (fire, environmental phenomenon...) or of operators (faintness, emergency, etc.), Human error in remote monitoring and control (e.g. situation unawareness, data misinterpretation, RCC capacity overload), Human error in remote maintenance

Understand risks	• ROC capacities • Operational envelopes with deadlines for manning and to take control

Anticipate/ predict	• Information dashboard for supervising/ control • Redundance of manning capacity • Procedures for collaboration between ROCs • Simulations of situation and calculation of consequences
Absorb/ withstand	• Barriers to avoid errors or reduce consequences • Hand-over to another ROC in case mother ROC is not capable of following the operation
Respond/ recover	• Communicate regular status to involved vessels, personnel, external resources for support/ rescue • Call another ROCs • Facilitate support to vessels and rescue resources • Activate fail-safe sequences for operation control
Adapt/ learn	• Update requirements and procedures for operations and support • Simulator training for practising operators and supervisors • Validate and update hand-over processes, time windows for actions or fail-safe sequences
IPA	• *Competence*: From a ROC perspective it will be important to understand risks also when operating remotely. Som perceptions cannot be directly addressed to an operator, such as weather. To build awareness of the possible factors, competence must include more than only navigational. • *Commitment*: Hand-over processes between ROC-MASS/ICT. • *Collaboration*: Building trust between ROC-MASS and with other traffic/service providers. • *Continuous learning*: Latency in communication is a high relevance factor. In case of received data with high latency, a ROC operator must do executional commands based on old data (i.e. data detected a minute ago and not in real time). Must be trained for.

8.Hazards for the security

Examples: Wilful 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. pirate/ terrorist attack), Failure in data confidentiality (e.g. data interception by unauthorized 3rd party), Cyber virus spread from port facilities

Understand risks	• Cyber risks, operational risks • Capacities and build barriers
Anticipate/ predict	• Monitoring communication link to ROC • Situational awareness from sensors and by observations from internal and external sources • Join networks that predict risk
Absorb/ withstand	• Build barriers and redundance to avoid threats and attacks (e.g. back-up systems) • Monitoring communication link • Automated call for external assistance
Respond/ recover	• Launch safety systems (e.g. initiate fail-safe sequences, warning and alarms) • Manually or automated control of operation (e.g. communication link, alert and alarm system) • Identify, inform and collaborate with emergency assistance resources • Inform relevant search and rescue authorities
Adapt/ learn	• Validate and update security procedures and how to recover from attacks, and update requirements and regulations • Update training materials and methods
IPA	• *Competence*: Technical competence on detecting cyber-attacks. Competence on how to withstand and to enter a safe mode. Competence on external threats, as well as how to combat them. • *Commitment*: To external service providers helping to build fire walls and to avoid attacks. Avoid using high-risk data and networks. • *Collaboration*: With government and service providers that can assist in case of attacks. • *Continuous learning*: Understand the geo-risk picture and the consequences of being attacks, and train how to recover or go to safe mode.

9.Natural disasters (suggested by the authors):

Examples: Extreme weather, Slides, flooding etc.

Understand risks	• Natural disaster risks • Local community and national vulnerability

	• Mapping of resources and responsibilities
Anticipate/ predict	• Monitoring and observations of geographical and environmental state
Absorb/ withstand	• Automated alert and call for local, regional, and national external assistance
Respond/ recover	• Identify, inform and collaborate with emergency assistance resources • Inform authorities
Adapt/ learn	• Validate and update procedures, requirements and regulations • Update training
IPA	• Competence: Knowledge of potential natural disasters in the specific geographical area. • Commitment: Plans and procedures for emergency operations and responsibilities. • Collaboration: All involved stakeholders, emergency resources, in addition to local, regional and national/international authorities. • Continuous learning: Local, regional and national/international requirements and procedures, in addition to simulations and training

5. Discussion

In this paper we have described the process of building resilience into a MTS. We have used a list of hazards defined by Bureau Veritas (2019) and have added the 4C's as a holistic, cross-domain planning framework for enabling optimal, safe and efficient MASS operation reflecting upon the hazards groups (IPA). We have further used the resilient curve in five functional phases. All this to emphasise that it is necessary to involve expertise with relevant competence and professional knowledge to consider potential risk conditions and identify the most critical or significant ones regards MASS operation. By doing this exercise we have identified the importance of strengthening the planning focuses at the different planning levels; Strategic and operational. The planning should consider known threats, but also prepare for the unknown by familiarisation of the IPA and the resilience curve. We know that new types of threats and risk will occur because of autonomy, but we should have a recovery plan in place where possible. We have highlighted the need for coordination, as well as the need for integration between stakeholders, ICT, and humans in charge of operation. We have further emphasised that resilience planning must be included at all planning levels, where the humans and the ICT are closely integrated to achieve a resilient MTS. Resilience planning is important for a successful implementation of a MTS.

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