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An assessment of the potential impact of unmanned vessels on maritime transportation safety

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ISSAV, TU Delft, 21.03.2018

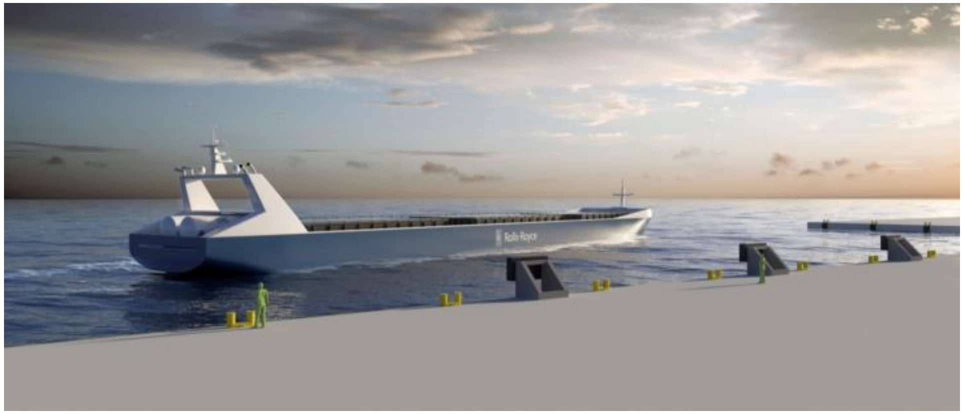
Agenda

- **Introduction**
- **Methods suitable for safety assessment and results obtained**
  - What-if analysis
  - Causal model
  - System-theoretic approach
- **Discussion**
- **Concluding remarks**

Introduction

Unnamed vessels:

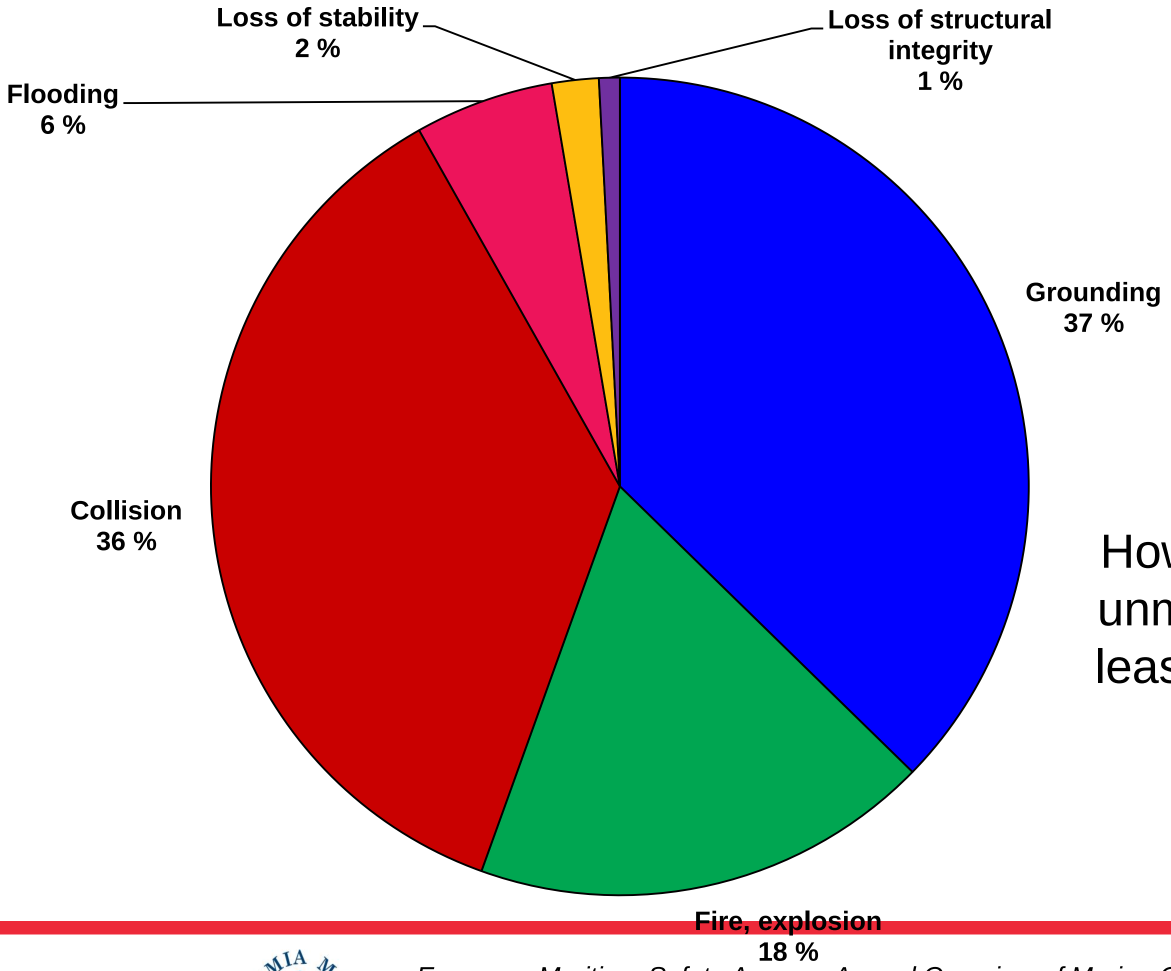
- Expected to enter into operation by the mid of next decade
- No or extremely limited crew on board
- Operating by remote control or autonomously
- Highly-advanced technology
- Environmentally friendly
- Cost-effective
- Safe?



AAWA. (2016). Remote and Autonomous Ships The next steps. London.

Introduction

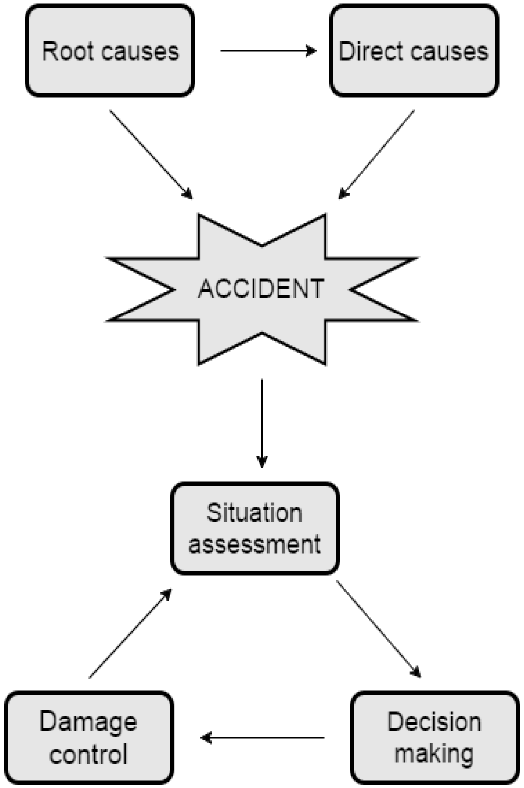
’Manned’ shipping accidents by type - global values



How to ensure that unmanned ships at least do not reduce the safety of maritime transportation?

European Maritime Safety Agency. Annual Overview of Marine Casualties and Incidents 2014. Lisbon: 2015.

What-if analysis of autonomous vessels' safety



WHAT-IF ANALYSIS

EVALUATION OF UNMANNED SHIP'S ACCIDENT'S LIKELIHOOD:

1. Assess qualitatively the potential occurrence of each HFACS-MA causal category in future maritime accidents where unmanned ships are involved;
2. Review historical accident reports for manned ships to determine the causal factor(s) leading to the accidents;
3. Attribute each defined causal factor to causal categories as per HFACS-MA;
4. Assess qualitatively the impact of the unmanned ships' introduction on accident's likelihood, based on knowledge extracted in Step 3 and classification scheme in Step 1.

EVALUATION OF ACCIDENT'S CONSEQUENCES:

1. Determine impact on unmanned ship's accident output based on outcome factors.

LIKELIHOOD AND CONSEQUENCES ASSESSMENT

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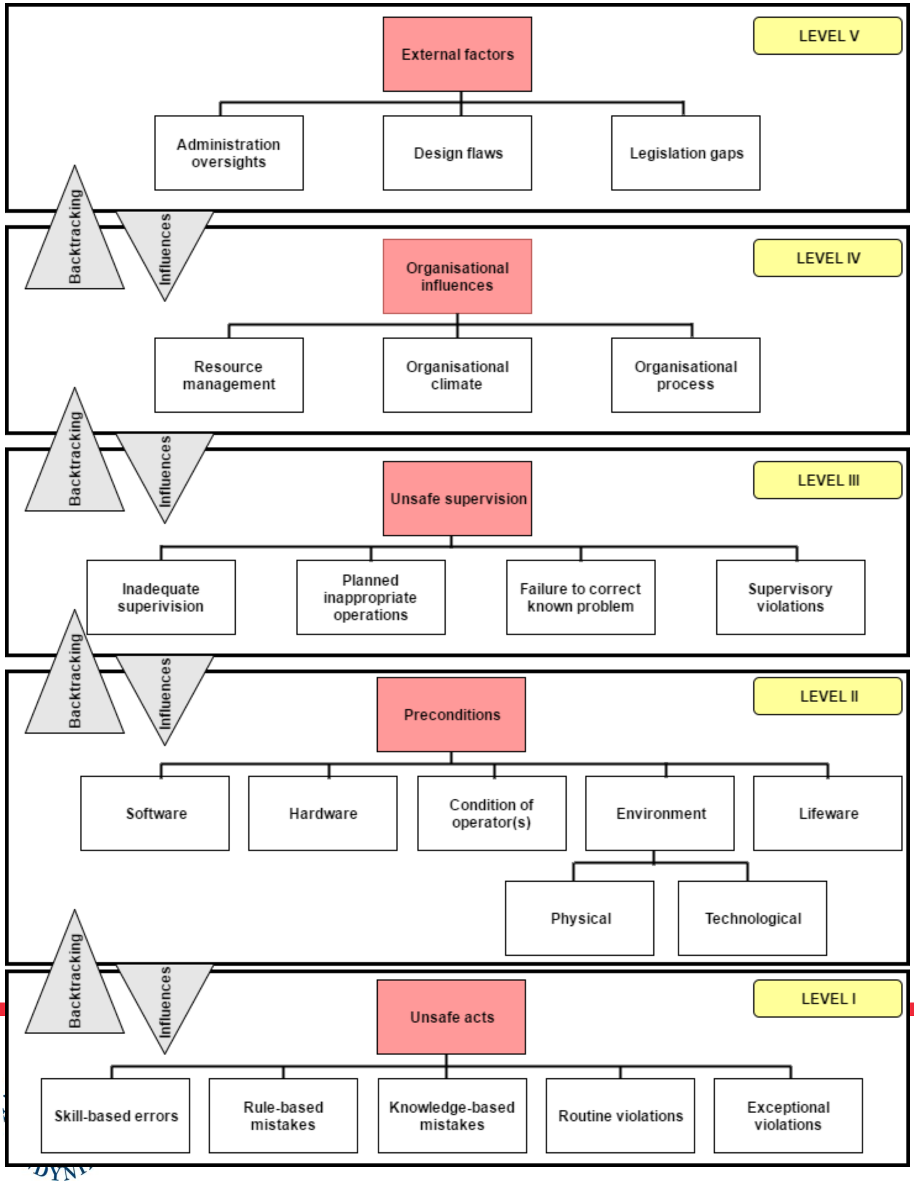
K. Wróbel, J. Montewka, and P. Kujala, "Towards the assessment of potential impact of unmanned vessels on maritime transportation safety," Reliab. Eng. Syst. Saf., vol. 165, no. September, pp. 155–169, 2017.

What-if analysis – accident likelihood

The overview of HFACS-MA framework applied



LEVEL V

External factors

Administration oversights

Design flaws

Legislation gaps

Backtracking

Influences

LEVEL IV

Organisational influences

Resource management

Organisational climate

Organisational process

Backtracking

Influences

LEVEL III

Unsafe supervision

Inadequate superivision

Planned inappropriate operations

Failure to correct known problem

Supervisory violations

Backtracking

Influences

LEVEL II

Preconditions

Software

Hardware

Condition of operator(s)

Environment

Lifeware

Physical

Technological

Backtracking

Influences

LEVEL I

Unsafe acts

Skill-based errors

Rule-based mistakes

Knowledge-based mistakes

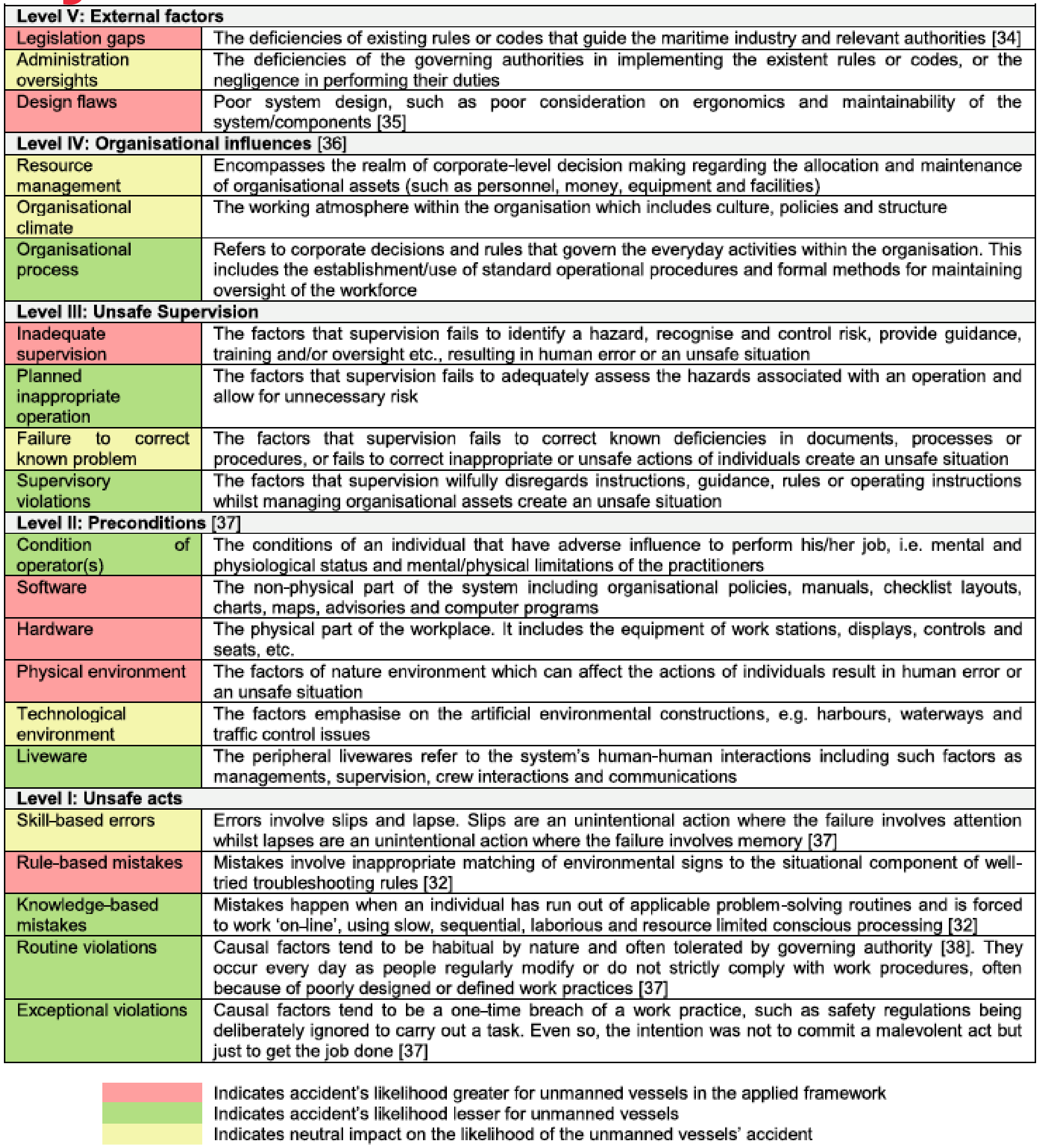
Routine violations

Exceptional violations

K. Wróbel, J. Montewka, and P. Kujala, "Towards the assessment of potential impact of unmanned vessels on maritime transportation safety," Reliab. Eng. Syst. Saf., vol. 165, no. September, pp. 155–169, 2017.

What-if analysis – accident likelihood

Brief description of HFACS-MA causal categories applied



Level V: External factors	
🟥 Legislation gaps	The deficiencies of existing rules or codes that guide the maritime industry and relevant authorities [34]
🟨 Administration oversights	The deficiencies of the governing authorities in implementing the existent rules or codes, or the negligence in performing their duties
🟥 Design flaws	Poor system design, such as poor consideration on ergonomics and maintainability of the system/components [35]
Level IV: Organisational influences [36]	
🟨 Resource management	Encompasses the realm of corporate-level decision making regarding the allocation and maintenance of organisational assets (such as personnel, money, equipment and facilities)
🟨 Organisational climate	The working atmosphere within the organisation which includes culture, policies and structure
🟩 Organisational process	Refers to corporate decisions and rules that govern the everyday activities within the organisation. This includes the establishment/use of standard operational procedures and formal methods for maintaining oversight of the workforce
Level III: Unsafe Supervision	
🟥 Inadequate supervision	The factors that supervision fails to identify a hazard, recognise and control risk, provide guidance, training and/or oversight etc., resulting in human error or an unsafe situation
🟩 Planned inappropriate operation	The factors that supervision fails to adequately assess the hazards associated with an operation and allow for unnecessary risk
🟨 Failure to correct known problem	The factors that supervision fails to correct known deficiencies in documents, processes or procedures, or fails to correct inappropriate or unsafe actions of individuals create an unsafe situation
🟩 Supervisory violations	The factors that supervision wilfully disregards instructions, guidance, rules or operating instructions whilst managing organisational assets create an unsafe situation
Level II: Preconditions [37]	
🟩 Condition of operator(s)	The conditions of an individual that have adverse influence to perform his/her job, i.e. mental and physiological status and mental/physical limitations of the practitioners
🟥 Software	The non-physical part of the system including organisational policies, manuals, checklist layouts, charts, maps, advisories and computer programs
🟥 Hardware	The physical part of the workplace. It includes the equipment of work stations, displays, controls and seats, etc.
🟥 Physical environment	The factors of nature environment which can affect the actions of individuals result in human error or an unsafe situation
🟨 Technological environment	The factors emphasise on the artificial environmental constructions, e.g. harbours, waterways and traffic control issues
🟩 Liveware	The peripheral livewares refer to the system's human-human interactions including such factors as managements, supervision, crew interactions and communications
Level I: Unsafe acts	
🟨 Skill-based errors	Errors involve slips and lapse. Slips are an unintentional action where the failure involves attention whilst lapses are an unintentional action where the failure involves memory [37]
🟥 Rule-based mistakes	Mistakes involve inappropriate matching of environmental signs to the situational component of well-tried troubleshooting rules [32]
🟩 Knowledge-based mistakes	Mistakes happen when an individual has run out of applicable problem-solving routines and is forced to work 'on-line', using slow, sequential, laborious and resource limited conscious processing [32]
🟩 Routine violations	Causal factors tend to be habitual by nature and often tolerated by governing authority [38]. They occur every day as people regularly modify or do not strictly comply with work procedures, often because of poorly designed or defined work practices [37]
🟩 Exceptional violations	Causal factors tend to be a one-time breach of a work practice, such as safety regulations being deliberately ignored to carry out a task. Even so, the intention was not to commit a malevolent act but just to get the job done [37]

🟥	Indicates accident's likelihood greater for unmanned vessels in the applied framework
🟩	Indicates accident's likelihood lesser for unmanned vessels
🟨	Indicates neutral impact on the likelihood of the unmanned vessels' accident

K. Wróbel, J. Montewka, and P. Kujala, "Towards the assessment of potential impact of unmanned vessels on maritime transportation safety," Reliab. Eng. Syst. Saf., vol. 165, no. September, pp. 155–169, 2017.

What-if analysis – accident consequences

We assigned the value of ‘consequences **greater for unmanned ships** whenever at least one of the following outcome factors was identified in an accident report:

- crew had to directly intervene by either inspecting ship’s enclosed spaces or manually reconfiguring its sub-systems;
- crew had to cooperate with other actors under pressure of time;
- crew was obligated to assist other seafarers should the vessel they collided with need to be abandoned;
- decisions on further actions could not be efficiently taken from remote command post;
- better maintenance of on board equipment before accident could have limited its outcome.

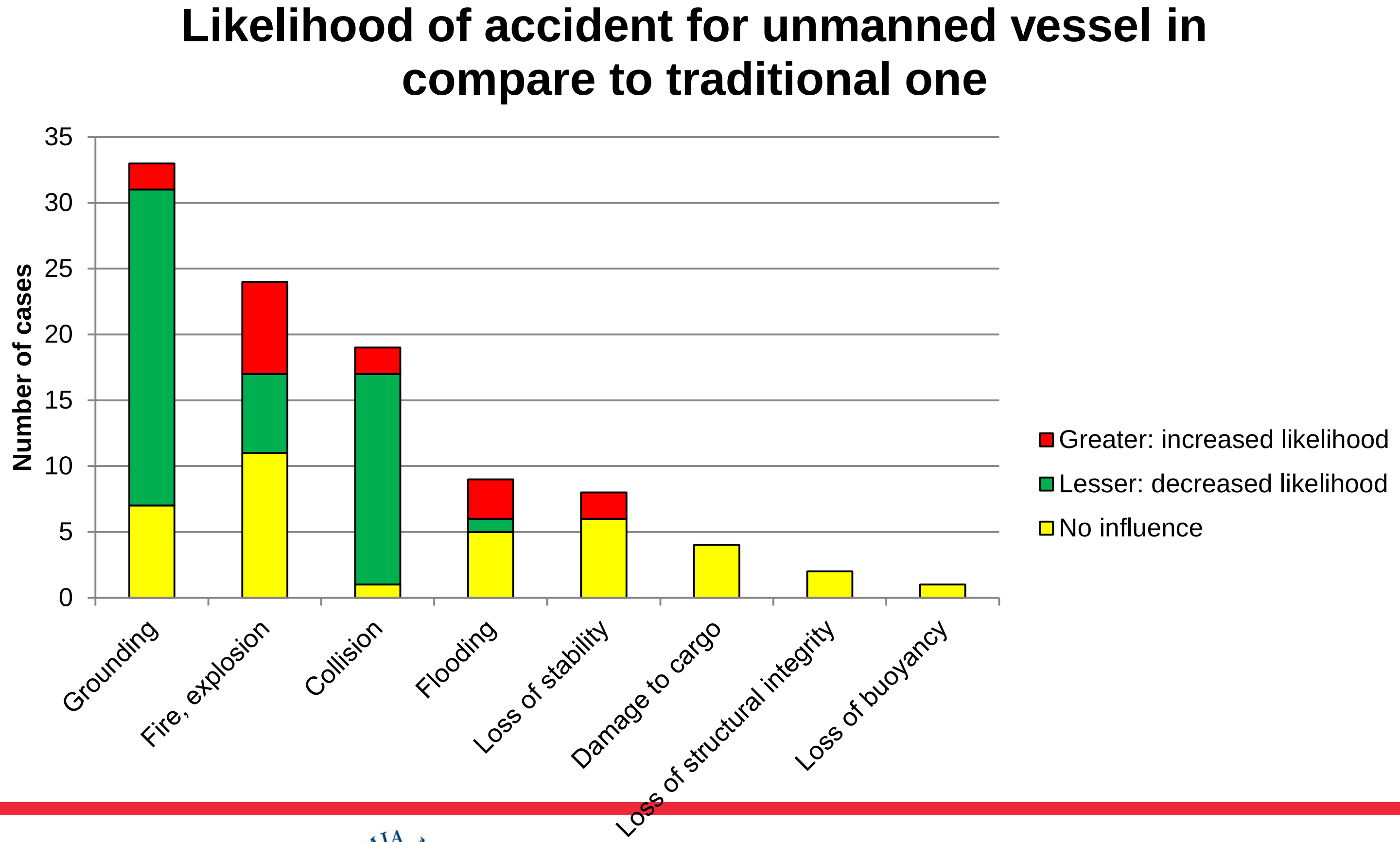
We assigned the value of ‘consequences **lesser for unmanned ships**:

- whenever an accident report mentioned fatalities, serious injury or it was evident that humans’ presence on board during an accident restricted number of possible options of counteracting the effects of accident (e.g. when a person was missing in muster station and so CO_2 could not be released);

Should the circumstances of ‘greater’ and ‘lesser’ outcome occur simultaneously, the value was assigned based on more detailed analysis regarding which of them would be more relevant, with potential for avoiding fatalities greatly lowering the hypothetical consequences.

What-if analysis – results

How will the autonomous vessels affect maritime safety?



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What-if analysis – results

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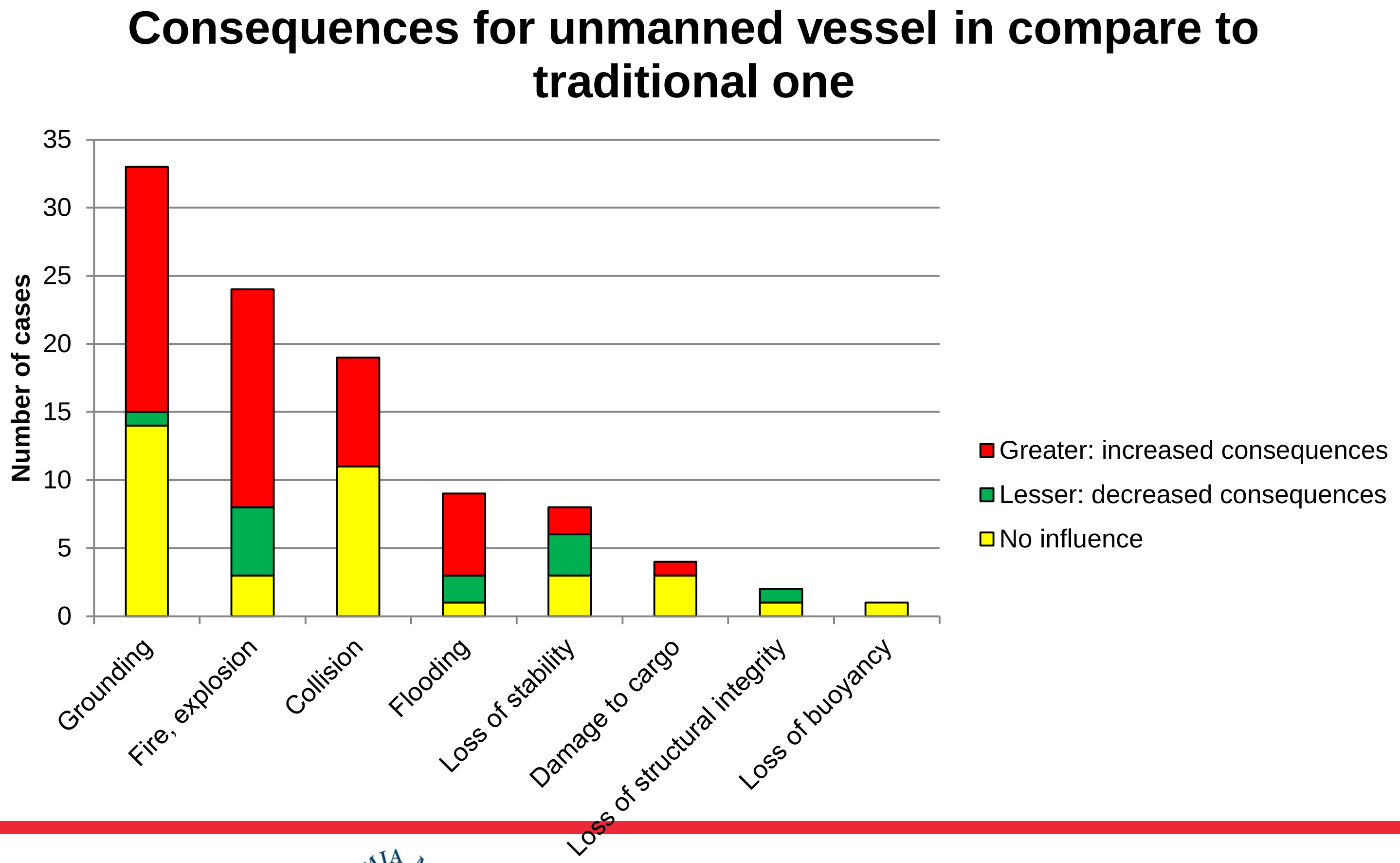

K. Wróbel, J. Montewka, and P. Kujala, “Towards the assessment of potential impact of unmanned vessels on maritime transportation safety,” Reliab. Eng. Syst. Saf., vol. 165, no. September, pp. 155–169, 2017.

What-if analysis – results

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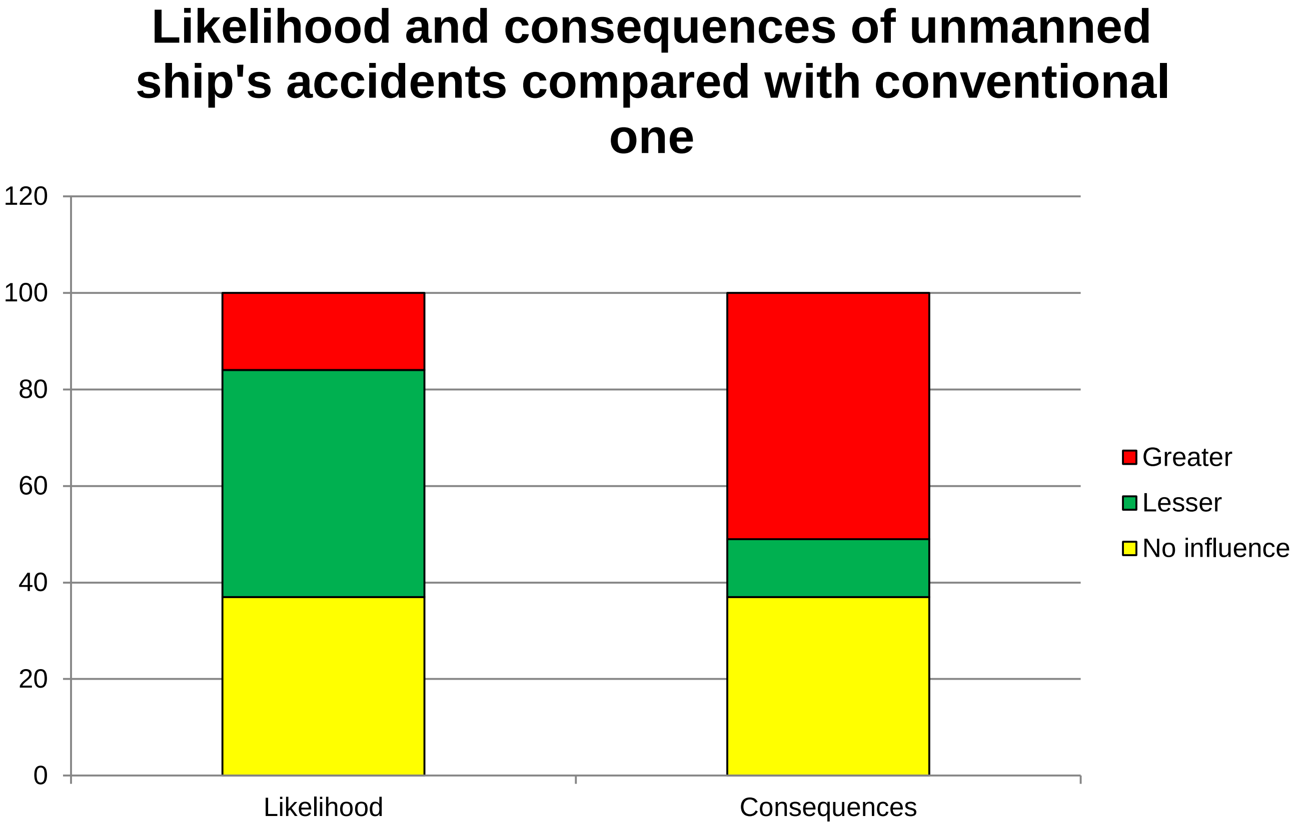
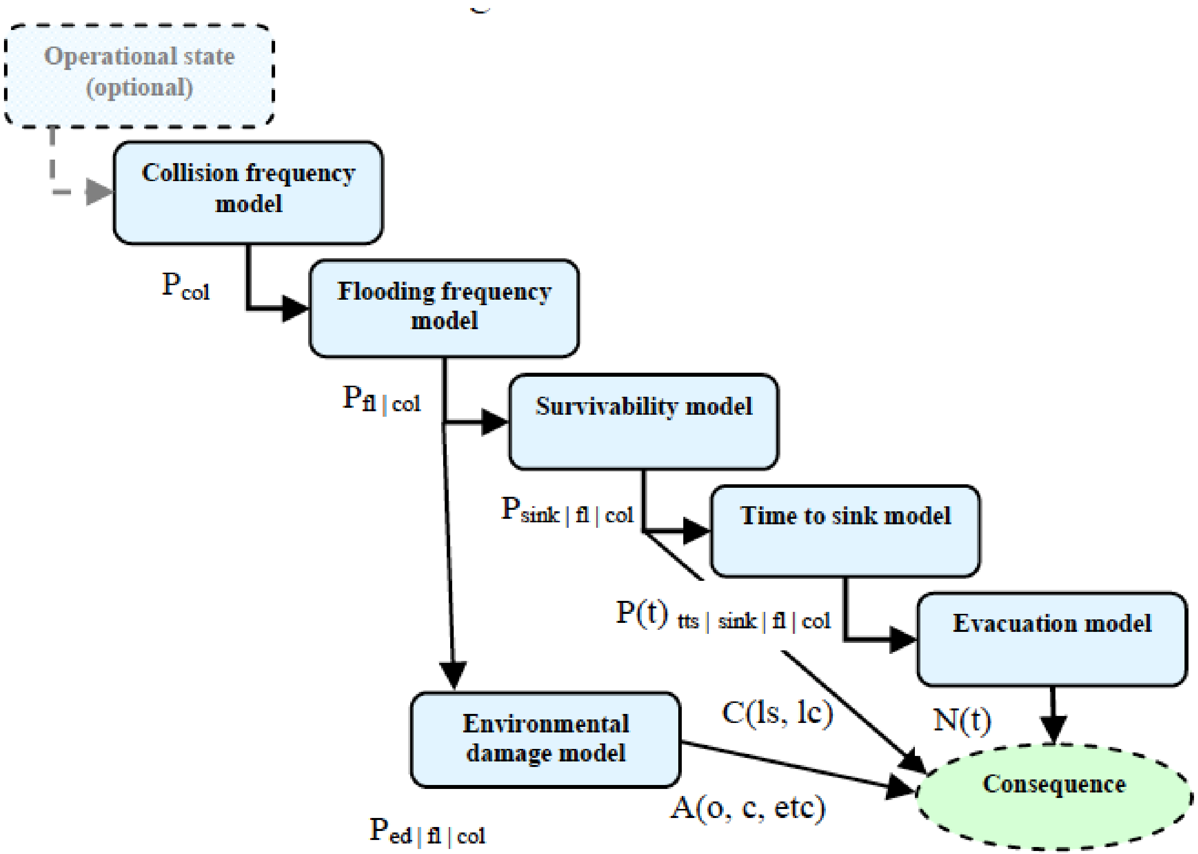


K. Wróbel, J. Montewka, and P. Kujala, “Towards the assessment of potential impact of unmanned vessels on maritime transportation safety,” *Reliab. Eng. Syst. Saf.*, vol. 165, no. September, pp. 155–169, 2017.

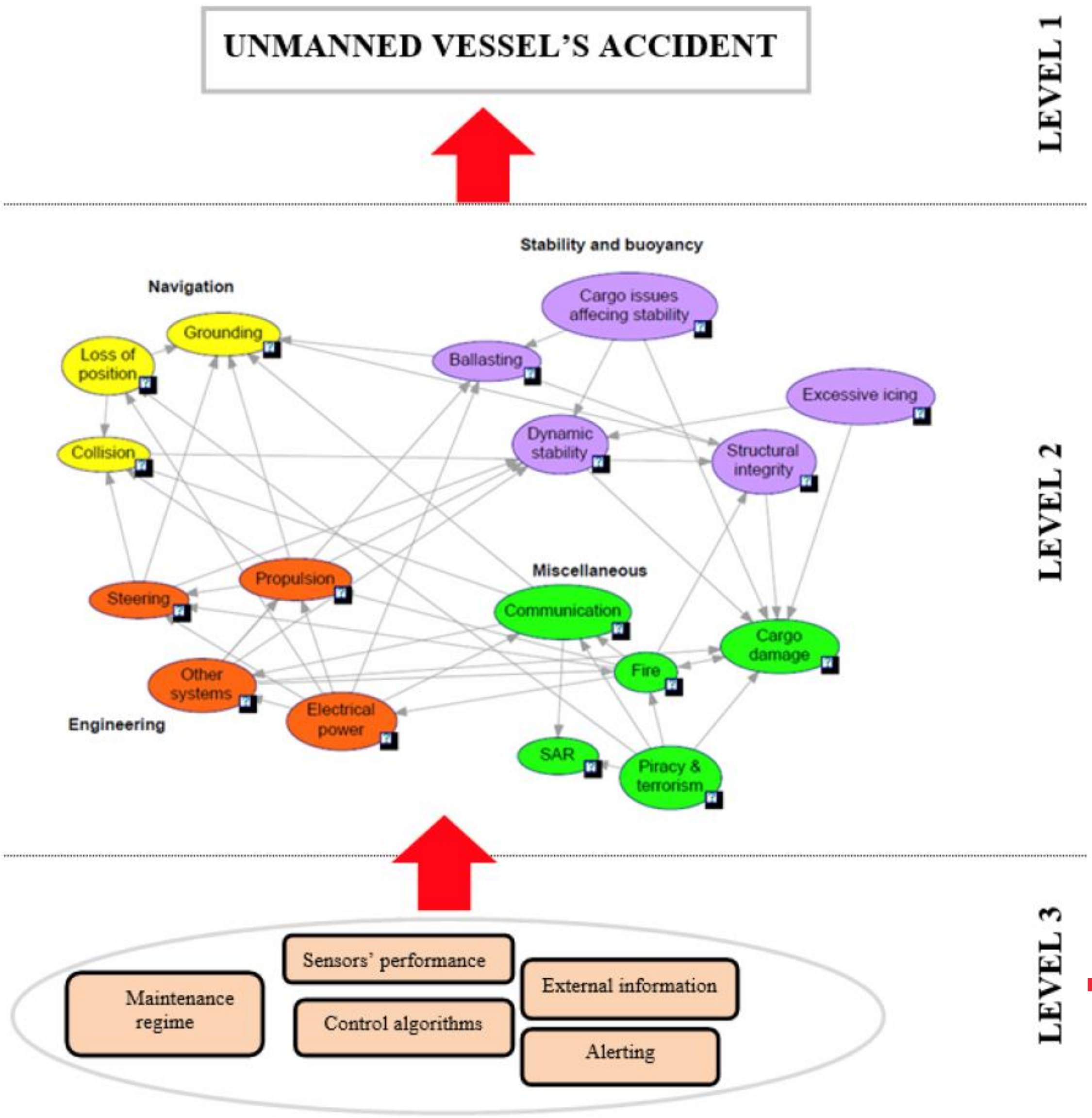
Causal risk model

A standarized risk model for ship-ship collision



E. Vanem, R. Puisa, and R. Skjong, "Standardized Risk Models for Formal Safety Assessment of Maritime Transportation," in Proceedings of the ASME 28th International Conference on Ocean, Offshore and Arctic Engineering OMAE, 2009, pp. 51–61.

Causal risk model



- Model of potential failure propagation during the autonomous vessel's accident

- Model allows for safety quantification in terms of risk level

- Major challenge – lack of data

- Other (qualitative) methods may be better to elaborate on safety and the ways to control it

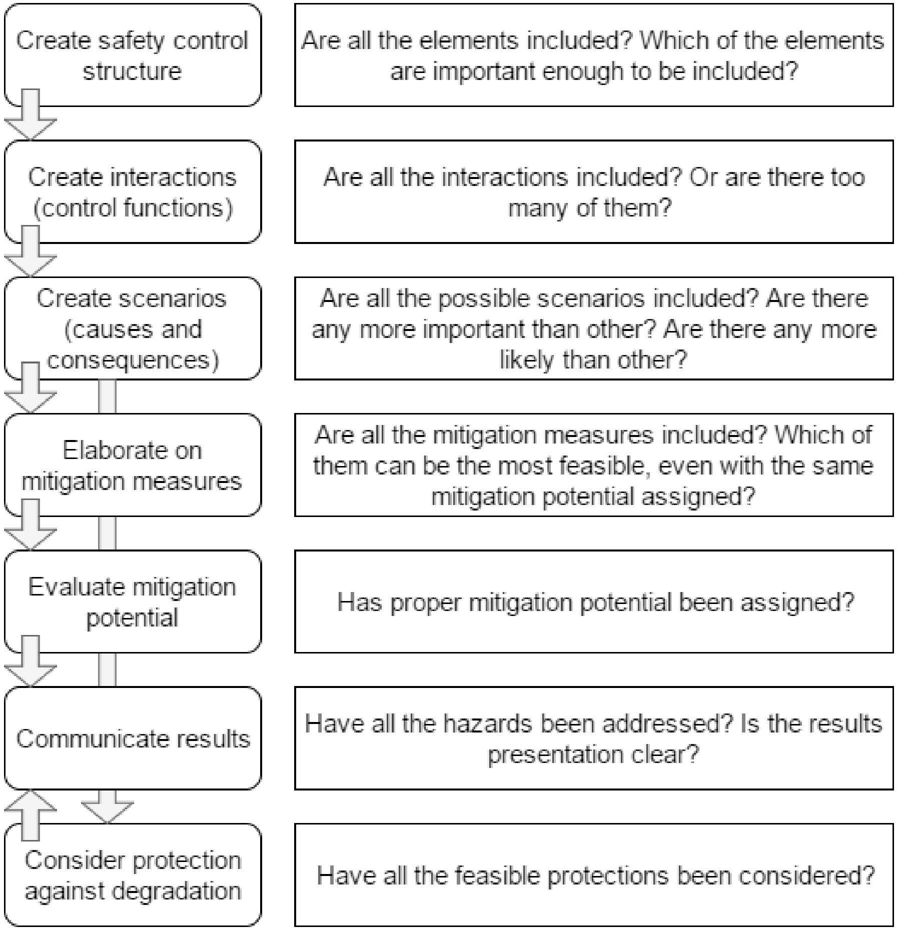
K. Wrobel, P. Krata, J. Montewka, and T. Hinz, "Towards the Development of a Risk Model for Unmanned Vessels Design and Operations," TransNav, Int. J. Mar. Navig. Saf. Sea Transp., vol. 10, no. 2, pp. 267–274, 2016.

Systemic approach to control the safety

System-Theoretic Process Analysis (STPA) is a method of assessing system’s safety by analysing the interactions between its components and the ways in which those can be unsafe.

The nature of such interactions shall ensure that the system as a whole remains within safety limits.

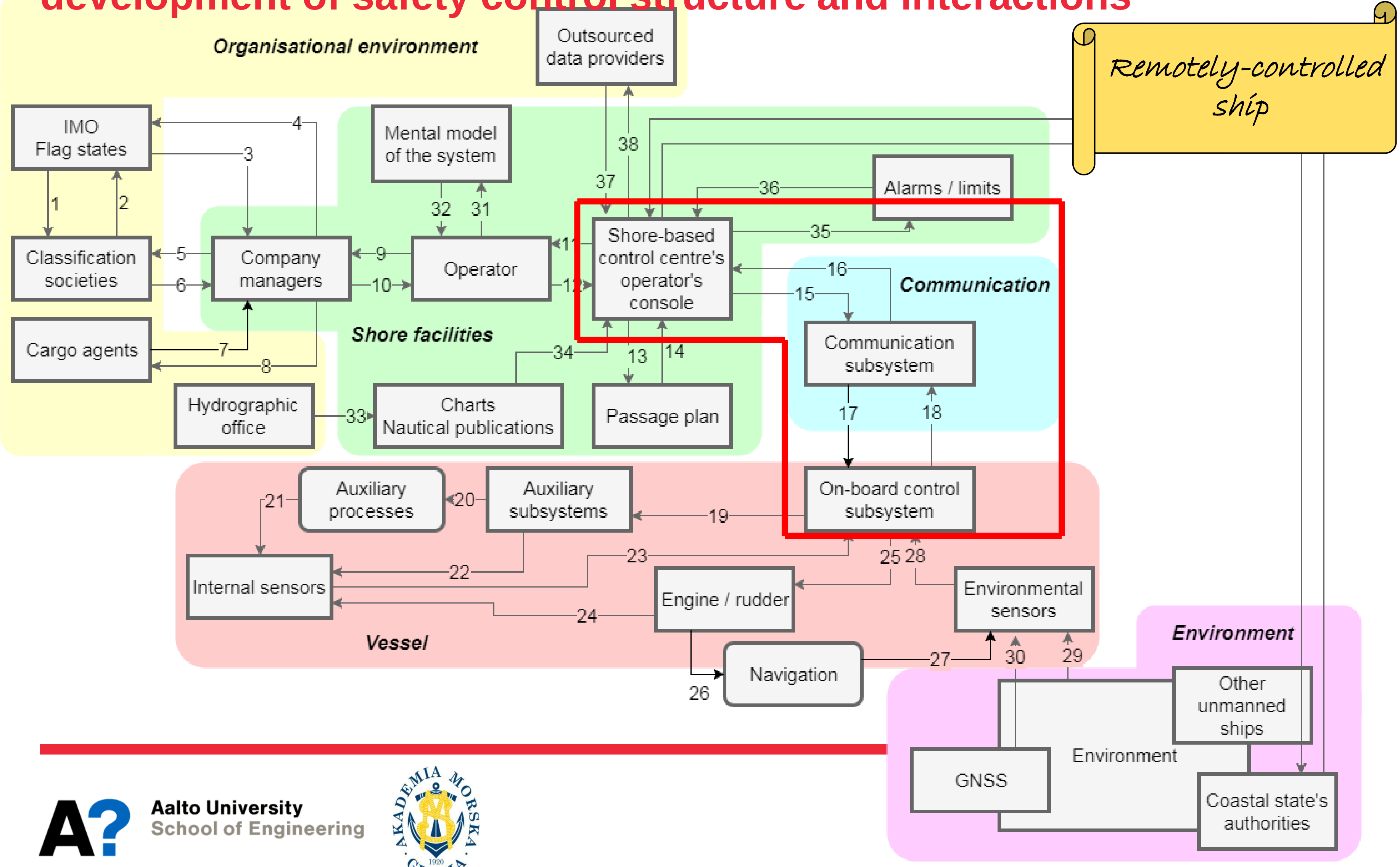
The aim is **not to quantify the safety** (mainly due to lack of data) **but to ensure that it is controlled in proper manner**.



Create safety control structure	Are all the elements included? Which of the elements are important enough to be included?
Create interactions (control functions)	Are all the interactions included? Or are there too many of them?
Create scenarios (causes and consequences)	Are all the possible scenarios included? Are there any more important than other? Are there any more likely than other?
Elaborate on mitigation measures	Are all the mitigation measures included? Which of them can be the most feasible, even with the same mitigation potential assigned?
Evaluate mitigation potential	Has proper mitigation potential been assigned?
Communicate results	Have all the hazards been addressed? Is the results presentation clear?
Consider protection against degradation	Have all the feasible protections been considered?

Systemic approach to control the safety –

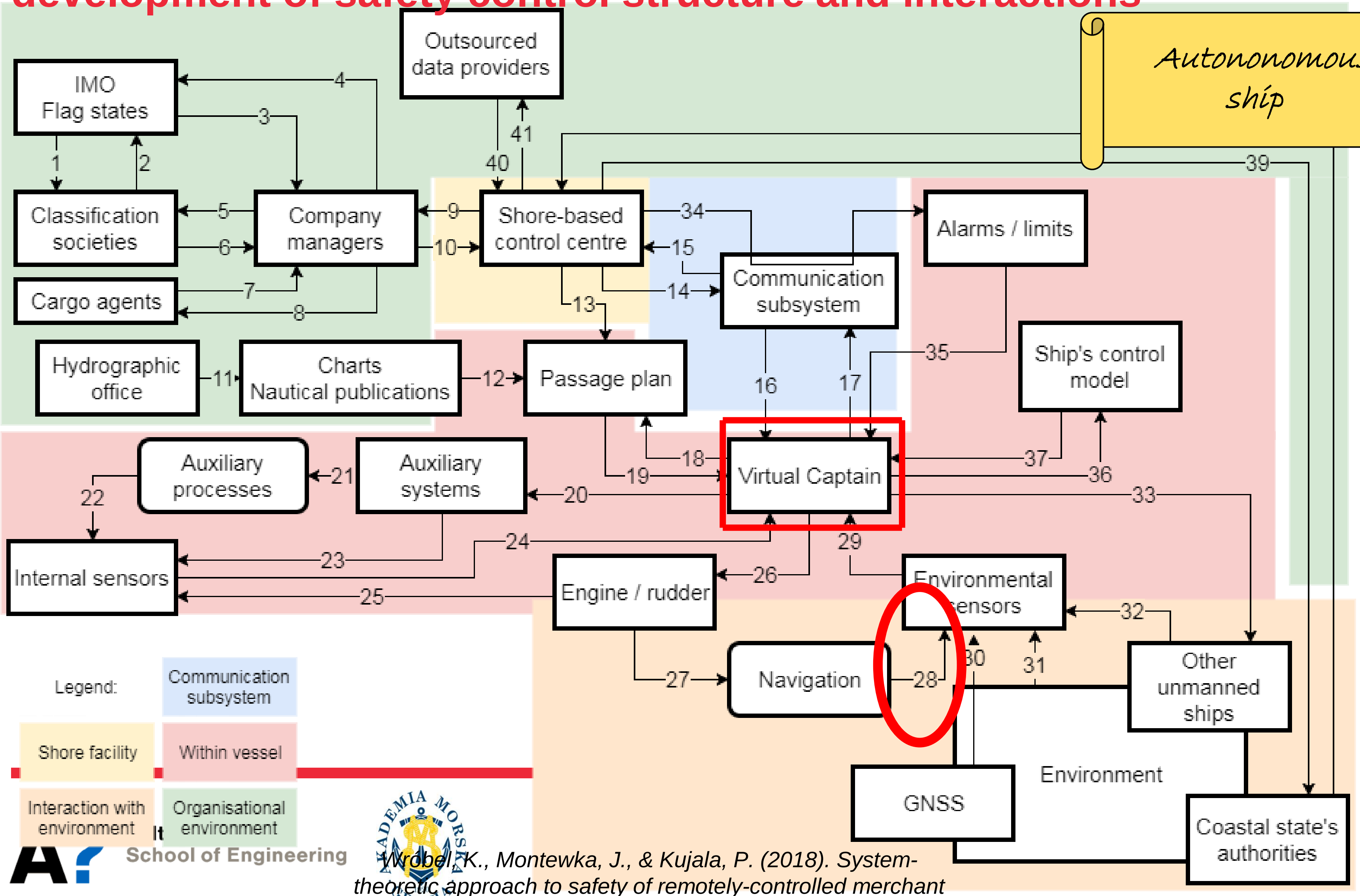
development of safety control structure and interactions



Wróbel, K., Montewka, J., & Kujala, P. (2018). System-theoretic approach to safety of remotely-controlled merchant vessel. Ocean Engineering, 152, 334–345.

Systemic approach to control the safety –

development of safety control structure and interactions

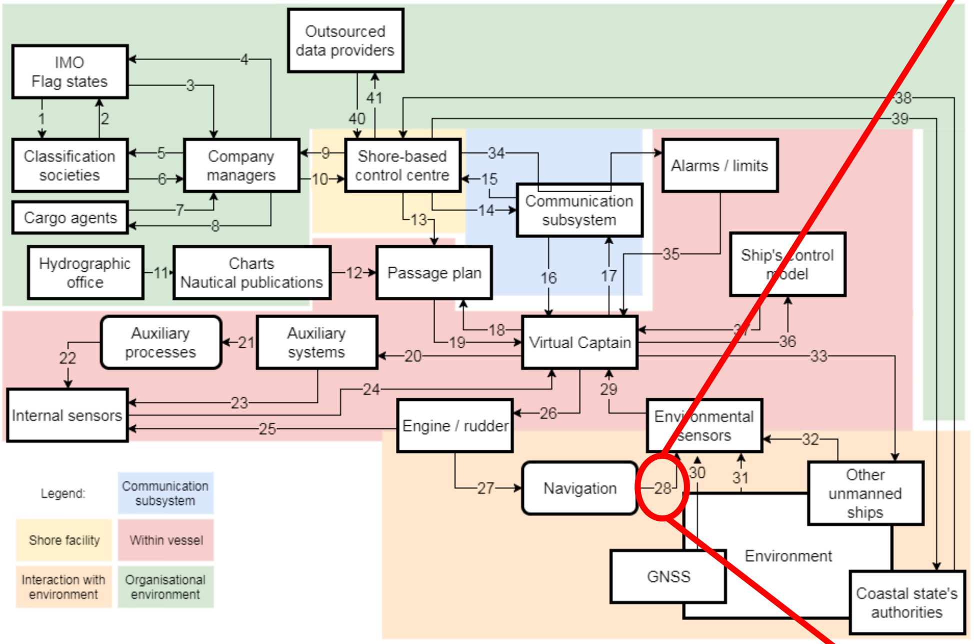


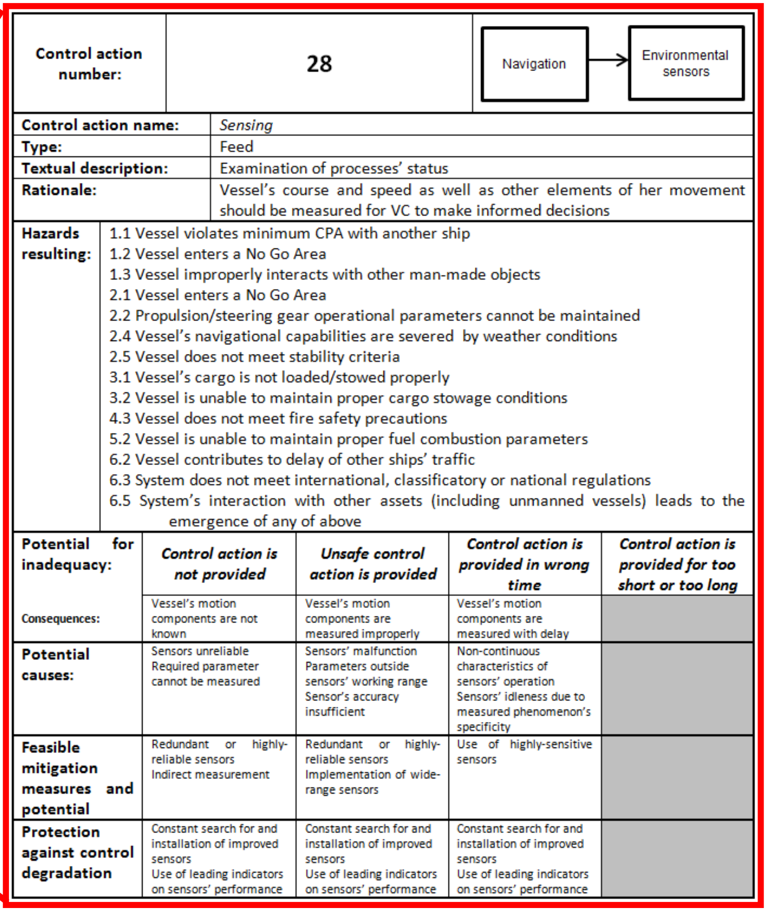
Autononomous ship

Wróbel, K., Montewka, J., & Kujala, P. (2018). System-theoretic approach to safety of remotely-controlled merchant vessel. Ocean Engineering, 152, 334–345.

Systemic approach to control the safety –

elaboration on mitigation measures and potential





Control action number:	**28**		Navigation → Environmental sensors	
Control action name:	*Sensing*			
Type:	Feed			
Textual description:	Examination of processes' status			
Rationale:	Vessel's course and speed as well as other elements of her movement should be measured for VC to make informed decisions			
Hazards resulting:	1.1 Vessel violates minimum CPA with another ship 1.2 Vessel enters a No Go Area 1.3 Vessel improperly interacts with other man-made objects 2.1 Vessel enters a No Go Area 2.2 Propulsion/steering gear operational parameters cannot be maintained 2.4 Vessel's navigational capabilities are severed by weather conditions 2.5 Vessel does not meet stability criteria 3.1 Vessel's cargo is not loaded/stowed properly 3.2 Vessel is unable to maintain proper cargo stowage conditions 4.3 Vessel does not meet fire safety precautions 5.2 Vessel is unable to maintain proper fuel combustion parameters 6.2 Vessel contributes to delay of other ships' traffic 6.3 System does not meet international, classificatory or national regulations 6.5 System's interaction with other assets (including unmanned vessels) leads to the emergence of any of above			
Potential for inadequacy:	***Control action is not provided***	***Unsafe control action is provided***	***Control action is provided in wrong time***	***Control action is provided for too short or too long***
Consequences:	Vessel's motion components are not known	Vessel's motion components are measured improperly	Vessel's motion components are measured with delay	
Potential causes:	Sensors unreliable Required parameter cannot be measured	Sensors' malfunction Parameters outside sensors' working range Sensor's accuracy insufficient	Non-continuous characteristics of sensors' operation Sensors' idleness due to measured phenomenon's specificity	
Feasible mitigation measures and potential	Redundant or highly-reliable sensors Indirect measurement	Redundant or highly-reliable sensors Implementation of wide-range sensors	Use of highly-sensitive sensors	
Protection against control degradation	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	Constant search for and installation of improved sensors Use of leading indicators on sensors' performance	

What is it?

Why analysed?

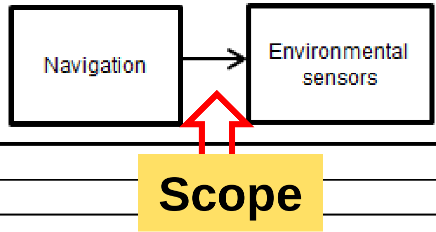
What can be the results of failure?

What can cause a failure?

How can a failure be prevented?

How to make sure that risk does not reappear?

Control action number: 28



Control action name: *Sensing*

Type: Feed

Textual description: Examination of processes' status

Rationale: Vessel's course and speed as well as other elements of her movement should be measured for VC to make informed decisions

Hazards resulting:

1.1 Vessel violates minimum CPA with another ship
1.2 Vessel enters a No Go Area
1.3 Vessel improperly interacts with other man-made objects
2.1 Vessel enters a No Go Area
2.2 Propulsion/steering gear operational parameters cannot be maintained
2.4 Vessel's navigational capabilities are severed by weather conditions
2.5 Vessel does not meet stability criteria
3.1 Vessel's cargo is not loaded/stowed properly
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Potential for inadequacy:	***Control action is not provided***	***Unsafe control action is provided***	***Control action is provided in wrong time***	***Control action is provided for too short or too long***
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Systemic approach to control the safety –

elaboration on mitigation measures and potential

A total of 48 control functions have been analysed with respect to their position within the system structure, potential scenarios leading to their inadequacy and consequences of such.

Furthermore, potential ways of mitigating such inadequacies were elaborated and evaluated by assignment of the mitigation potential.

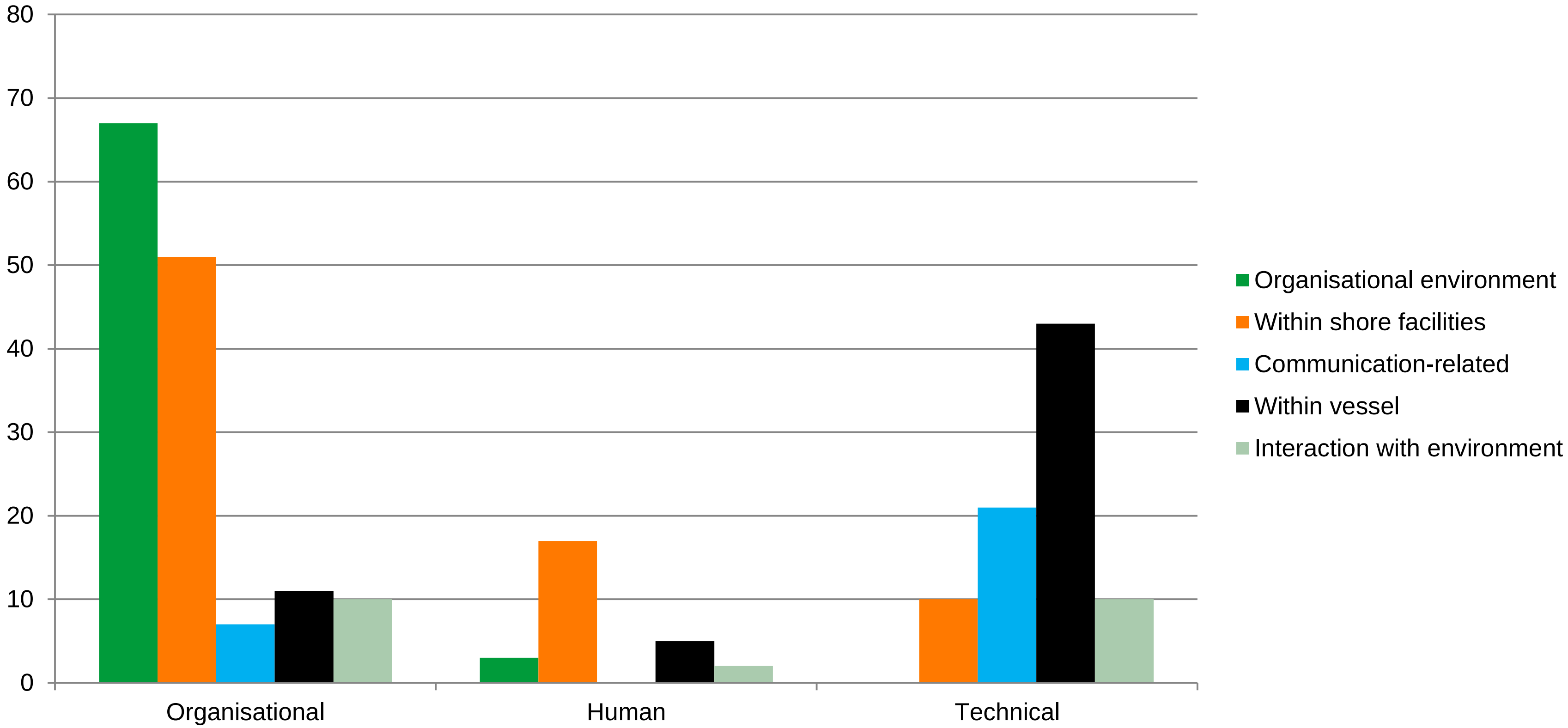
A total of 252 recommendations on mitigation measures implementation have been elaborated, each of them pertaining to one of three groups:

- liveware,
- software,
- hardware.

By 'liveware' we understand all organisational, legal and operational factors in which a human plays a major and direct part.

Systemic approach to control the safety –

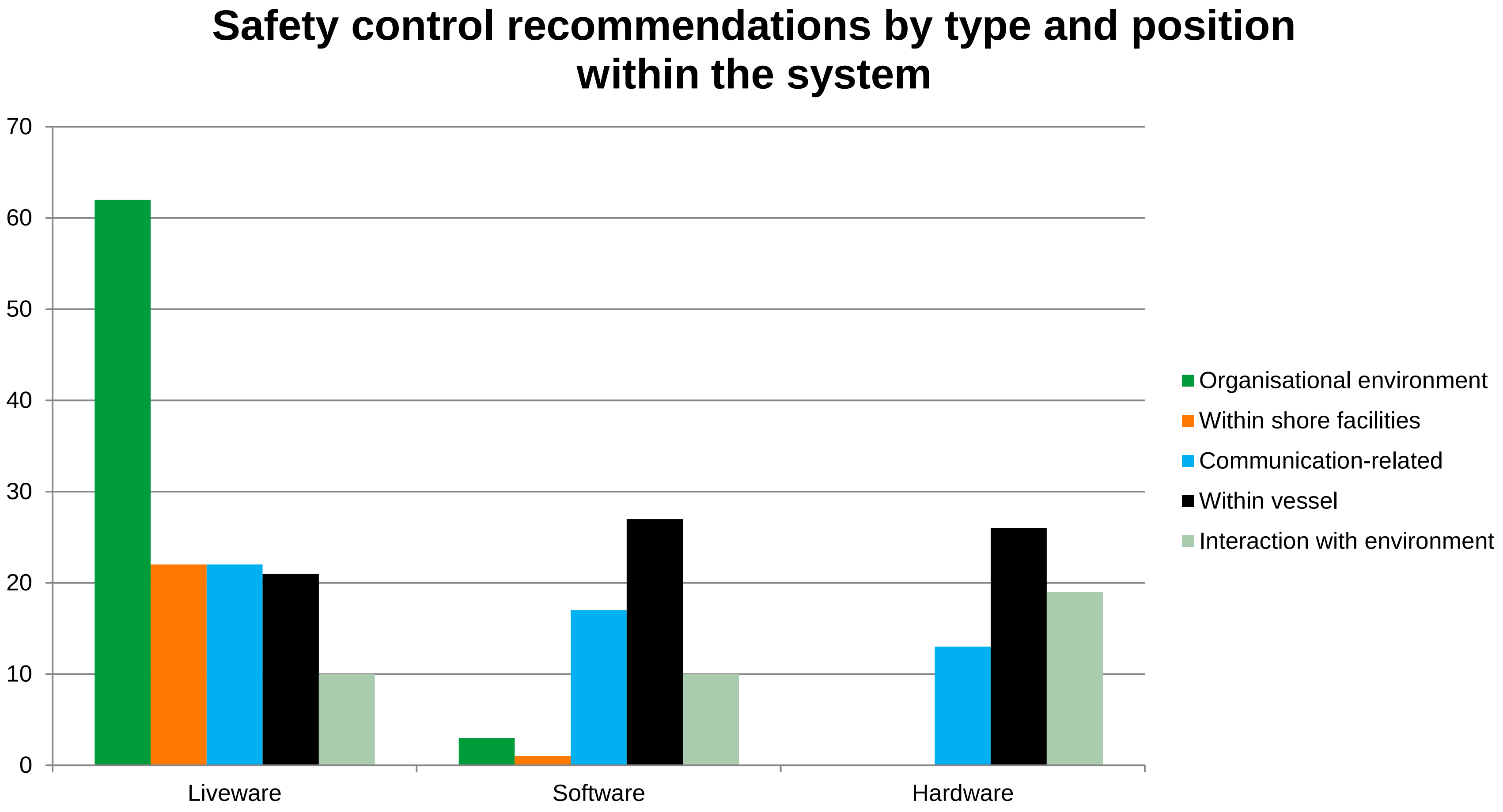
communication of the results



Safety control recommendations by type and position within the system

Systemic approach to control the safety –

communication of the results



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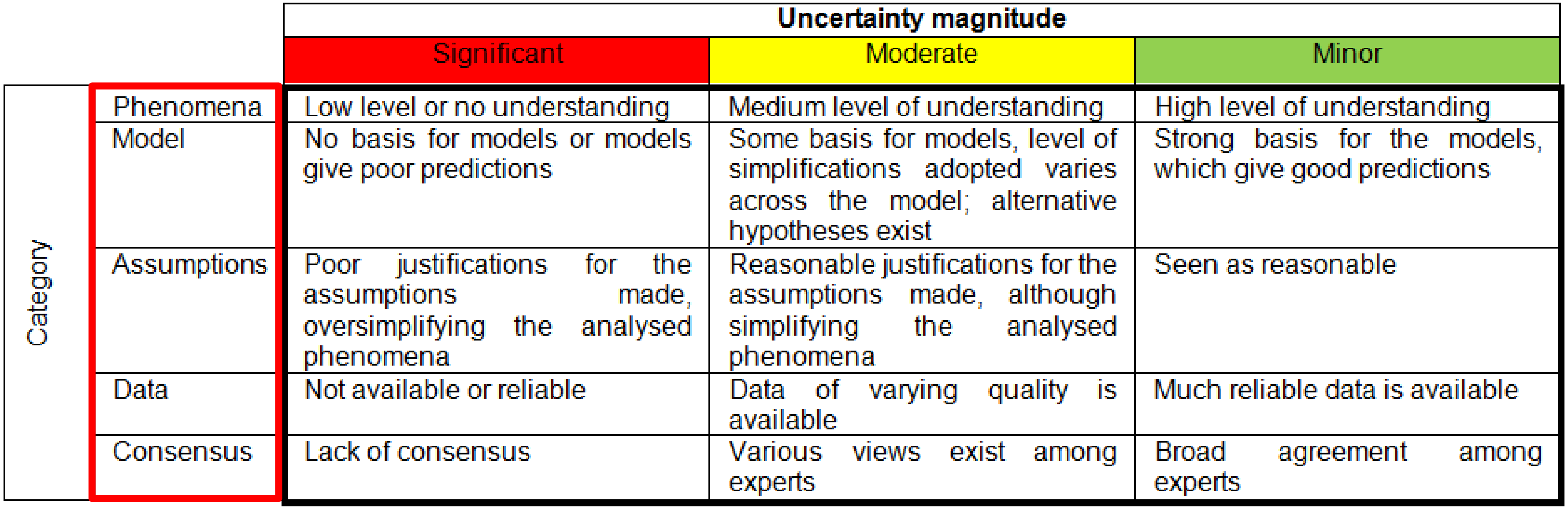
Systemic approach to control the safety –

communication of the results – handling the uncertainty

Uncertainties pertaining to the outcome of the study come as a result of the unmanned shipping technology being in its infancy. No empirical data or reliable models of such ships' safety performance is available.

The subjective uncertainty assessment, borrowed from the risk analysis, and applied in system-theoretic approach tends to reflect the analyst's level of background knowledge in each of five categories:



		Uncertainty magnitude		
		Significant	Moderate	Minor
Category	Phenomena	Low level or no understanding	Medium level of understanding	High level of understanding
	Model	No basis for models or models give poor predictions	Some basis for models, level of simplifications adopted varies across the model; alternative hypotheses exist	Strong basis for the models, which give good predictions
	Assumptions	Poor justifications for the assumptions made, oversimplifying the analysed phenomena	Reasonable justifications for the assumptions made, although simplifying the analysed phenomena	Seen as reasonable
	Data	Not available or reliable	Data of varying quality is available	Much reliable data is available
	Consensus	Lack of consensus	Various views exist among experts	Broad agreement among experts

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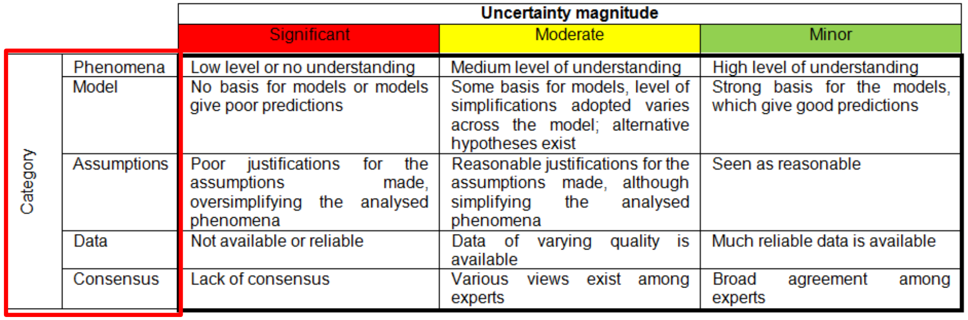
Flage, R. & Aven, T. 2009. Expressing and communicating uncertainty in relation to quantitative risk analysis. Reliability & Risk Analysis: Theory & Application 2(13), 9-18.

Systemic approach to control the safety – communication of the results – handling the uncertainty

Control function number:	27				Engine / rudder → Navigation			
Potential causes:	Control functions #21,26 inadequate Machinery unreliable Consumables not provided		Control functions #21,26 inadequate Machinery having insufficient capacity Machinery improperly designed/installed		Control functions #21,26 inadequate Delays related to equipment's specificity and processes controlled Improper process management algorithms		Control functions #21,26 inadequate Improper process management algorithms	
Feasible mitigation measures and potential	Rigorous maintenance regime Redundant machinery Resilience-based design Procedures on consumables' management	3 3 1 3	Capacity surpluses by design Extensive testing	3 3	Implementation of leading performance indicators	3	Implementation of leading performance indicators	3



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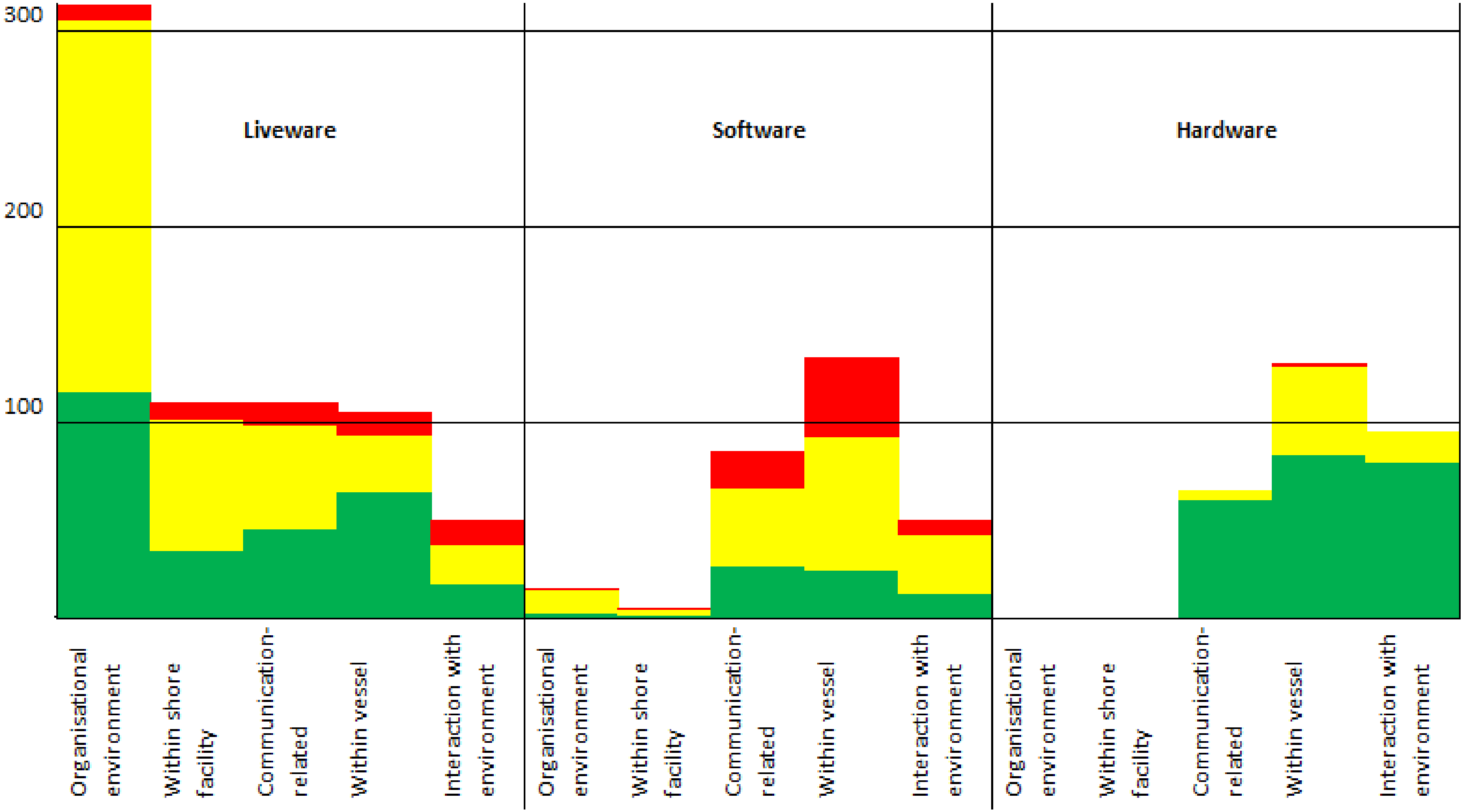
Systemic approach to control the safety –

communication of the results – handling the uncertainty

Breakdown of the uncertainties by its magnitude, type of relevant mitigation measure and position within the system



Systemic approach to control the safety – results in details

For the full catalogue of measures which can be taken to ensure unmanned ships' safety, please refer to the following scientific papers:

- Wróbel, K., Montewka, J., Kujala, P. (2018). *System-theoretic approach to safety of remotely-controlled merchant vessel*. Ocean Engineering, 152, 334–345.
- Wróbel, K., Montewka, J., Kujala, P. *Towards the development of a system-theoretic model for safety assessment of autonomous merchant vessels*. Submitted to Reliability Engineering & System Safety, awaiting final decision.

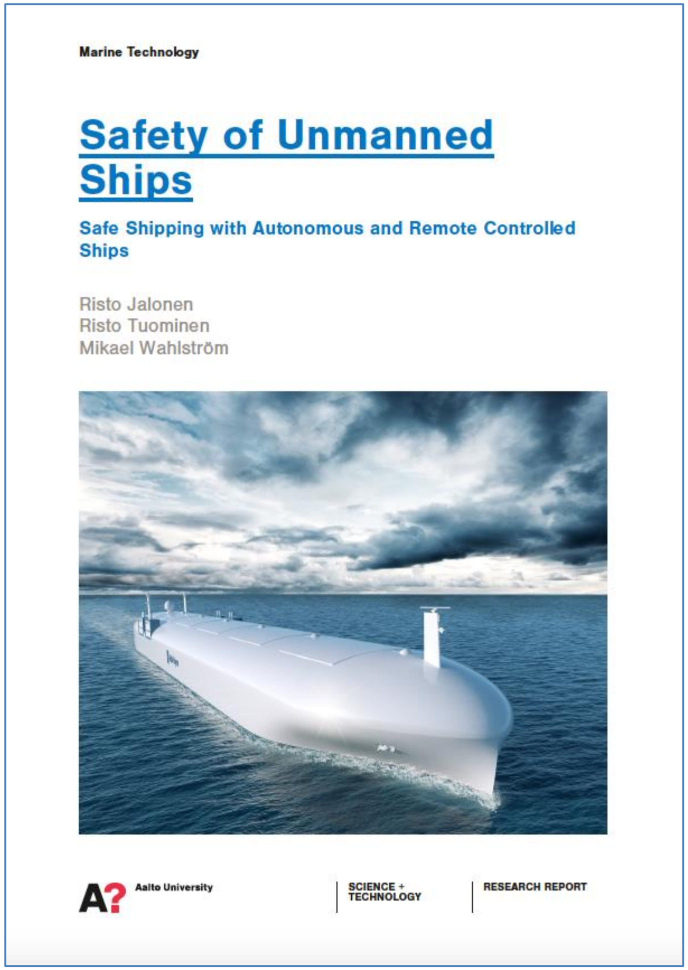
Discussion

- The lack of data pertaining to the actual design and performance of unmanned vessels’ system did not allow for a quantitative analysis.
- It has also caused the qualitative analysis to be performed on a very low level of details.
- Therefore, the level of risk in unmanned ships’ operation could not be evaluated quantitatively.
- Instead, certain measures aiming in ensuring safety have been elaborated and suggested.

Concluding remarks

- Unmanned vessels can potentially reduce the likelihood of maritime accidents. Meanwhile, their consequences can become more serious. This can be attributed to the fact that failure propagation could not be properly safeguarded against as there will be no crew to control the damage.
- Therefore, certain safety recommendations must be created and implemented. Concurrent application of various safety assessment methods can be of use in this case.
- Feasibility of certain solutions is burdened with significant uncertainties – more research is required.
- Unfortunately, the present stage of technology development does not allow for highly-detailed analysis. However, this may change in the nearest future.

Further readings



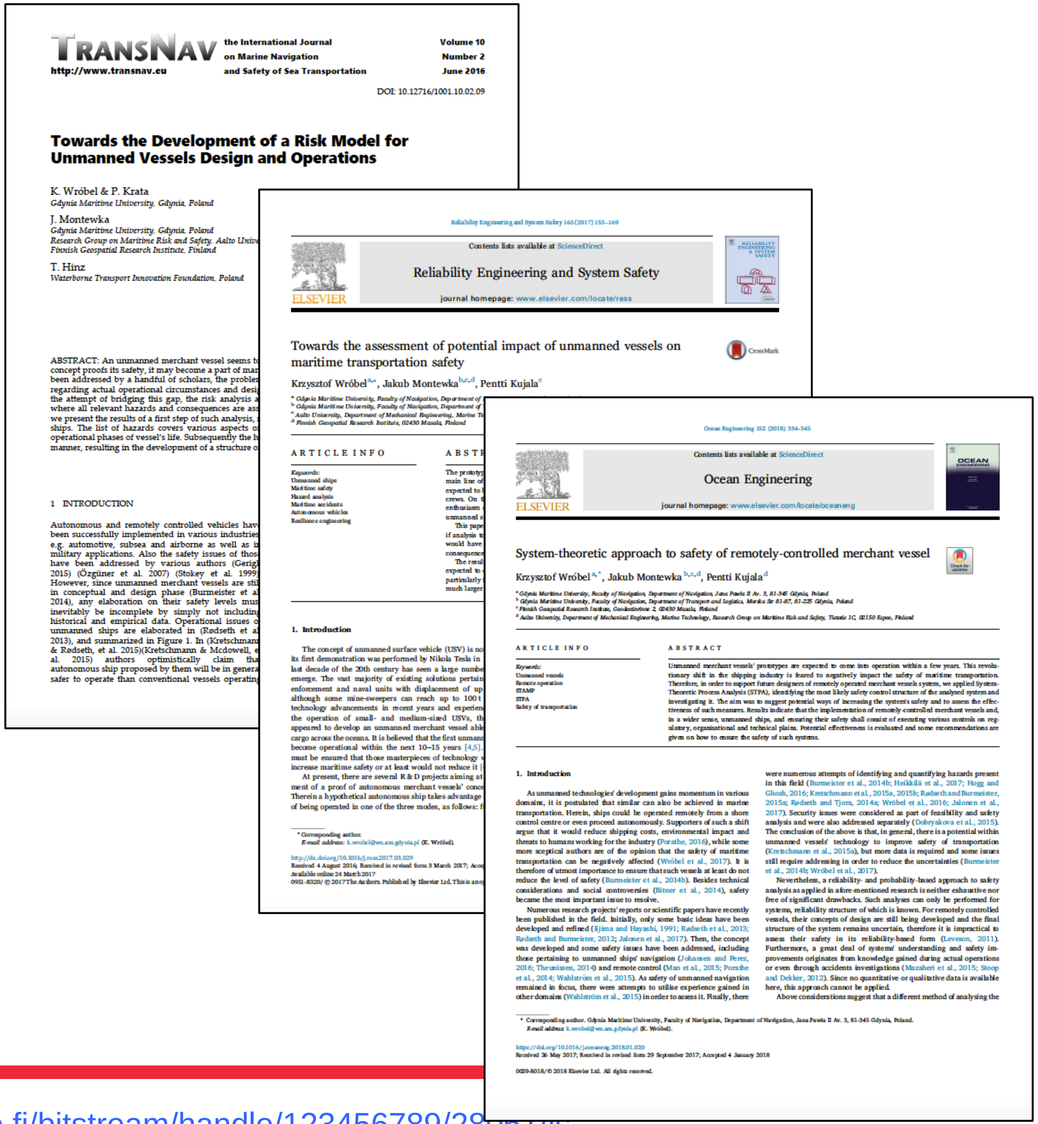
Marine Technology

Safety of Unmanned Ships

Safe Shipping with Autonomous and Remote Controlled Ships

Risto Jalonen
Risto Tuominen
Mikael Wahlström

Aalto University | SCIENCE + TECHNOLOGY | RESEARCH REPORT



TRANSNAV the International Journal on Marine Navigation and Safety of Sea Transportation
http://www.transnav.eu
Volume 10
Number 2
June 2016
DOI: 10.12716/1001.10.02.09

Towards the Development of a Risk Model for Unmanned Vessels Design and Operations

K. Wróbel & P. Krata
Gdynia Maritime University, Gdynia, Poland
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Gdynia Maritime University, Gdynia, Poland
Research Group on Maritime Risk and Safety, Aalto Unive
Finnish Geospatial Research Institute, Finland
T. Hinz
Waterborne Transport Innovation Foundation, Poland

ABSTRACT: An unmanned merchant vessel seems to
concept proofs its safety, it may become a part of mar
been addressed by a handful of scholars, the problem
regarding actual operational circumstances and desig
the attempt of bridging this gap, the risk analysis a
where all relevant hazards and consequences are ass
we present the results of a first step of such analysis,
ships. The list of hazards covers various aspects of
operational phases of vessel's life. Subsequently the h
manner, resulting in the development of a structure o

1 INTRODUCTION

Autonomous and remotely controlled vehicles have
been successfully implemented in various industries
e.g. automotive, subsea and airborne as well as in
military applications. Also the safety issues of those
have been addressed by various authors (Gerigh
2015) (Özgüner et al. 2007) (Stokey et al. 1999)
However, since unmanned merchant vessels are stil
in conceptual and design phase (Burmeister et al
2014), any elaboration on their safety levels mus
inevitably be incomplete by simply not including
historical and empirical data. Operational issues o
unmanned ships are elaborated in (Rødseth et al
2013), and summarized in Figure 1. In (Kretschmann
& Rødseth, et al. 2015)(Kretschmann & Mcdowell, e
al. 2015) authors optimistically claim tha
autonomous ship proposed by them will be in genera
safer to operate than conventional vessels operating

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Towards the assessment of potential impact of unmanned vessels on maritime transportation safety

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A R T I C L E I N F O

Keywords:
Unmanned ships
Maritime safety
Hazard analysis
Maritime accidents
Autonomous vehicles
Resilience engineering

A B S T R

The prototyp
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1. Introduction

The concept of unmanned surface vehicle (USV) is no
its first demonstration was performed by Nikola Tesla in
last decade of the 20th century has seen a large numbe
emerge. The vast majority of existing solutions pertain
enforcement and naval units with displacement of up
although some mine-sweepers can reach up to 100 t
technology advancements in recent years and experien
the operation of small- and medium-sized USVs, th
appeared to develop an unmanned merchant vessel able
cargo across the oceans. It is believed that the first unmann
become operational within the next 10–15 years [4,5].
must be ensured that those masterpieces of technology w
increase maritime safety or at least would not reduce it [
At present, there are several R & D projects aiming at
ment of a proof of autonomous merchant vessels' conce
Therein a hypothetical autonomous ship takes advantage
of being operated in one of the three modes, as follows: f

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System-theoretic approach to safety of remotely-controlled merchant vessel

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A R T I C L E I N F O

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STPA
Safety of transportation

A B S T R A C T

Unmanned merchant vessels' prototypes are expected to come into operation within a few years. This revolutionary shift in the shipping industry is feared to negatively impact the safety of maritime transportation. Therefore, in order to support future designers of remotely operated merchant vessels system, we applied System-Theoretic Process Analysis (STPA), identifying the most likely safety control structure of the analysed system and investigating it. The aim was to suggest potential ways of increasing the system's safety and to assess the effectiveness of such measures. Results indicate that the implementation of remotely-controlled merchant vessels and, in a wider sense, unmanned ships, and ensuring their safety shall consist of executing various controls on regulatory, organisational and technical plains. Potential effectiveness is evaluated and some recommendations are given on how to ensure the safety of such systems.

1. Introduction

As unmanned technologies' development gains momentum in various domains, it is postulated that similar can also be achieved in marine transportation. Herein, ships could be operated remotely from a shore control centre or even proceed autonomously. Supporters of such a shift argue that it would reduce shipping costs, environmental impact and threats to humans working for the industry (Porathe, 2016), while some more sceptical authors are of the opinion that the safety of maritime transportation can be negatively affected (Wróbel et al., 2017). It is therefore of utmost importance to ensure that such vessels at least do not reduce the level of safety (Burmeister et al., 2014b). Besides technical considerations and social controversies (Bitner et al., 2014), safety became the most important issue to resolve.

Numerous research projects' reports or scientific papers have recently been published in the field. Initially, only some basic ideas have been developed and refined (Iijima and Hayashi, 1991; Rødseth et al., 2013; Rødseth and Burmeister, 2012; Jalonen et al., 2017). Then, the concept was developed and some safety issues have been addressed, including those pertaining to unmanned ships' navigation (Johansen and Perez, 2016; Theunissen, 2014) and remote control (Man et al., 2015; Porathe et al., 2014; Wahlström et al., 2015). As safety of unmanned navigation remained in focus, there were attempts to utilise experience gained in other domains (Wahlström et al., 2015) in order to assess it. Finally, there were numerous attempts of identifying and quantifying hazards present in this field (Burmeister et al., 2014b; Heikkilä et al., 2017; Hogg and Ghosh, 2016; Kretschmann et al., 2015a, 2015b; Rødseth and Burmeister, 2015a; Rødseth and Tjora, 2014a; Wróbel et al., 2016; Jalonen et al., 2017). Security issues were considered as part of feasibility and safety analysis and were also addressed separately (Dobryakova et al., 2015). The conclusion of the above is that, in general, there is a potential within unmanned vessels' technology to improve safety of transportation (Kretschmann et al., 2015a), but more data is required and some issues still require addressing in order to reduce the uncertainties (Burmeister et al., 2014b; Wróbel et al., 2017).

Nevertheless, a reliability- and probability-based approach to safety analysis as applied in afore-mentioned research is neither exhaustive nor free of significant drawbacks. Such analyses can only be performed for systems, reliability structure of which is known. For remotely controlled vessels, their concepts of design are still being developed and the final structure of the system remains uncertain, therefore it is impractical to assess their safety in its reliability-based form (Leveson, 2011). Furthermore, a great deal of systems' understanding and safety improvements originates from knowledge gained during actual operations or even through accidents investigations (Mazaheri et al., 2015; Stoop and Dekker, 2012). Since no quantitative or qualitative data is available here, this approach cannot be applied.

Above considerations suggest that a different method of analysing the

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Advanced Autonomous Waterborne Application - AAWA

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VTT

TAMPERE UNIVERSITY OF TECHNOLOGY

Turun yliopisto
University of Turku

Åbo Akademi

Thank you !