Risk Analysis on Marine Autonomous Surface Ships based on Systems Theory-An Application of the NET-HARMS method

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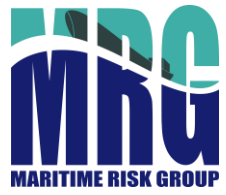

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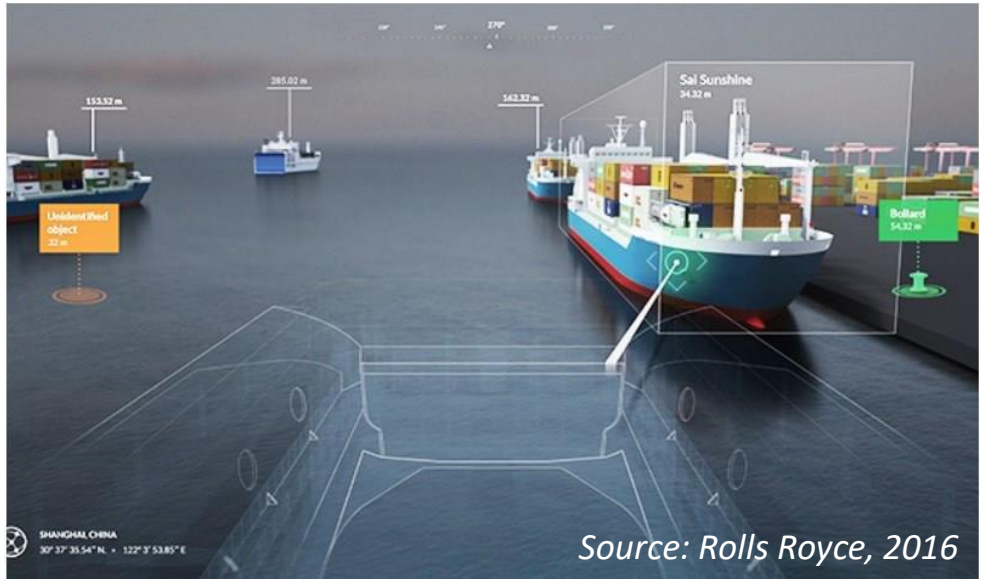
Introduction



Source: Rolls Royce, 2016

SEAMLESS project

Research on Maritime Autonomous Surface Ship (MASS) has highlighted some primary challenges:

- ensuring that autonomous systems and/or vessels will be at least as safe as conventional ones *(Rolls Royce 2016)*,
- approaching holistically MASS systems to understanding the increased complexity of them *(Salmon et al. 2022)*,
- defining the system, including both human and software components, which are often not explicitly handled in traditional system models *(Zhou et al. 2020)*,
- developing new methodologies for hazard identification and risk assessment to address the emerging risks and increased complexity of MASS *(Basnet et al. 2019)*,
- assessing how safety can be affected according to the changes on the level of autonomy *(Ventikos et al. 2023)*.

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Introduction

The research focuses on two key aspects:

- ✓ The application of the systems thinking method **NET-worked Hazard Analysis & Risk Management System (NET-HARMS)** to identify risks on a MASS system.

- ✓ To propose a methodology for the combination of EAST-BL findings with the **Risk Based Assessment Tool (RBAT)** (DNV-GL, 2021) study risk model to access the identified risks.

The YARA Birkenland

To **evaluate the results** of NET-HARMS and **assess** its utilisation to the hazard identification and risk assessment process on MASS.

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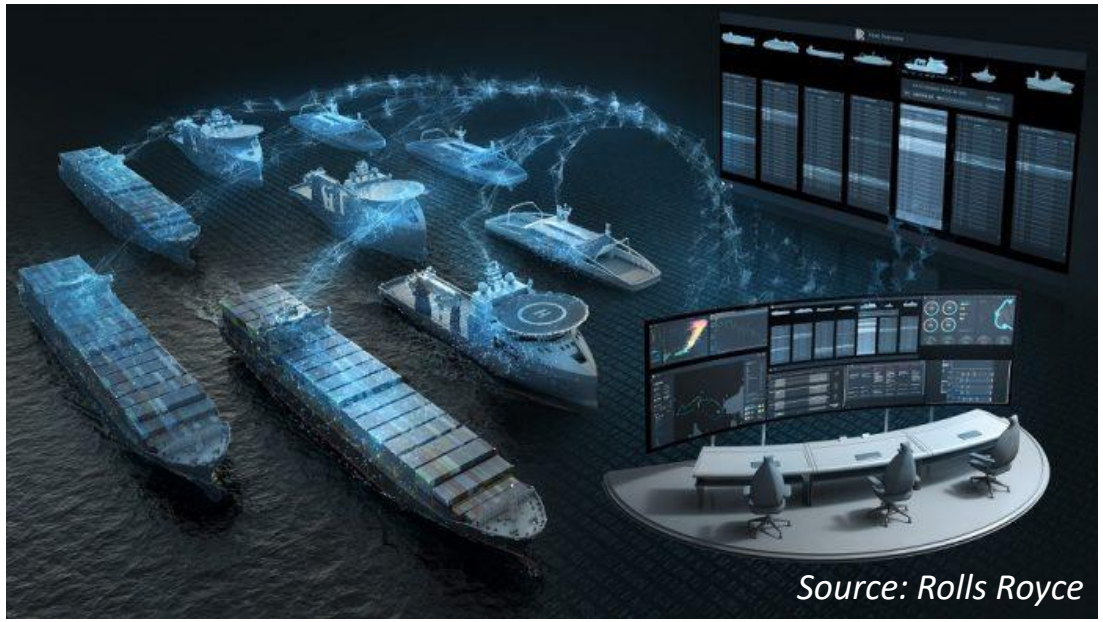
Background

Systems Thinking methods**:**

- have the axiom that behavior, safety, and accidents are emergent properties arising from non-linear interactions between multiple components across sociotechnical systems,
- consider the interactions and interdependencies between different system components (including the role of humans),
- can reveal potential hazards that might be missed when examining parts in isolation *(Salmon et al. 2022)*.


Source: Rolls Royce

- Systems Theoretic Process Analysis (STPA) *(Chaal et al. 2020)*
- Event Analysis of Systemic Teamwork Broken Links (EAST-BL) *(Ventikos et al. 2023)*
- **NET-worked Hazard Analysis & Risk Management System (NET-HARMS)** *(Dallat et al. 2018)*

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Background

Bayesian Networks are:

1) probabilistic graphical models *(Jensen & Nielsen 2007).*
2) a set of variables
3) conditional dependencies (directed acyclic graph) *(Thieme et al. 2018)*:
    I. historical data
    II. expert judgment
    III. real-time information

Innovative Methods

DNV, 2020 (HAZID-FTA-RCO)
DNV, 2021 (RBAT)
Zhou et al., 2021 (STPA – SynSS)
Ventikos & Louzis, 2022 (bio-inspired safety)

Hybrid methods

Utne et al., 2020 (STPA - BBN)
Gao et al., 2021 (DBN – DFT)
Itoh et al., 2021 (SWIFT – STPA)
Ventikos et al., 2023 (EAST-BL – RBAT)

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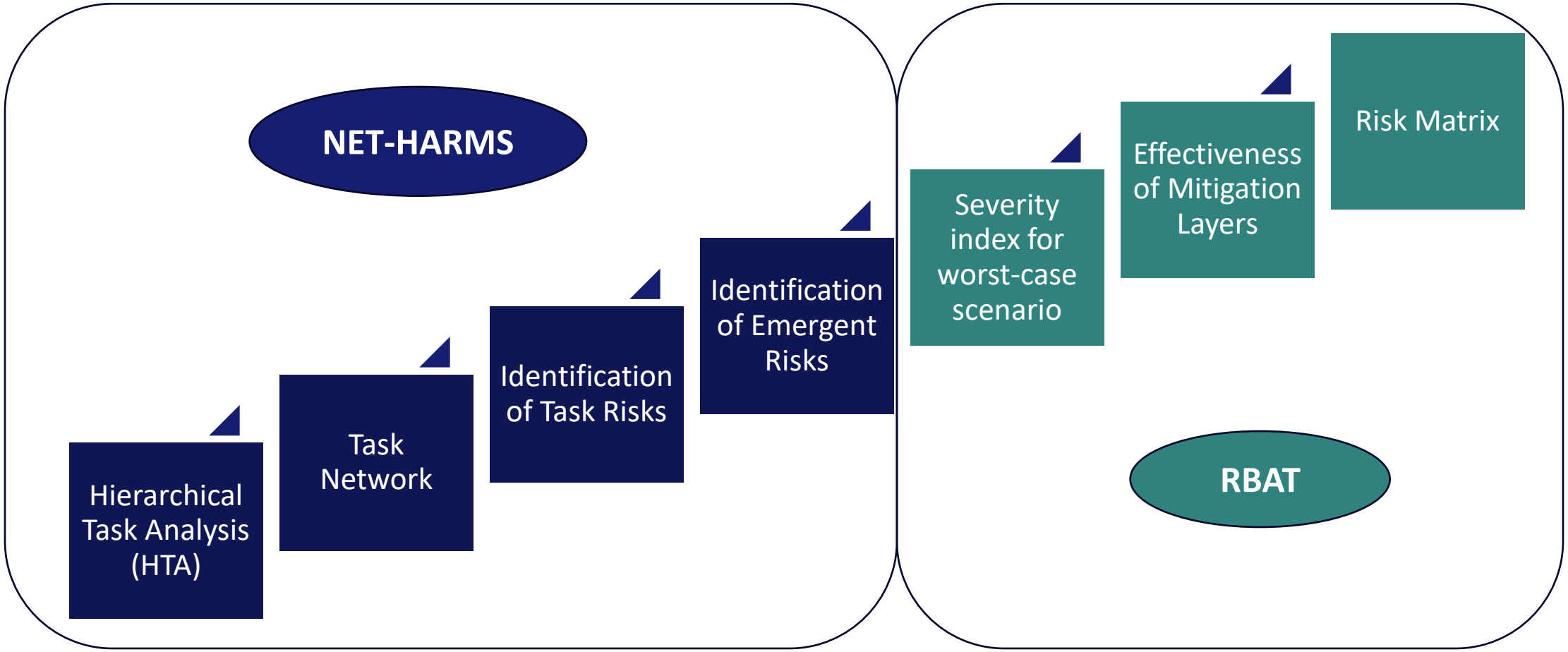
Methodology



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Methodology (NET-HARMS)

NET-worked Hazard Analysis & Risk Management System, NET-HARMS *(Dallat et al. 2018)*

- Is the newest systems-based risk assessment method in Human Factors Engineering (HFE).
- Is universally applicable, enabling its use across various domains *(Hulme et al. 2021).*

Recognizes not only the risks associated with specific tasks but also emergent risks *(Salmon et al. 2022)*.

Advantages:

- Is designed to surpass current risk assessment approaches that concentrate on the sharp-end by identifying risks throughout entire systems, including government and regulatory levels *(Dallat et al. 2018)*.
- By constructing the HTA and task network, analysts are able to gain a comprehensive understanding of the system being examined *(Stanton 2006).*

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Methodology (RBAT)

Risk = *f*(Severity, Effectiveness of mitigation layers)

Table 3-5: Risk matrix based on evaluation of available risk mitigating measures

Effectiveness of risk mitigation layers	Severity					
	No effect	Negligible	Minor	Significant	Severe	Catastrophic
Low	Low	Medium	High	High	High	High
Moderate	Low	Low	Medium	High	High	High
Medium	Low	Low	Medium	Medium	High	High
High	Low	Low	Low	Medium	Medium	High
Very high	Low	Low	Low	Low	Medium	Medium
Extremely high	Low	Low	Low	Low	Low	Medium

Table 3-2: Severity index for worst-case outcomes

Severity	Effects on human safety
No effect	No injuries
Negligible	Superficial injury
Minor	Single injury or multiple minor injures
Significant	Single serious or multiple injuries
Severe	Single fatality or multiple serious injuries
Catastrophic	Multiple fatalities (more than one)

Table 3-4: Effectiveness of mitigation layers

Effectiveness	Description
Very high	At least three effective *independent* mitigation layers that for the assessed scenario can prevent losses regardless failure cause.
High	At least two effective *independent* mitigation layers that for the assessed scenario can prevent losses regardless failure cause.
Medium	At least one effective *independent* mitigation layer that for the assessed scenario can prevent losses regardless failure cause.
Moderate	At least one *internal* mitigation layer that can prevent losses from random *hardware* failures. The control function has additional capacities for self-recovery from other types of failures, however, for the assessed scenario these are not effective regardless failure cause.
Low	The control function has some capacities for self-recovery, however for the assessed scenario these are expected to have a limited effect.

(Source: DNV, 2021)

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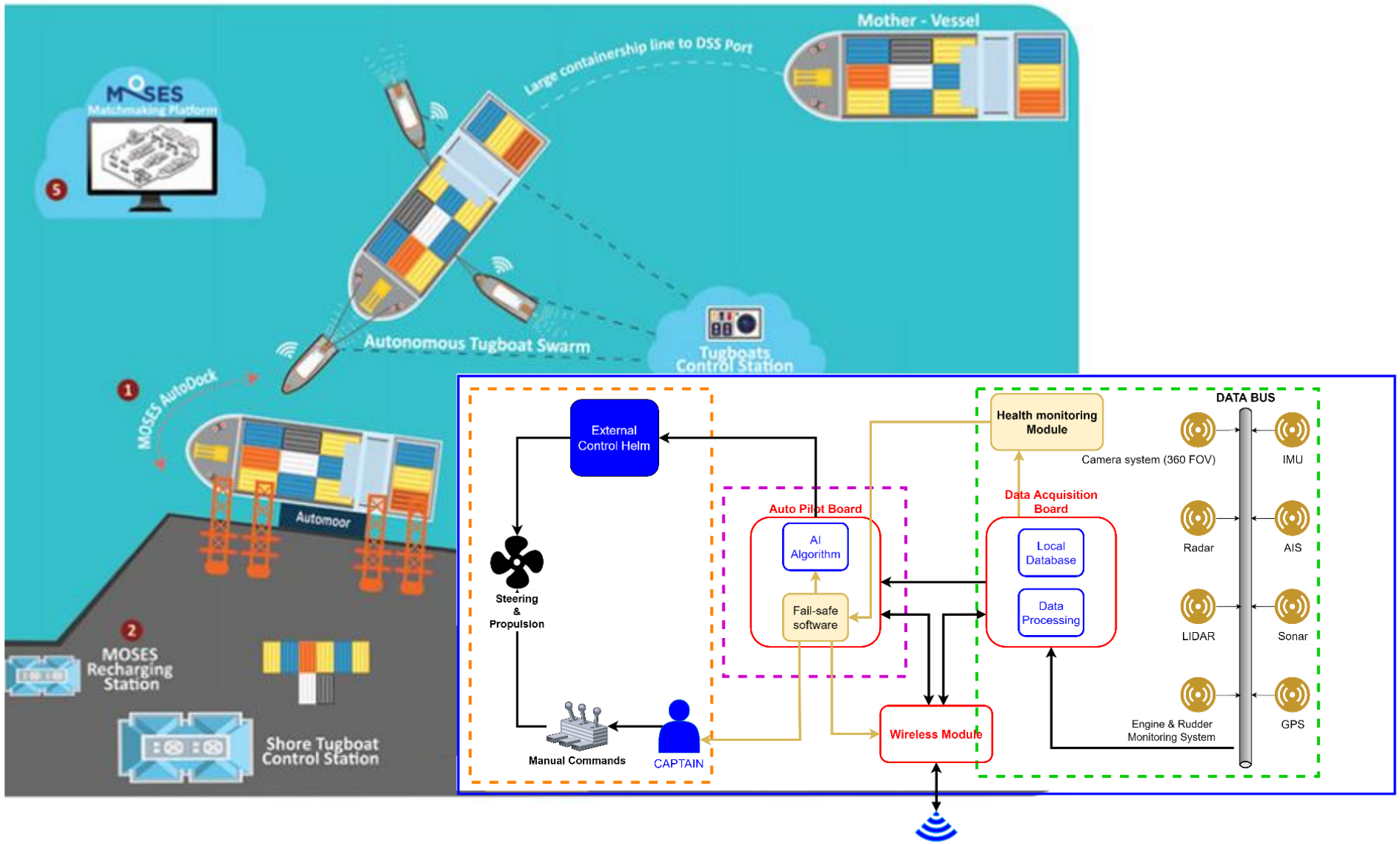
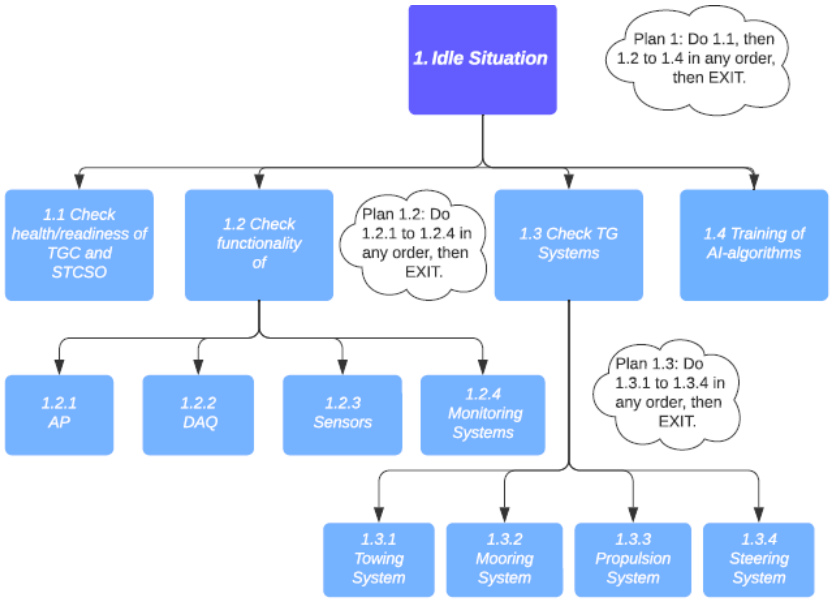
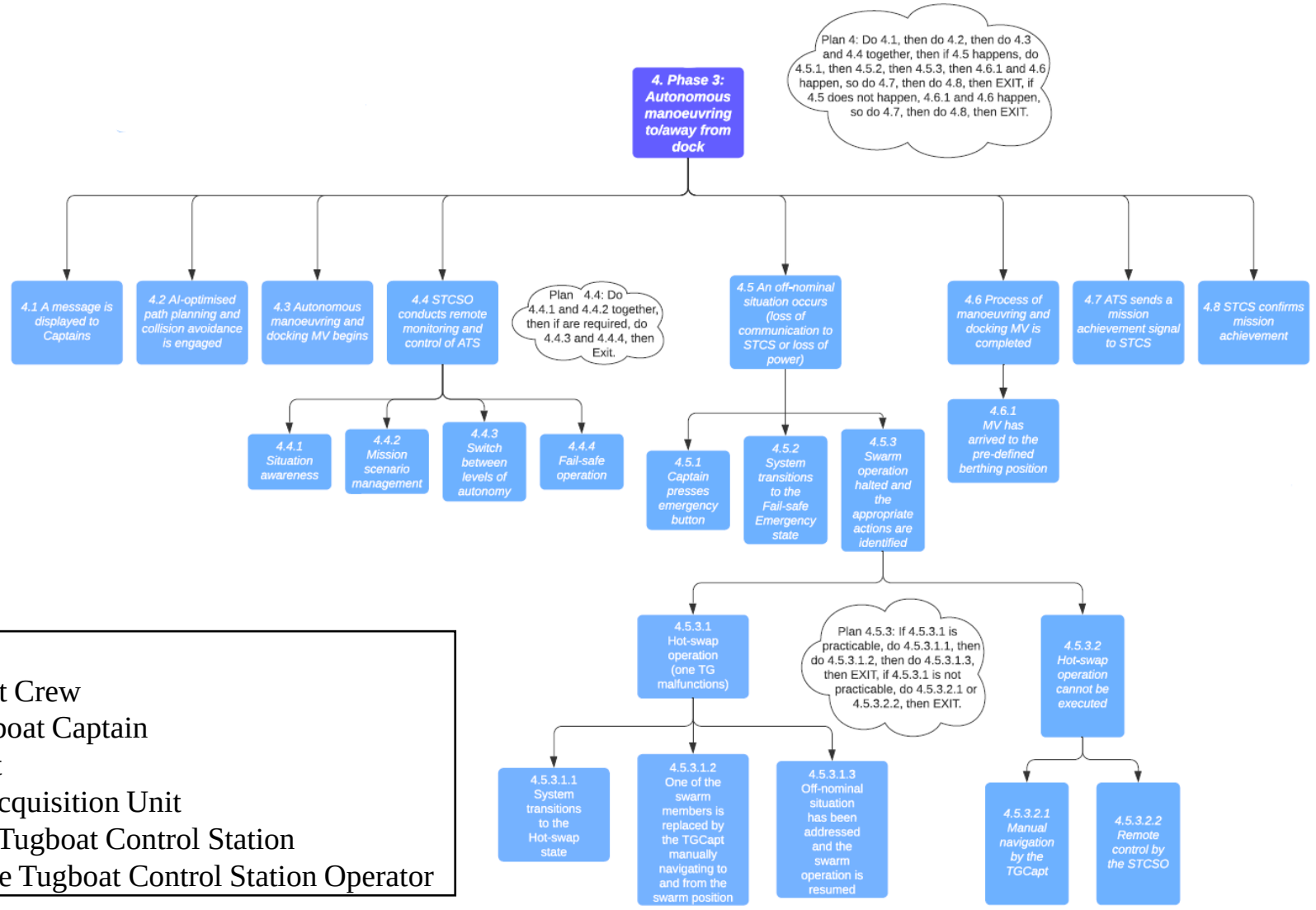
Case Study (Autonomous Tug swarm)



(MOSES EU project)

Case Study (HTA Diagram)





Plan types:

- Linear
- Non-Linear
- Simultaneous
- Branching
- Selection

TG: Tugboat
TGC: Tugboat Crew
TGCapt: Tugboat Captain
AP: AutoPilot
DAQ: Data Acquisition Unit
STCS: Shore Tugboat Control Station
STCSO: Shore Tugboat Control Station Operator

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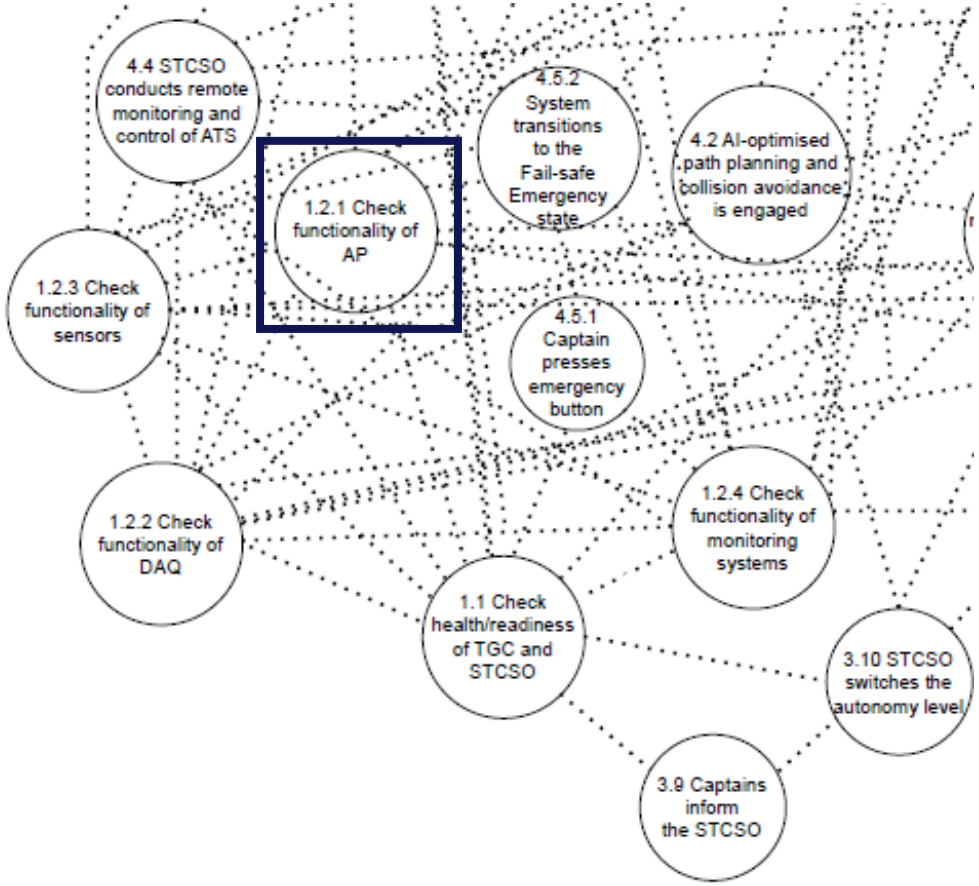
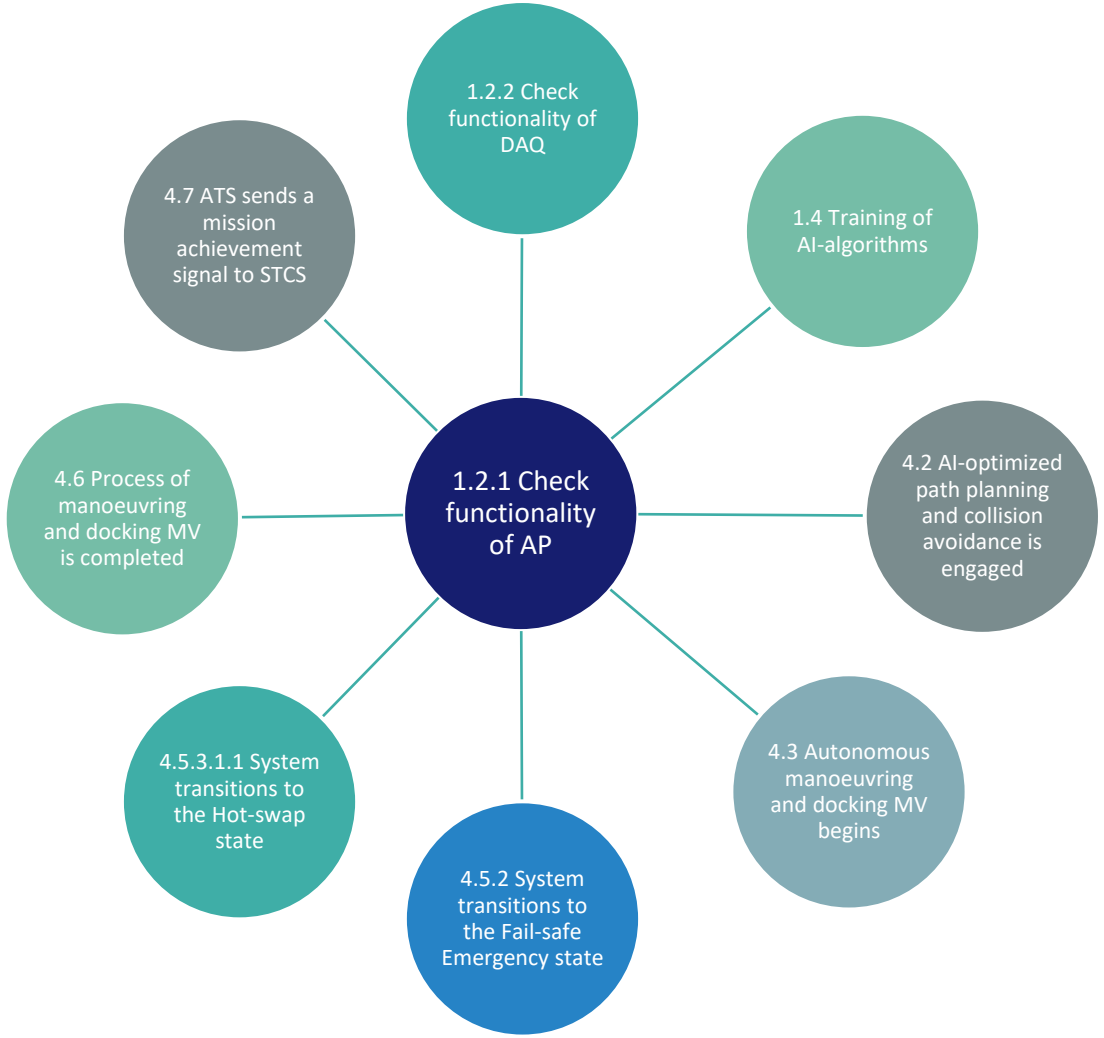
Case Study (Task Network)





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Results (Identification of Task Risks)

Behaviour	Risk Modes
Task	T1 – Task mistimed T2 – Task omitted T3 – Task completed inadequately T4 – Inadequate task object T5 – Inappropriate task
Communication	C1 – Information not communicated C2 – Wrong information communicated C3 – Inadequate information communicated C4 – Communication mistimed
Environmental	E1 – Adverse environmental con ditions

HTA Sub-goal	Risk Mode	Task Risk Description	Task Risk Consequences
1.1 Check adequacy/health/ readiness of TGC and STCSO	T1	The check of the training-familiarization level of crew/captains/STCSO was done before the end of the training induction.	It is not quaranteed that TGC and STCSO are adequately trained.
	T2	The check of the training-familiarization level of crew/captains/STCSO was not done.	It is not quaranteed that TGC and STCSO are trained.
	T2	The check of TGC was not done.	Some of the members may not be healthy/ready for the process.
	T2	The check of STCSO was not done.	STCSO may not be healthy/ready for the process.
	T3	The check of the training-familiarization level of crew/captains/STCSO was inadequately done.	It is not quaranteed that TGC and STCSO are adequately trained.
	T3	The check of TGC was done only once.	TGC may face issues after the check.
	T3	The check of STCSO was done only once.	STCSO may face issues after the check.
4.2 AI-optimised path planning and collision avoidance is engaged	T1	AI-optimised path planning and collision avoidance is engaged too late.	Potential for incorrect or not optimised path planning and implementation. Potential for collision with static or dynamic obstacles.
	T2	AI-optimised path planning and collision avoidance is not engaged.	
4.4 STCSO conducts remote monitoring and control of ATS	T1	Remote monitoring and control of ATS delayed.	STCSO has not the situation awareness. STCSO does not manage mission scenario. STCSO is not ready to switch between levels of autonomy. STCSO is not ready for a fail-safe operation.
	T2	STCSO does not conduct remote monitoring and control of ATS.	
	T3	STCSO conducts remote monitoring and control of ATS inappropriately.	
	T4	MS are inadequate.	

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Results (Identification of Emergent Risks)

Emergent Risks:

- ‘What is the impact of this risk happening at task X on the related task Y?’
- Risks that surface due to the interplay of risks identified in the previous stage *(Salmon et al. 2022)*.

Risk Mode	Task Risk Description	Related Task	Emergent Risk Mode	Emergent Risk Description	Emergent Risk Consequences	Em.Risk Sev.	Em. Risk Mit. Eff.	Emergent Risk Level
T1/C4	The functionality of AP was checked very quickly.	4.2 AI-optimised path planning and collision avoidance is engaged	T1	AI-optimised path planning and collision avoidance is engaged too late.	Potential for incorrect or not optimised path planning and implementation. Potential for collision with static or dynamic obstacles.	Severe	High	Medium
T2	The functionality of AP was not checked.							
T3	The functionality of AP was checked only once.							
T4	The functionality of AP was checked by a inadequately trained member.							
C1	Information not communicated or gathered by the person who checked the functionality of AP.		T2	AI-optimised path planning and collision avoidance is not engaged.		Severe	High	Medium
C2	Wrong information communicated regarding the functionality of AP.							
C3	Insufficient information communicated regarding the functionality of AP.							
T1/C4	The functionality of AP was checked very quickly.	4.3 Autonomous manoeuvring and docking MV begins	T1	The beginning of the autonomous manoeuvring and docking has been delayed.	Potential traffic caused by MV's delayed docking/undocking.	Minor	High	Low
T2	The functionality of AP was not checked.							
T3	The functionality of AP was checked only once.							
T4	The functionality of AP was checked by a inadequately trained member.							
C1	Information not communicated or gathered by the person who checked the functionality of AP.		T2	Autonomous manoeuvring and docking MV does not begin.	Autonomous manoeuvring and docking MV can not be completed. Potential traffic caused by MV's non docking/undocking.	Severe	High	Medium
C2	Wrong information communicated regarding the functionality of AP.							
C3	Insufficient information communicated regarding the functionality of AP.							

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Conclusions

- NET-HARMS Methodology: Effective for hazard identification and risk assessment in MASS, covering all autonomy levels.
- Application to Case study: Addresses safety for varying autonomy levels and human roles.
- Challenges: Insufficient data for final probability calculations, time-consuming, and risk repetition.
- RBAT Combination: Addresses the gap in NET-HARMS at the stage of calculating the probability.

Future research:

- Validation and improvement of NET-HARMS, focus on risks of autonomous and remotely operated ships.
- Consideration of the conditional probability dependence between task risks and emergent risks.

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