Resilience – a prerequisite for autonomous shipping?

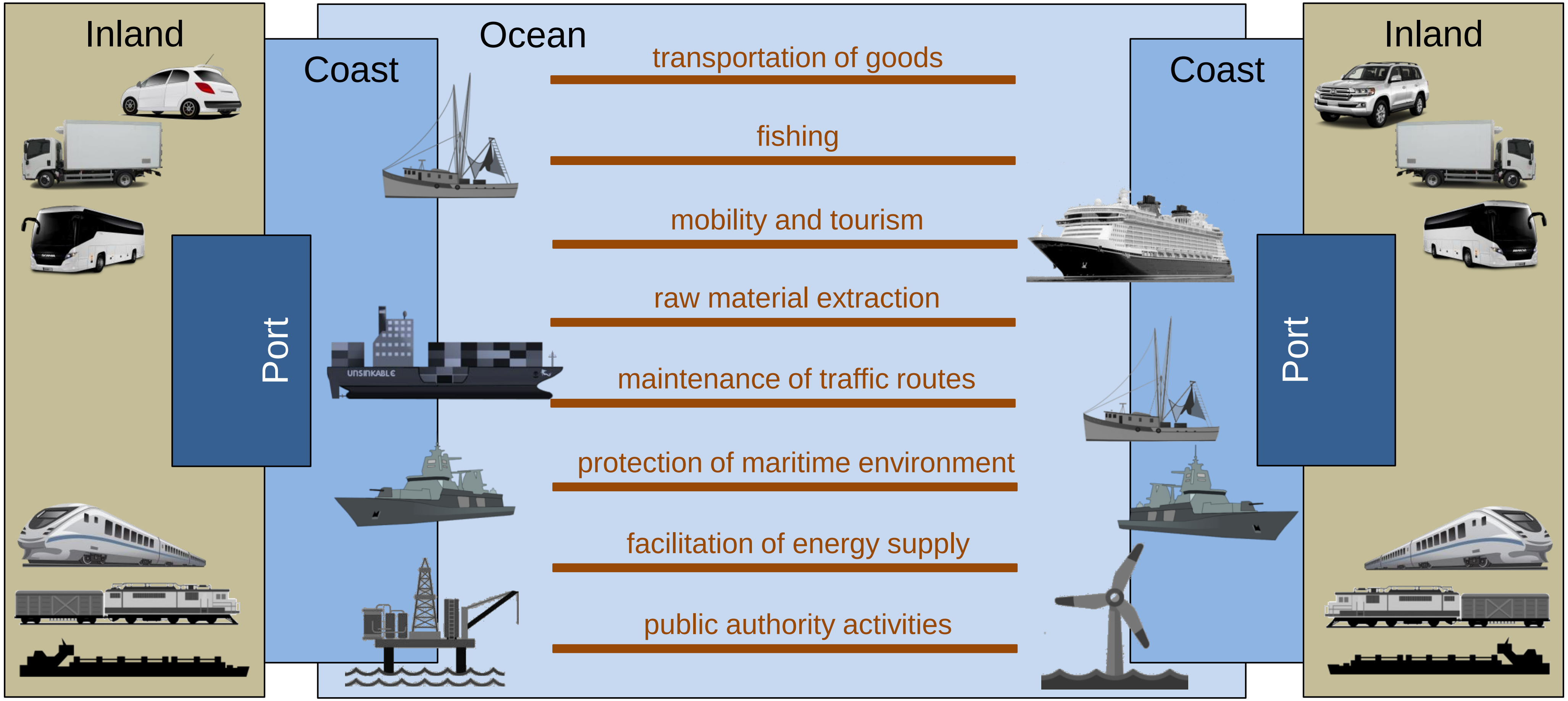
ISIS-MTE Session: Autonomous Ship Technologies

C. P. Wrede
Dr. E. Engler
Dr. D. Göge

DLR

Background

Efficient Operation and Utilization of Shipping



Simplified functional ship model

Efficient and safe operation during ship‘s life-cycle: during voyages and at transshipment points

Cost-efficient performance of shipping (to meet functionality & performance)

Protection of life, goods, and environment (to ensure safety and security)

Power Supply

- ✓ *Power Generation*
- ✓ *Power Distribution*
- ✓ *Automatic Power Supply Systems*

Propulsion and Gears

- ✓ *Propulsion*
- ✓ *Gear*
- ✓ *Main Engine Remote Control*

Navigation

- ✓ *Situation Awareness*
- ✓ *Voyage and Route Planning*
- ✓ *Maneuvering, Monitoring & Control*

Cargo Operation

- ✓ *Cargo Loading/uploading*
- ✓ *Cargo Monitoring*

Communication

- ✓ *Internal/external Exchange of Nautical Data*
- ✓ *AIS, VDES,….*

DLR

Simplified functional ship model

Efficient and safe operation during ship‘s life-cycle: during voyages and at transshipment points

Cost-efficient performance of shipping (to meet functionality & performance)

Protection of life, goods, and environment (to ensure safety and security)

Safety and Security Management

Power Supply

- ✓ *Power Generation*
- ✓ *Power Distribution*
- ✓ *Automatic Power Supply Systems*

Propulsion and Gears

- ✓ *Propulsion*
- ✓ *Gear*
- ✓ *Main Engine Remote Control*

Navigation

- ✓ *Situation Awareness*
- ✓ *Voyage and Route Planning*
- ✓ *Maneuvering, Monitoring & Control*

Communication

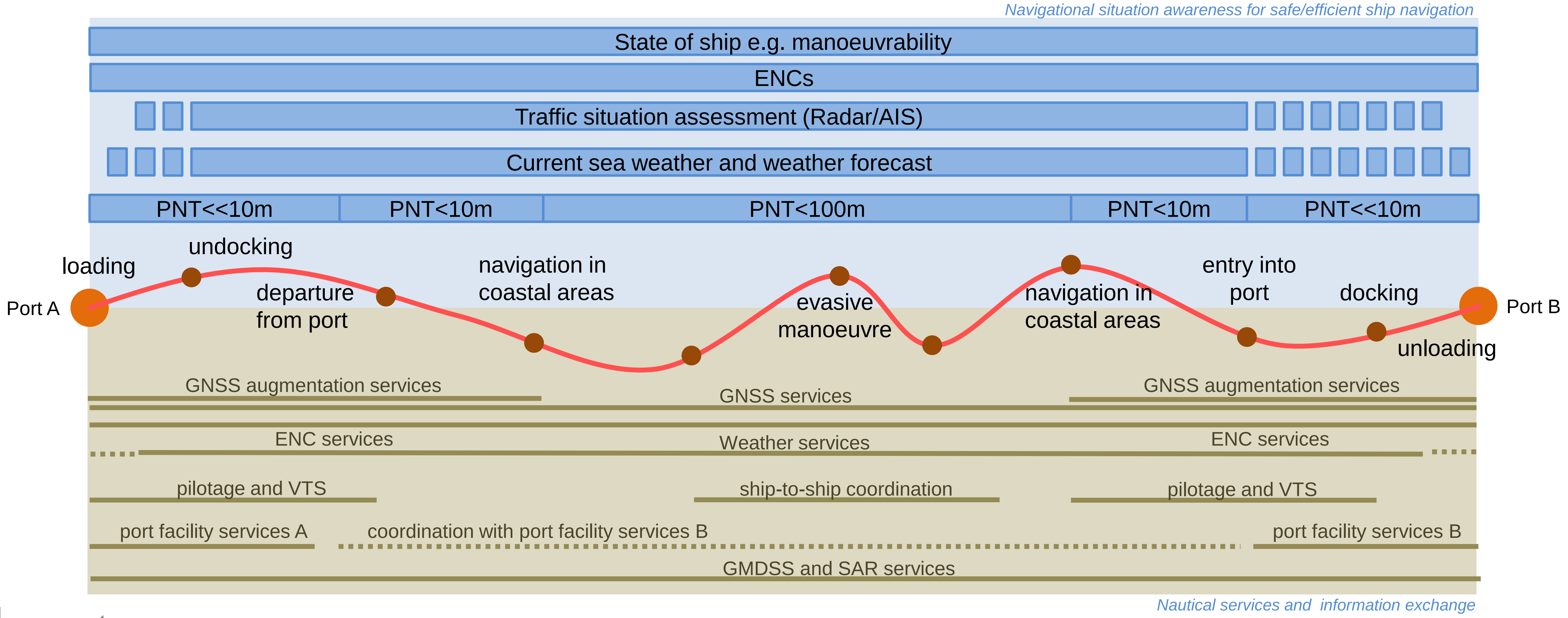
- ✓ *Internal/external exchange of Nautical Data*
- ✓ *AIS, VDES,….*

Cargo Operation

- ✓ *Cargo Loading/Unloading*
- ✓ *Cargo Monitoring*

Voyage

Examples of internal/external information demand and support by services for ship navigation



Automation vs. Autonomy
Harmonization of terms

Automatization
- The process of making an action of a higher animal reflexive (English).
- Processes of a system are performed and controlled by machines (German: Mechanisierung vs. Automatisierung)

Automation
- Act or process of converting the controlling of a machine or device to a more automatic system, such as computer or electronic controls.

Autonomy
- Self-government as freedom to act or function independently (as far as possible in relation to needed information)
- The capacity of a system to make a decision about its actions without the involvement of another system or operator.

Variety of definitions under discussion to describe the level of autonomy for ships (MSC 99/5/6)

Bureau Veritas	operation	decision	control
1) human operated	automated or manual	all done by human	all done by human
2) human directed	automated	supported, but done by human	all done by human
3) human delegated	automated	must be confirmed by human	must be confirmed by human
4) human supervised	automated	human will be informed	automated
5) fully autonomous	automated	human is informed in case of emergency	automated

Automation vs. Autonomy

Harmonization of terms

Automatization

- The process of making an action of a higher animal reflexive (English).
- Processes of a system are performed and controlled by machines (German: Mechanisierung vs. Automatisierung)

Automation

- Act or process of converting the controlling of a machine or device to a more automatic system, such as computer or electronic controls.

Autonomy

- Self-government as freedom to act or function independently (as far as possible in relation to needed information)
- The capacity of a system to make a decision about its actions without the involvement of another system or operator.

Variety of definitions under discussion to describe the level of autonomy for ships (MSC 99/5/6)

Norwegian Forum for Autonomous Ships (NFAS)

	Level	Description
1	Decision support	Decision support and advice to crew on bridge, crew decides.
2	Automatic bridge	Automated operation, but under continuous supervision by crew.
3	Remote control	Unmanned continuously monitored and directly controlled by shore.
4	Automatic ship	Unmanned under automatic control, supervised by shore.
5	Constrained autonomous	Unmanned, partly autonomous, supervised by shore.
6	Fully autonomous	Unmanned and without supervision.

Autonomous Shipping

Try to structure and generalize the definitions

- System of Systems „Shipping““
  - System „Ship“
    - Crew
    - Technical ship systems
  - System „Communication“
  - System „Shore-side services“
    - Technical service systems
    - Service operator

Set of main functions and tasks to operate a ship as transport carrier:

- functions/tasks have to be performed (p), controlled (c)
- status of used components and data have to be monitored (m), analysed (a)
- conditions and threat situation have to be surveyed (s), evaluated (e)

Set of means for decision making (d) and intervention (i)

	Crew	Technical ship systems	Technical service systems	Service operator
Automation				
	m, a, s, e → d → c	p, c	s, e → d	i partially possible
	d → c	m, a, s, e → d & p, c	s, e → d	i partially possible
from decision support to remote controlling				
	d → c	m, a, s, e → d & p, c	a, s, e → d	a, e → d
	i partially possible	m, a, s, e → d & p, c	a, s, e → d	a, e → d → c
from remote controlled to autonomous operation				
	i on request	m, a, s, e → d & p, c	a, s, e → d	a, e → d → c
		m, a, s, e → d → p, c	a, s, e → d	i on request

DLR

Autonomous Shipping
Challenges and thesis

Full-autonomous ship operation requires that all shipside systems and processes including information exchange and coordination with stakeholders and parties are fully automated.

Challenges in this context are e.g.:

- provision of reliable connectivity and communication as required
- protection of the cyber space needed for automated operation
- intelligent situation awareness systems to automate decision making and system controlling
- fully automated ship operation (operation of system-of-systems including adjustment to changes)
- fully automated health and safety management (adaptive maintenance, repair, restoration, recover)

Source: Rolls-Royce – Kevin Daffey

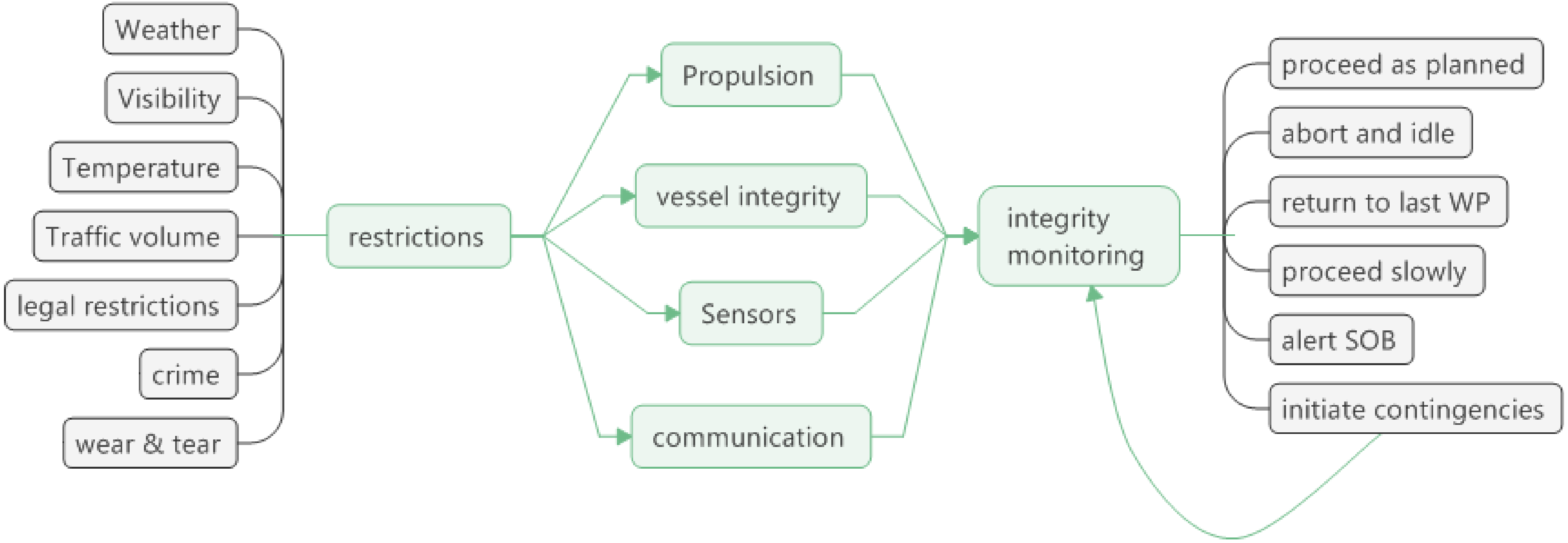
IMO considers the technology needed for Maritime Autonomous Surface Ships (MASS) as available.

- in minimum, it has to be proved

Thesis:

- intelligent situation awareness has to cover more then navigational and nautical aspects of ship operation.
- every situation awareness has to take into account the integrity of data and the trustworthiness of information.
- 100% reliability is really impossible, therefore resilience becomes to a design and operation criteria of ships

System-of-System View
Automatization and Autonomization



Operational Aspects towards fully autonomous vessels

Aspects and consequences

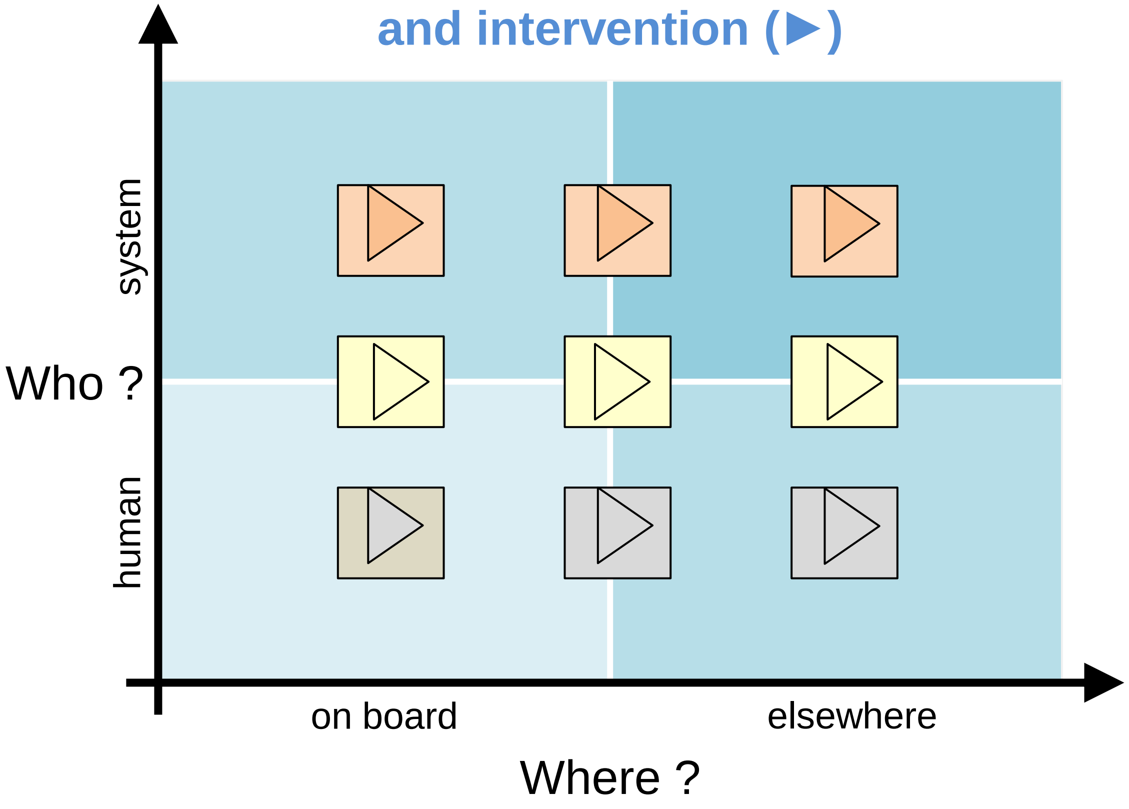
Operational aspects

- No ship can be operated autonomously for an infinite time.
- No ship can operate autonomously under all conditions.
- A safe operation requires the adjustment of ship's operation mode (used level of autonomy) to changing conditions.
- The adjustment has to be based on monitoring/surveying of ship's state and surrounding conditions taking into account the specific operational capabilities.

The operational concept

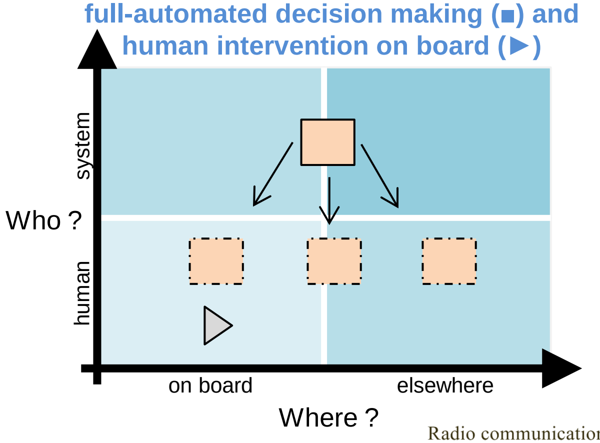
- has to be tailored to
  - the expected duration of a voyage
  - the variety of expected conditions while underway
- should take into account
  - the intended operational area and associated restrictions and requirements
  - the proactive and reactive behavior on disturbances, interruptions as well as emerging threats and occurred attacks

Operational concepts in relation to combinations of decision making (■) and intervention (▶)



Operational Concept – Case I

On-board crew for human intervention



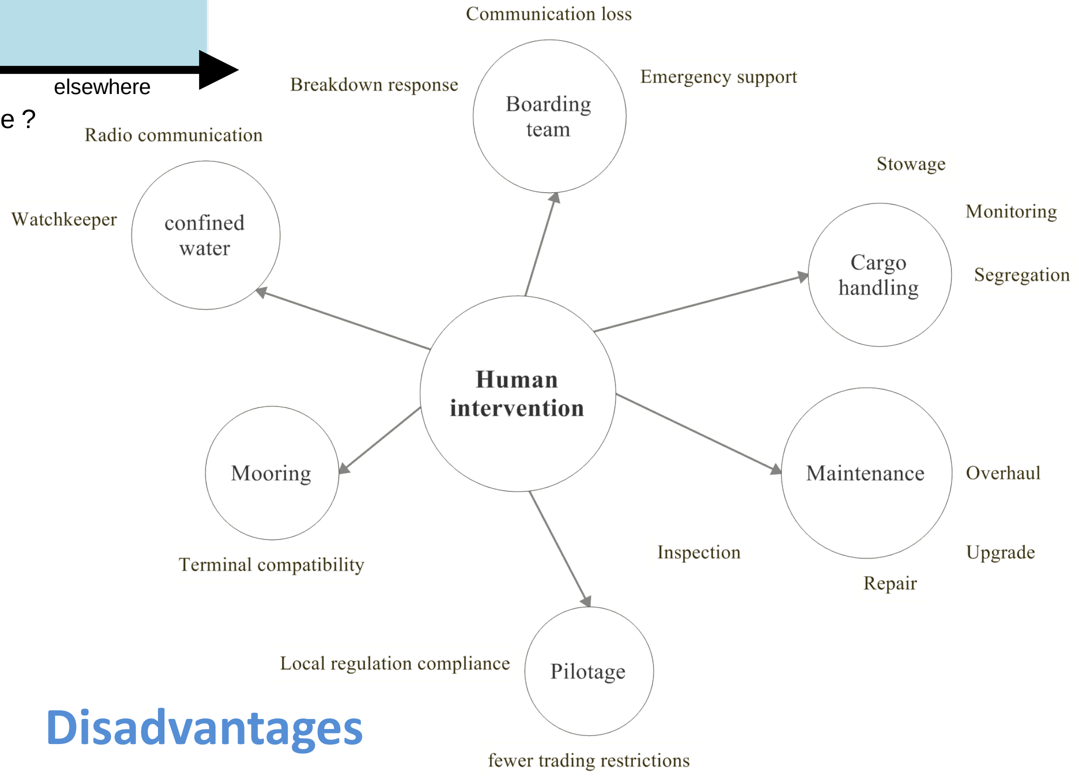
Principles:

- Autonomous operation whenever it is evaluated
  - as safe (within system boundaries)
  - and efficient (financially reasonable and tolerable)
- Human takeover of operation and decision making whenever
  - a lack/loss of system capability is identified
  - or it is legally required

Challenge:

- reliable and comprehensive situation awareness
- unambiguous specification of system boundaries
- just-in-time detection of lacks/losses of capability for autonomous operation by system itself or by human
- clear intervention procedures

Scope of monitoring and interventions

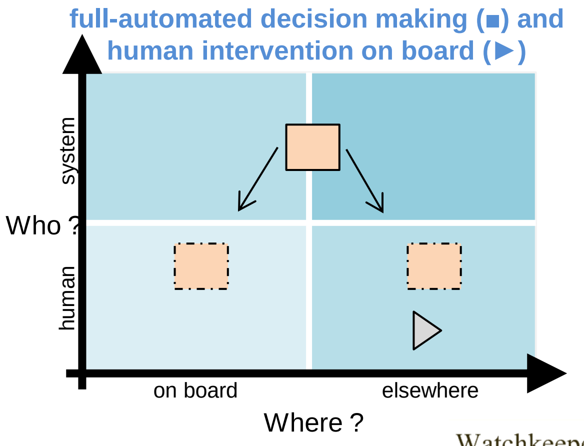


Disadvantages

Accommodation (wheelhouse) is required for on-board crew.

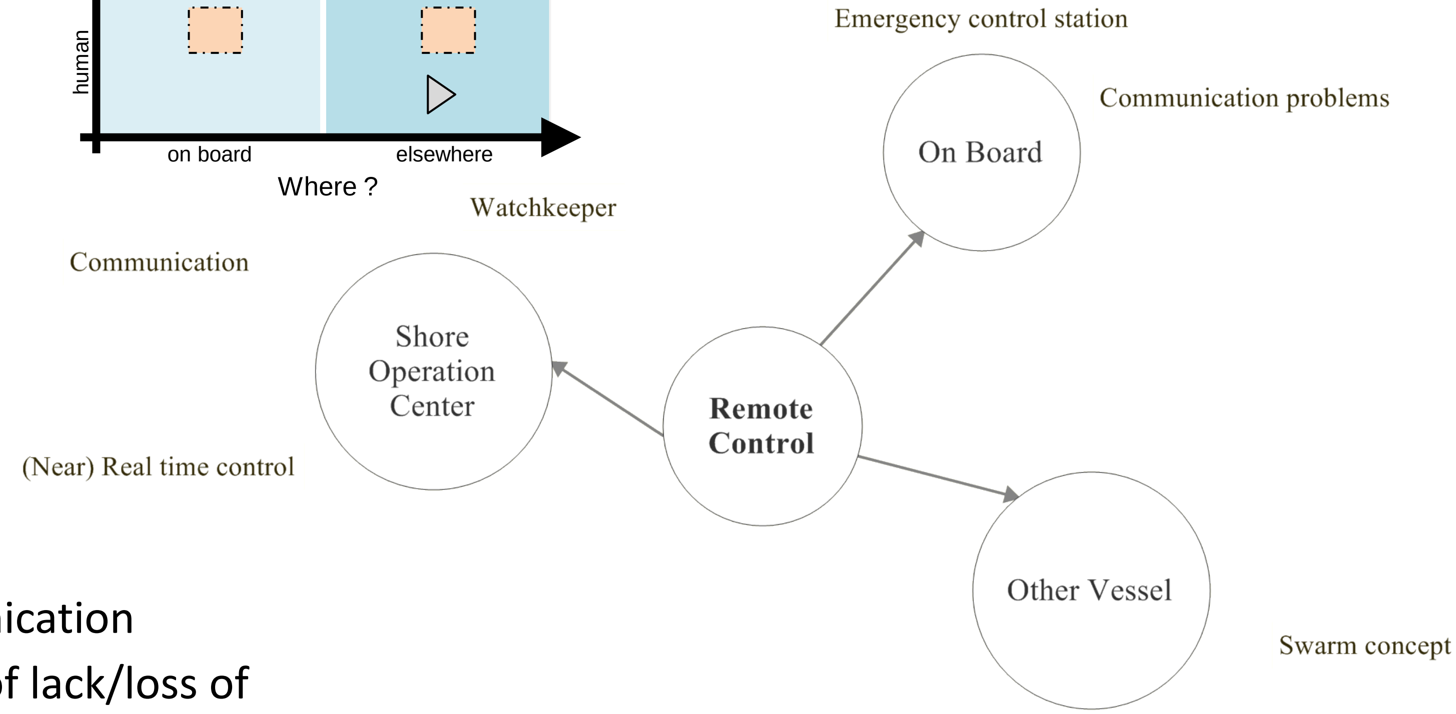
Operational Concept – Case II

On-shore/on-board crew for human intervention



Principles: see case I and

- full-autonomous monitoring, evaluation and reporting of ship status for on-shore intervention
- human takeover
  - of decision making & intervention by remote control
  - of operation takes time to bring crew on board of ships



Challenge: see case I

- reliable, resilient, and powerful communication
- extended fall-back procedures in times of lack/loss of information provision and exchange
- New business case for on-board intervention crew
- Shore operation centre adds a new legal dimension
- ELSA in relation to shared responsibilities

Disadvantages: see case I

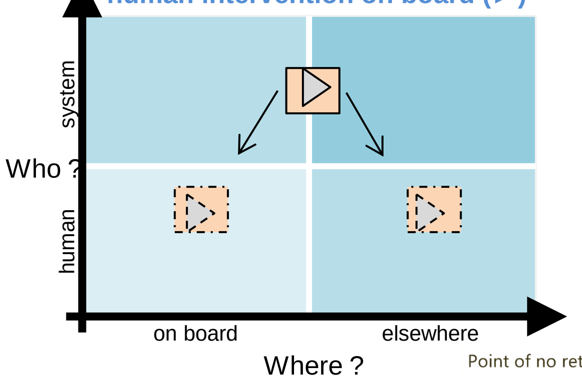
- feasibility of boarding depends on weather
- shore personnel and communication costs

DLR

Operational Concept – Case III

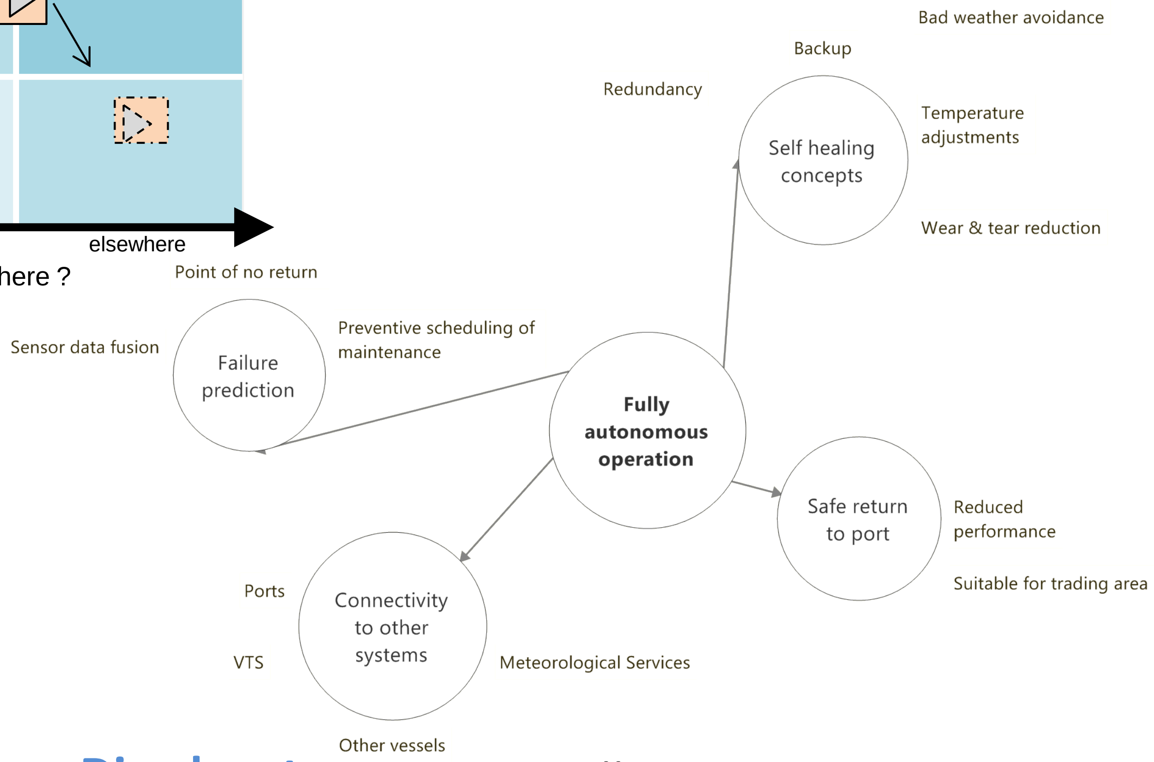
full-autonomous operation of ship

full-automated decision making (■) and human intervention on board (▶)



Principles:

- see case II
- human intervention only on request of autonomous system
- human intervention and remote control are primary means of emergency management



Challenge:

- see case II
- empowerment of ship for self-assessment of changes in situation, status, and conditions
- self-detection of emergency cases in relation to system boundaries and abilities
- self-initiation of situation-related intervention means
- ELSA for mixed traffic

Disadvantages: see case II

- costs for the provision of extended service portfolio to maintain autonomous-operated ships
- high-functional reliability of systems and interactions

Resilience
Definitions

International Maritime Organisation (IMO MSC1./Circ.1575)

Resilience is the ability of a system to detect and compensate external and internal disturbances, malfunction and breakdowns in parts of the system. This should be achieved ***without loss of functionalities and preferably without degradation of their performance***.

European Commission

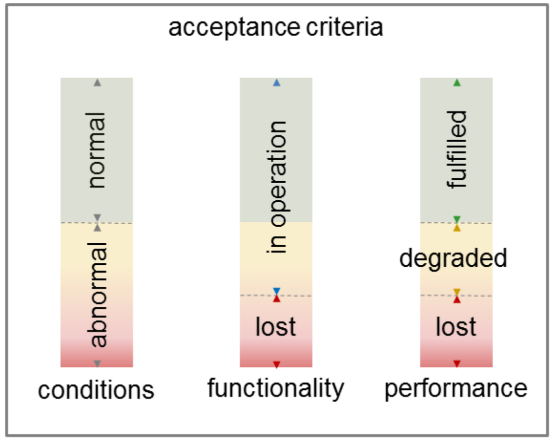
Resilience is the “ability of an individual, a household, a community, a country or a region to withstand, to adapt, and to quickly recover from stresses and shocks”

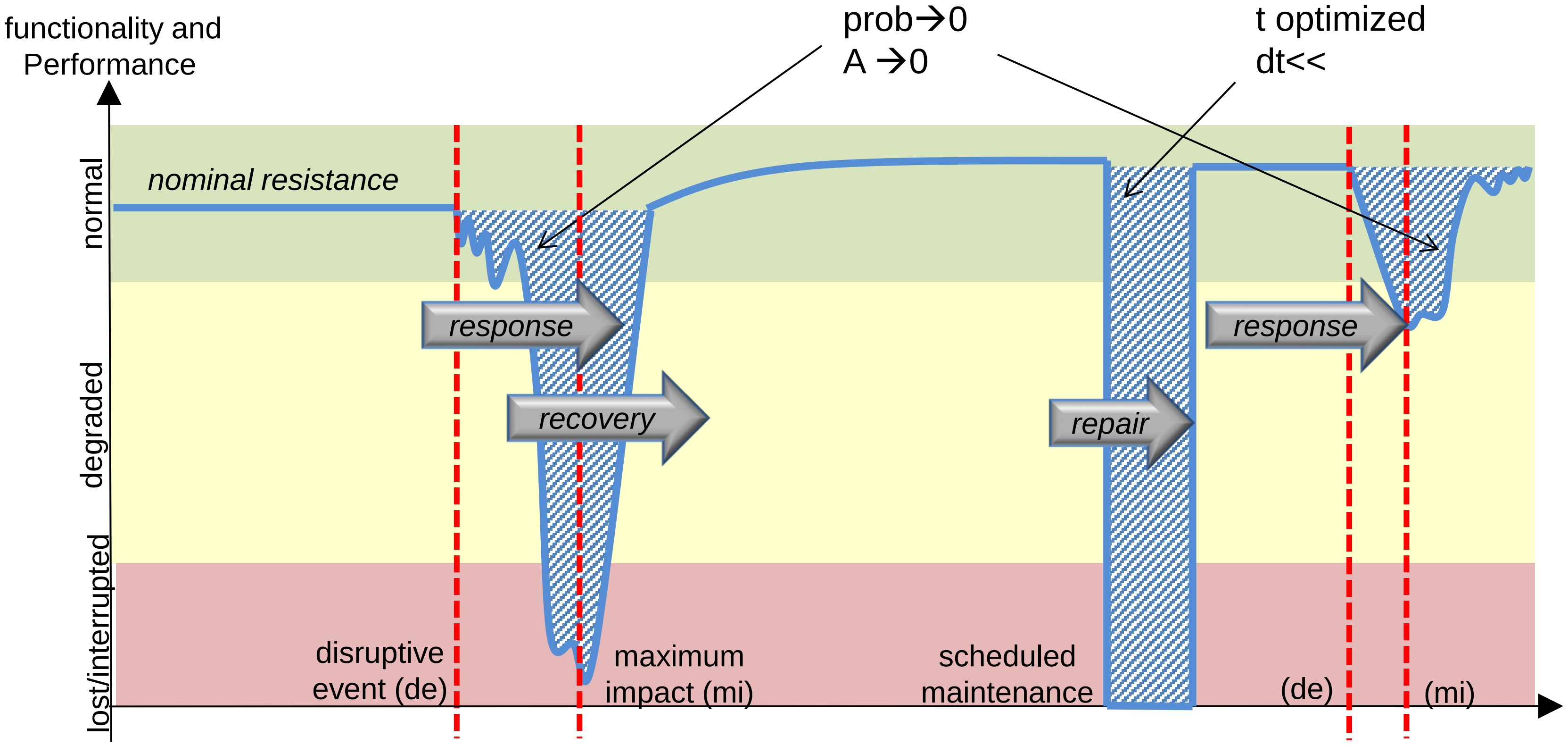
United Nations Office for Disaster Risk Reduction

Resilience is “the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, ***including through the preservation and restoration of its essential basic structures and functions”***

Resilience
A life-cycle consideration

Resilience stands for
- maintenance of functionality and performance
- adjustment to changing conditions
- minimizing of negative impacts on life, goods, and environment





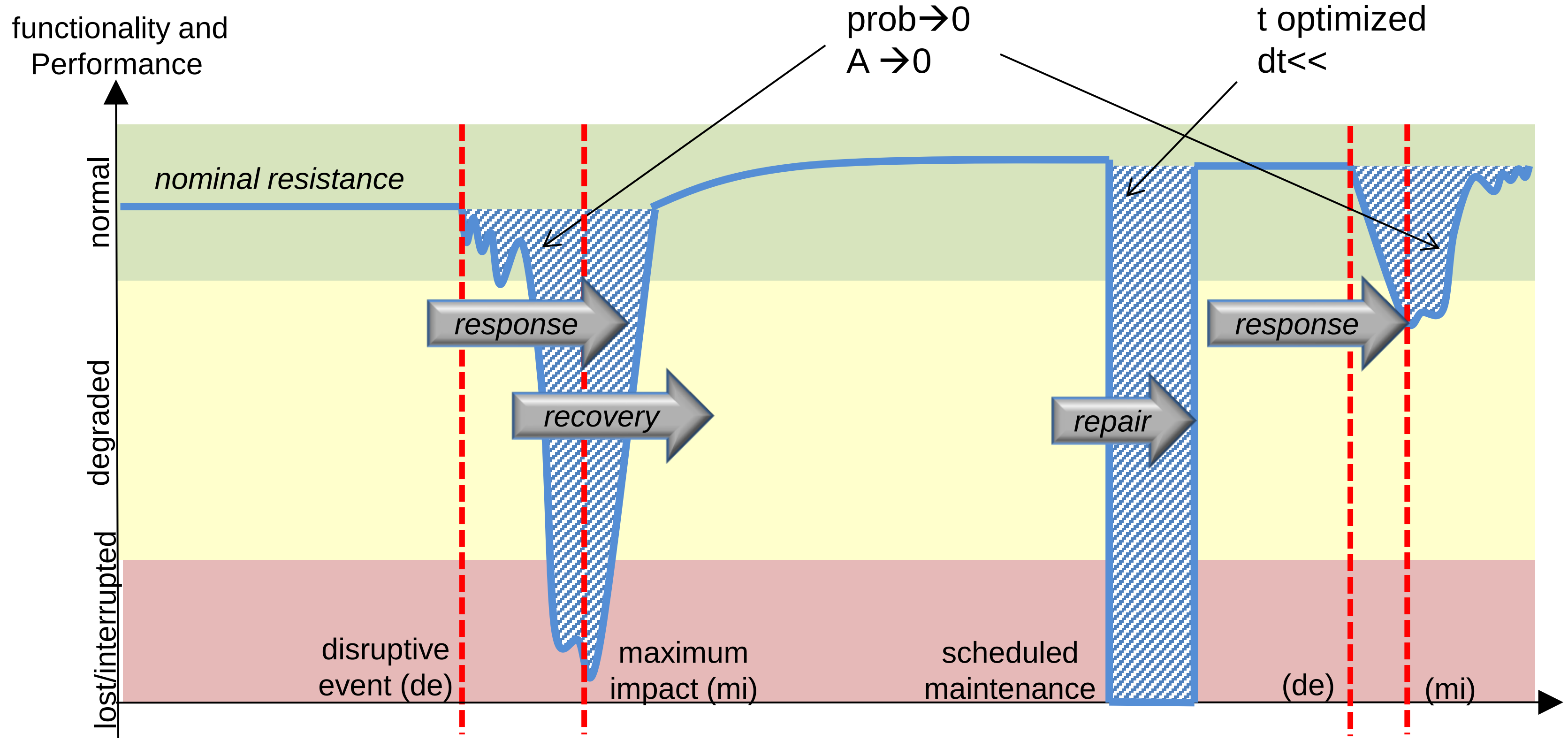
Resilience is
- a design target (normal operation of system under specified conditions)
- an operational challenge (monitoring/surveying to establish situation awareness and to detect emerging threats)
- the capability to react and adjust to internal and external changes (proactive and reactive safety and risk management)

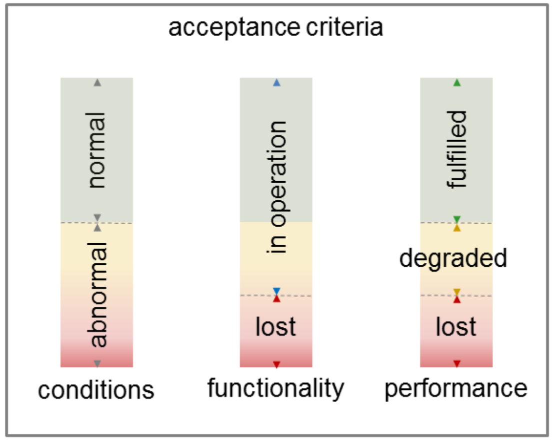
Resilience

A life-cycle consideration

Resilience stands for

- maintenance of functionality and performance
- adjustment to changing conditions
- minimizing of negative impacts on life, goods, and environment





Resilience is

- a design target (normal operation of system under specified conditions)
- an operational challenge (monitoring/surveying to establish situation awareness and to detect emerging threats)
- the capability to react and adjust to internal and external changes (proactive and reactive safety and risk management)

Resilience Engineering – relevance to autonomous shipping

©Kongsberg 2018

Starting point:

- Replacement of a key function from a System-of-System perspective
- No existing data
- Balance between safety, reliability and efficiency for a specific purpose

Approach:

- Identify relevant conditions (technological, environmental, operational, legal)
- Determine how functionality and performance are affected by varying condition parameters
- Analyze the relevance of these functionality and performance variations for the ability to operate a vessel
- Assess the ability to detect condition, performance and functionality changes and the reliability of this ability to derive information about the resilience level of the vessel

Resilience Engineering application example

- **Swarm Concept I (lead vessel)**

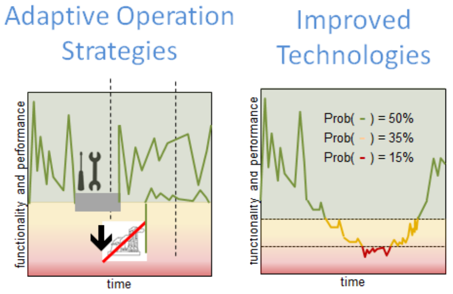
Principles:

- Autonomous operation limited to
  - Navigational tasks
  - Situational awareness contribution
- Human operation required for
  - Passage planning
  - Remote control/Monitoring
  - Technical troubleshooting
  - Repair/Towage
  - Communication

Benefits:

- Remote connection limited to short distances
- Trade specific scalability
- Technical fault restauration ability allows reduced reliability design
- Redundancy within swarm on higher system level
- Lower cyber vulnerability due to avoidance of long distance remote access

©RFNC-VNIEF 2018



©Schönknecht 1979

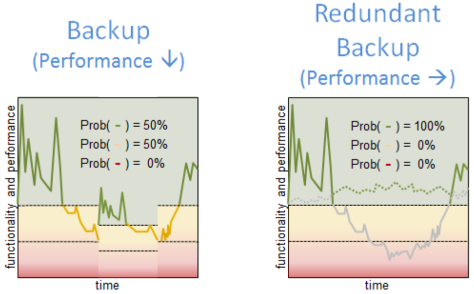
Resilience Engineering application example

- **Swarm Concept II**

Principles:

- Fully autonomous operation
- Capability to self organise
  - Data validation
  - Redundancy /back up
- Lessons learned from previous concept remain valid

©RFNC-VNIEF 2018



©Schönknecht 1979

Benefits:

- Redundancy of many functions is achieved in the swarm
- External sensors can be combined for better information quality
- Problems of accessibility in remote areas can be avoided by utilising swarm support capabilities (towage)

Conclusions

- Hybrid solutions with the potential to operate under different levels of autonomy are desirable
- Capability to sustain time periods with reduced functionality without causing harm to environment, cargo or asset will be required
- Navigation is not the key problem to be solved to enable autonomous vessel operations but the integration of the vessels in the maritime environment and operational context
- Removal of the human element causes operational and legal consequences which require new understanding of the vessel as a system within a system-of-systems
- Resilient vessel operation will allow for a smooth integration of autonomous vessels in the maritime domain
- An autonomous vessel will be seaworthy, if its resilience level is measurable and appropriate for the ordinary perils of the intended voyage
- Resilience consideration at the design phase will ensure a vessel's suitability for its purpose and allow for a safe and efficient utilization

Thanks for your attention !