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How to facilitate resilient operations when advances in automation continue to lead the maritime industry into uncharted waters?

Kay Fjørtoft, Even Holte, SINTEF Ocean

Maritime Resilience Management of an Integrated Transport System (MARMAN)

- The **vision** of the project is "*to enable resilient, safe and efficient planning, management and operations of an automated integrated transport system in a complex future*".
- The **overall objective** is to "*develop a resilience-based knowledge foundation for governance, management and work practice ensuring a safe and secure integrated Maritime Transport Systems (MTS) when implementing connected and automated vessels (CAV)*".

Managing the integrated maritime transport system

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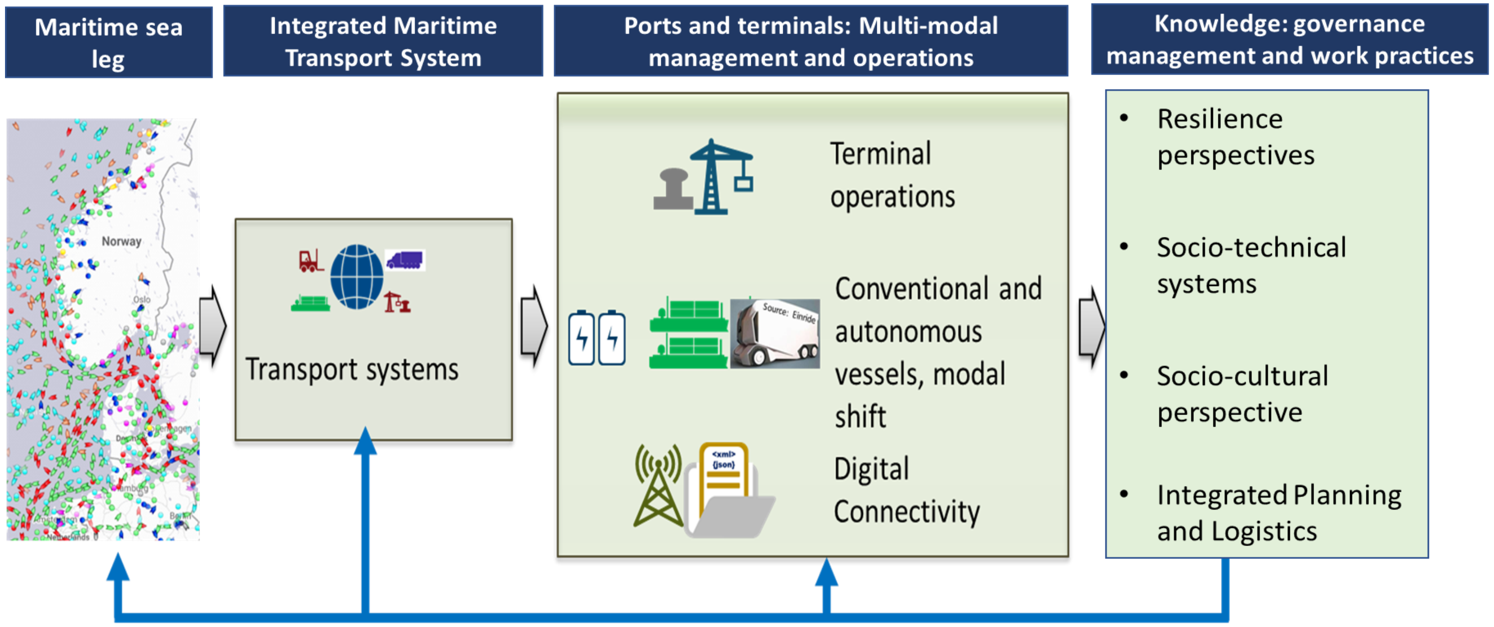
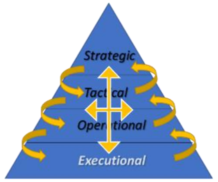


- New vulnerabilities, brittleness?
  - Management and operational practices
- Socio-technical system
  - vessels, ports, terminals, control centre operators
- New competence needs
  - Regulatory
  - Managerial
  - Operational
- More complex, interconnected, automated

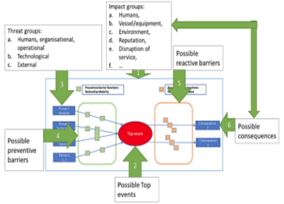
Main work approach

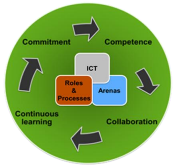
State of the Art → Main Achievements → Novel and ambitious aspects

The integrated Maritime Transport System



State-of-the-art knowledge	Main advancements	Novel or ambitious aspects
	The Integrated maritime transport system	
• Limited coordination and collaboration sea – land • RE is not part of planning practices • Lack of planning competence supporting intermodal transport • Lack of integration between strategic, tactic and operational planning	**Theoretical:** Use perspectives on integrated planning and resilience in implementation of more automated transport **Methodological**: Integrating IPL model with RE perspectives in models for management of automated shipping in MTS **Competence:** Combining RE, IPL and knowledge on management at different levels **Empirical:** Holistic data collection for integrated transport system management	**Integrated planning facilitated by:** • New methods supporting resilient and efficient planning of MTS operations. • New knowledge on risk management within an integrated maritime transport system





Linking work packages and publications

The integrated maritime transport system		
2024	Ramstad, Lone Sletbakk; Stene, Trine Marie; Fjørtoft, Kay Endre; Holte, Even Ambros	Automation in the Maritime Transport System – A Framework for Planning Resilient Operations Journal of Physics: Conference Series (JPCS) 2867 2024 1/012033
2024	Mørkrid, Odd Erik; Fjørtoft, Kay Endre; Hagaseth, Marianne; Holte, Even Ambros	Assessment of resilience in a maritime autonomous transport system
2023	Fjørtoft, Kay Endre; Holte, Even Ambros; Stene, Trine Marie; Ramstad, Lone Sletbakk	Integrated Planning for safe and efficient maritime autonomous transport operations
2023	Stene, Trine Marie; Fjørtoft, Kay Endre; Ramstad, Lone Sletbakk	Successful autonomous transport – The need for coordination and integration of strategical and operational management
2022	Fjørtoft, Kay Endre; Holte, Even Ambros	Implementing operational envelopes for improved resilience of autonomous maritime transport
2022	Stene, Trine Marie; Fjørtoft, Kay Endre; Holte, Even Ambros	Future Maritime Transport Systems and Integrated Planning

Ports and terminals: Onshore management practices		
2025	Stene, Trine Marie; Ramstad, Lone Sletbakk	Knowledge Strategies Facilitating Future Port Development and Management. ECKM, European Conference on Knowledge Management, Finland, 4-5 September 2025
2025	Braga, Fjørtoft	ICMASS: MASS Operation in port calls
2023	Stene, Trine Marie; Fjørtoft, Kay Endre; Ramstad, Lone Sletbakk	Successful autonomous transport – The need for coordination and integration of strategical and operational management.
2023	Fjørtoft, Kay Endre; Parvasi, Seyed Parsa; Nesheim, Dag Atle; Wennersberg, Lars Andreas Lien; Mørkrid, Odd Erik; Psaraftis, Harilaos	Assessing the resilience of sustainable autonomous shipping: New methodology, challenges and opportunities
2022	Stene, Trine Marie; Kongsvik, Trond	The Relevance of Resilience Engineering and Community Resilience for Future Maritime Transport Systems

Across sectors and countries		
2024	Ramstad, Lone Sletbakk; Stene, Trine Marie; Fjørtoft, Kay Endre; Holte, Even Ambros	Automation in the Maritime Transport System – A Framework for Planning Resilient Operations Journal of Physics: Conference Series (JPCS) 2867 2024 1/012033
2025	Stene, Trine Marie; Ramstad, Lone Sletbakk	Knowledge Strategies Facilitating Future Port Development and Management , ECKM

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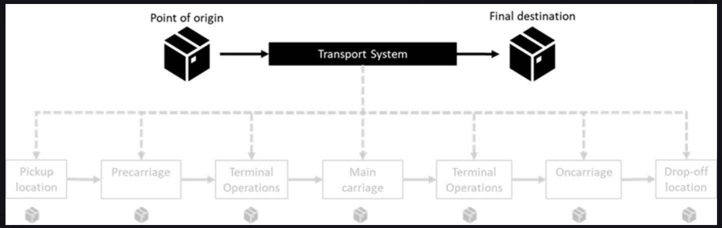
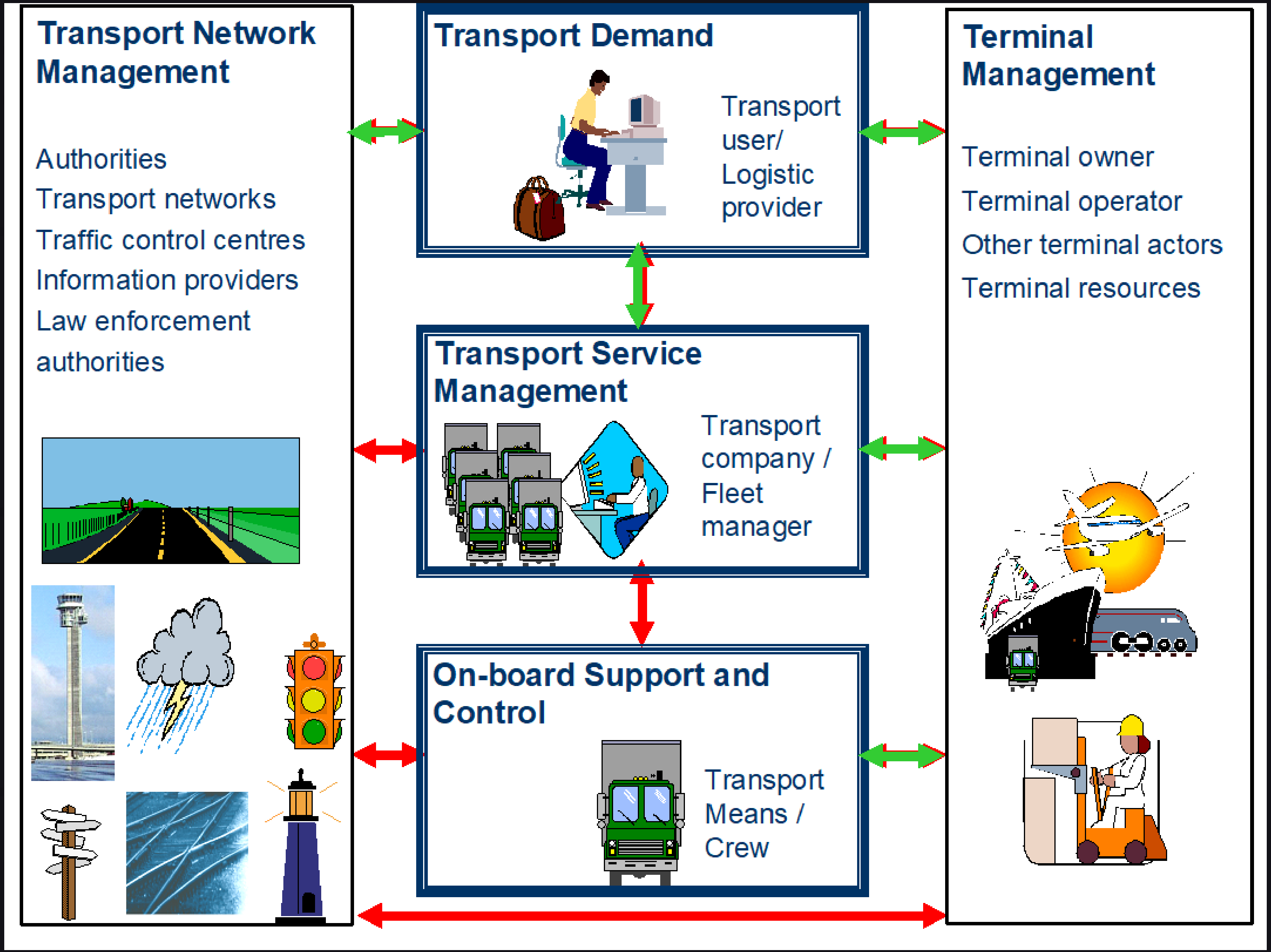
75 år


Point of origin
Final destination
Transport System
Pickup location
Precarriage
Terminal Operations
Main carriage
Terminal Operations
Oncarriage
Drop-off location


Transport Network Management
Authorities
Transport networks
Traffic control centres
Information providers
Law enforcement authorities
Transport Demand
Transport user/ Logistic provider
Transport Service Management
Transport company / Fleet manager
On-board Support and Control
Transport Means / Crew
Terminal Management
Terminal owner
Terminal operator
Other terminal actors
Terminal resources

The «BIG» technological transport picture

- Remote Operation Centre
- Traffic Control Centre
- Situational Awareness Centre
- Remote Support Centre
- Emergency Centre

- Autopilot - Maintains heading, altitude, speed
- Flight Management System (FMS)
- Traffic Collision Avoidance System
- Fully automated landing under pilot supervision
- Automation in ground services
- Drones and situational awareness
- Remote tower operation

Autonomous Solution	Function	Example
Autonomous ships (USVs)	Fully unmanned navigation	Yara Birkeland, SEA-KIT
Autonomous ferries	Self-routing & docking	Finferries Falco
Collision avoidance AI	Applies COLREGs autonomously	Commercial vessel trials, Bastøferga
Autonomous docking	Automated berthing	ABB, Wärtsilä systems
Autonomous tugs	Towage & port work	Keppel Marine trials
Offshore autonomous vessels	Survey, inspection	USV fleets, Reach
Port autonomy	Smart vessel/yard coordination	Global smart-port pilots
Autonomous SAR craft	Search/rescue missions	Specialized USVs

- Fully Autonomous Ships
- Autonomous Navigation & Collision Avoidance Systems
- Autonomous Tugs and Workboats
- Autonomous Offshore & Inspection Vessels
- Autonomous Port Operations
- Autonomous Search & Rescue (SAR) Vehicles

- Cruise control, Adaptive cruise control, Lane keeping
- Blind spot monitoring
- Parking sensors
- Traffic sign recognition
- Hill-start assist
- Autonomous driving systems
- Platooning
- Road maintenace

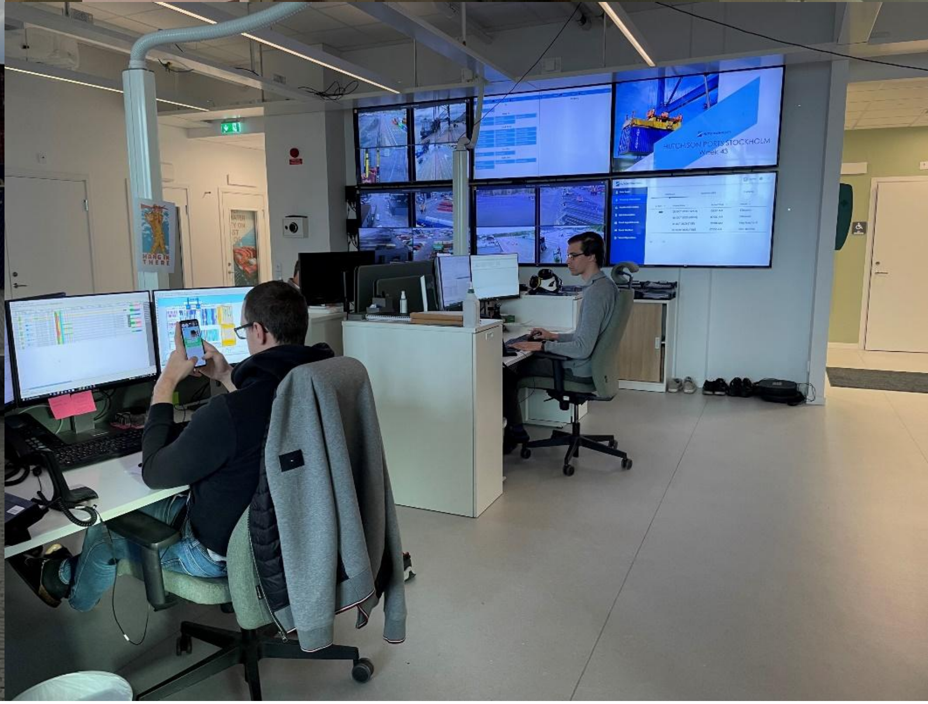
- Autonomous Ship Docking
- Autonomous Harbour Patrol & Security Vessels
- Autonomous Port Logistics Management, gates & customs handlling

- Fully driverless train operations
- Automatic Train Operation (ATO) with Real-Time Decision Making
- Autonomous Track Inspection Vehicles / Robots
- Autonomous Yard Operations
- Autonomous Passenger Flow and Platform Management
- Predictive and Autonomous Maintenance Systems


MAERSK
MAERSK
MAERSK
EVERGREEN
MAXIMUM OCCUPANTS
RCQC 0
40'
20'
20'
40'
45'


EVERGREEN
EVERGREEN
EVERGREEN


HUTCHISON PORTS
STOCKHOLM



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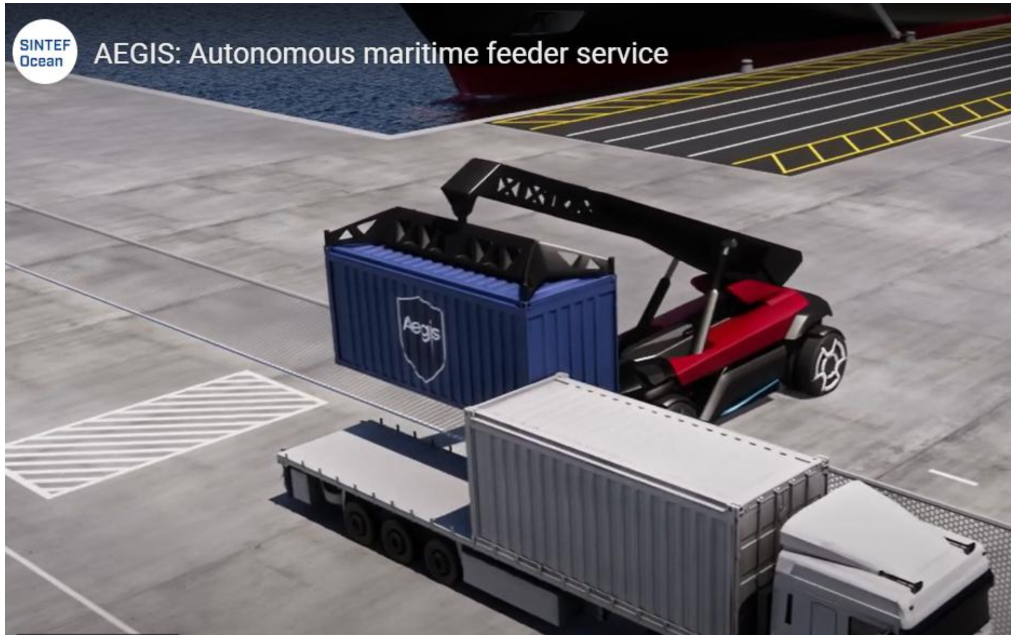
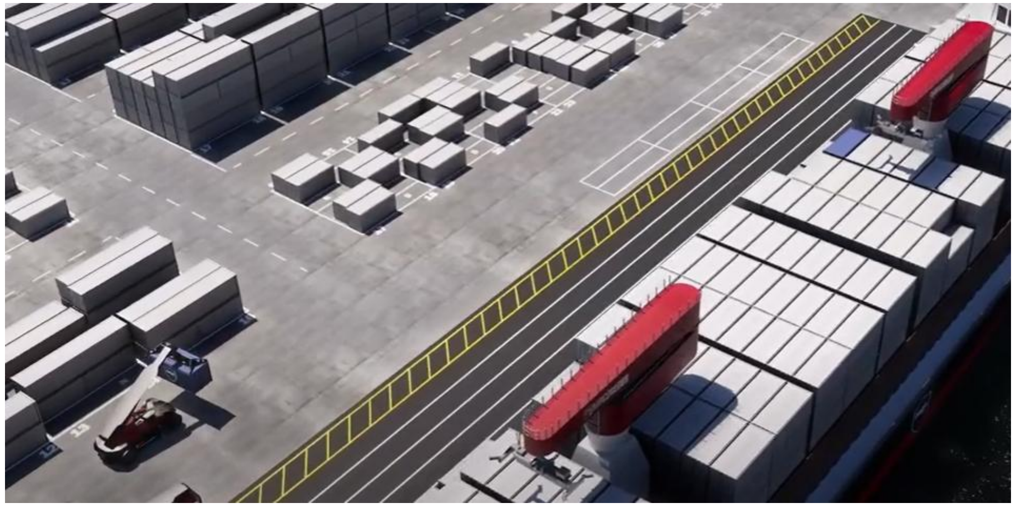
Why Maritime Autonomy Matters

- ## Increased Safety: Most maritime accidents are caused by human error.
  - Autonomous systems can:
    - monitor sensor data continuously
    - react faster and more consistently than humans
    - operate in hazardous environments (storms, ice, darkness)
    - operate 24/7 without fatigue or breaks
    - Access to Dangerous or Hard-to-Reach Areas
- ## Reduced Operational Costs
  - Fewer crew members → lower labor and operational expenses. ROC operation.
  - More efficient route planning and fuel use through optimized navigation. JIT Sailing.
  - Smaller or no accommodation spaces required (especially offshore).
- ## Environmental Benefits
  - Precise operations reduce emissions.
  - Supports greener logistics and better resource efficiency.
- ## Technological Progress and Competitive Advantage
  - Advances in AI, sensors, and digitalization make autonomy increasingly viable.
  - Nations and companies leading in autonomy gain an edge in the future maritime market.
- ## More Efficient Logistics
  - Small autonomous vessels can be used in urban waterways and short-sea shipping.
  - Autonomous barges and port operations enable Just-In-Time logistics.
  - Easier integration with drones and autonomous land-based transport.





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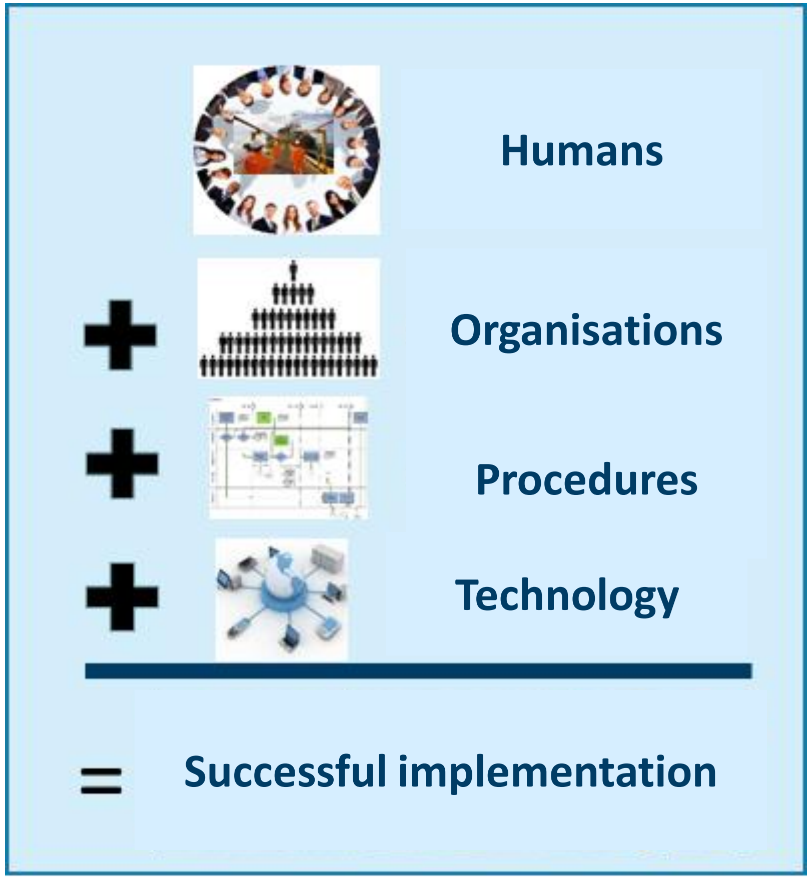
Key Risks Introduced by Autonomy

- System Failures & Technical Malfunctions
  - Autonomous solutions rely heavily on: sensors, cameras, GPS, algorithms
    If any of these fail, it leads to incorrect decisions or lose situational awareness.
- Cyber security Threats
  - Hacking, spoofing (false GPS signals), data manipulation
- Reduced Human Oversight
  - With fewer or no humans: unexpected hazards may go undetected
  - Small anomalies may not be noticed until they grow into major problems
  - Humans are often better at interpreting ambiguous situations.
- Complex Decision-Making in Edge Cases
  - AI systems may struggle with: unusual weather, uncharted obstacles, unpredictable traffic situations
  - They may not handle rare scenarios as well as an experienced mariner or operator.
- Regulatory and Legal Uncertainty
  - Autonomous regulations is not in place: maritime law, collision regulations (COLREGs), liability frameworks
  - It is not always clear who is responsible when something goes wrong.
  - Acceptance & Trust Issues
- Connectivity Dependence
  - Loss of communication links can limit control. Remote control or operation.
- Geographical Risks
  - Systems are tailored to operate in a defined district/area



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Operational Measures for Resilient Autonomous Transport

- **Continuous Monitoring:** Real-time system health, predictive maintenance, fault alerts.
- **Robust Remote Operations:** Redundant control centers, human-on-the-loop, standardized comms.
- **Safe Operating Procedures:** Fallback modes, emergency stop, geo-fencing, go/no-go criteria.
- **Secure Communications:** Encrypted channels, anti-spoofing, anti-jamming, security updates.
- **Maritime Traffic Integration:** COLREGs compliance, port/VTS coordination, dynamic routing.
- **Environmental Adaptation:** Adjust to weather, waves, sensor degradation, real-time risk models.
- **Training & Human Competence:** Simulator training, handover protocols, incident-recovery drills.
- **Documentation & Learning:** Full logging, audits, post-operation review, continuous improvement.

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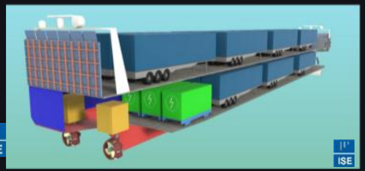


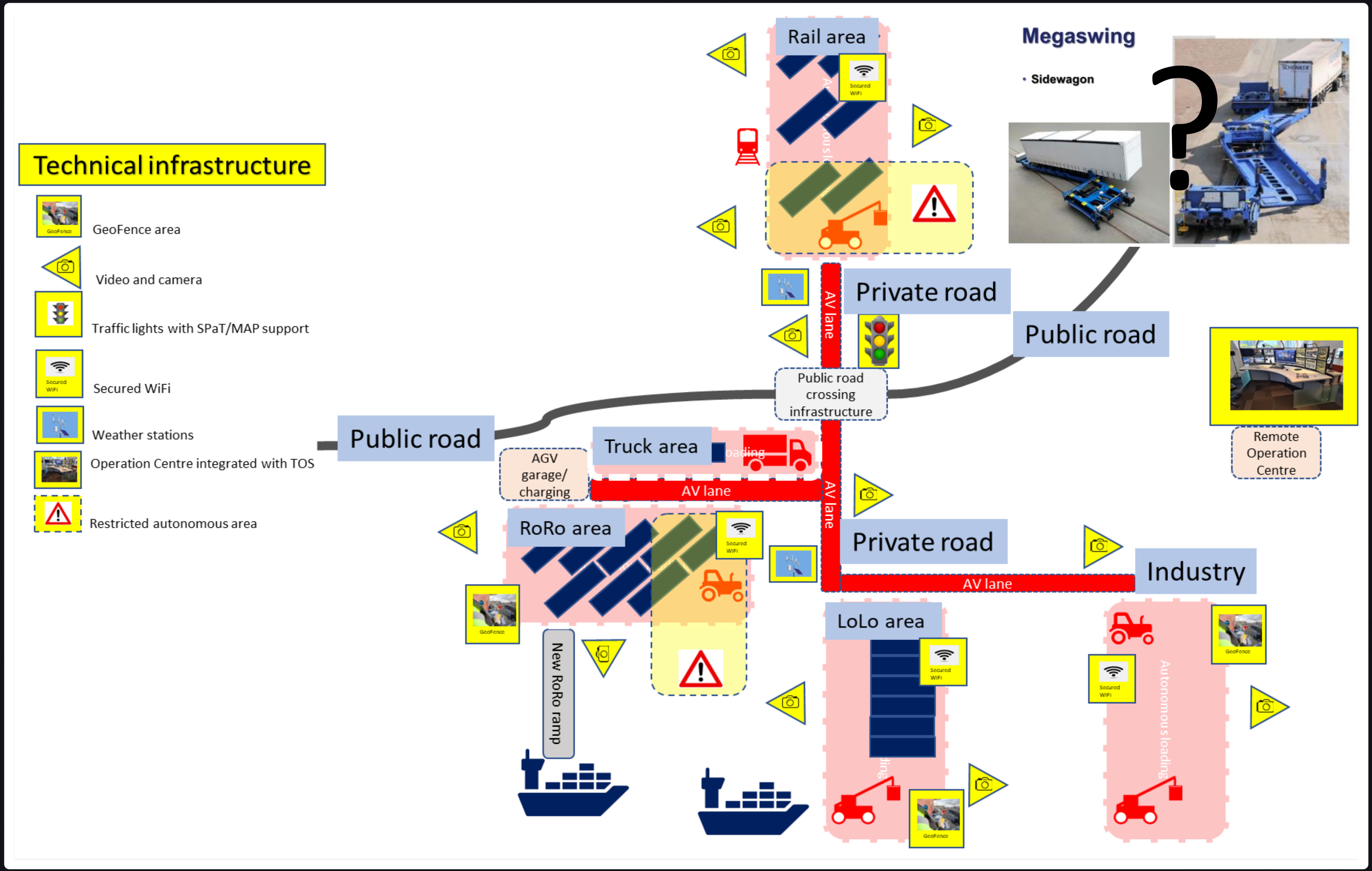
Humans

+ Organisations

+ Procedures

+ Technology

= Successful implementation



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Selected achievements

- Operational envelope to assign responsibilities
- MASS Operations in port calls
- Integrated Planning for Autonomous transport operations (IPA)
- Detection and mitigation of autonomous risk

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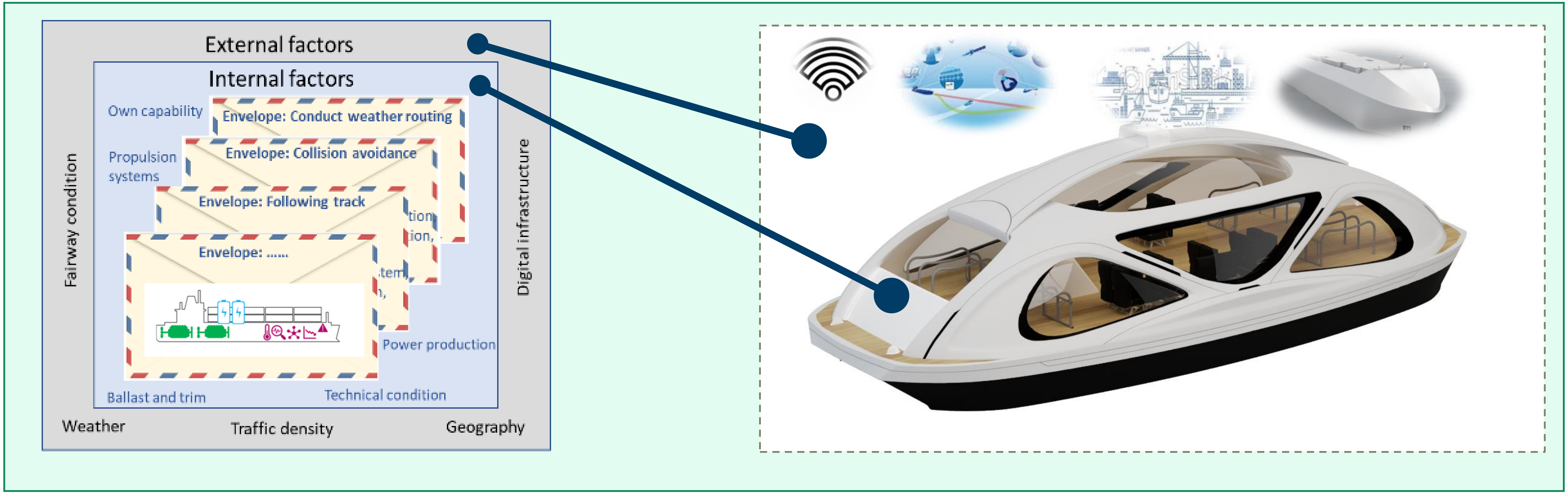
Operational envelope to assign responsibilities

- For designing the human-automation interface and for testing and approval of the automation systems. There can be several envelopes that together play a role in an operation.
  - The Handover between automation and human becomes critical



Time constraints - Handover between automation and human

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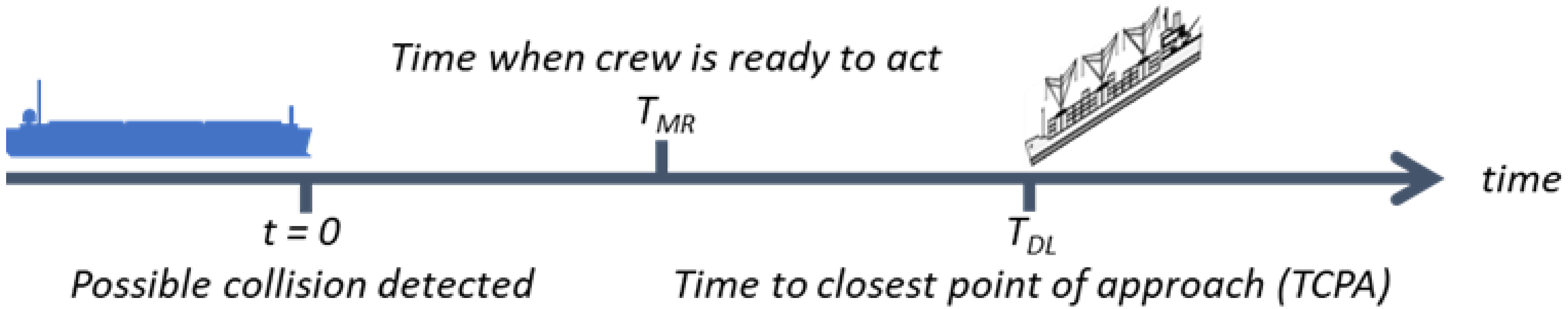
- T_{MR}: **maximum response time.** The time interval from when the automation warns about the need for human assistance to the human operator is able to give the correct response
- T_{DL}: **response deadline.** This is the worst case, i.e. potentially shortest time from a potential problem is detected by the automation to the automation has to activate a fall-back procedure and enter an MRC (Minimum Risk Condition).



Operator control

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Time parameters

	Description	T_{MR}	T_{DL}
1	**Operator in control**: The operator is directly in control of the ship. Hand-over time is not relevant	0	0
2	**Operator supervision**: Automation is used to assist operator, and operator is overseeing the operation and needs only a short time to gain situational awareness when actions are needed	10 sec	20 sec
3	**Operator at site**: An operator is at the control position but is working with other tasks and will need time to gain situational awareness.	120 sec	200 sec
4	**RCC operator**: A remote operator in the ROC is needed to resolve the situation. This could be similar to the ROC operator needs to be mobilised from other tasks.	120 sec	200 sec
5	**Operator available**: The operator is available, but is in another location, possibly sleeping, and will need several minutes to reach the control position and to regain safe control.	10 min	12 min
6	**No operator**: There is no operator and automation must be able to handle all operations by itself (T_{MR} is the duration of the operation or the voyage).	NN	NN

Examples only

System ask for human assistance → RCC time to gain awareness → Time to overlap between ICT and humans →

- $T_{MR} > T_{DL}$ → ICT must take control before humans in place
- $T_{MR} < T_{DL}$ → Humans in place and take control

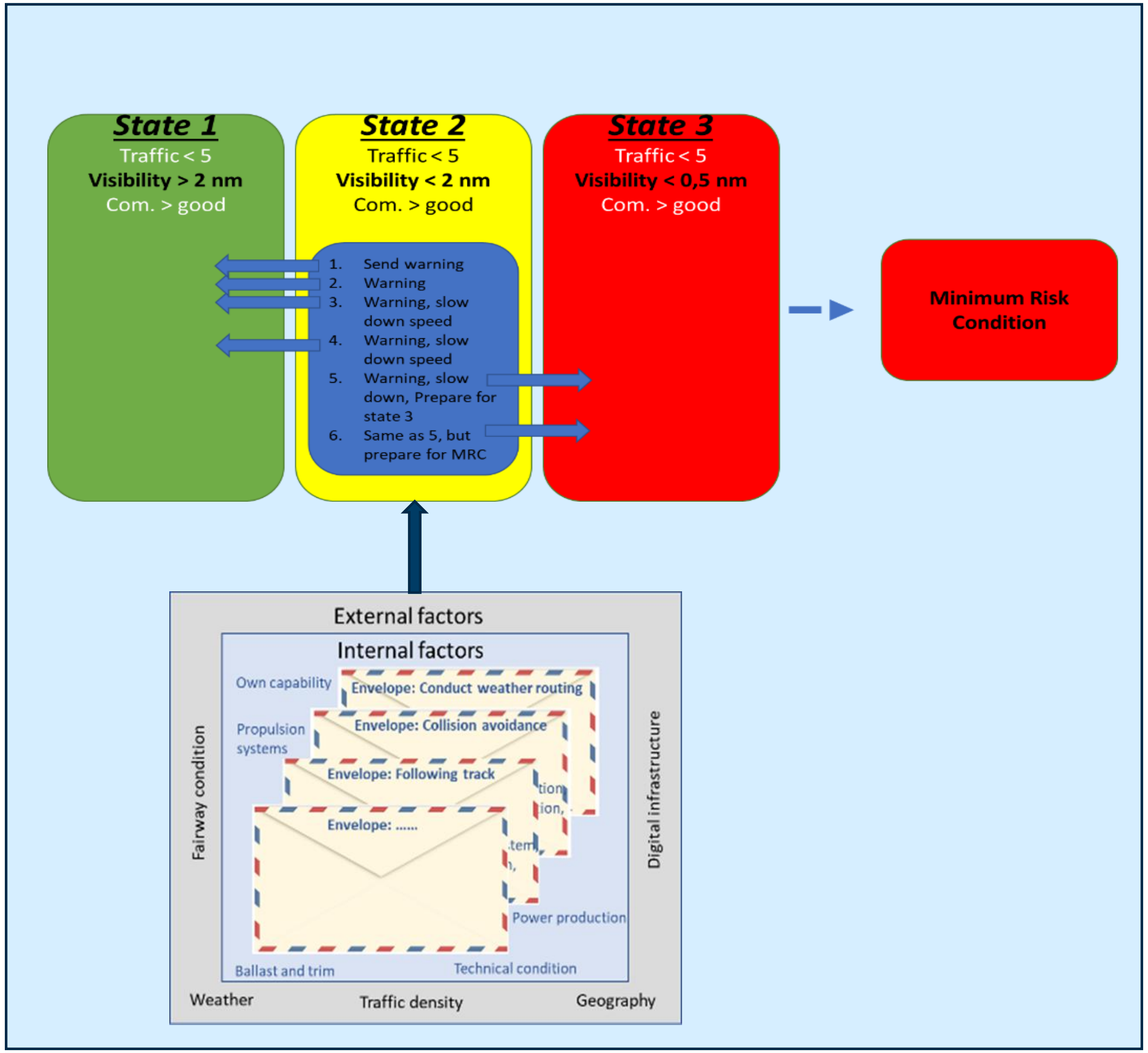
→ MRC/Fall back?

Time →

The time parameters must be design out of the operational envelope, with the time parameters following the specific operations

Operational Envelope: Following track

- New sub-envelopes to be introduced in the different states
- Must determine critical human response requirements
- Must determine critical technology
- Must determine critical operational factors



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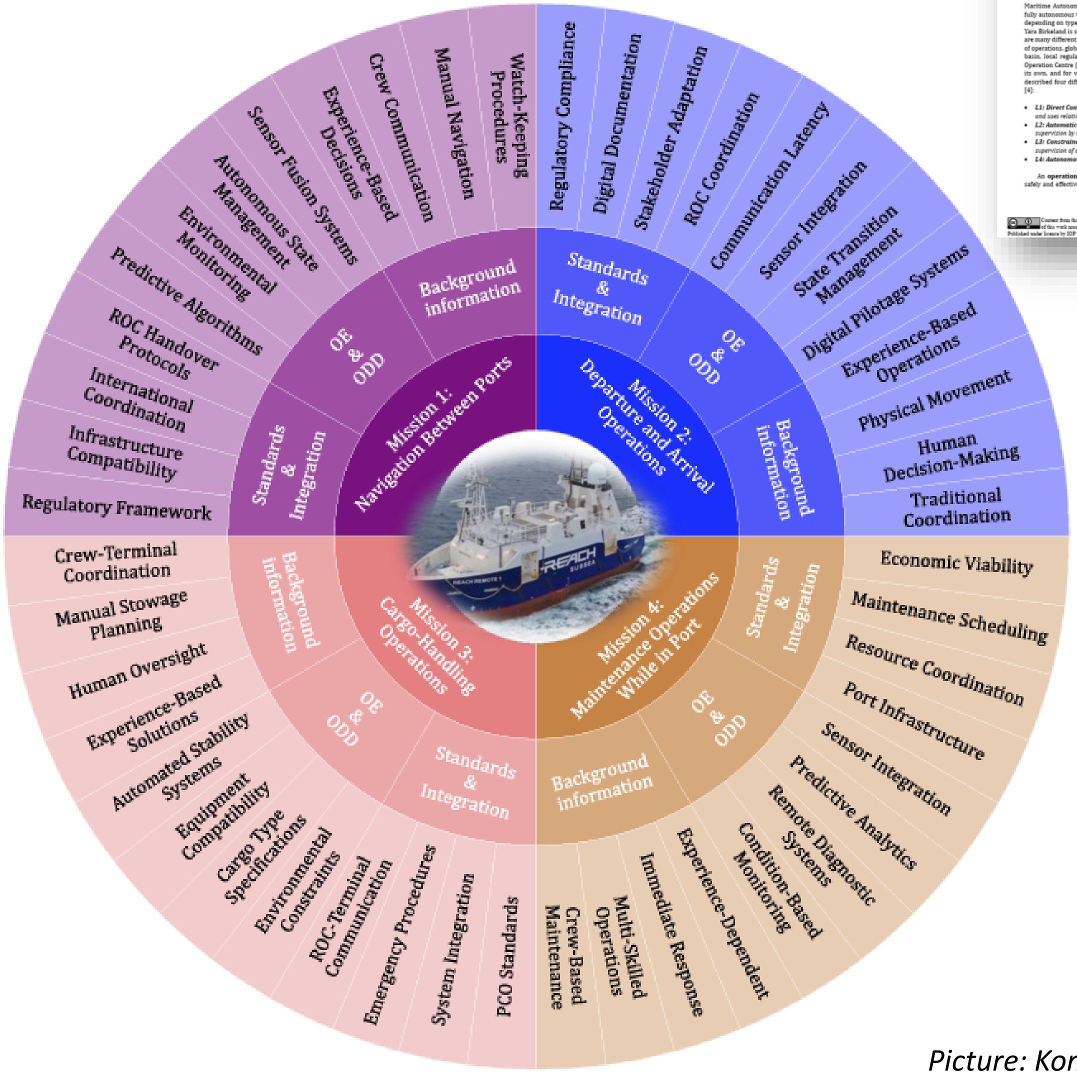
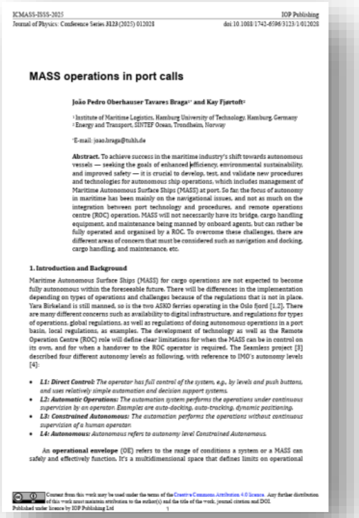
MASS Operations in port calls

- ICMASS-25: MASS Operations in port calls
- Compared conventional with autonomous operation
  - M1: Navigation between ports
  - M2: Departure and arrival
  - M3: Cargo handling
  - M4: Maintenance
- Standards and integration
- OE&ODD
- Background Information





Picture: Kongsberg Maritime

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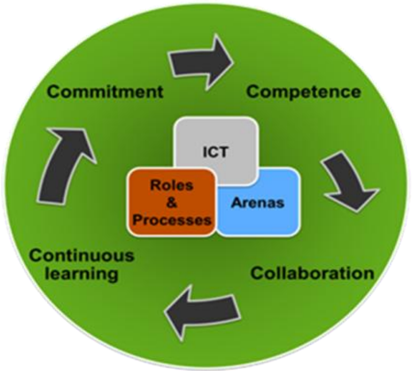
Integrated Planning for Autonomous transport operations (IPA)

Integrated Planning (IPL)

- "A holistic, *cross-domain planning* enabling optimal *resource allocation* and actively *prioritization* for safe and efficient operations"
  - Integrating *people*, *work processes* and *technology*
  - Integration different *management levels* (from government to operational practise)

Basic IPL **capabilities**:

1. Human and cultural – 4Cs:
   - Competence
   - Collaboration
   - Commitment
   - Continuous learning
2. Enabling (structural factors): ICT, Arenas, Roles and processes



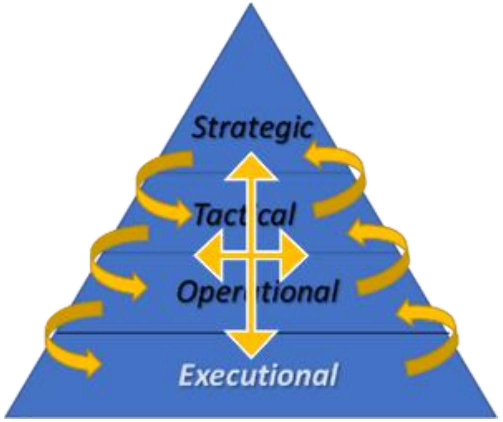
IPL for Autonomous transport (IPA)

Resilience – Gap between

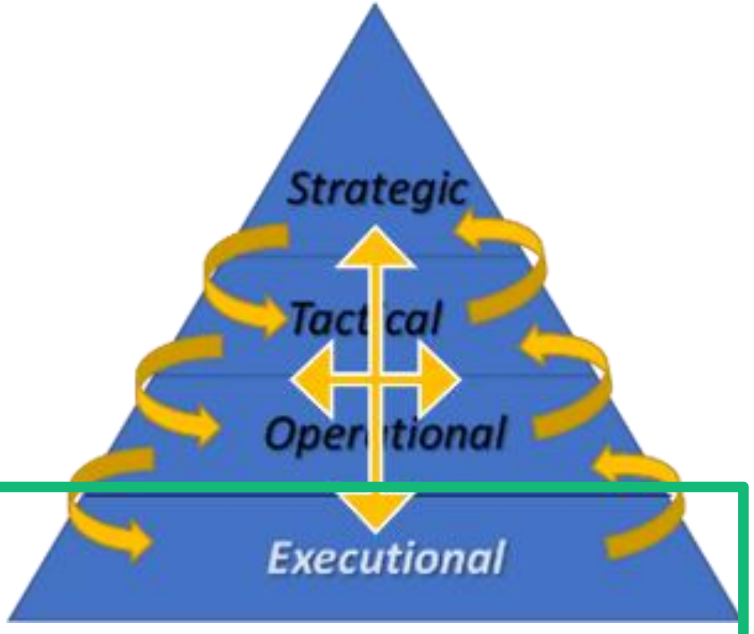
- *Work-as-imagined* (WAI) Strategical and tactical levels
- *Work-as-actually-Done* (WAD) Operational and executional level

Need for coordination between WAI and WAD **stakeholders** (responsible for manually and automated operations):

- Authority
- Regulator
- Strategical planning manager
- Traffic management
- Network manager
- Emergency manager



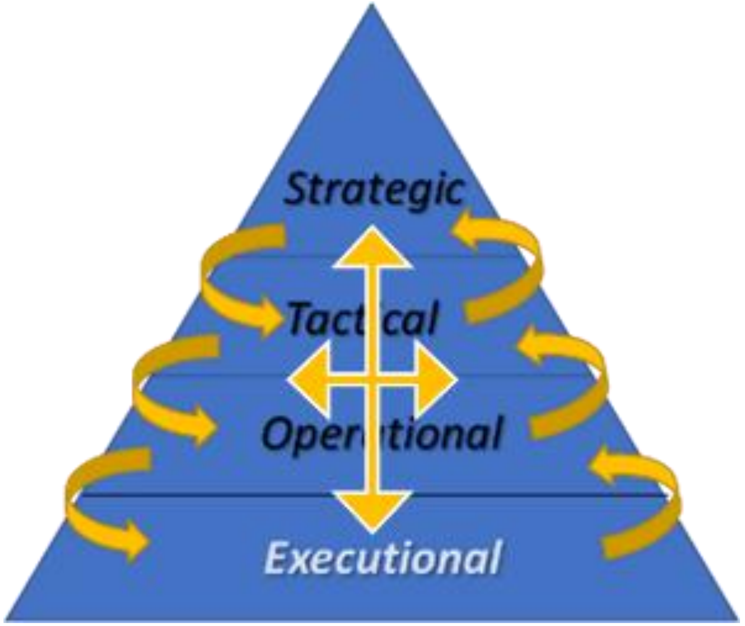
Integrated Planning for Autonomous Operations (IPA)

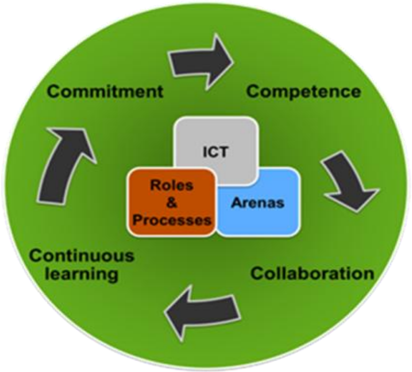


Dynamic Planning

Planning level	Definitions
Strategic planning	• Has a long-time perspective. • This is normally CAPEX intensive costs planning. • Typical stakeholders involved in this planning process will be infrastructure owners/managers, strategically planners, transport service providers and owners, regulators and government • Examples of plans that will be of importance for IPA are technological investments, operational management, safety and security, CONOPS (Concept of Operation), risk assessment, resilience, standards, and emergency preparedness.
Tactical planning	• The *tactical planning* has a shorter time-horizon than the strategic. • It includes a more detailing and updated planning quality with reference to strategic plans. • It will also be important to include more human oriented planning, such as training and competence building at this level.
Operational planning	• *Operational planning* has an even shorter time-horizon than tactical. • It is a continuation from tactic planning, but where the planning quality is more accurate with more detailed information and instruction regards operations of means and handling of the cargo to be transported. • For IPA this planning data will be used when designing the operational envelopes. For an autonomous ship system this includes the definition of what conditions the ship can operate, with operational boarder and constraints as examples.
Executional planning	• In an IPA framework a new fourth level is likely to be included, called the *executional planning* level. • The planning focus will be on a short time horizon, more digital driven, where normally real-time data is used for decisions making. • It focuses on technological operations, such as to provide commands/instructions for how the autonomous execution of the technology should be done. • In some cases, the technology is capable to do their own decisions based on sensor data (i.e. traffic, weather, positioning). • The hand-over processes between technology and ROC must be planned for, for example by use of operational envelopes where the state and activity diagrams are designed.

Integrated Planning for Autonomous Operations (IPA)





4C	Competence, Commitment, Collaboration, Continuous learning

AUTONOMY – RESILIENCE

Competence

- Understand limitations and vulnerability

Commitment

- Between traffic centres in case of failures in infrastructure, between ICT and humans

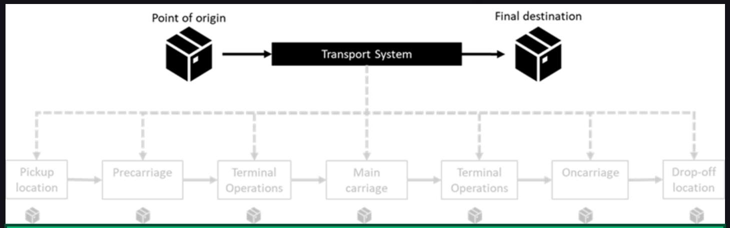
Collaboration

- Between ROC – Terminal – Traffic centres – other traffic
- Between ICT and ROC

Continuous learning

- Understand consequences in degradation of navigation support, and local constraint parametres
- Understand technological self learning – explainable AI

Resiliens



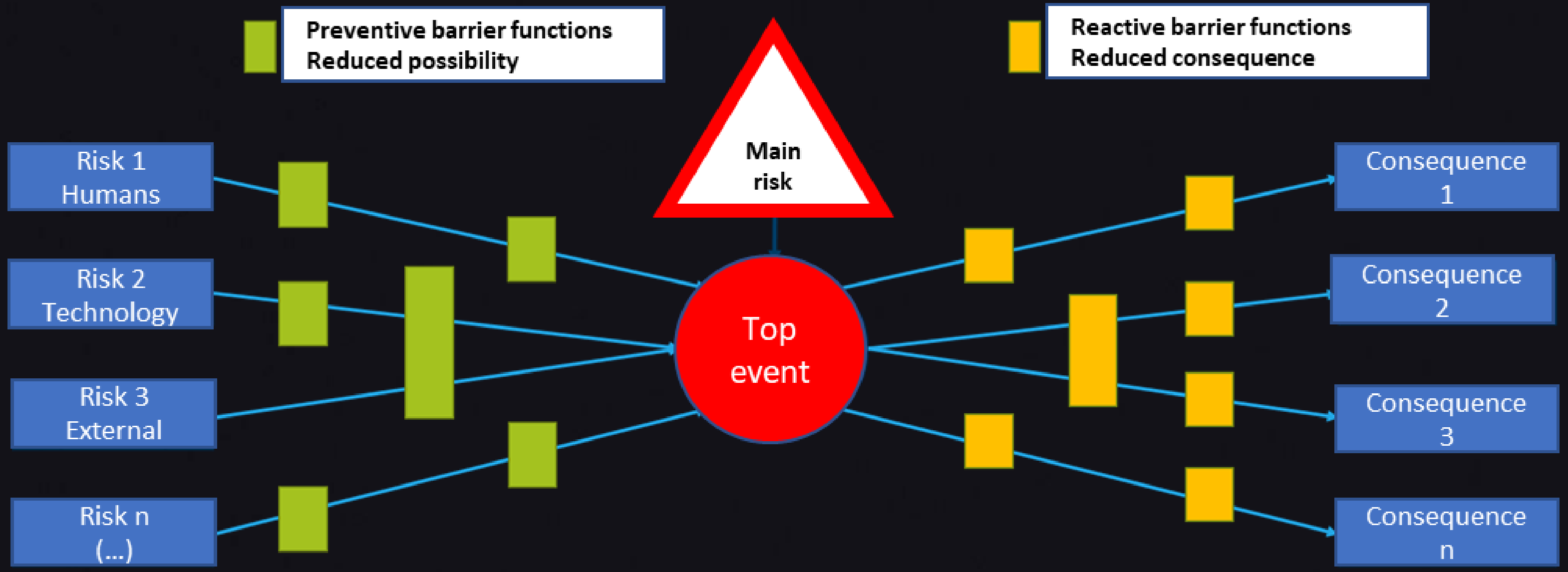
What is required of resilience in the transport system?

The goal is to understand the transport system’s ability to handle disruptions by planning for barriers:

How to avoid disruption?

- Reducing the likelihood of safety- and security-related events
- Reducing the likelihood of operational events, through pre- and reactive barriers

We need safety, security, and resilience.



Detection and mitigation of autonomous risk

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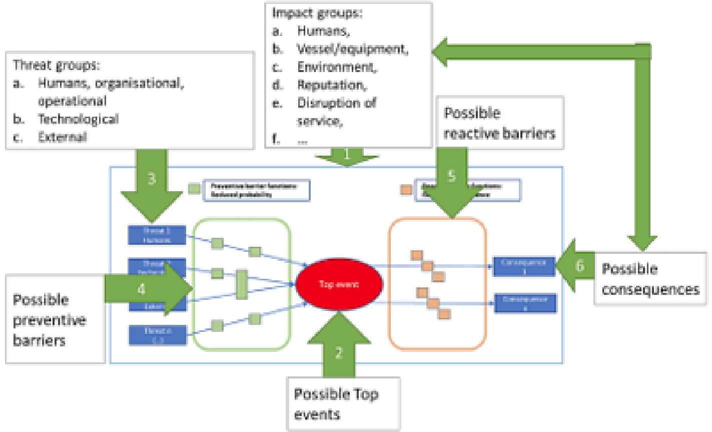
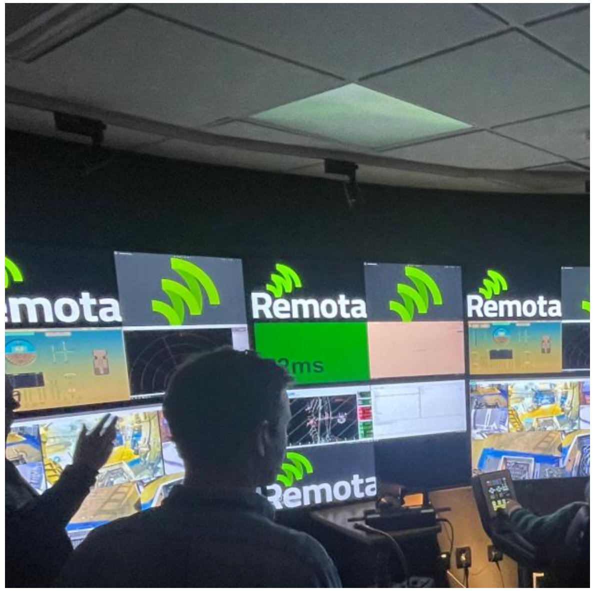


Sources of threats.

#	Sources of threats
Human, organizational, and operational sources of threats	
1	Terminal workers and crew, external service providers, terminal workers, operation centre
2	Collaboration, low planning quality, information exchange between parties/ ICT-systems, procedures
Technological sources of threats	
3	Communication, remote operation, cyber attacks
4	Navigation and steering system, geotagging, geofencing
5	Vessels, Crane, Port equipment and resources
External sources of threats	
6	Weather, Parts of the route is closed (sea-leg, terminal, gate, etc.), tide and low water, strike, etc.
7	Other external factors (e.g., other ship traffic, construction work)



Threats sources passengers, crew, and terminal workers.

#	Threats sources terminal workers and crew, external service providers, operation centre
1	Crew and terminal workers with unforeseen medical needs (cardiac arrest, malaise, seizures, and loss of consciousness, etc.).
2	Crew and terminal with unintentional or erratic behaviour – acting out and/or under the influence of drugs.
3	Crew and terminal workers with inadequate ability to handle.
4	Crew, drivers, and terminal workers in shock and/or with an irrational reaction pattern (e.g., in the event of an accident, stress).
5	Accidents within the transport systems, as example crew falls into the water at the quay side ("Man overboard" observed and not observed).
6	Crushing injuries for crew and terminal workers (especially boarding and alighting).
7	Lack of control over the number of people at the terminal area or on board the loading zone at a vessel.
8	Stress due to low staffing, crews/terminal workers have too many tasks that must be handled in parallel.
9	Lack of control over what crew/workers carry on board which can be threat source.
10	Lack of competence (for example in control centres, medical expertise, technical expertise).
11	Insufficient information for training of operators and crew (vessel, ROC, terminal, drivers, …).
12	Inadequate procedures and liability maps.
13	Use of open fire on board or at the terminal (incl. Smoking).
14	Language problem between the involved stakeholders and workers
15	Lack of procedural understanding in cargo operation
16	Lack of common situational awareness of the operation
17	Poor planning quality or operational knowledge
18	The ability to stop loading or transport operations (access to control/operation system or contact with operational staff)
19	External service providers are not receiving authority to do maintenance work
20	External service providers are not familiar with the safety or operational instructions to perform their work

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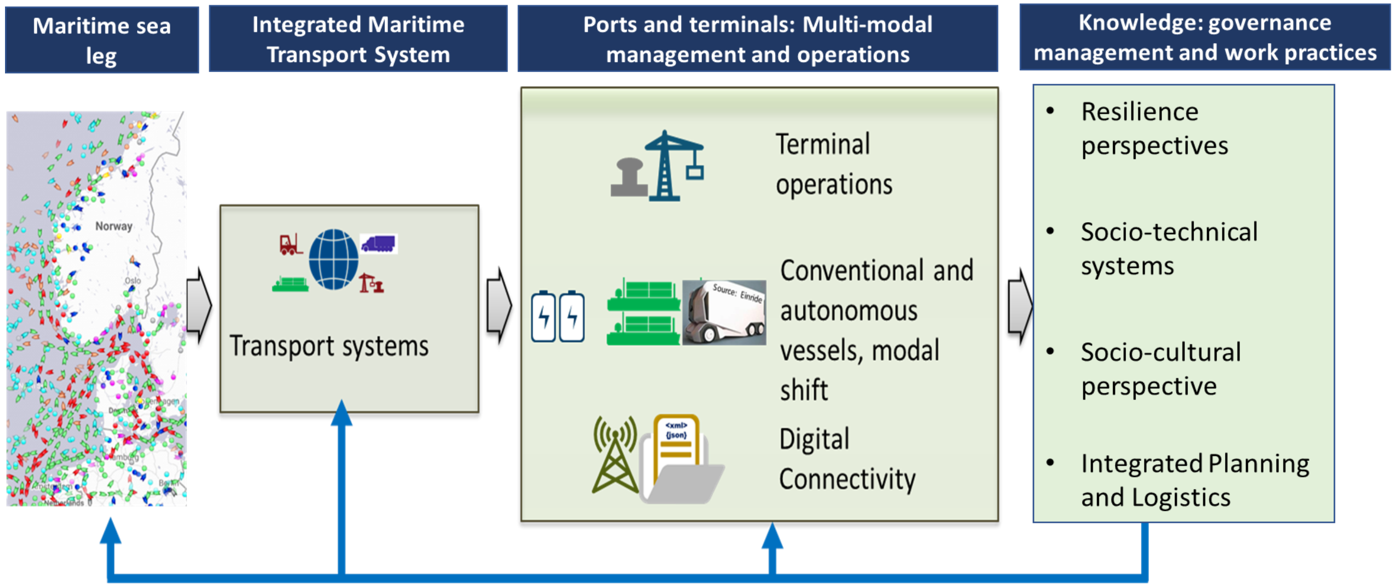
Summary of MARMAN contributions to IMTS

How to facilitate resilient operations when advances in automation continue to lead the maritime industry into uncharted waters?



- New vulnerabilities, brittleness?
  - Management and operational practices

Studies on challenges by introducing autonomy

- Socio-technical system
  - vessels, ports, terminals, control centre operators

Studies on successful implementation

- New competence needs
  - Regulatory
  - Managerial
  - Operational

Studies on IPA and 4C, Human and ICT

- More complex, interconnected, automated

Studies on how to use resilience in IMTS