The utilization of STPA on the ship navigation system

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The National Technical University of Athens

- ***NTUA*** is is the oldest Technical University in Greece, founded in 1837
- ***School of Naval Architecture and Marine engineering*** is one of the ***9 schools*** consisting NTUA

The NTUA campus

The Maritime Risk Group (MRG)

- ***Maritime Risk Group (MRG)*** is a ***research group*** based in ***NTUA***, led by professor Nikolaos P. Ventikos

- ***Areas of expertise:***
  - Maritime safety & transport
  - Risk analysis and assessment, risk based design
  - Human element
  - Resilience & systems engineering
  - Autonomous shipping
  - Environmental engineering

- ***Coordination and participation in major national, EU and regional research and innovation projects***

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Contents

- Why are leading indicators important for preventing maritime accidents?
- Why was STPA selected and how was it applied for this study?
- Which indicators were identified?
- Which are the next steps?

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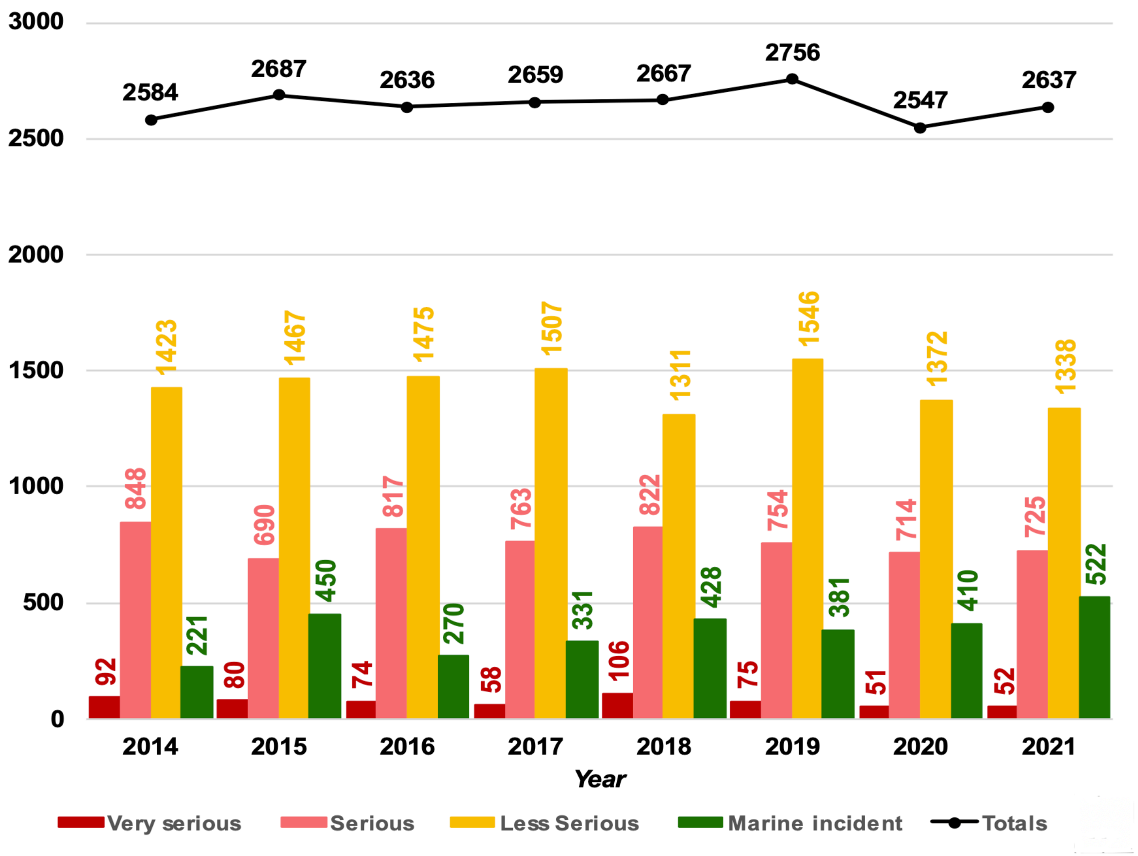
Introduction – Maritime accidents

- ***Navigation accidents*** are common and ***human action*** is the most reported cause (EMSA, 2022)

- An analysis of 573 navigational accidents (reported in EMCIP by the EU members) showed (EMSA, 2022):
    - Collision: 44.3%
    - Grounding: 40.2%
    - Contact: 15.5 %

Number of marine casualties and incidents

(ships flying a flag of one of the EU Member States and occurred within EU)

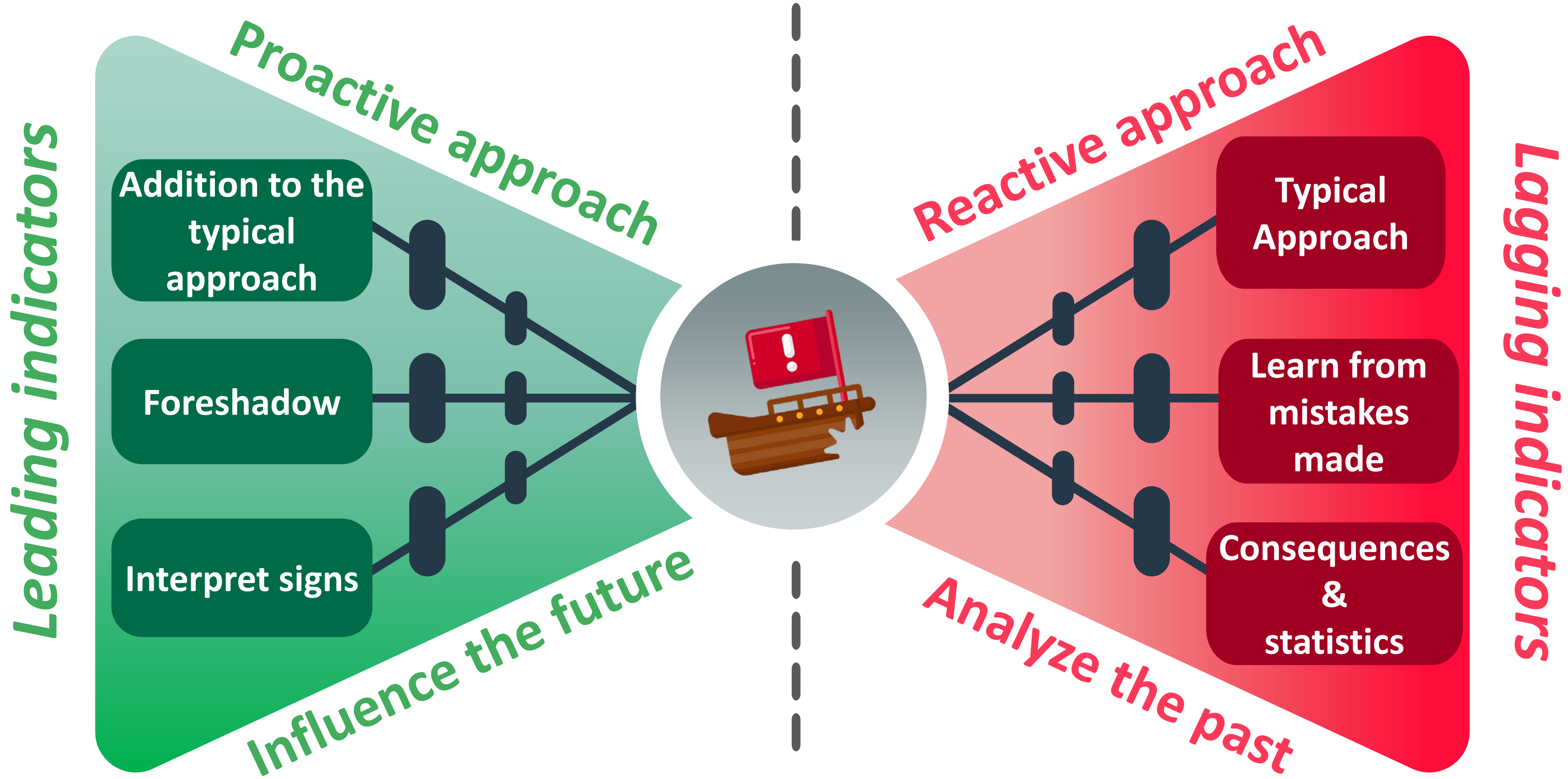


(Source: EMSA annual overview, 2022)

Safety Performance & Leading Indicators

Leading indicators are safety metrics that are associated with and precede an undesirable consequence. (ABS, 2014)

Safety performance is the measured outcome of safety efforts, that indicate frequency and severity of incidents in time or in other scale. (Jalonen, 2019)



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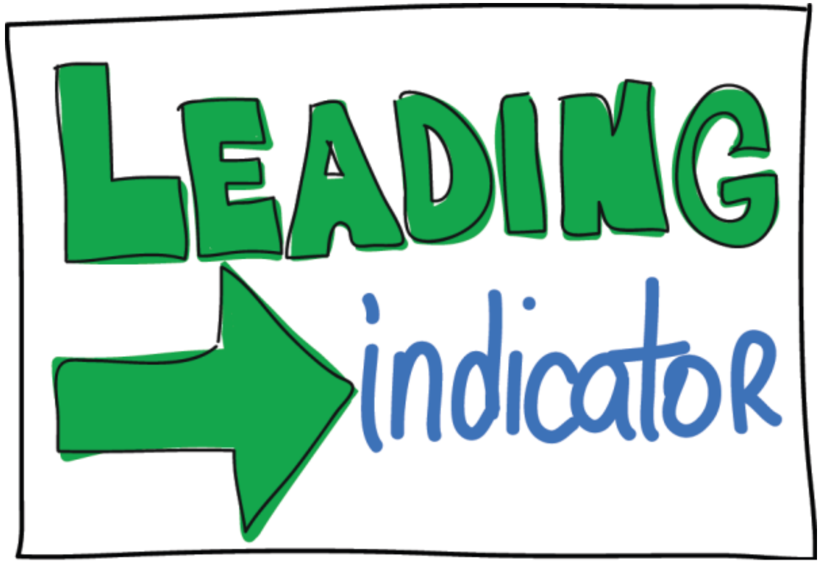
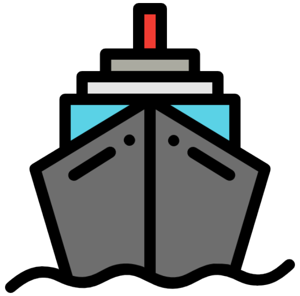
Leading Indicators

- Nevertheless, the importance of using them in daily practice ***in the maritime domain*** remains ***under-investigated*** (Wrobel et al., 2021)
- ABS has developed a method for identification of leading indicators, which is based on choosing from a list of pre-defined metrics those that have a statistically significant correlation to safety performance (ABS, 2014)
- But, a lot of efforts focused on developing leading indicators has provided only ***limited success***. A systems-theoretic, assumption-based approach ***could be more successful*** (Leveson, 2015)





Why have we chosen STPA?

- Several applications of the STPA method in the maritime domain have been published, dealing with ***autonomous ships*** (Zou, 2018), offshore supply vessel ***dynamic positioning systems*** (Abrecht, 2016) etc.
- ***But***, to the best of our knowledge, STPA ***has not been used for identifying leading indicators*** in the ***maritime domain***
- Indicators used in the maritime domain (KPIs – ***similar to*** leading indicators):
  - Training days per officer (www.shipping-kpi.com)
  - Number of port state control observations per inspection (Fälth and Ljungqvist, 2013)
  - Number of near misses reported per employee (ABS, 2014)
- ***STPA strong points:*** 1) Based on ***knowledge*** and ***expertise*** on how the system in question works, 2) Considers interactions among system components

Identification of leading indicators

5. UCAs

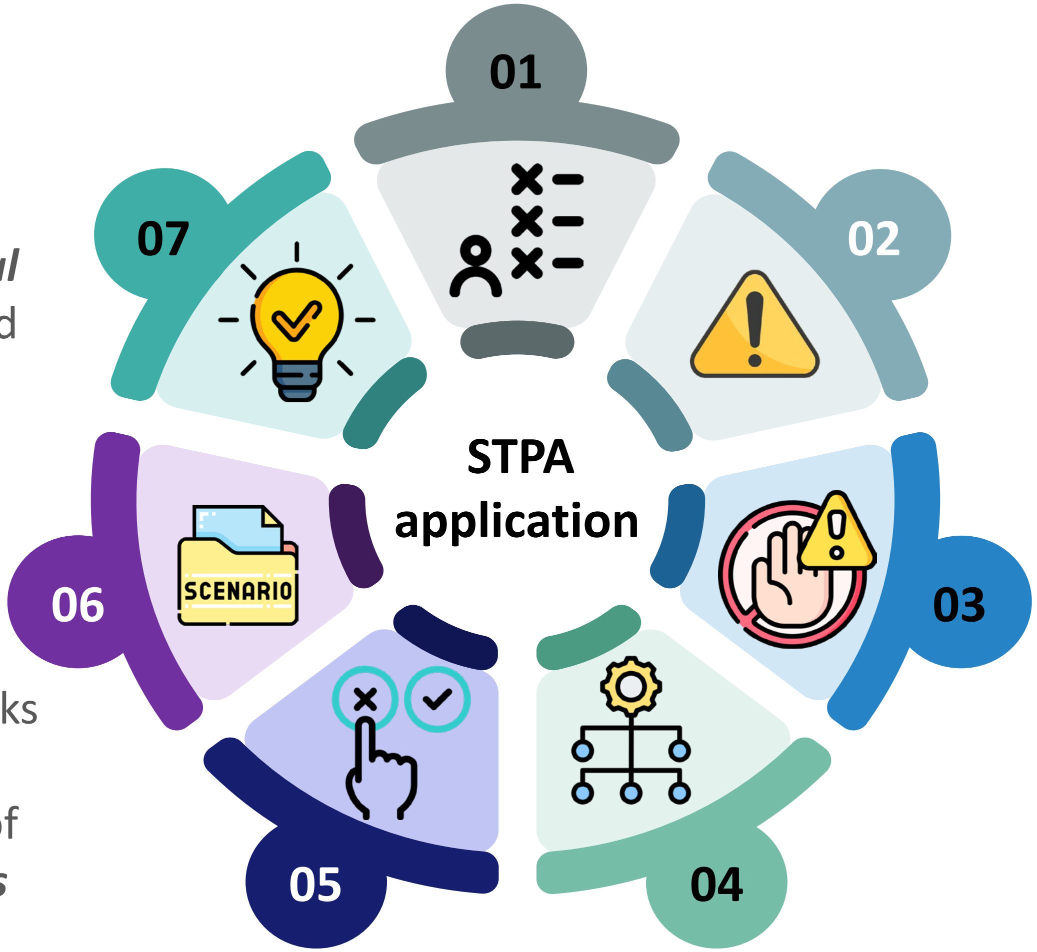
- Definition of various UCAs

6. Loss scenarios

- A loss scenario describes the ***causal factors*** that can lead to UCAs and possibly to hazards

7. Assumption based Leading indicators

- A series of ***assumptions*** are made under which the system works smoothly. The LI emerge from the ***measurement*** and quantification of the ***violation of these assumptions***



1. Losses

- Definition of a series of losses

2. Hazards

- Definition of hazards and connection with losses

3. System level constraints

- Definition of SLCs and connection with hazards and eventually with losses

4. Control structure

- Responsibilitiies
- Control actions & Feedback

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Evaluation of leading indicators

The proposed leading indicators are evaluated with ***specific criteria***
(Grabowski et al. 2017, Hale 2009, Leveson 2015)

1. Ease of data retrieval

The data needed to define each indicator should be as ***easily accessible*** as possible

2. Validity-reliability

Leading indicators must ***correctly give the measurement*** on which their application is based

3. Ease of implementation

The leading indicators must be ***acceptable*** from the crew members and make them ***actively participate*** in their implementation process

4. Cost-effectiveness

Cost-effective in terms of man-hours and technology required for their application, in relation to the results they offer

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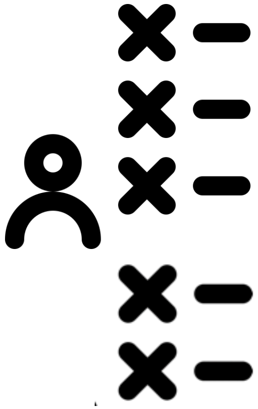
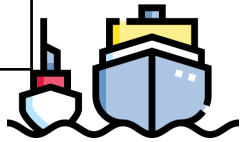
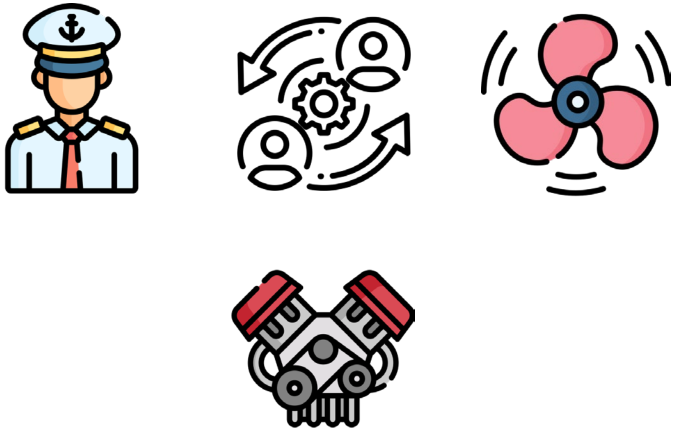
Definition of losses and system boundaries



Safety-related Losses	Description
L-1	Loss of human life or injury
L-2	Loss of stability of the ship
L-3	Loss of ship's structural integrity/watertightness
L-4	Loss of equipment
L-5	Environmental loss/pollution

Loss of the ship

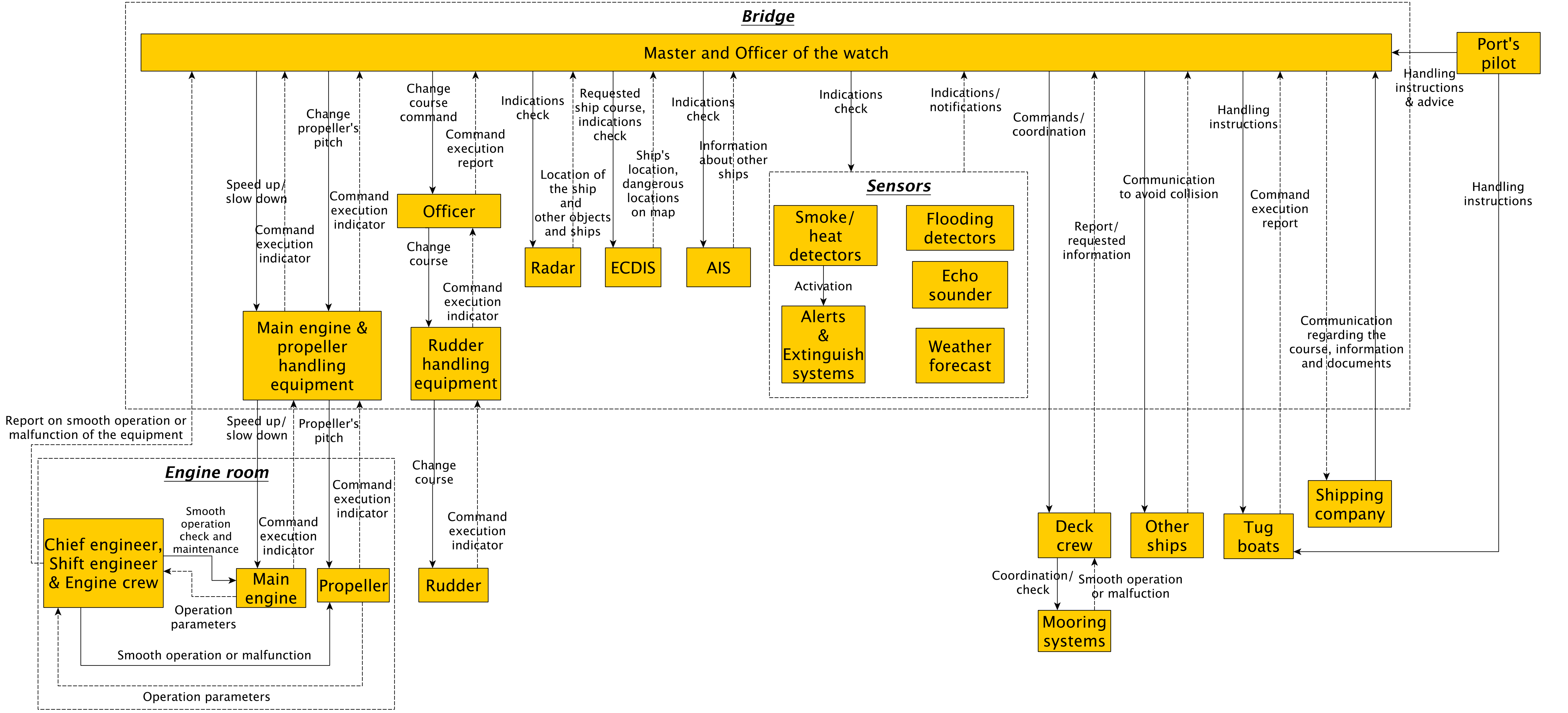




Hazards and System level constraints

Hazards	System Level Constraints	Possible Loss
H-1: The ship is very close to another ship or object	**SC-1:** Safe distance should always be kept and the crew must be aware when it is violated	L-1, L-2, L-3, L-5
H-2: The ship is approaching shallow water	**SC-2:** Depth should be continuously monitored	L-1, L-2, L-3, L-5
H-3: The ship's propulsion system is operating beyond the permissible limits	**SC-3:** Avoid operation beyond the permissible limits (emergency cases are excluded)	L-4
H-4: Flooding of contiguous watertight compartments	**SC-4:** The possibility of progressive flooding should be monitored and detected on time	L-1, L-2, L-5
H-5: Fire spread	**SC-5:** Heat and smoke detectors should trigger an alarm and extinguishing systems	L-1, L-2, L-4, L-5
H-6: Exceeding the safe operating limits of the mooring systems	**SC-6:** Deck crew must be well trained, and equipment properly maintained and inspected	L-1

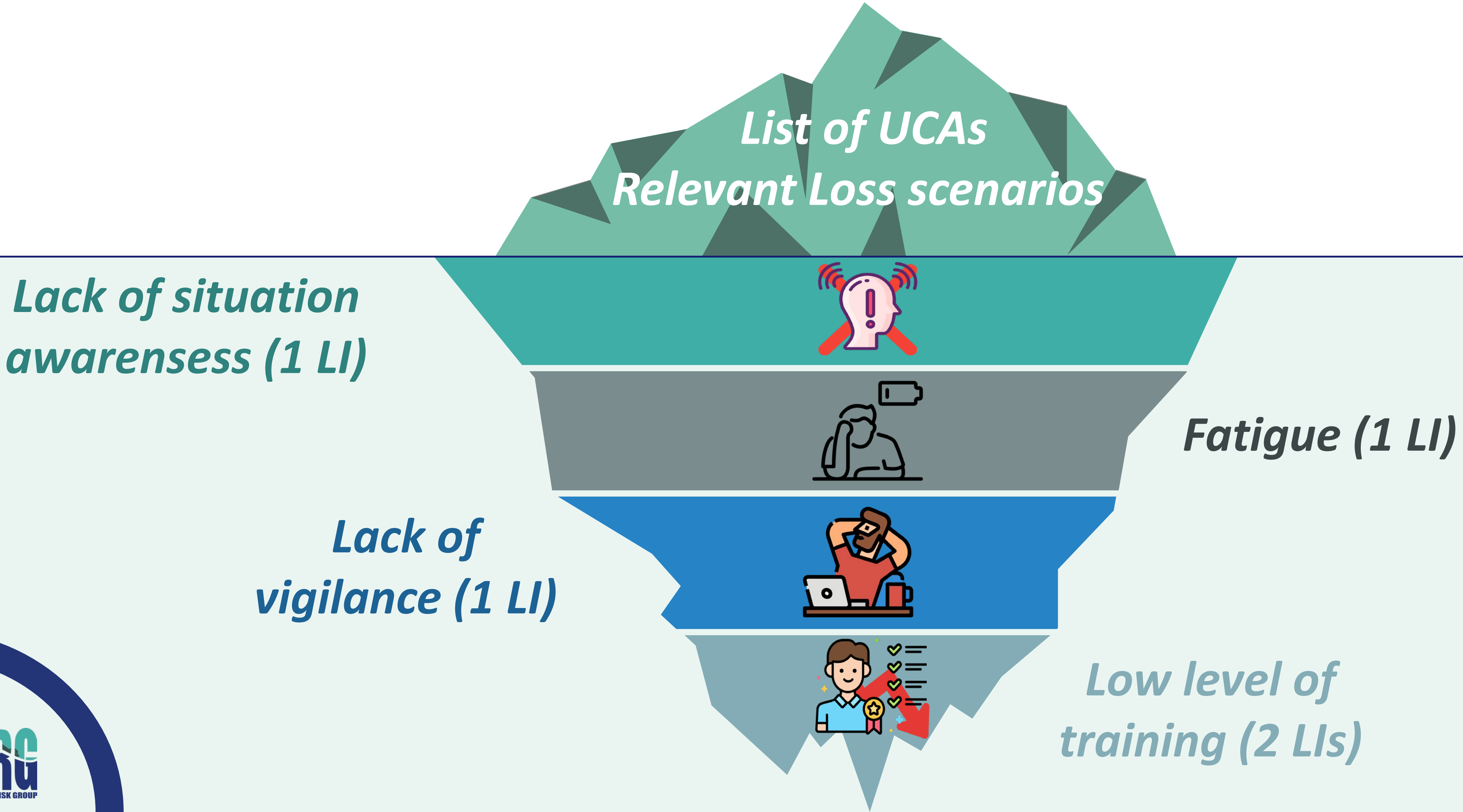
Control structure diagram



Unsafe Control Actions (UCAs)

Control action	Receiver	Not providing causes hazard	Providing causes hazard	Incorrect Timing/Order	Stopped too soon/Applied too long
Speed up or slow down	Propulsion system handling equipment	**UCA**: The Master did not speed up or slow down when he should have **[H-1, H-2]**	**UCA**: The Master speeded up when he should have slowed down or vice versa **[H-1, H-2, H-3]** **UCA**: The Master speed up or slowed down more or less than he should have **[H-1, H-2, H-3]**	**UCA**: The Master speeded up or slowed down later or earlier than he should have **[H-1, H-2]**	**UCA**: The Master speeded up or slowed down for a longer than the necessary period **[H-1, H-2, H-3]**

Assumption Based Leading Indicators



Assumption Based Leading Indicators

<u>LI1</u>: The number of steps the Master takes during his shift *(use of smartwatch)*

- ***Assumption:*** The more the Master moves around during his shift, the better view he has of the situation on board
- ***Potential breach consequences:*** *the Master may not be aware of a developing dangerous situation due to not observing the surrounding environment or not monitoring the navigational equipment*

Lack of situation awareness related scenarios and UCAs

- ***UCA:*** The Master did not speed up or slow down when he should have **[H-1, H-2]**
- ***Scenario 1: The Master was not aware that the ship was approaching another object/ship***
- ***Scenario 2:*** The Master was aware that the ship was approaching another ship/object, but he misjudged the situation
- ***Scenario 3:*** The Master was aware that the ship was approaching another ship/object, but he incorrectly used the navigation equipment

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Data retrieval	Validity-reliability	Implementation	Cost-effectiveness

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Assumption Based Leading Indicators

***LI2*: The consecutive working hours of the crew members** *(utilization of the rest hours declared by the shipping company)*

- ***Assumption:*** The crew has the appropriate performance to execute their duties properly
- ***Fatigue*** related scenarios and UCAs

Data retrieval	Validity-reliability	Implementation	Cost-effectiveness

***LI3*: The number of times an alarm was triggered by the Bridge Navigational Watch and Alarm System (BNWAS)**

- ***Assumption:*** *Bridge crew members have adequate attention and concentration to perform their duties correctly*
- ***Lack of vigilance*** related scenarios and UCAs

Data retrieval	Validity-reliability	Implementation	Cost-effectiveness

Assumption Based Leading Indicators

***LI4**: The crew's reaction times in decision-making and handling of equipment* *(real or VR tests)*

- ***Assumption:*** The crew always performs correctly and on time
- ***Low level of training*** related scenarios and UCAs

Data retrieval	Validity-reliability	Implementation	Cost-effectiveness

***LI5**: The number of unsafe behaviours of the bridge crew members observed during navigational audits (by the superintendent of the shipping company and by an external agent - 3rd party)*

- ***Assumption:*** *The behavior of the bridge crew during the navigational audits is evaluated as "safe"*
- ***Low level of training*** scenarios and UCAs

Data retrieval	Validity-reliability	Implementation	Cost-effectiveness

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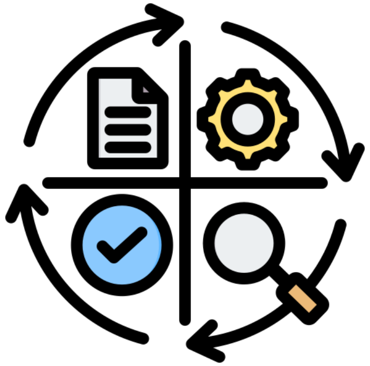
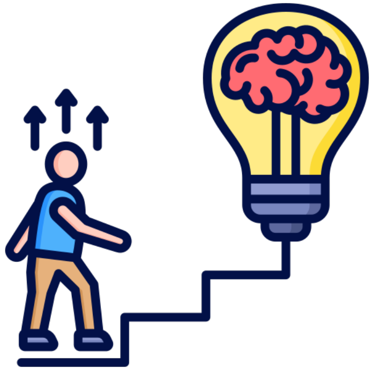
Conclusions and future research

- The indicators must be applied in ***real conditions*** and be ***evaluated over time on their efficiency***
- The leading indicators should be associated with quantitative ***targets*** and ***acceptable limits***
- The identification of ***more*** leading indicators that ***satisfy all the evaluation criteria*** could be a subject of ***future research***





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Thank you!

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