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HAZARD ANALYSIS PROCESS FOR AUTONOMOUS VESSELS

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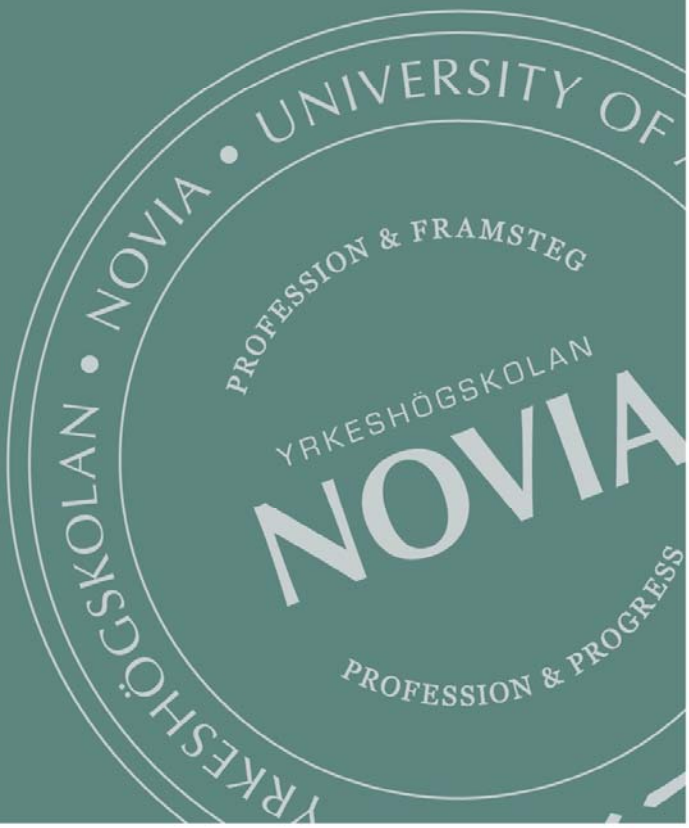

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Hazard Analysis Process for Autonomous Vessels

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Sammanfattning:

Eng:

This report introduces a systemic process for an initial hazard analysis in the operative context of autonomous vessels. The process facilitates executing an initial analysis of safety hazards in the earliest design phase before the planning of ship design, materials, structures, components, systems and the services linked to the functioning of an autonomous vessel. The process attempts to produce information to make the systematic integration of safety controls that need to be implemented in an initial safety management strategy.

In this report, the process is applied to analyse the safety hazards in the foreseen functioning of two concepts of autonomous ferries operating in urban waterways in and near the city of Turku in Finland. The process first identifies the main type of accidents and hazards in the operational context of these ferries. It then proposes high-level safety controls to mitigate the hazards and prevent these accidents. The controls are subsequently used as a basis for developing an initial safety management strategy for autonomous ferries and their operational system. This provides a systematic representation of safety controls in the operative context of autonomous ferries.

The full process is composed of five different steps to elaborate a systematic analysis of hazards and to define safety controls for mitigating and preventing the identified hazards. These controls are the basis of the initial safety management strategy of autonomous vessels and their operational system. This report was done as part of the ÄlyVESI – Smart City Ferries research, development and innovation project.

Smart City Ferries, the ÄlyVESI project, was a conceptualisation, product development and innovation project realised by cities, businesses and universities 1.10.2016 – 31.5.2018. The project explored, developed and tested new technologies and intelligent urban waterborne traffic solutions and services. Novia University of Applied Sciences, Turku University of Applied Sciences, Aalto University and the City of Turku carried out the project in co-operation. The project was funded by the 6Aika-program of the European Regional Development Fund. In addition, the project was funded by the Finnish Transport Safety Agency and the cities of Helsinki and Espoo.

Sve:

Denna rapport introducerar en systematisk process för en inledande riskanalys gällande autonoma fartygs operation. Denna process underlättar utförandet av en inledande analys av säkerhetsrisker i det tidiga design skedet före planeringen av fartyget, dess material, strukturer, komponenter och system och de tjänster som är anknutna till hur ett autonomt fartyg fungerar. På basen av denna process försöker man säkerställa ändamålsenlig information för integreringen av de systematiska säkerhetskontroller som bör vara implementerade i en inledande säkerhetsstrategi.

I denna rapport tillämpas säkerhetsriskanalysen på två planerade koncept där autonoma färjor opererar i urbana farvatten i och i närheten av Åbo stad i Finland. Processen identifierar först huvudtyperna av olyckor och risker i färjornas operativa kontext. Sedan föreslås elementära säkerhetskontroller för att minska riskerna och undvika olyckor. Kontrollerna tillämpas därefter som en bas för utvecklingen av en

inledande säkerhetsstrategi för autonoma färjor och dessas operativsystem. Detta möjliggör en systematisk representation gällande säkerhetskontroller för operation av autonoma färjor.

Hela processen består av fem olika steg för att utveckla en systematisk analys av risker och för att definiera säkerhetskontroller för att minska eller förhindra de identifierade riskerna. Dessa kontroller är basen för den inledande säkerhetsstrategin för autonoma fartyg och deras operativ system. Denna rapport är en del av ÄlyVESI- Smarta Stadsfärjor forsknings-, utvecklings- och innovationsprojektet.

Smarta Stadsfärjor, ÄlyVESI projektet, var ett konceptifierings-, produktutvecklings- och innovationsprojekt förverkligat av städer, företag och universitet under tiden 1.10.2016 – 31.5.2018. Projektet undersökte, utvecklande och testade nya teknologier och intelligent urban sjövägstrafik och tjänster. Projektet utfördes som ett samarbete mellan Yrkeshögskolan Novia, Turun Ammattikorkeakoulu, Aalto-yliopisto och Åbo stad. Projektet finansierades av 6Aika-programmet och Europeiska regionala utvecklingsfonden. Därtill finansierades projektet av Trafiksäkerhetsverket och städerna, Helsingfors och Esbo.

Sök- och nyckelord:

Hazards, autonomous vessels, Älyvesi, urban waterways, ferries

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HAZARD ANALYSIS PROCESS FOR AUTONOMOUS VESSELS

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1. Introduction

Autonomous vessels need to operate with the support of entire smart systems (Vermesan and Friess 2013). The industry involved in the development of autonomous vessels is aware about this and are constantly investing to create smart autonomous maritime systems (Teivainen 2017). Safety represents an essential aspect for ensuring the correct functioning of such a system. Autonomous vessels have the initial expectation that they have to be at least as safe as the most advanced manned ships (Rødseth and Burmeister, 2015; Jalonen et al. 2017). ÄlyVESI - Smart City Ferries is an R&D and innovation project between cities, technology companies and universities. The aim is to research and develop new solutions and services for intelligent transport. The project enables companies to develop new business in the marine technology and ICT sectors, at the same time keeping management and design of safety as one of the main priorities.

This report introduces a systemic process for an initial hazard analysis in the operative context of autonomous vessels. The process facilitates executing an initial analysis of safety hazards in the earliest design phase before the planning of ship design, materials, structures, components, systems and the services linked to the functioning of an autonomous vessel. The process attempts to produce information to make the systematic integration of safety controls that need to be implemented in an initial safety management strategy.

In this report, the process is applied to analyse the safety hazards in the foreseen functioning of two concepts of autonomous ferries operating in urban waterways in and near the city of Turku in Finland. The process first identifies the main type of accidents and hazards in the operational context of these ferries. It then proposes high-level safety controls to mitigate the hazards and prevent these accidents. The controls are subsequently used as a basis for developing an initial safety management strategy for autonomous ferries and their operational system. This provides a systematic representation of safety controls in the operative context of autonomous ferries.

The full process is composed of five different steps to elaborate a systematic analysis of hazards and to define safety controls for mitigating and preventing the identified hazards. These controls are the basis of the initial safety management strategy of autonomous vessels and their operational system. This initial safety management strategy provides itemized information that is relevant for planning, designing and constructing autonomous vessels and their entire operational system. The execution of steps one to four produces itemized information that is systematically connected. Step five focuses on representing the main components emerged from the analysis: the hazards, their safety controls, the logic principle of the safety controls, and the link to the accidents that these listed components aim to prevent or respond to. The entire process is described in Section 3.2.

2. Background

The hazard analysis presented in this study focuses on two specific concepts of autonomous ferries for urban transport.

Autonomous ferry “A”
This first concept has a mission to transport passengers across the Aura River in the city of Turku. The distance navigated by this ferry is about 100 meters in total. The total passenger capacity for this autonomous ferry is not yet defined but current ferries (man controlled) with similar missions in the same operational area have a maximum capacity of 75 passengers. The operational function of the ferries is described as follows:

a) Passengers board the ferry while she is docked
b) The boarding process is finalized
   b.1) The access gate on the pier is closed
   b.2) The access door on the vessel in closed
c) The ferry undocks
d) The ferry begins her voyage
e) The ferry reaches the other side of the river and docks
f) The passengers disembark the ferry (after this is concluded operation “a” is repeated)

Autonomous ferry “B”
This second concept has the mission to transport passengers from downtown Turku to the Island of Ruissalo. The ferry will navigate in the river Aura, navigate through a sheltered sea area for a short time, and reach her destination in Ruissalo. The distance navigated is around 8 km. The passenger capacity in this concept has not yet been defined neither, but the estimated passenger capacity is about 120 passengers. The operational function of the ferry is similar to that of ferry “A”.

3. Proposed Process for Hazard Analysis

3.1 Process foundations

The process of analysis, proposed in this report, is based on a safety engineering approach linked to the System- Theoretic Process Analysis (STPA) included within the Systems-Theoretic Accident Modelling and Processes (STAMP) (Leveson, 2011). STAMP is a new approach to depict and review the function of safety from a systemic perspective. It analyses accidents by making a review of the entire socio-technical system (Chatzimichailidou and Dokas, 2015). STAMP provides a systemic way to model safety for producing a better understanding about how accidents occur and how they can be prevented (Fleming et al., 2013).

STAMP promotes hazard analysis that goes beyond component failures. This is supported with the STPA, a hazard analysis technique that identifies accident scenarios that encompass the entire accident process by including design errors, component interactions, and other social, organizational, and management factors in the analysis (Leveson, 2011). Previously, both STAMP and STPA have been satisfactorily applied in the analysis of safety of autonomous systems in other transportation domains such as the automobile and aviation industries (Chen et al. 2015; Hinchman et al. 2012; Oscarsson et al. 2016).

The proposed process focuses on defining accidents that can occur in a specific mission and operational context of an autonomous vessel. It identifies and analyses hazards that can lead to defined accidents. The process is extended to incorporate a description of the hazards' causal factors, and a comprehensive definition and review of potential actions to mitigate the risk. The process includes a systematic representation of safety controls and an initial definition of the safety management strategy.

The proposed process for hazard analysis is performed based on the available knowledge, which consists of judgments and assumptions. The purpose is to provide a systematic and itemized initial list of safety controls in order to establish a consistent initial safety management strategy for further development in later design stages.

3.2 The hazard analysis process

3.2.1 Step one: Definition of accidents and identification of hazards:

Step one defines the types of accidents covered in the analysis. For this purpose, we define the concept of accident in accordance with Valdez Banda and Goerlandt (2017):

> *Accident represents an undesired and unplanned event that results in a loss and affectations, including loss of human life or injury, property damage, equipment damage or environmental pollution, delays in the system operations and repair costs.*

The accident identification consists of specifying the accident types, which may cause the specified effects on the operational functioning of the autonomous vessel. In this initial analysis phase, the identification of accidents focuses on determining and describing the most critical accidents, which the safety controls, and the initial safety management strategy aim to prevent and/or provide a post-accidental response to.

The hazard identification focuses on the definition of those hazards, which can lead to the defined accidents. The aim is to detect a certain system state or set of conditions, which in a particular set of worst-case conditions in the operational context, lead to the defined accidents (Leveson, 2011). This enables the development of the initial systematic connection between the accidents and their linked hazards.

3.2.2 Step two: Detailed hazard description and initial definition of mitigation actions:

Step two elaborates detailed descriptions and effects of the hazards, providing a comprehensive argumentation about the relevancy of specific hazards, and a qualitative estimation of their potential severity and type of consequences.

This step continues with the identification of potential causal factors of the hazard. This describes the hazard as a combination of system state and conditions that could influence the effect of the hazard occurrence.

The second step concludes with identifying the possible hazard mitigation actions. This part is essential to represent the initial specifications of the safety controls, which are the core element of the initial safety management strategy (Leveson et al. 2009). These mitigation strategies are flexible to include diverse forms of mitigation actions including for example the implementation of technology, management procedures, reviews, and testing programs. The aim is to create an extensive and coherent list of mitigation actions. At this point, the actions have to be preliminary assessed to estimate the complexity and costs of their actual implementation. Finally, each mitigation action has to be categorized based on their intended mitigation control strategy. For this, the process includes the following four categories:

i. The defined mitigation action attempts to reduce the damage if the accident occurs
ii. The defined mitigation action attempts to reduce the likelihood that the hazard results in an accident.
iii. The defined mitigation action attempts to reduce the likelihood that the hazard will occur.
iv. The defined mitigation action attempts to completely eliminate the hazard

3.2.3 Step three: Definition of the safety controls:

Step three focuses on defining safety controls based on the adopted mitigation actions. This task demands the review and prioritization of mitigations actions that will be further developed as the safety controls of the initial safety management strategy. The aim is to assess if the safety controls are objective and relevant before continuing their analysis and development into the initial safety management strategy of the autonomous vessel.

3.2.4 Step four: Identification of unsafe control actions (UCAs) and redefinition of the safety controls

The identification of UCAs and redefinition of the safety controls are executed by following the STPA analysis process. The objective is to analyse each hazard and the safety controls defined to it. The phases of the STPA process are:

a) For each defined safety control, identify unsafe control actions (UCAs) that could lead to a hazardous state in the system. Hazardous states result from inadequate controls or enforcement of the safety control. These can occur because:
   - A control action for safety is not provided or followed
   - An unsafe control action is provided
   - A safety control is provided too early or too late
   - A safety control is stopped too soon or applied too long

b) Define why and how UCAs could occur
   - Examine the elements included in the functioning of the safety control
   - Consider how the safety control could degrade over the time

c) The STPA process includes a redefinition of the function of the safety control. The redefinition states how the safety control mitigates the identified UCAs. This provides a clear definition of the actual logic principle behind the functioning of the safety control.

3.2.5 Step five: Representation of the initial safety management strategy

The execution of step one to step four produce itemized information that is systematically connected. Step five focuses on representing the main components emerged from the analysis: the hazards, their safety controls, the safety controls logic principle, and the link to the accidents that these listed components aim to prevent or respond to. This step provides a detailed representation of the initial safety management strategy of the autonomous vessel.

4. Process application

4.1 Expert consultation

In order to apply the proposed process to analyse the hazards of the described Ferry A and B, experts in different industry domains were consulted. Appendix 1 describes the background and expertise areas for each participating expert.

Initially, two experts (experts A and B) executed steps one and two of the process, which produced preliminary information for the following steps.

A group of experts, with specialization and knowledge in fields relevant to the initial hazard mitigation actions recognized in steps one and two, continued the process. They executed steps three and four in four separate workshops. In the workshops, preliminary information was validated and analysed further.

Step five was executed by one expert (expert B). Expert B compiled the information gathered in the process to a representation of the initial safety management strategy. Table 1 presents the tasks given for the experts in in process application.

Table 1. Task descriptions for the experts

Process Step	**Task**
One	Define accidents and identify the hazards that can lead to them: • *Are the defined accidents the most relevant for analysis?* • *Is the list of identified hazards complete?*
Two	a) Execute STAMP preliminary hazard analysis for each hazard identified in step one b) Review the preliminary hazard analysis by answering the following questions: • *Is the hazard description relevant and accurate?* • *Is the list of the causal factors sensible?* • *Are the mitigation actions relevant?* • *Is there any other mitigation action to be included?* • *Do you agree with the scales given to the cost/difficulty and the categorization of the mitigation control actions?*
Three	Based on the mitigation actions, define which of these should be further analysed and redefined as safety controls.
Four	STPA implementation a) Define potential unsafe control actions for each safety control. Consider the following aspects: • The function of the safety control is not provided and/or enough • The provision of the safety control's function is wrong • The function of the safety control is provided at the wrong time • The function of the safety control is provided for too long or too short b) Define the potential causes of the unsafe controlled actions (UCAs) c) Redefine the safety control and specify how it mitigates the hazard and the defined UCAs
Five	Representation of the initial safety management strategy

4.2 Process application outcome

4.2.1 Accident types and identification of hazards: step one

Accident	Hazards
1. Allision with a pier	H1. Object detection sensor error H2. AI software failure H3. Technical fault (e.g. mechanical failure) H4. Heavy weather/sea conditions H5. Strong currents H6. Position reference equipment failure
2. Collision with a moving object	
2.1 Collision with another vessel	H1. Object detection sensor error H2. AI software failure H3. Technical fault (e.g. mechanical fault)
2.2 Collision with a small moving target (e.g. canoe, SUP-board, etc.)	H1. Object detection sensor error H2. AI software failure H3. Technical failure (e.g. mechanical failure)
3. Collision with a fixed object (e.g. buoys, beacons, etc.)	H1. Object detection sensor error H2. AI software failure H3. Technical fault (e.g. mechanical failure) H4. Heavy weather/sea conditions H5. Strong currents H6. Position reference equipment failure
4. Grounding	H2. AI software failure H3. Technical failure (e.g. mechanical failure) H6. Position reference equipment failure H4. Heavy weather/sea conditions H5. Strong currents
5. Bottom touch	H2. AI software failure H3. Technical failure (e.g. mechanical failure) H6. Position reference equipment failure H4. Heavy weather/sea conditions H5. Strong currents
6. Capsizing/ Sinking	H7. Overloading of the vessel H8. Shifting of weights H9. Flooding
7. Fire on board	H10. Ignition of electrical equipment or wiring H11. Passenger starting a fire
8. Man over board	H12. Unintended falling overboard H13. Intended jumping overboard
9. Medical emergency on board	H14. Person(s) getting injured H15. Person(s) medical condition
10. Medical emergency on pier	H14. Person(s) getting injured H15. Person(s) medical condition

4.2.2 Steps 2 to 4: detailed hazard description, definition of safety controls, identification of unsafe control actions (UCAs) and redefinition of the safety controls

Hazard 1. Object detection sensor error

Hazard	H1. Object detection sensor error		
Hazard effect/ description	*Provide extra details regarding the designated severity rating* In case of object detection sensor error, the information about objects around the vessel is not reliable and thus the vessel may not be able to navigate safely and avoid collisions with moving objects according to the rules of the road or collisions with fixed objects. This hazard may not affect the ship operation significantly in most cases, but in a more severe scenario, the hazard can have a negative impact on people, property, and environment. It can result in injuries, loss of human life, severe damage or loss of property (own and others property) and environmental effects such as oil spills or other damage of sensitive sea areas.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Loss of power - Equipment malfunction - Dirt - Icing - Overheating - Equipment interference - Inappropriate maintenance - Incorrect sensor set and/or positioning of the sensors - Targets impossible to detect - Interference - Corrupted readings - Complete equipment failure		
Mitigation strategy		*Cost/Difficulty*	*Priority (1-4) **
	- Sensor system redundancy and diversity	High	4
	- UPS (Uninterrupted Power Source)	Low	3
	- Appropriate heating, cooling and cleaning systems	Medium	3
	- Thorough commissioning of equipment set	Medium	3/4
	- Appropriate and continuous maintenance program	Low	3
	- Continuous system diagnosis and proof testing	Low	3
	- Autonomous Integrity monitoring	Low	2

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis

(1) Safety control
SC 1. Sensor system redundancy and diversity SC 2. UPS (Uninterrupted Power Source) SC 3. Appropriate heating, cooling, and cleaning systems SC 4. Thorough commissioning of equipment set SC 5. Appropriate and continuous on board maintenance program SC 6. Continuous system diagnosis and proof testing SC 7. Autonomous Integrity monitoring
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety control
SC 1 Sensor system redundancy and diversity

UCA 1. Sensor does not function properly and there is no other sensor available
Potential causes
- Lack of economic resources

UCA 2. Equipment chosen to provide the redundancy are not suitable
Potential causes
- Lack of economic resources
- Lack of knowledge of sensors characteristics when planning the equipment set needed

UCA 3. Sensor failure is not detected
Potential causes
- Sensor diagnosing does not cover all necessary areas

UCA 4. External or common cause failure takes several equipment down at the same time
Potential causes
- Inappropriate system design
- Incorrect installation
- Incorrect usage
- Environmental conditions

Redefining of the safety control
Sensor system redundancy and diversity:
- If one sensor fails the redundancy ensures there will be another sensor functioning
- Equipment chosen to provide the redundancy have to be the correct ones in order to provide the user with the required information at all times

SC 2 UPS (Uninterrupted Power Source)

UCA 1. There is a disturbance in the vessel's power system and the equipment is not backed up with UPS
Potential causes
- Lack of economic resources
- Lack of understanding of the importance of the UPS

UCA 2. The UPS does not work
Potential causes
- UPS is not charged
- UPS is not connected correctly
- UPS is broken

UCA 3. The UPS takes too long to switch on
Potential causes
- Errors in UPS function

UCA 4. The capacity of the UPS is not sufficient to provide power for the equipment as long as needed or the capacity in terms of power and/or energy of the UPS is exceeded
Potential causes
- The disturbance lasts longer than was expected in the planning stage
- Wrong type of UPS

Redefining of the safety control
UPS (Uninterrupted Power Source):
- If there is a disturbance in the vessel's power system the UPS can temporarily provide power for the critical equipment
- When the UPS setup is planned, installed and maintained properly, the user can count on a reliable backup system

SC 3 Appropriate heating, cooling and cleaning systems

UCA 1. Equipment is not able to function properly in winter conditions
Potential causes
- Equipment does not have heating function

- Extremely low temperatures
- Icing

UCA 2. Equipment is not able to function properly due to high temperatures
Potential causes
- Equipment does not have cooling function
- Extremely high temperatures
- The systems are located close to heat sources

UCA 3. Equipment lens is dirty
Potential causes
- Sea water spray
- Bird feces

UCA 4. Condensation inside equipment
Potential causes
- Leakage
- Temperature changes
- Fault on the equipment design
- Humid climate
- Location on-board

Redefining of the safety control
Appropriate heating, cooling and cleaning systems:
- By applying sensors with proper heating and/or cooling systems it can be ensured that they function properly in all operating conditions
- By applying sensors with automatic cleaning systems it can be ensured that they function properly outdoors

SC 4 Thorough commissioning of equipment set

UCA 1. The equipment set has not been properly tested or not tested at all before operation
Potential causes
- Lack of economic resources
- Test plan is not appropriate
- Lack of time

Redefining of the safety control
Thorough commissioning of equipment set:
- When the equipment set is thoroughly tested and certified (preferably by an independent body) it ensures that the equipment function properly, are compatible and the operation can be run safely.

SC 5 Appropriate and continuous on board maintenance program

UCA 1. There is no on board maintenance program
Potential causes
- Lack of economic resources
- Lack of understanding of the importance of the maintenance program

UCA 2. The maintenance program does not cover the necessary elements and the life cycle of the hardware.
Potential causes
- Lack of competence

UCA 3. The maintenance program is not followed
Potential causes
- Lack of time (work overload)
- Lack of economic resources
- Lack of understanding of the importance of the maintenance program

UCA 4. Maintenance is not done properly
Potential causes

- Lack of commitment
- Lack of competence
- Human error or mistake
- Lack of economic resources

Redefining of the safety control
Appropriate and continuous maintenance program:
- By implementing an on board maintenance program it can be ensured that all critical systems remain functional at all times
- A well planned maintenance program covers all necessary areas on board and it is adjusted separately for each vessel
- Maintenance done timely and accordingly to the program by competent personnel ensures smooth operation of the sensors

SC 6. Continuous system diagnosis and proof testing

UCA 1. There is no continuous system diagnosis and proof testing
Potential Causes
- Lack of economic resources
- Lack of planning
- It cannot be performed due to the effects on operation

UCA 2. The continuous system diagnosis and proof testing do not cover all necessary functions
Potential causes
- Lack of economic resources
- Lack of planning
- Tests cannot be performed due to the effects on operation

UCA 3. The test is not able to recognize problems
Potential causes
- Wrong test design
- Changes in the system

Redefining of the safety control:
Continuous system diagnosis and proof testing:
- Continuous system diagnosis and regular proof testing ensure that the system functions as it should
- Test design should be planned carefully and updated after changes in the system in order to cover all the necessary functions and recognize potential problems
- Possible effect on the operation should be taken into account in planning

SC 7. Autonomous Integrity monitoring

UCA 1. There is no integrity monitoring
Potential causes
- Lack of economic resources
- Lack of planning
- Lack of understanding

UCA 2. Integrity monitoring gives wrong information
Potential Causes
- Common cause failure
- Wrong design
- Changes in the system

Redefining of the safety control:
Autonomous Integrity monitoring:
- Well designed and up to date integrity monitoring systems ensure that the data used has not been damaged or manipulated

Hazard 2. AI software failure

Hazard	H2. AI software failure		
Hazard effect/ description	*Provide extra details regarding the designated severity rating* In case of an AI software failure a vessel may not be able to navigate safely or follow the rules of the road. AI failure may lead to collision, allision, grounding or bottom touching. The hazard can have a negative impact on people, property, and environment. It can result in injuries, loss of human life, severe damage or loss of property (own and other people's property) and environmental effects such as oil spills or other damage of sensitive sea areas.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Architecture design failure - Coding error in algorithm/algorithms - Error in algorithm specifications - Situation unknown to AI - Loss of power - Overheating - Inappropriate maintenance - Software update - Error in learning data - Misleading safety function requirement - Changes in the system - Computer failure		
Mitigation strategy		*Cost/Difficulty*	*Priority (1-4) **
	- Thorough planning, testing and commissioning of AI software	High	4
	- Computer and software redundancy	Low	3
	- UPS (Uninterrupted Power Source)	Low	3
	- Appropriate cooling for computers	Low	3
	- Appropriate and continuous on board maintenance programs	Low	3
	- Robust system design	High	4
	- Appropriate system (software) design and maintenance processes	High	3

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis:

(1) Safety control
SC 1. Thorough planning, testing and commissioning of AI software SC 2. Computer and software redundancy SC 3. UPS (Uninterrupted Power Source) SC 4. Appropriate cooling for computers SC 5. Appropriate and continuous on board maintenance programs SC 6. Robust system design SC 7. Appropriate system (software) design and maintenance processes
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety control
SC 1 Thorough planning, testing and commissioning of AI software UCA 1. Thorough planning, testing and commissioning of AI are not done *Potential causes* - Lack of economic resources - Lack of time

- Lack of competence

UCA 2. Insufficient planning, testing and commissioning of AI
Potential causes
- Poor knowledge of operational conditions
- Lack of economic resources
- Lack of time
- Lack of competence

Redefining of the safety control
Thorough planning, testing and commissioning of AI:
- Thorough planning, testing and commissioning of AI software ensure that the software is robust and free of errors
- Applicable standards should be followed

SC 2 Computer and software redundancy

UCA 1. Computer breaks down and there is no computer and software redundancy
Potential causes
- Lack of economic resources
- Lack of space
- Poor design of the system

UCA 2. Secondary computer does not take over in case of a failure
Potential causes
- Signalling error
- No physical connection between computers
- Malfunction of the secondary computer
- Primary computer does not successfully pass the information to the secondary computer to take over
- No physical connection between computers

Redefining of the safety control
Computer and software redundancy:
- Computer and software redundancy ensure availability of the AI functions at all times

SC 3 UPS (Uninterrupted Power Source)

UCA 1. There is a disturbance in the vessel's power system and the AI system is not backed up with UPS
Potential causes
- Lack of economic resources
- Lack of understanding of the importance of the UPS

UCA 2. The UPS does not work
Potential causes
- UPS is not charged
- UPS is not connected correctly
- UPS is broken

UCA 3. The UPS takes too long to switch on
Potential causes
- Errors in UPS function

UCA 4. The capacity of the UPS is not sufficient to provide power for the AI system as long as needed or the capacity in terms of power and/or energy of the UPS is exceeded
Potential causes
- The disturbance lasts longer than expected in the planning stage
- Wrong type of UPS

Redefining of the safety control
UPS (Uninterrupted Power Source):
- If there is a disturbance in the vessel power system the UPS can temporarily provide power for the critical equipment

- When the UPS-setup is planned, installed and maintained properly, the user can count on a reliable backup system

SC 4 Appropriate cooling for computers

UCA 1. Computer does not function reliably due to overheating.
Potential causes
- The cooling is not adequate
- The cooling is broken
- Wrong location of the computer (limited space and inappropriate conditions)
- Loss of power

Redefining of the safety control
Appropriate cooling for computers:
- In order to function properly all computer components must be kept within permissible operating temperature limits
- Cooling systems should be selected carefully. Both the waste heat produced by the computer components and possible external heat sources should be taken in to account.

SC 5 Appropriate and continuous on board maintenance programs

UCA 1. There is no on board maintenance program
Potential causes
- Lack of economic resources
- Lack of understanding of the importance of the maintenance program

UCA 2. The maintenance program does not cover the necessary elements and the life cycle of the hardware.
Potential causes
- Lack of competence

UCA 3. The maintenance program is not followed
Potential causes
- Lack of time (work overload)
- Lack of economic resources
- Lack of understanding of the importance of the maintenance program

UCA 4. Maintenance is not done properly
Potential causes
- Lack of commitment
- Lack of competence
- Human error or mistake
- Lack of economic resources

UCA 5. Software updates are not done and the system is not capable to correct detected issues
Potential causes
- Lack of time
- Lack of commitment
- Lack of competence
- Human error or mistake

UCA 6. Software update creates an inappropriate function in the system
Potential causes
- Wrong settings in the software for the update
- Errors in the update
- Changes in the interface of the equipment or software modules

UCA 7. Software and hardware do not match
Potential causes
- Configuration management issues
- Interrupted update process

Redefining of the safety control

Appropriate and continuous on board maintenance programs:

- By implementing an on board maintenance program it can be ensured that all critical systems remain functional at all times
- A well planned maintenance program covers all necessary areas on board and it is adjusted separately for each vessel
- Maintenance done timely and accordingly to the program by competent personnel ensures smooth operation
- Special attention should be paid not only to the properly timed software updates but also to the updating process.

SC 6. Robust system design

UCA 1. Without robust system design it is not possible to detect and cope with poor and/or missing data

Potential causes

- Lack of economic resources
- Lack of commitment
- Lack of competence
- Failure modes are not taken into account

UCA 2. Single point failure takes the whole system down

Potential causes

- Lack of system understanding
- Failure modes are not taken into account

Redefining of the safety control

Robust system design:

- Robust system design should be able to isolate failures in the system and allow for the rest of the system to continue operating.

SC 7. Appropriate system (software) design and maintenance processes

UCA 1. User requirements are not known or taken into account and the final product is not the expected.

Potential causes

- Poor communication between customer and developer
- Customer is not competent to define needs
- Lack of time
- Lack of interest

UCA 2. System requirements are not clear for the developers and do not cover relevant issues

Potential causes

- Poor documentation
- Poor communication between developers and sales people

UCA 3. System design does not meet expectations

Potential causes

- Poor documentation
- Poor communication
- The design is not reviewed

UCA 4. System implementation does not meet expectations

Potential causes

- Poor documentation
- Missing review of the implementation
- Human coding error
- Poor or missing testing

UCA 5. Software is not verified properly

Potential causes

- Customer and system requirements cannot be compared due to poor documentation
- Lack of time
- Lack of economic resources

UCA 6. Change management is not working properly

Potential causes - Change requirements are not communicated properly - Effect analysis of changes is not performed *Redefining of the safety control* Appropriate system (software) design and maintenance processes: - Ensure that the system meets customer's expectations - Requires good communication between customer, sales people and developers, but also good documentation - Special attention should be paid to reviews throughout the process and software verification at the end - Change management must not be forgotten

Hazard 3. Technical fault (e.g. mechanical failure)

Hazard	H3. Technical fault (e.g. mechanical failure)			
Hazard effect/ description	*Provide extra details regarding the designated severity rating* In case of technical fault, the vessel may e.g. lose her steering or propulsion power that may lead to collision with a moving or fixed object, allision with a pier, grounding or bottom contact. The hazard can have a negative impact on people, property and environment. It can result in injuries, loss of human life, severe damage or loss of property (own and others property) and environmental effects such as oil spills or other damage of sensitive sea areas.			
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Inappropriate maintenance - Manufacturing defect - Incorrect technical design - Vandalism			
Mitigation strategy	- Redundancy of critical systems - Thorough planning, testing and commissioning of all technical systems - Appropriate and continuous maintenance programs - Distance monitoring and fault detection of the technical systems		*Cost/Difficulty* High High Low High	*Priority (1-4) ** 4 4 3 3
**Mitigation priority scale*	*Level* 4 3 2 1	*Description* Eliminate Prevent Control Reduce	*Detailed description* Complete elimination of the hazard Reduction of the likelihood that the hazard will occur Reduction of the likelihood that the hazard results in an accident Reduction of the damage if the accident occurs	

STPA Analysis:

(1) Safety controls
SC 1. Redundancy of critical systems SC 2. Thorough planning, testing and commissioning of all technical systems SC 3. Planned and predictive maintenance programs SC 4. Remote monitoring and fault detection of technical systems
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety controls
SC 1. Redundancy of critical systems UCA 1. There is no redundancy for critical systems and any single failure can cause vessel operation to stop *Potential causes* - Lack of resources - Lack of competence - Poor planning

UCA 2. The critical equipment have not been identified correctly
Potential causes
- Lack of resources
- Lack of competence
- Poor planning

UCA 3. Critical systems have been changed without proper analysis of the effects on the system
Potential causes
- Lack of change management
- Lack of economic resources
- Lack of time
- Lack of competence
- Lack of spare parts available
- Poor documentation

Redefining of the safety control
Redundancy of critical systems:
- With redundancy in the systems the effect of a single failure can be minimized
- Redundancy and system integration should be taken into account already in the planning stage
- Proper testing and commissioning of the systems verifies that all critical systems have been identified
- Changes in the system should be managed with a proper protocol/ process

SC 2. Thorough planning, testing and commissioning of all technical systems

UCA 1. Autonomous operations have not been taken into account in the whole system design
Potential causes
- Lack of economic resources
- Lack of knowledge and experience
- Lack of system integration

UCA 2. The tests fail to recognize the problem or potential fault in the systems
Potential causes
- Lack of knowledge of operational conditions
- Only subsystems have been tested

UCA 3. The commissioning is not done thoroughly
Potential causes
- Lack of time
- Lack of economic resources
- Lack of supervision on client's side
- Lack of knowledge and experience
- Poor documentation

Redefining of the safety control
Thorough planning, testing and commissioning of all technical systems:
- The process should be done in good cooperation with designers, buyers, builders, suppliers and regulators. The autonomous status of the vessel should be taken into account throughout the process
- New and efficient practices for commissioning and testing of autonomous vessel systems should be developed in cooperation with the relevant stakeholders

SC 3. Planned and predictive maintenance programs

UCA 1. The system fails due to the lack of maintenance
Potential causes
- There is no maintenance program
- The maintenance program is not followed
- Lack of economic resources

UCA 2. The maintenance done is not of the right type or it is done poorly
Potential causes
- Lack of knowledge about the system

- Lack of commitment UCA 3. Maintenance programs fail to take into account interaction between systems *Potential causes* - Poor planning - Lack of knowledge about the system connections *Redefining of the safety control* Planned and predictive maintenance programs: - With proper maintenance programs the safety of the vessel can be ensured, the number of technical faults minimized and the life cycle of technical systems maximized - Maintenance programs have to take into account the system interactions
SC 4. Distance monitoring and fault detection of technical systems UCA 1. Without distance monitoring and fault detection technical faults will not be detected *Potential causes* - Lack of money - Lack of trust on distance operations UCA 2. Distance monitoring and/or fault detection of technical systems do not work *Potential causes* - Electromagnetic noise - Poor quality of the data - Quality of the data is not monitored - Failure in the data link on-board and/or ashore *Redefining of the safety control* Distance monitoring and fault detection of technical systems: - The safe and effective operation of an autonomous vessel requires distance monitoring and fault detection. Remote monitoring increases the reliability of the operation and reduces off hire time - Without proper monitoring of the data quality, distant monitoring and fault detection systems cannot produce reliable information

Hazard 4. Heavy weather/sea conditions

Hazard	H4. Heavy weather/sea conditions		
Hazard effect/ description	*Provide extra details regarding the designated severity rating* If the weather or sea conditions caused by wind, gusts, waves, swell, thunder or weather fronts are too heavy for the vessel she may come to the limits of her ability to manoeuvre and steer in a controlled way. This may lead to collision with a fixed object, allision with a pier, grounding or bottom contact. The hazard can have a negative impact on people, property and environment. It can result in injuries, severe damage or loss of property (own and others property) and environmental effects such as oil spills or other damage of sensitive sea areas.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Unexpected change of conditions - Lack of operational limits or incorrect operational limits - Weather and sea conditions have not been monitored properly - Local conditions differ from the surrounding areas - Inaccurate weather forecasts - Ice conditions		
Mitigation strategy	- Correctly set and followed operational limits - Weather routing and constant weather and sea state monitoring - Vessels equipped with adequate environmental sensors for detecting local conditions	*Cost/Difficulty* Low Medium	*Priority (1-4) ** 4 3

	- Keeping vessels steady against the wind and waves or heading to an emergency harbour or anchorage - Constant monitoring and predictions of vessels' capability	Medium Low Medium	3 2 2

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

Hazard 5. Strong currents

Hazard	H5. Strong currents		
Hazard effect/ description	*Provide extra details regarding the designated severity rating* Strong currents affect vessels' steering, especially when manoeuvring with slow speed. This may lead to allision with a pier or collision with a fixed object. In some cases it may also lead to grounding or bottom contact. The hazard can have negative impact on people, property and environment. It can result in injuries, severe damage or loss of property (own and others property) and environmental effects such as oil spills or other damage of sensitive sea areas.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Lack of knowledge of local currents in rivers and archipelagos - Lack of monitoring the current effecting the vessel and taking it into account		
Mitigation strategy	- Knowledge of local currents - Constant monitoring of the current and adjusting the steering accordingly - Constant monitoring and predictions of vessels' capability	*Cost/Difficulty* Low Medium Medium	*Priority (1-4) ** 2 2 2

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis (combines hazards 4 and 5):

(1) Safety controls
SC 1. Correctly set and followed operational limits SC 2. Weather routing and constant weather and sea state monitoring SC 3. Vessel equipped with adequate environmental sensors for detecting local conditions SC 4. Keeping the vessel steady against the wind and waves or heading to an emergency harbour or anchorage SC 5. Knowledge of local currents and other local environmental conditions SC 6. Constant monitoring of the currents and adjusting the steering accordingly SC 7. Constant monitoring and predictions of vessels capability
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety controls
SC 1. Correctly set and followed operational limits UCA 1. Shipping company has not set operational limits for the vessel *Potential causes*

- Lack of competence
- Lack of understanding the importance of setting the operational limits
- Lack of control measures for ensuring that the limits are programmed to the system

UCA 2. Operational limits set by the shipping company are too high for the safe operation of the vessel
Potential causes
- Lack of competence
- Lack of information about vessel's features
- Pressure from outside the shipping company
- Lack of external verification
- Company takes intended risk

UCA 3. Operational limits set for the vessel are not followed
Potential causes
- Error in detecting the conditions affecting vessel
- Error in algorithms
- Pressure from outside the shipping company
- Lack of monitoring from the remote monitoring centre

Redefining of the safety control
Correctly set and followed operational limits:
- Permanent operational limits set by the shipping company and acknowledged by all the parties involved, ensure that the operations are stopped before the safety of a vessel is compromised
- Correct operational limits can be determined by considering vessels' features, capability to manoeuvre and operating areas
- If limits and automatic procedures - for cases when limits are crossed - are programmed in the vessel systems, the limits are followed without the need to make decisions case by case. Thus decision making is not exposed to human error
- Sending an alarm to the remote monitoring centre - when limits are crossed – acts as a double check, ensuring that the vessel has time to cease her operations safely

SC 2. Weather routing and constant weather and sea state monitoring

UCA 1. Environmental conditions are not taken into account when planning vessels' routes
- Lack of competence
- Lack of information about the conditions affecting vessels en route

UCA 2. Weather and sea state are not constantly monitored when the vessel is in operation
- Lack of economic resources
- Lack of understanding of the importance of the environmental information
- Lack of equipment
- Information is not received from local environmental sensors or the information is not correct

UCA 3. Vessel's route is not changed accordingly when environmental conditions require doing so
- Error in detecting the conditions affecting the vessel
- Error in algorithms
- Lack of monitoring
- Used weather forecasts used are not reliable

Redefining of the safety control
Weather routing and constant weather and sea state monitoring:
- Checking the weather forecasts should always be part of the route planning. Checking the forecast automatically against the plan (also in the permanent routes between two points) every time before departure ensures vessel safety
- Constant automatic monitoring of the weather forecasts as well as the local real-time weather data during the trip ensure the safety along the whole way. Receiving weather forecast from more than one source gives redundancy and allows comparison
- With pre-planned alternative routes programmed to the system, vessels can automatically be safely re-routed if necessary. Re-routing functions should always be properly tested in the commissioning stage.

SC 3. Vessels equipped with adequate environmental sensors for detecting local conditions

UCA 1. Vessels are not equipped with adequate and appropriate sensors for monitoring the conditions around them
- Lack of economic resources
- Lack of knowledge of sensor characteristics or of understanding the needs when planning the sensor set for vessels
- The sensors chosen are not planned to be used in cold climates
- Lack of guidance (regulations)

UCA 2. There is not enough redundancy in environmental sensors
- Lack of economic resources
- Lack of competence

Redefining of the safety control
Vessels equipped with adequate environmental sensors for detecting local conditions:
- With proper equipment on board (or along the route), vessels are able to react also to sudden local changes in the conditions
- In winter conditions proper and reliable operation can be guaranteed if local needs and equipment characteristics as well as redundancy needs, are considered carefully already when planning the vessel.

SC 4. Keeping the vessel steady against the wind and waves, heading to an emergency harbour or anchoring

UCA 1. In case the weather/sea conditions change suddenly over the operational limits, the vessel continues on her route normally instead of choosing a safer option for the situation
Potential causes
- There are no emergency harbours programmed in the system
- Lack of monitoring the environmental conditions
- Lack of monitoring from the remote monitoring centre
- It is safer to continue

Redefining of the safety control
Keeping the vessel steady against the wind and waves, heading to an emergency harbour or anchoring :
- If an unexpected weather change makes continuing on the route unsafe, automatic route specific contingency actions (such as driving with minimum manoeuvring speed against the wind etc. or re-routing the vessel to a suitable emergency harbour) programmed to the system are necessary precautions

SC 5. Knowledge of local currents and other local environmental conditions

UCA 1. Information about local currents and local environmental conditions in rivers and archipelagos have not been gathered
Potential causes
- Lack of competence
- Lack of existing information or up to date information
- Lack of commitment

UCA 2. Information about local currents and local environmental conditions have not been taken into account when planning vessel routes
Potential causes
- Lack of competence
- Lack of commitment

Redefining of the safety control
Knowledge of local currents and other local environmental conditions:
- Available information about the local currents and frequent weather conditions is a valuable tool when planning the vessel and her routes. Especially in archipelagos, lakes and rivers there can be strong local currents, places where fog regularly forms or where the wave height rises above the normal level

SC 6. Constant monitoring of the current and adjusting the steering accordingly

UCA 1. There is no equipment available to monitor the current in real time
Potential causes
- Lack of economic resources
- Lack of suitable equipment in the market
- There is no actual need to measure the current

UCA 2. Current monitoring system does not function correctly
Potential causes
- Lack of maintenance
- Error in equipment

UCA 3.Current monitoring information is not connected to the AI and steering equipment
Potential causes
- Lack of economic resources

UCA 4. The reaction time to drifting is too long
Potential causes
- Error in programming
- Lack of competence

Redefining of the safety control
Constant monitoring of the current and adjusting the steering accordingly:
- Vessels reliably equipped to monitor real time currents and to automatically adjust the steering accordingly, without delays, are able to manoeuvre and dock safely and smoothly

SC 7. Constant monitoring and predictions of vessel capability

UCA 1. Vessel capability is not monitored
Potential causes
- Lack of economic resources
- Lack of competence
- Lack of commitment

UCA 2. Information of the vessel capability is not used to adjust the operational limits or the operation
Potential causes
- Lack of economic resources
- Lack of competence
- Lack of commitment

Redefining of the safety control
Constant monitoring and predictions of vessel capability:
- With constant monitoring and predictions of vessel capability, vessels are able to adjust operational limits and operation in general when necessary. There might be external or internal factors that require lowering the operational limits temporarily

Hazard 6. Position reference equipment failure

Hazard	H6. Position reference equipment failure
Hazard effect/ description	*Provide extra details regarding the designated severity rating* If the position reference equipment fail or give incorrect information, vessels cannot navigate safely. This may lead to allision with pier or collision with a fixed object, grounding or bottom touching. The hazard can have a negative impact on people, property, and environment. It can result in injuries, severe damage or loss of property (own and others property) and environmental effects such as oil spills or other damage of sensitive sea areas.
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Loss of power - Intentional satellite position system jamming - Unintentional satellite positioning jamming - Satellite position system spoofing - Poor satellite availability - Effect of rain etc. on local position reference systems - Dirt (on local position system sensor)

	- Equipment malfunction - Inappropriate maintenance		
Mitigation strategy		*Cost/Difficulty*	*Priority (1-4) **
	- Equipment (sensor) redundancy	High	4
	- Combination of local and satellite position reference systems	High	2
	- Satellite positioning equipment with jamming detection and/or anti-jamming function	Low	3
	- UPS (Uninterrupted Power Source)	Low	3
	- Appropriate heating, cooling and cleaning for local position reference systems	Medium	3
	- Thorough installation and commissioning of equipment set	Medium	3/4
	- Appropriate and continuous on board maintenance programs	Low	3
	- Continuous system diagnosis and proof testing	Low	3
	- Autonomous integrity monitoring	Low	2

	Level	*Description*	*Detailed description*
**Mitigation priority scale*	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis:

(3) Safety control
SC 1. Equipment (sensor) redundancy SC 2. Combination of local and satellite position reference systems SC 3. Satellite positioning equipment with jamming detection and/or anti-jamming function SC 4. UPS (Uninterrupted Power Source) SC 5. Appropriate heating, cooling and cleaning for local position reference systems SC 6. Thorough installation and commissioning of equipment set SC 7. Appropriate and continuous on board maintenance program SC 8. Continuous system diagnosis and proof testing SC 9. Autonomous Integrity monitoring
(4) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety control
SC 1 Equipment (sensor) redundancy UCA 1. Sensor does not function properly and there is no redundancy in the system *Potential causes* - Lack of economic resources - Poor planning UCA 2. Sensor failure is not detected due to the lack of information from other equipment to be compared with *Potential causes* - Lack of economic resources - Poor planning UCA 3. External or common cause failures take several equipment down at the same time *Potential causes* - Inappropriate system design - Incorrect installation - Incorrect usage - Environmental conditions *Redefining of the safety control*

Equipment (sensor) redundancy
- If one sensor fails the redundancy ensures there is another sensor functioning
- System design must have adequate diagnosis function in order to recognize sensor failures and perform the switch over procedure when necessary
- Equipment used to provide redundancy should be completely independent from one another to reduce the risk of a common cause failure taking them down at the same time

SC 2 Combination of local and satellite position reference systems

UCA 1. Positioning is based on satellite positioning only and vessels e.g. lose position because of satellite system failures or poor satellite availability
Potential causes
- Lack of economic resources
- Inappropriate system design

UCA 2. Satellite positioning reference equipment give incorrect information and there is no local positioning information to compare it with
Potential causes
- Lack of economic resources
- Inappropriate system design

UCA 3. Positioning is based on local position reference systems only and vessels e.g. lose position due to poor weather conditions
- Lack of economic resources
- Inappropriate system design

Redefining of the safety control
Combining different types of local and satellite position reference systems:
- Using a combination of local and satellite position reference systems provides reliable position information in different conditions and locations
- Helps to detect possible errors in the information

SC 3. Satellite positioning equipment with jamming detection and/or anti-jamming function

UCA 1. Vessel loses her position due to jamming
Potential causes
- Lack of economic resources
- Lack of certified equipment in the market

UCA 2. Vessel receives wrong or inaccurate position information due to jamming
Potential causes
- Lack of economic resources
- Lack of certified equipment in the market

Redefining of the safety control
Satellite positioning equipment with jamming detection and/or anti-jamming function
- Jamming detection ensures that the jamming is noticed and users can switch to local position reference systems
- An anti-jamming function reduces the risk of losing position or receiving wrong/inaccurate position information due to GPS jamming

SC 4 UPS (Uninterrupted Power Source)

UCA 1. There is a disturbance in a vessel's power system and the equipment is not backed up with UPS
Potential causes
- Lack of economic resources
- Lack of understanding of the importance of the UPS

UCA 2. The UPS does not work
Potential causes
- UPS is not charged
- UPS is not connected correctly
- UPS is broken

UCA 3. It takes too long for the UPS to switch on and the GPS equipment needs to reacquire the position fix
Potential causes
- Errors in UPS function
- Poor planning
- Lack of economic resources

UCA 4. The capacity of the UPS is not sufficient to provide power for the equipment as long as needed or the capacity in terms of power and/or energy of the UPS is exceeded
Potential causes
- The disturbance lasts longer than expected in the planning stage
- Wrong type of UPS

Redefining of the safety control
UPS (Uninterrupted Power Source):
- If there is a disturbance in the vessel power system, the UPS can temporarily provide power for critical equipment
- When the UPS setup is planned, installed and maintained properly, the user can count on a reliable backup system
- For the GPS system a UPS with a quick switch-on function is critical. In case of power loss, the GPS equipment needs to reacquire the position fix, something which can take several minutes at worst.

SC 5 Appropriate heating, cooling and cleaning for local position reference systems

UCA 1. Equipment is not able to function properly in winter conditions
Potential causes
- Equipment does not have heating function
- Extremely low temperatures
- Icing

UCA 2. Equipment does not function properly due to high temperatures
Potential causes
- Equipment does not have cooling function
- Extremely high temperatures
- The systems are located close to heat sources

UCA 3. Equipment lens is dirty
Potential causes
- Sea water sprays
- Bird feces

UCA 4. Condensation inside equipment
Potential causes
- Leaking
- Temperature changes
- Fault on the equipment design
- Humid climate
- Location on-board

Redefining of the safety control
Appropriate heating, cooling and cleaning systems:
- By applying sensors with proper heating and/or cooling systems it is ensured that they function properly in all operating conditions
- By applying sensors with automatic cleaning systems it is ensured that they function properly outdoors

SC 6 Thorough installation and commissioning of equipment set

UCA 1. Position of the GPS antenna has a limited sky view
Potential causes
- Limited space
- Poor planning

UCA 2. GPS antenna is placed too close to radio equipment causing interference
Potential causes
- Limited space
- Poor planning

UCA 3. GPS antenna cable length and amplification are not optimized
Potential causes
- Poor planning

UCA 4. Local position reference system's sensor head or antenna view is blocked by obstacles
Potential causes
- Limited space
- Poor planning
- Poor change management

UCA 5. The equipment set has not been properly tested, or not tested at all, before operation
Potential causes
- Lack of economic resources
- Test plan is not appropriate
- Lack of time

Redefining of the safety control
Thorough installation and commissioning of equipment set:
- Placing of the GPS antenna has to be optimal with regards to the sky view and distance to transmitting radio equipment
- Installation of the GPS antenna and cabling have to be thoroughly planned and performed by a certified supplier
- An unobstructed sensor head and antenna view is essential when using local position reference systems
- When the equipment set is thoroughly tested and certified (preferably by an independent body) it ensures that the equipment function properly, are compatible and the operation can be run safely.

SC 7 Appropriate and continuous on board maintenance program

UCA 1. There is no on board maintenance program
Potential causes
- Lack of economic resources
- Lack of understanding the importance of maintenance programs

UCA 2. The maintenance program does not cover the necessary elements and the life cycle of the hardware.
Potential causes
- Lack of competence

UCA 3. The maintenance program is not followed
Potential causes
- Lack of time (work overload)
- Lack of economic resources
- Lack of understanding of the importance of the maintenance program

UCA 4. Maintenance is not done properly
Potential causes
- Lack of commitment
- Lack of competence
- Human error or mistake
- Lack of economic resources

Redefining of the safety control
Appropriate and continuous maintenance program:
- By implementing an on board maintenance program it can be ensured that all critical systems remain functional at all times
- A well planned maintenance program covers all necessary areas on board and it is adjusted separately for each vessel

- Maintenance done timely and accordingly to the program by competent personnel ensures the smooth operation of the sensors

SC 8. Continuous system diagnosis and proof testing

UCA 1. There is no continuous system diagnosis and proof testing
Potential Causes
- Lack of economic resources
- Lack of planning
- It cannot be performed due to the effects on operation

UCA 2. The continuous system diagnosis and proof testing do not cover all necessary functions
Potential causes
- Lack of economic resources
- Lack of planning
- Tests cannot be performed due to the effects on operation

UCA 3. The test is not able to recognize problems
Potential causes
- Wrong test design
- Changes in the system

Redefining of the safety control:
Continuous system diagnosis and proof testing:
- Continuous system diagnosis and regular proof testing ensures that the system functions as it should
- Test design should be planned carefully and updated after changes in the system in order to cover all the necessary functions and recognize potential problems
- Possible effect on the operation should be taken into account in the planning

SC 9. Autonomous Integrity monitoring
UCA 1. There is no integrity monitoring
Potential causes
- Lack of economic resources
- Lack of planning
- Lack of understanding

UCA 2. Integrity monitoring gives wrong information
Potential Causes
- Common cause failure
- Wrong design
- Changes in the system

UCA 3. Integrity monitoring is not able to recognize spoofing signals
Potential Causes
- Lack of competence
- Poor planning
- Lack of certified equipment in the market

Redefining of the safety control:
Autonomous Integrity monitoring:
- Well designed and up to date integrity monitoring systems ensure that the data has not been damaged or manipulated

Hazard 7. Overloading vessels

Hazard	H7. Overloading vessels
Hazard effect/ description	*Provide extra details regarding the designated severity rating* Overloading a vessel causes stability problems and affects her manoeuvring characteristics. It may lead to capsizing or sinking of the vessel.

	The hazard can have negative impact on people, property and environment. It can result in injuries, loss of human life, severe damage or loss of property and environmental effects such as oil spills or other damage of sensitive sea areas.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Too many passengers - Too much cargo - Added permanent weights like equipment etc.		
Mitigation strategy	- Automated door type passenger gates which do not allow more than maximum number of passengers on board - Clear rules, weighing and monitoring of the cargo taken on board - In case of adding permanent weights on board stability calculations and tests to be redone - Automatic continuous monitoring of vessel stability (draft, trim, list and GM), vessels programmed not to leave pier if over the limits.	*Cost/Difficulty* High Low Low Medium	*Priority (1-4) ** 4 4 4 4

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis:

(1)Safety controls
SC 1. Automated door type passenger gates which do not allow more than maximum number of passengers on board SC 2. Clear rules, weighing and monitoring of the cargo taken on board SC 3. In case of adding permanent weights on board stability calculations and tests to be redone SC 4. Automatic continuous monitoring of the vessel's stability (draft, trim, list and GM), vessel programmed not to leave pier if over the limits.
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety controls
SC 1. Automated passenger gates which do not allow more than maximum number of passengers on board UCA 1. There is no system to count the number of the passengers on board *Potential causes* - Lack of economic resources - Lack of technology - Lack of planning UCA 2. There is a system but it is not reliable *Potential causes* - Passengers stay on-board for a second trip - Unaccounted persons (people without ticket, wheelchair users, family with children, bikes, baby strollers) who come on board via another route - Lack of economic resources - Lack of technology - Lack of planning - Lack of maintenance - Function error UCA 3. The passenger gate separates family members (parents and children) *Potential cause* - The vessel is full *Redefining of the safety control*

Automated passenger gates which do not allow more than maximum number of passengers on board:

- With reliable passenger count, the overloading of the vessel and the exceeding of maximum number of passengers can be avoided
- Systems have to take into account people staying on-board, people without ticket, wheelchairs, families with children, bikes, baby strollers etc. that do not board the vessel through the gates. The gate should not separate parents and children
- The possible solutions for counting reliably could be e.g. automatic software and camera systems that compare the amount of passengers going in and out, defining a boarding process and boarding areas in pier, or emptying the vessel completely before reloading

SC 2. Clear rules, weighing and monitoring of the cargo taken on board

UCA 1. Vessels are overloaded because there is no knowledge of weight of cargo on board

Potential causes

- There is no system in place to monitor weights
- Lack of economic resources
- Lack of commitment

UCA 2. There is a system for weighing the cargo but it is not reliable

Potential causes

- Calibration is not done
- Lack of maintenance
- Error in the system

Redefining of the safety control

Clear rules, weighing and monitoring of the cargo taken on board:

- By monitoring the vessel trim, list and draft, weight of the vessel can be calculated
- The possible means that can be used are e.g. pressure sensors, echo sounder or visual reading of drafts

SC 3. In case of adding permanent weights on board stability calculations and tests to be redone

UCA 1. The added weights are not recorded

Potential causes

- Lack of oversight
- Lack of economic resources
- Lack of time

UCA 2. The recorded weights are inaccurate

Potential causes

- Lack of information
- Lack of knowledge
- Lack of commitment
- Lack of oversight

UCA 3. The stability tests/calculations are not updated

Potential causes

- Lack of information
- Lack of knowledge
- Lack of commitment
- Lack of oversight
- Lack economic resources

Redefining of the safety control

In case of adding permanent weights on board stability calculations and tests to be redone

- If stability calculations are not up to date, the vessel operation may not be safe and according to regulations

SC 4. Automatic continuous monitoring of vessel stability (draft, trim, list and GM), vessel programmed not to leave pier if over the limits

UCA 1. There is no system to continuously monitor vessel stability

Potential causes

- Poor planning

- Lack of economic resources
- Lack of oversight

UCA 2. Vessel does not leave pier even though the vessel is loaded correctly or leaves the pier overloaded
Potential causes
- Equipment malfunction (inaccuracy)
- Lack of redundancy

UCA 3. There is only one monitoring system with no redundancy
Potential causes
- Lack of economic resources
- Poor planning

Redefining of the safety control
Automatic continuous monitoring of the vessel's stability (draft, trim, list and GM), vessel programmed not to leave the pier if over the limits
- There should always be real-time information available of the vessel's stability in order to operate safely. By programming the safety limits allowed to the system, leaving pier can be prevented in unsafe stability situations
- With redundant monitoring systems, unnecessary stops in operation or unsafe situations caused by an equipment malfunction can be minimized

Hazard 8. Shifting of weights

Hazard	H8. Shifting of weights		
Hazard effect/ description	*Provide extra details regarding the designated severity rating* Shifting of weights on board affect vessel stability dramatically, especially if the weights are shifted to upper levels of the vessel or the shifting weights create free surfaces. This hazard may lead to capsizing or sinking of vessels. The hazard can have a negative impact on people, property and environment. It can result in injuries, loss of human life, severe damage or loss of property and environmental effects such as oil spills or other damage of sensitive sea areas.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - All passengers moving to one side - Cargo starts moving - Water from fire fighting create free surfaces - Poor planning		
Mitigation strategy		*Cost/Difficulty*	*Priority (1-4) **
	- Passenger instructions on quay and on board	Low	3
	- Vessel design	Medium	4
	- Firefighting systems that use very little water or no water at all	High	4
	- Anti-heeling system	High	4
	- Remote monitoring centre monitors vessels stability and instructs people by voice if necessary	High	2

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis:

(1) Safety controls
SC 1. Passenger instructions on quay and on board SC 2. Vessel design SC 3. Firefighting systems that use very little water or no water at all SC 4. Anti-heeling system SC 5. Remote monitoring centres monitor vessel stability and instructs people by voice if necessary
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety controls
SC 1. Passenger instructions on quay and on board UCA 1. Passenger instructions regarding weight distribution are poor or not easy enough to understand *Potential causes* - Poor planning UCA 2. Passengers do not familiarize themselves with the instructions *Potential causes* - Positioning of the instructions - Visual look of the instructions - Language barrier - Time constraint - Wrong means for providing instructions *Redefining of the safety control* Passenger instructions on quay and on board: - Good passenger information is clear, simple and does not leave place for misunderstandings - If the information is visually interesting and the means for giving it are correct, people are more likely to read, listen or watch it
SC 2. Vessel design UCA 1. The design does not prevent the people from crowding or falling to one side of the vessel *Potential causes* - Poor interior design - Lack of seating - Lack of natural dividers UCA 2. The vessel lists considerably in case of the crowding of people to one side *Potential causes* - Poor initial stability UCA 3. Cargo and storage spaces do not have any compartments that would prevent items from moving to one side of the vessel *Potential causes* - Poor design *Redefining of the safety control* Vessel design: - With good vessel design, passenger and cargo movements and stability can be controlled. E.g. seating arrangements can be used as natural dividers and the vessel can be designed with very high initial stability.
SC 3. Firefighting systems that use very little water or no water at all UCA 1. The use of large amount of firefighting water creates free surfaces and may endanger the vessel stability *Potential causes* - Poor design - Lack of economic resources - Wrong type of firefighting system *Redefining of the safety control* Firefighting systems that use very little water or no water at all:

- When selecting the firefighting system to be installed on board, the stability and the free surface effects caused by the firefighting water should be taken into account
SC 4. Anti-heeling system UCA 1. Vessels have no anti-heeling system, listing can not be corrected and causes danger or discomfort for passengers *Potential causes* - Lack of economic resources - Poor initial ship design UCA 2. Malfunctioning of anti-heeling systems may endanger vessel safety *Potential causes* - Poor safety planning *Redefining of the safety control* - If the vessel is designed with anti-healing system that compensates for small heels, it increases the comfort and safety of the passengers. However, a possible malfunction of the system must not be able to endanger the safety of the vessel
SC 5. Remote monitoring centres monitor vessel stability and instruct people by voice if necessary UCA 1. People on board panic, don't know what to do or act irrationally, because the system for instructing people by voice does not exist *Potential causes* - Poor planning of vessel's safety features - Lack of economic resources UCA 2. Connection between the vessels and the monitoring centres does not work *Potential causes* - Technical problem - Lack of redundancy UCA 3. The way of giving instructions is not suitable and they are not followed onboard *Potential causes* - Poor planning - Psychological factors have not been considered deep enough in planning the messages - Person in charge of the situation has not been properly trained *Redefining of the safety control* Remote monitoring centres monitor vessel stability and instruct people by voice if necessary: - Calming the passengers is necessary in order to keep them functional and prevent irrational actions that make the situation worse. With detailed instructions, untrained people are able to perform operations they would not be able to do on their own - Persons giving instructions have to be well trained in basic ship stability as well as crowd and crisis management - There has to be redundancy in the connection between vessels and shore and it has to be reliable

Hazard 9. Flooding

Hazard	H9. Flooding
Hazard effect/ description	*Provide extra details regarding the designated severity rating* Vessels taking in water may lose stability and capsize or sink very quickly. The hazard can have negative impact on people, property and environment. It can result in injuries, loss of human life, severe damage or loss of property and environmental effects such as oil spills or other damage of sensitive sea areas.
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Penetration of the hull - Fire fighting with large amounts of water - Large amounts of rain

	- Heavy listing that allows water to flood the main deck from the openings			
Mitigation strategy			*Cost/Difficulty*	*Priority (1-4) **
	- Double hull and compartments		High	4
	- Well planned and built piping systems		medium	4
	- Automatic monitoring system for tanks, pipes, and cofferdams		High	2
	- Fire extinguishing systems that use very little water or no water at all		High	3
	- Good drainage system on the deck		Low	3
	- Effective bilge pumps		Medium	2
**Mitigation priority scale*	*Level*	*Description*	*Detailed description*	
	4	Eliminate	Complete elimination of the hazard	
	3	Prevent	Reduction of the likelihood that the hazard will occur	
	2	Control	Reduction of the likelihood that the hazard results in an accident	
	1	Reduce	Reduction of the damage if the accident occurs	

STPA Analysis:

(1) Safety controls
SC 1. Double hull and compartments SC 2. Well planned and built piping systems SC 3. Automatic monitoring systems for tanks, pipes and cofferdams SC 4. Fire extinguishing systems that use very little water or no water at all SC 5. Good drainage system on the deck SC 6. Effective bilge pumps
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety controls
SC 1. Double hull and compartments UCA 1. Single hull allows large amounts of water to flood spaces under the waterline very quickly if penetrated Potential causes - Lack of economic resources - Poor planning - Lack of space - Weight of vessels UCA 2. Vessels lose stability due to water moving freely inside the hull Potential causes - Lack of economic resources - Poor planning - Lack of space - Weight of the vessel *Redefining of the safety control* Double hull and compartments: - A double hull and compartmented structure help vessels maintain stability in case of an accident
SC 2. Well planned and built piping systems UCA 1. Bursting of a single wall pipe allows water (or other liquids) to leak to the spaces inside the hull *Potential causes* - Lack of economic resources - Weight of the vessel - Lack of space UCA 2. Rigid metal piping breaks due to vibrations or pressure shocks *Potential causes* - Lack of economic resources - Metal piping is easy to plan

UCA 3. Complex piping systems with many connection points are more likely to break and leak
Potential causes
- Poor planning
- Poor installation
- Lack of knowledge from client's side

UCA 4. There are only system drawings and no production drawings and the construction worker has to make decisions about details
Potential causes
- Lack of economic resources
- Lack of time
- Lack of knowledge from client's side

Redefining of the safety control
Well planned and built piping system:
- Using double wall pipes, correct materials for pipes and connection points depending on the needs, makes the piping system resistant and less likely to break
- Good planning, building, testing, and oversight of the whole process make the piping system reliable, easy to use and maintain

SC 3. Automatic monitoring systems for tanks, pipes, bilges, and cofferdams

UCA 1. If autonomous vessels without automatic monitoring systems for tanks, bilges and cofferdams suffer accidents, vessel stability problems and possible leaks cannot be detected
Potential causes
- Lack of economic resources
- Poor planning

UCA 2. A burst pipe in the engine room is not noticed
Potential causes
- Lack of economic resources
- Poor planning

Redefining of the safety control
Automatic monitoring system for tanks, pipes, bilges, and cofferdams:
- Leaks and bursts in hull and piping can be detected quickly by an automatic monitoring system
- In case of an accident, vessels stability can be evaluated and possible actions planned accordingly
- The function of the monitoring system needs to be also monitored

SC 4. Fire extinguishing systems that use very little water or no water at all

UCA 1. Vessel loses her stability due to the large amount of water used in firefighting.
Potential causes
- Poor planning
- Wrong type of fire extinguishing system
- Fire extinguishing system is used for too long
- Lack of competence
- Wrong firefighting tactics

UCA 2. Firefighting water damages vessel equipment.
Potential causes
- Wrong type of firefighting system

Redefining of the safety control
Fire extinguishing systems that use very little water or no water at all:
- Reduce the possibility that a firewater causes stability problems to the vessel and therefore allows the system to be used as long as necessary
- May damage the vessel's equipment less compared to a situation when large amounts of water is used in firefighting
- A good solution could be to use aerosol system (potassium based) for fire extinguishing and water mist system for cooling

SC 5. Good drainage system on deck

UCA 1. Rainwater and sea spray flood the deck and weaken vessel stability due to lack of efficient drainage system
Potential causes
- Poor planning
- Poor installation

UCA 2. Drainage system is blocked by ice in winter conditions
Potential causes
- Extremely cold temperatures
- No heating system

UCA 3. Drainage systems are blocked by dirt or debris.
Potential causes
- Poor maintenance
- Vandalism by passengers

Redefining of the safety control
Good drainage systems on deck:
- Removes water from the deck efficiently and reduces possible stability problems
- Winter conditions and possibility of passengers sticking litter etc. into the drainage have to be taken into account when planning the drainage system

SC 6. Effective bilge pumps

UCA 1. Bilge pumps are not effective enough to pump out the water coming in from a penetration in the hull.
Potential causes
- Lack of economic resources
- Poor planning

UCA 2. Bilge pumps break and there is no redundancy
Potential causes
- Lack of economic resources
- Poor planning

UCA 3. The bilge pumps are not connected to the emergency power system
Potential causes
- Lack of economic resources
- Poor planning

Redefining of the safety control
Effective bilge pumps:
- Keep the vessel afloat if there is water in the engine room and give time for the evacuation of the passengers
- Protect vessel equipment and systems in case of flooding
- Pump redundancy and emergency power systems have to be taken into account

Hazard 10. Ignition of electrical equipment and wiring

Hazard	H10. Ignition of electrical equipment and wiring
Hazard effect/ description	*Provide extra details regarding the designated severity rating* Electrical equipment and wiring are potential ignition places for fires on board autonomous vessels. The hazard can have a negative impact on people, property and environment. It can result in injuries, loss of human life, severe damage or loss of property (own and others property) and environmental effects such as oil spills or other damage of sensitive sea areas.
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Inappropriate selection of electrical equipment and wiring - Wear and tear of wiring

	- Loose connections - Overloads - Short circuits - Power surges - Overheating - Maintenance problems		
Mitigation strategy		*Cost/Difficulty*	*Priority (1-4) **
	- Thorough planning and commissioning of electrical equipment and wiring	Low	3
	- Appropriate cooling and heating for electrical systems	Medium	3
	- Preventive maintenance programs	Low	3
	- Circuit breakers and fault current protection	Low	4
	- Automatic fire extinguishing systems inside electrical cabinets	Medium	1
	- Automatic fire detection, alarm and extinguishing systems in engine spaces	Medium	1

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis:

(1) Safety controls
SC 1. Thorough planning and commissioning of electrical equipment and wiring SC 2. Appropriate cooling and heating for electrical systems SC 3. Preventive maintenance programs SC 4. Circuit breakers and fault current protection SC 5. Automatic fire extinguishing systems inside electrical cabinets SC 6. Automatic fire detection, alarm and extinguishing systems in engine spaces
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety control
SC 1. Thorough planning and commissioning of electrical equipment and wiring UCA 1. Wrong equipment and wiring or their installations cause fires or cause fires to spread more rapidly than necessary *Potential causes* - Lack of knowledge - Lack of oversight UCA 2. Information used in the planning does not correlate with the use of the system *Potential causes* - Lack of information - Project schedule - Change of an operational profile UCA 3. Testing is poorly planned and done *Potential causes* - Lack of economic resources - Lack of time - Lack of knowledge - Lack of oversight - Lack of information *Redefining of the safety control* Thorough planning and commissioning of electrical equipment and wiring:

- Ensure that components, wiring and equipment chosen are correct for the actual use of the vessel and the installation and penetrations are done properly
- The testing of the electrical equipment and wiring detects the possible faults in the system

SC 2. Appropriate cooling and heating for electrical systems

UCA 1. Overheating of the equipment break the equipment or causes a fire
Potential causes
- No cooling system installed
- Cooling of the surrounding space is not adequate
- Change of environmental conditions
- Fault in component or equipment

UCA 2. Condensation causes a short circuit in electrical equipment
Potential causes
- No heating system installed
- Change of environmental conditions
- Outdoor equipment with no thermal insulation

Redefining of the safety control
Appropriate cooling and heating for electrical systems
- By providing appropriate cooling and heating for electrical systems, problems caused by overheating and humidity can be prevented

SC 3. Preventive maintenance programs

UCA 1. Dust in the equipment may result in overheating and ignition
Potential causes
- Lack of maintenance

UCA 2. Loose connections may result in overheating and ignition
Potential causes
- Lack of maintenance
- Vibrations
- Poor installation
- Wrong component type

UCA 3. Malfunction of the circuit breakers or other protection components e.g. arc protection systems
Potential causes
- Lack of maintenance
- Component failure

Redefining of the safety control
Preventive maintenance programs:
- By checking the cleanliness, connections and proper function of electrical equipment and wiring as well as protection equipment regularly, the risk of ignition of electrical equipment and wiring can be reduced.

SC 4. Circuit breakers and fault current protection

UCA 1. Circuit breaker does not open or cut off the power
Potential causes
- Malfunction of the circuit breaker
- Protection relay does not give the opening order to the circuit breaker
- Component failure

Redefining of the safety control
Circuit breakers and fault current protection:
- Circuit breakers and fault current protection protect equipment and prevent ignition of electrical equipment and wiring

SC 5. Automatic fire extinguishing systems inside electrical cabinets

UCA 1. Without extinguishing systems inside the cabinets, fire can spread to the surrounding spaces

Potential causes
- Poor planning
- Lack of economic resources
- Weight and space issues

UCA 2. The capacity of the extinguishing system is too small to extinguish the fire
Potential causes
- Poor planning
- Lack of knowledge

UCA 3. Too high capacity of the aerosol or gas extinguishing systems build up pressure and increase the fire instead of extinguishing it
Potential causes
- Poor planning
- Lack of knowledge

Redefining of the safety control
Automatic fire extinguishing systems inside electrical cabinets:
- Prevent spreading of the fire to the surrounding spaces and reduce damage to the equipment
- Special attention should be paid to defining the capacity of the extinguishing system

SC 6. Automatic fire detection, alarm and extinguishing systems in engine spaces

UCA 1. Fire in the engine spaces cannot be detected
Potential causes
- Wrong type of detectors
- Wrong location of detectors
- Not enough detectors
- Equipment malfunction
- Poor maintenance

UCA 2. Alarm systems are not connected directly to the remote monitoring centre; the information about the situation is not forwarded
Potential causes
- Poor planning of vessels' safety features
- Lack of economic resources

UCA 3. Fire fighters may not be able to enter or extinguish the fire in the engine room
Potential causes
- Heat and fire gases
- Difficulties in entering the engine spaces

UCA 4. Extinguishing systems are not capable to extinguish the fire
Potential causes
- Lack of power
- Malfunction
- Lack of maintenance
- Poor planning
- Capacity is too small or too large
- Wrong timing

Redefining of the safety control
Automatic fire detection, alarm and extinguishing systems in engine spaces:
- Automatic and effective fire detection and alarm systems provide the ship systems and remote operation centre information about the situation without delay. Detector locations, types and number of detectors should be planned carefully
- Automatic extinguishing systems are the quickest and safest way to extinguish engine room fires in autonomous vessels. Firefighters may not be able to enter the engine spaces physically at all
- Attention should be paid to choosing the right type of extinguishing systems and defining the right capacity for spaces

Hazard 11. Passenger starting a fire

Hazard	H11. Passenger starting a fire		
Hazard effect/ description	*Provide extra details regarding the designated severity rating* Passengers may start fires in passenger spaces by careless forbidden acts. The hazard can have a negative impact on people, property, and environment. It can result in injuries, loss of human life, severe damage or loss of property (own and others property) and environmental effects such as oil spills or other damage of sensitive sea areas.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Smoking or putting cigarette ash or stubs in trash bins - "Horseplay" i.e. playing with a lighter - Deliberate act, arson		
Mitigation strategy	- Smoke detectors and automatic fire extinguishing systems in passenger spaces - No smoking signs - Video surveillance system - Both automatic and manual fire alarm systems in passenger spaces with direct contact to remote monitoring centres - Use of inflammable and fire resistant materials in passenger spaces - Possibility for the passengers to extinguish a fire	*Cost/Difficulty* Medium Low High Low Low Low	*Priority (1-4) ** 2 3 2/3 2 3 2

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis:

(1) Safety controls
SC 1. Smoke detectors and automatic fire extinguishing systems in passenger spaces SC 2. No smoking signs SC 3. Video surveillance systems SC 4. Both automatic and manual fire alarm systems in the passenger spaces with direct access to remote monitoring centres SC 5. Use of inflammable and fire resistant materials in passenger spaces SC 6. Possibility for the passengers to extinguish fires
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety control
SC 1. Smoke detectors and automatic fire extinguishing systems in passenger spaces UCA 1. Fire in passenger spaces is not detected *Potential causes* - Wrong type of detectors - Wrong location of the detectors - Not enough detectors - Equipment malfunction - Poor maintenance UCA 2. Extinguishing systems are not capable to extinguish the fire *Potential causes* - Lack of power - Malfunction - Lack of maintenance

- Poor planning
- Capacity is too small or too large
- Wrong timing

Redefining of the safety control
Smoke detectors and automatic fire extinguishing systems in passenger spaces:
- Smoke detectors are the most suitable device to detect fire in passenger spaces. Use of additional flame detectors could however also be considered. It is essential to get the information about the fire immediately. Delays in this information endangers the whole rescue operation
- When choosing extinguishing systems for passenger spaces the safety of the passengers should be priority number one. E.g. low-pressure water mist systems with concealed nozzles would be a safe and reliable option in unmanned vessels.

SC 2. No smoking signs

UCA 1. Passenger smokes on board and starts a fire
Potential causes
- Lack of respect to the law
- Intoxication

Redefining of the safety control
No smoking signs:
- Smoking is one of the most likely reasons for having fire in passenger spaces. No smoking signs inform passengers that smoking on board is not allowed

SC 3. Video surveillance system

UCA 1. Without active video surveillance the preventive factor cannot be achieved
Potential causes
- Lack of economic resources

UCA 2. Video is not streamed ashore from the vessel in real time.
Potential causes
- Technical problem
- Lack of redundancy
- Lack of economic resources

UCA 3. There is no reaction to a situation captured in the video surveillance system
Potential causes
- Lack of commitment
- Work overload
- Lack of training and/or instructions
- Human machine interface limitations

UCA 4. Video surveillance does not perform properly
Potential causes
- Bad planning
- Problems in data transfer
- Technical problems with the camera
- Lack of redundancy
- Lack of economic resources
- Power source malfunction
- Quality of the picture affected by weather conditions
- Different lighting conditions have not been taken into consideration

Redefining of the safety control
Video surveillance system:
- Awareness of the video surveillance system can prevent erratic passenger behaviour. With active monitoring, dangerous situations can be identified and intervened in real-time
- Reliable real-time data transfer ashore is an essential part of the system if monitored manually ashore
- Appropriate technical specifications of the system should be planned and implemented efficiently
- The video surveillance system itself has to be efficiently monitored

SC 4. Both automatic and manual fire alarm systems on the passenger spaces with direct access to remote monitoring centres

UCA 1. Passengers on board have no easy and quick way to send alarm about fire in passenger spaces
Potential causes
- Poor planning of vessels' safety features
- Lack of economic resources

UCA 2. Smoke detectors are activated but no alarm is given to the passengers
Potential causes
- Poor planning
- Malfunction

UCA 3. Alarm systems are not connected directly to the remote monitoring centres and information about the situation is not forwarded.
Potential causes
- Poor planning of vessels' safety features
- Lack of economic resources

Redefining of the safety control
Both automatic and manual fire alarm systems in the passenger spaces with direct contact to remote monitoring centres:
- It is essential to get information about fires immediately to remote monitoring centres. Delays in this information endanger the whole rescue operation. In some cases, passengers may notice the fire earlier than the automatic system and need to be able to send the alarm manually
- Passengers need to be informed about the activated alarm

SC 5. Use of inflammable and fire resistant materials in passenger spaces

UCA 1. Flammable and non-fire resistant materials allow the fire to spread quickly
Potential causes
- Lack of economic resources
- Lack of knowledge
- Priority of passenger comfort

Redefining of the safety control
Use of inflammable and fire resistant materials in passenger spaces:
- The material used in passenger spaces has significant effect in passenger safety in case of fire
- The amount of plastic should be kept low

SC 6. Possibility for the passengers to extinguish a fire

UCA 1. Available firefighting equipment is too complicated to be used by untrained people
Potential causes
- Poor planning of vessel's safety features

UCA 2. Firefighting equipment are not properly placed, missing or not ready for use.
Potential causes
- Vandalism
- Poor planning
- Poor maintenance

Redefining of the safety control
Possibility for passengers to extinguish fires:
- Firefighting equipment on board should be easily available, simple, safe and easy to use for untrained persons
- Equipment should be placed so that they cannot be easily tampered, e.g. inside a cabinet with an alarm if opened

Hazard 12. Unintended falling overboard

Hazard	H12. Unintended falling overboard		
Hazard effect/ description	*Provide extra details regarding the designated severity rating* Unintended falling overboard from a vessel leads to man over board situations and salvage operations, which can be difficult in case of unmanned vessels and often require outside assistance. The hazard can have negative impact on people. It can result in injuries or loss of human life.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Children falling overboard under or between bars in open reeling structures - Passengers sitting on the reeling - Passengers reaching over the reeling - Open embarkation/disembarkation doors or no doors at all - Winter conditions (darkness, weather and ice conditions)		
Mitigation strategy		*Cost/Difficulty*	*Priority (1-4)*
	- Vessel design with closed and "unclimbable" reeling e.g. transparent inward curved plastic	Low	4
	- Vessel design with automated sliding door type passenger gates which don't open unless the vessel is firmly moored	High	4
	- Manual alarm systems in passenger spaces and piers with direct contact to remote monitoring centres	Medium	1
	- Video surveillance systems	Medium	3
	- Passenger instructions on quay and on board for mob situations	Low	3
	- Remote monitoring centres to calm down and instruct people by voice after alarms	Medium/High	1-3
	- Lifebuoys available	Low	1
	- Vessel to stop automatically in case of a man over board alarm	Low	1
	- Well planned and rehearsed procedures, suitable equipment and clear roles between authorities for recovering a person from the water	Medium	1
	- Possibility for other passengers to assist or recover a person from the water	Medium	1
	- Automatic warning message to be sent to the surrounding vessels	Low	1

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

Hazard 13. Intended jumping overboard

Hazard	H13. Intended jumping overboard
Hazard effect/ description	*Provide extra details regarding the designated severity rating* Intended jumping overboard from a vessel leads to man over board situations and salvage operations. These can be difficult in the case of unmanned vessels and often requires outside assistance. The hazard can have negative impact on people. It can result in injuries or loss of human life.
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Vessel design with open reeling structure, too low reeling or a reeling enabling climbing. - Jumping in case of emergency - People jumping for diverse reasons

Mitigation strategy		*Cost/Difficulty*	*Priority (1-4) **
	- Vessel design with closed and "unclimbable" reeling e.g. transparent inward curved plastic.	Low	4
	- Manual alarm systems in passenger spaces and piers with direct contact to remote monitoring centres and rescue centres	Medium	1
	- Video surveillance systems	Medium	3
	- Passenger instructions on quay and on board for mob situations	Low	3
	- Remote monitoring centres to calm down and instruct people by voice after alarms	Medium/high	1-3
	- Lifebuoys available	Low	1
	- Vessels to stop automatically in case of man over board alarms in order to prevent persons getting into the propeller	Low	1
	- Well planned and rehearsed procedures, suitable equipment and clear roles between authorities for recovering a person from the water	Medium	1
	- Possibility for other passengers to assist or recover a person from the water	Medium	1
	- Automatic warning message to be sent to surrounding vessels	Low	1

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis (combines hazards 12 and 13):

(1) Safety control
SC 1. Vessel design with closed and "unclimbable" reeling e.g. transparent inward curved plastic. SC 2. Vessel design with automated sliding door type passenger gates which don't open unless the vessel is firmly in pier SC 3. Manual alarm systems on the passenger spaces and piers with direct access to remote monitoring centres and rescue centres SC 4. Video surveillance systems SC 5. Passenger instructions on piers and on board for mob situations SC 6. Remote monitoring centres to calm down and instruct people by voice after alarms SC 7. Vessels to stop automatically in case of a man over board alarm SC 8. Well planned and rehearsed procedures, suitable equipment and clear roles between authorities for recovering a person from the water SC 9. Possibility for other passengers to assist or recover persons from the water SC 10. Automatic warning message to be sent to surrounding vessels
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety control
SC 1. Vessel design with closed and "unclimbable" reeling e.g. transparent inward curved plastic. UCA 1. Vessel has an open reeling structure (e.g. horizontal bars with large gaps in between) that enables falling overboard *Potential causes* - Safety has not been properly taken into account in the design - Lack of economic resources - Wish to have an attractive design (e.g. for sightseeing purposes) - Need to reduce weight of the vessel UCA 2. Reeling structure is easy to climb over

Potential causes
- Safety has not been properly taken into account in the design
- Lack of economic resources
- Easy way to get on board or off board in case of emergency

Redefining of the safety control
Vessel design with closed and "unclimbable" reeling e.g. transparent inward curved plastic:
- The best way to prevent man over board situations is to design vessels impossible or at least very difficult to jump or fall overboard from
- Emergencies have to be taken into account already in the initial design phase

SC 2. Vessel design with automated sliding door type passenger gates which don't open unless the vessel is firmly moored

UCA 1. Vessel design with open ends like in cable ferries enables passengers to fall or jump overboard.
Potential causes
- Safety has not been properly taken into account in design
- Lack of economic resources
- Easy way to get on-board or off-board in case of emergency

UCA 2. If doors open at the wrong time, passengers may fall or jump over board
Potential causes
- Sensor malfunction
- Intentional damaging of the door

Redefining of the safety control
Vessel design with automated sliding door type passenger gates which don't open unless the vessel is firmly in pier:
- Well-designed door structure with pressure sensors etc. is an effective way to control the movement of passengers and prevent man over board situations
- Passenger safety in case of door malfunction has to be taken into account

SC 3. Manual alarm systems in the passenger spaces and piers with direct contact to remote monitoring centres

UCA 1. Passengers on board have no easy and quick way to send alarm about man over board situation
Potential causes
- Poor planning of vessels' safety features
- Lack of economic resources

UCA 2. Alarm systems are not connected directly to remote monitoring centres; information about the situation is not forwarded
Potential causes
- Poor planning of vessels' safety features
- Lack of economic resources

Redefining of the safety control
Manual alarm systems in the passenger spaces and piers with direct access to remote monitoring centres and rescue centres:
- It is essential to get the information about mob situations immediately to the rescuers when someone falls or jumps into the water. Delays in this information endangers the whole rescue operation

SC 4. Video surveillance systems

UCA 1. Man over board situations are not noticed, because there are no video surveillance systems for monitoring passenger safety on board
Potential causes
- Poor planning of vessels' safety features
- Lack of economic resources

UCA 2. Video material from vessels is not monitored continuously, automatically or manually
Potential causes
- Lack of economic resources
- Lack of commitment

UCA 3. Video material is not streamed ashore from vessels in real time
Potential causes
- Technical problem
- Lack of redundancy
- Lack of economic resources

UCA 4. There is no reaction to situations captured in the video surveillance system
Potential causes
- Lack of commitment
- Work overload
- Lack of training and/or instructions
- Human machine interface limitations

UCA 5. Without active video surveillance the preventive factor cannot be achieved
Potential causes
- Lack of economic resources

UCA 6. Video surveillance does not perform properly
Potential causes
- Bad planning
- Problems in data transfer
- Technical problems with the camera
- Lack of redundancy
- Lack of economic resources
- Power source malfunction
- Quality of the picture affected by weather conditions
- Different lighting conditions have not been taken into consideration

Redefining of the safety control
Video surveillance system:
- If a person travels alone or falls over board without other passengers noticing, the situation can only be detected by technical means
- Reliable real-time data transfer ashore is an essential part of the system if a human does the monitoring
- Existence of video surveillance can prevent erratic behaviour. With active monitoring, persons can also interfere with the situations
- Technical specifications of the system should be planned and implemented efficiently
- The video surveillance system itself has to be monitored continuously

SC 5. Passenger instructions on quay and on board for man over board situation

UCA 1. Passenger instructions are poor or not easy enough to understand
Potential causes
- Poor planning

UCA 2. Passengers do not familiarize themselves with the instructions
Potential causes
- Positioning of the instructions
- Visual look of the instructions
- Language barrier
- Time constraint
- Wrong means for providing instructions

Redefining of the safety control
Passenger instructions on piers and on board for man over board situations:
- Other passengers on board are the best available resource in an emergency, if they know what to do
- Good passenger information is clear, simple and does not leave place for misunderstandings
- If the information is visually interesting and the means for giving it are correct, people are more likely to read, listen or watch it.

SC 6. Remote monitoring centres to calm down and instruct people by voice after alarms

UCA 1. People on board panic, don't know what to do or act irrationally, because the system for instructing people by voice does not exist

Potential causes

- Poor planning of vessels' safety features
- Lack of economic resources

UCA 2. Connection between vessels and the monitoring centres does not work

Potential causes

- Technical problems
- Lack of redundancy

UCA 3. The way of giving the instructions is not suitable and they are not followed on board

Potential causes

- Poor planning
- Psychological factors have not been considered deeply enough when planning the messages
- Persons in charge of the situation have not been properly trained

Redefining of the safety control

Remote monitoring centres to calm down and instruct people by voice after alarms:

- Calming of the passengers is necessary in order to keep them functional and prevent irrational actions that make the situation worse. With detailed instructions, untrained people are able to perform operations they would not be able to do on their own
- Persons giving instructions have to be well trained in the LSA functions as well as in crowd and crisis management
- Connections between vessel and shore have to be reliable and there have to be redundancies

SC 7. Vessel to stop automatically in case of man over board alarm

UCA 1. The vessel is not programmed to stop in case of a mob alarm and person in the water gets into the moving vessel's propeller

Potential causes

- Poor planning of vessels' safety features

UCA 2. Persons cannot be found again and/or the passengers are not able to assist because the vessel has continued on her route

Potential causes

- Poor planning of vessels' safety features

Redefining of the safety control

Vessels to stop automatically in case of man over board alarms:

- Stopping the vessel without delay after an alarm protects the person in the water and ensures that he/she can get all available help
- The propeller of the vessel should be properly covered if the engines are running at the man over board scene

SC 8. Well planned and rehearsed procedures, suitable equipment and clear roles between authorities for recovering a person from the water

UCA 1. Assistance for recovering a person from the water takes too long to arrive

Potential causes

- Information about the situation has not been received or is not correct
- Boats or personnel are not available close enough
- It is unclear who should respond to the situation

Redefining of the safety control

Well planned and rehearsed procedures, suitable equipment and clear roles between authorities for recovering a person from the water:

- In man over board situations there is no time for planning, only for well-rehearsed action
- Man over board situations may happen in areas where there is no help available close by. Co-operation between authorities increases the amount of available resources and speed up rescuing

SC 9. Possibility for other passengers or the vessel to assist or recover a person from the water

UCA 1. Vessel's hull and structure is designed so "safe" that the passengers on board cannot assist or recover anyone from the water
Potential causes
- High reeling without any "emergency exits"

UCA 2. The LSA equipment available are too complicated to be used by untrained people
Potential causes
- Lack of suitable equipment in the market
- Poor planning of vessels' safety features
- Lack of economic resources

UCA 3. Without automatic LSA equipment operated by the vessel, the person in the water may not get help
Potential causes
- Lack of suitable equipment in the market
- Poor planning of vessels' safety features
- Lack of economic resources

Redefining of the safety control
Possibility for other passengers or the vessel to assist or recover a person from the water:
- Autonomous vessels should be designed to protect people and keep them inside. However, there must be emergency exits and devices that can be used to pull a person on board from the water

- All LSA-equipment on board should be easily available, simple, safe and easy to use for untrained persons
- Automatic LSA equipment such as lifebuoys, ladders, slides, ramps, or emergency lighting should be automatically activated by the vessel

SC 10. Automatic warning message to be sent to surrounding vessels

UCA 1. An autonomous vessel does not inform the surrounding vessels about the mob situation and therefore they cannot assist.
Potential causes
- Poor planning of vessels' safety features
- Lack of suitable means to inform other vessels

UCA 2. Autonomous vessel does not inform the surrounding vessels about the mob situation and another vessel runs over the person in the water
Potential causes
- Poor planning of vessel's safety features
- Lack of suitable means to inform other vessels

Redefining of the safety control
An automatic warning message to be sent to surrounding vessels:
- Other vessels in the area are most likely the fastest available assistance, but only if they know the situation
- Without information about the mob situation, they are an imminent danger to the person in the water

Hazard 14. Persons getting injured

Hazard	H14. Persons getting injured		
Hazard effect/ description	*Provide extra details regarding the designated severity rating* Persons being injured may lead to medical emergencies on board or on piers. The hazard can have negative impact on people. It can result in injuries or loss of human life.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Slipping, tripping or falling - Violence by other passengers - Automatic doors with malfunction in the sensors		
Mitigation strategy	- Good lighting and air conditioning	*Cost/Difficulty* Low	*Priority (1-4) ** 3

	- Unobstructed access and non-slippery floor materials in piers and the vessel	Low	4
	- Manual alarm systems in the passenger spaces and on piers with direct contact to remote monitoring centres	Medium	1
	- Vessels re-route to the closest medical evacuation pier and transmit their position to the authorities.	Medium	1
	- Video surveillance systems	Medium	3
	- Passenger instructions on piers and on board for medical emergencies	Low	1
	- Remote monitoring centres to calm down and instruct people by voice after alarms	Medium	1
	- Well planned and rehearsed procedures for medical evacuation	Low	1
	- Possibility for other passengers to give first aid to injured persons	Low	1

**Mitigation priority scale*	*Level*	*Description*	*Detailed description*
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

Hazard 15. Person(s) medical condition

Hazard	H15. Person(s) medical condition		
Hazard effect/ description	*Provide extra details regarding the designated severity rating* If a passenger gets sick or has a seizure it may lead to a medical emergency on board or on a pier. The hazard can have negative impact on people. It can result in injuries or loss of human life.		
Causal factors	*Describe the hazard as system state. What conditions could influence the effect of the hazard occurrence?* - Movement of the vessel - Heat - Allergic reactions - Passengers not having necessary personal medication with them		
Mitigation strategy		*Cost/Difficulty*	*Priority (1-4) **
	- Good lighting and air conditioning	Low	3
	- Unobstructed access and non-slippery floor materials in piers and vessels	Low	4
	- Manual alarm systems in passenger spaces and piers with direct contact to remote monitoring centres	Medium	1
	- Vessels re-route to the closest medical evacuation pier and transmit their position to the authorities	Medium	1
	- Video surveillance systems	Medium	3
	- Passenger instructions on piers and on board for medical emergencies	Low	1
	- Remote monitoring centre to calm down and instruct people by voice after the alarm	Medium	1
	- Well planned and rehearsed procedure for medical evacuation	Low	1
	- Possibility for other passengers to give first aid to an injured person	Low	1

*Mitigation priority scale	Level	Description	Detailed description
	4	Eliminate	Complete elimination of the hazard
	3	Prevent	Reduction of the likelihood that the hazard will occur
	2	Control	Reduction of the likelihood that the hazard results in an accident
	1	Reduce	Reduction of the damage if the accident occurs

STPA Analysis (combines hazards 14 and 15):

(1) Safety control
SC 1. Good lighting and air conditioning SC 2. Unobstructed access and non-slippery floor materials in piers and the vessel SC 3. Manual alarm systems in the passenger spaces and on piers with direct contact to remote monitoring centre and rescue centre SC 4. Vessels re-route to the closest medical evacuation pier and transmit their position to the authorities SC 5. Video surveillance systems SC 6. Passenger instructions on piers and on board for medical emergencies SC 7. Remote monitoring centres to calm down and instruct people by voice after the alarm SC 8. Well planned and rehearsed procedures for medical evacuation SC 9. Possibility for other passengers to give first aid to injured persons
(2) Detecting potentially Unsafe Controlled Actions (UCAs) and (3) redefining the safety control
SC 1 Good lighting and air conditioning UCA 1. Person cannot see obstructions and accidentally falls *Potential causes* - Poor planning of light source locations and luminosity - Obstructions create shadows - Blackout UCA 2. High temperatures can trigger seizures or medical conditions *Potential causes* - Vessel design - Blackout - Inadequate AC system - Power saving *Redefining of the safety control* Good lighting and air conditioning: - Good lighting ensures that passengers can move safely - With proper temperature on board, passengers remain calm and alert, and it reduces the risk of seizures and medical conditions
SC 2 Unobstructed access and non-slippery floor materials in piers and vessels UCA 1. The entrance to vessels is not level *Potential causes* - Pier and vessel entrances are not on the same level - Steps UCA 1. Vessel or pier floors are covered with slippery coating and a passenger falls *Potential causes* - poor planning - Water, snow or ice on the floor - Spill or litter *Redefining of the safety control* Unobstructed access and non-slippery floor materials in piers and vessels - Unobstructed access and non-slippery floor material in piers and vessels ensure that passengers can move safely in all weather conditions
SC 3 Manual alarm systems in passenger spaces and piers with direct contact to remote monitoring centres

UCA 1. Passengers on board have no easy and quick way to send alarms in case of medical emergencies
Potential causes
- Poor planning of vessels' safety features
- Lack of economic resources
-

UCA 2. Alarm systems are not connected directly to the remote monitoring centres the information about the situation is not forwarded
Potential causes
- Poor planning of vessels' safety features
- Lack of economic resources

Redefining of the safety control
Manual alarm systems on the passenger spaces and piers with direct access to remote monitoring centre:
- It is essential to get the information about the medical emergency immediately to the authorities. Delay in this information endangers the safety of the patient

SC 4 Vessels re-route to the closest medical evacuation pier and transmit their position to the authorities

UCA 1. If vessels continue to the next planned pier there might arise a delay for patients to get the medical attention needed
Potential causes
- Poor planning and testing
- There is no alarm or information about the situation
- Software error

UCA 2. The information about the emergency pier does not reach the authorities or it is incorrect
Potential causes
- Poor planning and testing
- Conflicting information from different sources

Redefining of the safety control
Vessels re-route to the closest medical evacuation pier and transmit their position to the authorities:
- The patient safety has to be prioritized and medical attention reached as soon as possible
- Special attention should be payed to the information flow and the planning of emergency harbours

SC 5. Video surveillance systems

UCA 1. A medical emergency is not noticed, because there is no video surveillance system to monitor passenger safety on board
Potential causes
- Poor planning of vessel's safety features
- Lack of economic resources

UCA 2. Video material from the vessel is not monitored continuously, automatically or manually
Potential causes
- Lack of economic resources
- Lack of commitment
-

UCA 3. Video material is not transferred ashore from the vessel in real time.
Potential causes
- Technical problem
- Lack of redundancy
- Lack of economic resources

UCA 4. There is no reaction to situations captured in the video surveillance systems
Potential causes
- Lack of commitment
- Work overload
- Lack of training and/or instructions
- Human machine interface limitations

UCA 5. Video surveillance does not perform properly
Potential causes
- Bad planning
- Problems in data transfer
- Technical problems with the camera
- Lack of redundancy
- Lack of economic resources
- Power source malfunction
- Quality of the picture affected by weather conditions
- Different lighting conditions are not taken into consideration

Redefining of the safety control
Video surveillance system:
- If a person travels alone, situations can only be detected by technical means
- Reliable real-time data transfer ashore is an essential part of the system if a human does monitoring
- Technical specifications of the system should be planned and implemented efficiently
- The video surveillance system itself has to be monitored continuously

SC 6. Passenger instructions for medical emergencies on piers and on board

UCA 1. Passenger instructions are poor or not easy enough to understand
Potential causes
- Poor planning

UCA 2. Passengers do not familiarize themselves with the instructions
Potential causes
- Positioning of the instructions
- Visual look of the instructions
- Language barrier
- Time constraint
- Wrong means for providing instructions

Redefining of the safety control
Passenger instructions on piers and on board for medical emergencies:
- Other passengers on board are the best available resource in an emergency, if they know what to do
- Good passenger information is clear, simple and does not leave place for misunderstandings
- If the information is visually interesting and the means for giving it is suitable, people are more likely to read, listen or watch it.

SC 7 Remote monitoring centres to calm down and instruct people by voice after alarms

UCA 1. People on board panic, don't know what to do or act irrationally, because the system for instructing people by voice does not exist
Potential causes
- Poor planning of vessels' safety features
- Lack of economic resources

UCA 2. Connection between vessels and the monitoring centres does not work
Potential causes
- Technical problem
- Lack of redundancy

UCA 3. The way of giving instructions is not suitable and they are not followed on board
Potential causes
- Poor planning
- Psychological factors have not been considered deeply enough in planning the messages
- Persons in charge of the situation has not been properly trained

Redefining of the safety control
Remote monitoring centres to calm down and instruct people by voice after alarms:

- Calming of passengers if necessary in order to keep them functional and prevent irrational actions that make the situation worse. With detailed instructions, untrained people are able to perform operations they would not be able to do on their own
- Persons giving instructions have to be well trained in the medical first aid as well as in crowd and crisis management
- Connections between vessels and shore have to be reliable and include redundancies

SC 8 Well planned and rehearsed procedures for medical evacuation

UCA 1. Medical assistance takes too long to arrive

Potential causes

- Information about situations is not received or is not correct
- Boats or personnel are not available close enough
- It is unclear who should respond to the situation

Redefining of the safety control

Well planned and rehearsed procedures for medical evacuation:

- In medical emergencies, there is no time for planning, only for well-rehearsed action
- Medical emergencies may happen in areas where there is no help available close by. Co-operation between authorities increases the amount of available resources and speed up the process

SC 9 Possibility for other passengers to give first aid to injured persons

UCA 1. There is no first aid equipment

Potential causes

- Poor planning
- Lack of economic resources
- They have been stolen
- They have not been replaced after having been used

UCA 2. First aid equipment available are too complicated to be used by untrained people

Potential causes

- Poor planning
- Lack of economic resources
- Instructions are missing or bad

Redefining of the safety control

Possibility for other passengers to give first aid to injured persons:

- First aid equipment on board should be easily available, simple, safe and easy to use for untrained persons
- First aid equipment should be placed so that they cannot be easily tampered, e.g. inside cabinets with alarms if opened.

4.2.3 The representation of the initial safety management strategy for ferry A and B: step five

The initial safety management strategy for ferries A and B consists of 73 safety controls, which have different approaches for mitigating the 15 defined hazards and for preventing and responding to the 10 defined accidents.

Table 2 below presents the safety controls, their control logic principles and the risk they aim to mitigate. The safety controls are grouped by the hazard. The safety control types are categorized with colours: orange (controls that attempt to eliminate the hazard), yellow (controls for reducing the likelihood that the hazard will occur), green (controls for reducing the likelihood that the hazard results in an accident), and blue (controls for reducing the damage if the accident occurs).

Table 2. Safety controls, control logic principles and the risks mitigated, grouped by the hazards

Hazard 1. Object detection sensor error		
Safety Control (SC)	Control logic principle	Risks mitigated
1. Sensor system redundancy and diversity	If one sensor fails the redundancy ensures there is another sensor functioning. The equipment chosen to provide the redundancy has to be correct in order to provide the user with the required information at all times	> Lack of information due to error in a single sensor > Undetected sensor failure > External or common cause failure affecting all equipment simultaneously
1. UPS (Uninterrupted Power Source)	If there is a disturbance in the vessel power system the UPS can temporarily provide power for the critical equipment. When the UPS setup is planned, installed and maintained properly, the user can count on a reliable backup system	> Disturbances in vessels' power systems affect vessels' object detection sensors' operation > The UPS does not work or takes too long to switch on > The capacity of the UPS is not sufficient to provide power for the equipment
2. Appropriate heating, cooling and cleaning systems	By applying sensors with proper heating and/or cooling systems it can be ensured that they function properly in all operating conditions. Proper automatic cleaning systems ensure the appropriate function of the sensors outdoors	> Equipment is not able to function properly in winter conditions > Equipment is not able to function properly due to high temperatures > Equipment lens is dirty > Condensation inside equipment
3.Thorough commissioning of equipment set	When the equipment set is thoroughly tested and certified (preferably by an independent body) it ensures that the equipment function properly, are compatible and the operation can be run safely.	> The equipment set has not been properly tested or not tested at all before operation
4. Appropriate and continuous on board maintenance programs	By implementing an on board maintenance program it can be ensured that all critical systems remain functional at all times. A well planned maintenance program covers all necessary areas on board and it is adjusted separately for each vessel. Maintenance done timely and according to the program by competent personnel ensures the smooth operation of the sensors.	> There is no on board maintenance program > The maintenance program does not cover the necessary elements and the life cycle of the hardware > The maintenance program is not followed or the maintenance is not done properly
5. Continuous system diagnosis and proof testing	Ensures that the system functions as it should. Test design should be planned carefully and updated after changes in the system in order to cover all the necessary functions and recognize problems. Possible effect on the operation should be taken into account in the planning.	> There is no continuous system diagnosis and proof testing > The continuous system diagnosis and proof testing do not cover all necessary functions > The test is not able to recognize problems
1. Autonomous integrity monitoring	A Well designed and up to date integrity monitoring system ensures that the data has not been damaged or manipulated	> There is no integrity monitoring > Integrity monitoring gives wrong information
Hazard 2. Artificial Intelligence (AI) failure		
Safety Control (SC)	Control logic principle	Risks mitigated

2. Thorough planning, testing and commissioning of AI Software	Thorough planning, testing and commissioning of AI software ensure that the software is robust and free of errors. Applicable standards should be followed.	> Thorough planning, testing and commissioning of AI are not done > Insufficient planning, testing and commissioning of AI
6. Computer and software redundancy	Computer and software redundancy ensure the availability of the AI functions at all times	> Computer breaks down and there is not computer and software redundancy > Secondary computer does not take over in case of a failure
1. UPS (Uninterrupted Power Source)	If there is a disturbance in the vessel power system, the UPS can temporarily provide power for the critical equipment. When the UPS setup is planned, installed and maintained properly, the user can count on a reliable backup system	> Disturbances in vessels' power systems affect vessels' AI systems' operation > The UPS does not work or takes too long to switch on > The capacity of the UPS is not sufficient to provide power for the AI system as long as needed or the capacity in terms of power and/or energy of the UPS is exceeded
7. Appropriate cooling for computers	In order to function properly all computer components must be kept within permissible operating temperature limits. Cooling systems should be selected carefully. Both the waste heat produced by the computer components and possible external heat sources should be taken in to account.	> Computer does not function reliably due to overheating.
4. Appropriate and continuous on board maintenance programs	By implementing a maintenance program it can be ensured that all critical systems remain functional at all times. A well-planned maintenance program covers all necessary areas on board and it is adjusted separately for each vessel. Maintenance done timely and according to the program by competent personnel ensures smooth operation. Special attention should be paid not only to properly timed software updates but also to the updating process.	> There is no on board maintenance program > The maintenance program does not cover the necessary elements and the life cycle of the hardware > The maintenance program is not followed or the maintenance is not done properly > Software updates are not done and the system is not capable to correct detected issues > Software updates create inappropriate functions in the system > Software and hardware do not match
3. Robust system design	Robust system design should be able to isolate failures in the system and to let the rest of the system operate.	> Poor and/or missing data are not detected and coped with > Single point failures takes the whole system down
8. Appropriate system (software) design and maintenance processes	Ensure that the system meets customer expectations. Requires good communication between customers, sales people and developers, but also good documentation. Special attention should be paid to reviews throughout the process and software verification at the end. Change management must not be forgotten.	> User requirements are not known or taken into account and the final product is not the expected > System requirements are not clear for the developers and do not cover relevant issues > System design and system implementation do not meet expectations > Software is not verified properly > Change management is not working properly
3. Technical fault (e.g. mechanical failure)		
Safety Control (SC)	**Control logic principle**	**Risks mitigated**
4. Redundancy of critical systems	With redundancy in the systems the effect of the single failure can be minimized. Redundancy and system integration should be taken into account already in the planning stage. Proper testing and commissioning of the system verifies that all critical systems have been identified. Changes in the system should be managed with a proper protocol/ process.	> Single failures can cause vessel operation to stop > Critical equipment has not been identified correctly > Critical systems have been changed without proper analysis of the effects on the system
5. Thorough planning, testing and commissioning of all technical systems	The process should be done in good cooperation between the designer, buyer, builder, suppliers and regulators. The autonomous status of the vessel should be taken into account through the process. New and efficient practices for commissioning and testing autonomous vessel systems should be developed in cooperation with the relevant stakeholders.	> Autonomous operations have not been taken into account in the whole system design > Tests fail to recognize problems or potential faults in the systems > The commissioning is not done thoroughly
9. Planned and predictive maintenance programs	With proper maintenance programs the safety of the vessel can be ensured, the number of technical faults minimized and the life cycle of technical systems maximized. Maintenance programs have to take into account system interactions.	> The system fails due to the lack of maintenance > The maintenance done is not of the right type or it is done poorly > Maintenance programs fail to take into account interaction between systems

10. Distance monitoring and fault detection of technical systems	Safe and effective operation of autonomous vessels require distance monitoring and failure detection. Remote monitoring increases the reliability of the operation and minimizes off-hire periods. Without proper monitoring of the data quality, distance monitoring and fault detection systems cannot produce reliable information.	> Vessel faults are not detected > Distance monitoring and fault detection of technical systems do not work
4. Heavy weather/sea conditions + 5. Strong currents		
Safety Control (SC)	**Control logic principle**	**Risks mitigated**
6. Correctly set and followed operational limits	Permanent operational limits set by shipping companies and agreed between all the parties involved, ensure that operations are stopped before the safety of the vessel is compromised. Vessels' features, capability to manoeuvre and operating areas should be considered when setting the operational limits. When the limits and automatic procedures for situations when the limits are crossed are programmed in vessel systems, they are followed without the need to make decision case by case. Thus they are not exposed to human error. Sending an alarm to remote monitoring centres, when limits are crossed, acts as a double check in order to ensure that the vessel is able to cease her operations safely.	> Shipping companies have not set operational limits for the vessel. > Operational limits set by shipping companies are too high for safe operation of vessels > Operational limits set for vessels are not followed.
11. Weather routing and constant weather and sea state monitoring	Checking weather forecasts should always be part of route planning. Checking forecasts automatically against the plan (also in the permanent routes between two points) every time before departure ensures vessel safety. Constant automatic monitoring of weather forecasts as well as local real-time weather data during the trip, ensure the safety along the whole way. Receiving weather forecasts from more than one source gives redundancy and allows comparison. With pre-planned alternative routes programmed to the system, vessels can automatically be re-routed safely when necessary. Re-routing functions should always be properly tested in the commission stage.	> Environmental conditions are not taken into account when planning vessel routes > Weather and sea state are not constantly monitored when vessels are in operation > Vessel's route is not changed accordingly when environmental conditions require doing so.
12. Vessels equipped with adequate environmental sensors for local conditions	With proper equipment on board (or along the route), vessels are able to react also to sudden local changes in the conditions. Already when planning vessels, winter conditions and other local needs, equipment characteristics required in the area as well as redundancy needs should be considered carefully.	> Vessels are not equipped with adequate and appropriate sensors in order to monitor local conditions > There is not enough redundancy in environmental sensors
2. Keeping vessels steady against the wind and waves, heading to an emergency harbour or anchoring	If an unexpected weather change makes continuing on the route unsafe, automatic route specific contingency actions (such as driving with minimum manoeuvring speed against the wind etc. or re-routing vessels to a suitable emergency harbour) programmed to the system are necessary precautions.	> In case that the weather/sea conditions change suddenly over the operational limits, vessels continue on their routes normally instead of choosing a safer option for the situation.
3. Knowledge of local currents and other local environmental conditions	Available information about local currents and frequent weather conditions is a valuable tool when planning vessels and their routes. Especially in archipelagos, lakes and rivers there can be strong local currents, places where fog regularly forms or where the wave height rises above normal..	> Information about local currents and local environmental conditions in rivers and archipelagos has not been gathered > Information about local currents and local environmental conditions has not been taken into account when planning vessel routes
4. Constant monitoring of currents and adjusting the steering accordingly	Vessels reliably equipped to monitor affecting real time currents, automatically adjusting steering accordingly, without delay, are able to manoeuvre and dock safely and smoothly.	> There is no equipment available to monitor the current in real time > Current monitoring systems do not function correctly > Current monitoring information is not connected to the AI and steering equipment > Too long delays in the steering system to react to drifting.

5. Constant monitoring and predictions of vessels' capability	With constant monitoring and prediction of vessels' capability, vessels are able to adjust operational limits and operation in general when necessary. There might be external or internal factors that require lowering the operational limits temporarily.	> Vessel capability is not monitored > Information of vessel capability is not used to adjust the operational limits or operation.
6. Position reference equipment failure		
Safety Control (SC)	**Control logic principle**	**Risks mitigated**
7. Equipment (sensor) redundancy	If one sensor fails, redundancy ensures there is another sensor functioning. System design must include adequate diagnosing functions in order to recognize sensor failures and perform the switch over procedure when necessary. Equipment used to provide redundancy should be completely independent from one another to reduce the risk of a common cause failure taking it down at the same time	> Lack of information due to error in a single sensor > Sensor failures are not detected due to lack of information from other equipment to be compared with > External or common cause failures take several equipment down at the same time
6. Combinations of different types of local and satellite position reference systems	Combination of local and satellite position reference systems provide reliable position information in different conditions and locations, and help to detect possible errors in the information	> Positioning is based on satellite positioning only and vessel e.g. loses her position in case of a satellite system failure or poor satellite availability > Satellite positioning reference equipment gives incorrect information and there is no local positioning information to compare it with > Positioning is based on local position reference systems only and vessels e.g. lose position due to poor weather conditions
13. Satellite positioning equipment with jamming detection and/or anti-jamming function	Jamming detection ensures that jamming is noticed and users can switch to local position reference systems. An anti-jamming function reduces the risk of losing position or receiving wrong/inaccurate position information due to GPS jamming.	> Vessels lose position due to jamming > Vessels receive wrong or inaccurate position information due to jamming
1. UPS (Uninterrupted Power Source)	If there is a disturbance in the vessel power system, UPSs can temporarily provide power for critical equipment. When UPS setup is planned, installed and maintained properly, the user can count on reliable backup systems. For GPS systems a UPS with a quick switch on function is critical. In case of power loss GPS equipment need to reacquire the position fix which may take several minutes at worst case	> Disturbances in vessels' power systems affect operation of vessels' position reference equipment > The UPS does not work > The UPS takes too long to switch on and the GPS equipment needs to reacquire the position fix > The capacity of the UPS is not sufficient to provide power for the equipment as long as needed or the capacity in terms of power and/or energy of the UPS is exceeded
14. Appropriate heating, cooling and cleaning systems	By applying sensors with proper heating and/or cooling systems it can be ensured that they function properly in all operating conditions. Applying sensors with automatic cleaning systems ensure that they function properly outdoors	> Equipment is not able to function properly in winter conditions > Equipment is not able to function properly due to high temperature s > Equipment lenses are dirty > Condensation inside equipment
15. Thorough installation and commissioning of equipment set	Placing of GPS antennas has to be optimal with regards to sky view and distance to transmitting radio equipment. Installations of the GPS antennas and cabling have to be thoroughly planned and performed by certified suppliers. An unobstructed sensor head and antenna view is essential when using local position reference systems. When the equipment set is thoroughly tested and certified (preferably by an independent body) it ensures that the equipment functions properly, are compatible and the operation can be run safely.	> GPS antennas have limited sky view > GPS antennas are placed too close to radio equipment causing interference > GPS antennas' cable length and amplification are not optimized > Local position reference systems' sensor head or antenna view is blocked by obstacles > The equipment set has not been properly tested or not tested at all before operation.
16. Appropriate and continuous on board maintenance programs	By implementing on board maintenance programs it can be ensured that all critical systems remain functional at all times. A well-planned maintenance program covers all necessary areas on board and it is adjusted separately for each vessel. Maintenance done timely and accordingly to the program by competent personnel ensures smooth operation of the sensors	> There is no on board maintenance program > The maintenance program does not cover the necessary elements and the life cycle of the hardware > The maintenance program is not followed or the maintenance is not done properly.

17. Continuous system diagnosis and proof testing	Continuous system diagnosis and regular proof testing ensure that the system functions, as it should. Test design should be planned carefully and updated after changes in the system in order to cover all necessary functions and recognize potential problems. Possible effects on the operation caused by the tests should be taken into account in the planning	> There is no continuous system diagnosis and proof testing > The continuous system diagnosis and proof testing do not cover all necessary functions > The test is not able to recognize problems
1. Autonomous Integrity monitoring	Well designed and up to date integrity monitoring systems ensure that the data has not been damaged or manipulated	> There is no integrity monitoring > Integrity monitoring gives wrong information > Integrity monitoring is not able to recognize spoofing signals
7. Overloading of vessels		
Safety Control (SC)	**Control logic principle**	**Risks mitigated**
8. Automated passenger gates which do not allow more than maximum number of passengers on board	With reliable passenger count, overloading of vessels and exceeding of maximum number of passengers can be avoided. The systems have to take into account that people stay on-board, people travel without tickets, wheelchairs, and families with children, bikes, baby strollers etc. who can not board vessels though passenger gates. Gates should not separate parents and children. Possible solutions for counting reliably could be e.g. automatic software and camera systems that compare passengers going in and out, defining a boarding processes and boarding areas on the pier, or emptying the vessel completely before reloading.	> There is no system to count the number of passengers on-board > Passenger count system is not reliable > The passenger gates separate family members (parents and children)
9. Clear rules, weighing and monitoring of the cargo taken on board	By monitoring the vessel's trim, list and draft the weight of the vessel can be calculated. Possible solutions for calculating the weight are e.g. pressure sensors, echo sounders and visual readings of draft.	> Vessels are overloaded because there is no knowledge of weight of cargo on-board > Cargo weighing systems are not reliable
10. In case of adding permanent weights on board, stability calculations and tests to be redone.	If stability calculations are not up to date the vessel operation may not be safe and according to regulations.	>The added weights are not recorded >The recorded weights are inaccurate > The stability tests/calculations are not updated
11. Automatic continuous monitoring of vessels' stability (draft, trim, list and GM), and the vessel is programmed not to leave the pier if over the limits.	There should always be real-time information available about vessel stability in order to operate safely. By programming the safety limits allowed into the system, leaving a pier can be prevented in unsafe stability situations. With redundant monitoring systems, unnecessary stops in operation or unsafe situations caused by an equipment malfunction can be minimized	> There is no system to monitor vessel stability > Vessel does not leave pier even though the vessel is loaded correctly > The vessel leaves the pier overloaded > There is only one monitoring system with no redundancy
8. Shifting of weights		
Safety Control (SC)	**Control logic principle**	**Risks mitigated**
18. Passenger instructions on quay and on board	Good passenger information is clear, simple and doesn't leave place for misunderstandings. If the information is visually interesting and the means for providing it are correct, people are more likely to read, listen to or watch it.	> Passenger instructions regarding weight distribution are poor or not easy enough to understand > Passengers do not familiarize themselves with the instructions
19. Design of vessel	With good ship design, passenger and cargo movements and stability can be controlled. For example seating arrangements can be used as natural dividers and the vessel can be designed with a very high initial stability.	>The design does not prevent people from crowding or falling to one side of vessels > Vessels lists considerably in case of crowding of people on one side > Cargo and storage spaces do not have any compartments that would prevent items from shifting to one side of the vessel
12. Firefighting systems that use very little water or no water at all	When selecting firefighting systems to be installed on-board, stability and free surface effect caused by the firefighting water should be taken into account.	> The use of large amounts of firefighting water creates free surfaces and may endanger vessel stability.
13. Anti-heeling system	Anti-healing systems compensate for small heels and increases the comfort and safety of the passengers. However, a possible malfunction of	> Listing of vessels cannot be corrected and it causes danger or discomfort for the passengers. > Malfunctioning of the anti-heeling system may endanger the safety of the vessel

	the system must not be able to endanger the safety of the vessel.	
7. Remote monitoring centres monitor vessel stability and instruct people by voice if necessary	Calming of passengers is necessary in order to keep them functional and prevent irrational actions that make situations worse. With detailed instructions, untrained people are able to perform operations they would not be able to do on their own. Persons giving instructions have to be well trained in basic ship stability as well as crowd and crisis management. Connections between vessel and shore have to be reliable and there have to be redundancies.	> People on board panic, don't know what to do or act irrationally, because there is no system for instructing people > Connections between vessel and monitoring centres do not work > The way of giving instructions is not suitable and they are not followed onboard
9. Flooding		
Safety Control (SC)	Control logic principle	Risks mitigated
14. Double hull and compartments	A double hull and a compartmented structure help autonomous vessels to maintain stability in case of accidents.	> Single hull allows large amounts of water to flood the spaces under the waterline very quickly if penetrated. > Vessels lose stability due to the water moving freely inside the hull
15. Well planned and built piping system	Using double wall pipes and correct materials for pipes and connection points, depending on the systems, make the piping systems resistant and less likely to break. Good planning, building, testing, and oversight of the whole process make piping systems reliable, easy to use and maintain.	> Bursting of a single wall pipe allows the water (or other liquids) to leak to the spaces inside the hull. > Rigid metal piping breaks easier due to vibrations or pressure shocks than other types of piping. > Complex piping systems with many connection points are more likely to break and leak > There are only system drawings and no production drawings and construction workers have to make decisions about the details
8. Automatic monitoring systems for tanks, pipes, bilges, and cofferdams	Leaks and bursts in hull and piping can be detected quickly by automatic monitoring systems. In case of accidents, vessel stability can also be evaluated and possible actions planned accordingly. However, the function of the monitoring systems needs to be monitored itself.	> If an autonomous vessel, without an automatic monitoring system for tanks, bilges and cofferdams has an accident, vessel stability problems and possible leaks cannot be detected. > A burst pipe in the engine room is not noticed
20. Firefighting systems that use very little water or no water at all	Reduce the possibility that firefighting water causes stability problems to vessels and therefore allows systems to be used as long as necessary. May damage vessel equipment less compared to a situation when large amounts of water are used in firefighting. One good option could be to use aerosol systems (potassium based) for fire extinguishing and water mist systems for cooling	> Vessels lose stability due to large amounts of water used in firefighting > Firefighting water damages vessel equipment
21. Good drainage systems on deck	Remove water from the deck efficiently and reduce possible stability problems. Winter conditions have to be taken into account when planning drainage systems.	> Rainwater and sea spray flood the deck and weaken vessel stability due to the lack of efficient drainage systems > The drainage system is blocked by dirt or debris, or by ice in winter conditions
9. Effective bilge pumps	Keep the vessel afloat if there is water in the engine room and gives time for evacuating passengers. They protect vessel equipment and systems in case of flooding. Pump redundancy and emergency power systems have to be taken into account	> Bilge pumps are not effective enough to pump out the water coming in from a penetration in the hull > Bilge pumps break and there is no redundancy > Bilge pumps are not connected to the emergency power system
10. Ignition of electrical equipment and wiring		
Safety Control (SC)	Control logic principle	Risks mitigated
22. Thorough planning and commissioning of electrical equipment and wiring	Thorough planning and commissioning of electrical equipment and wiring ensure that the components, wiring and equipment chosen are the correct ones for the actual use of the vessel and the installation and penetrations are done properly. The testing of the electrical equipment and wiring, detects the possible faults in the system	> Wrong equipment and wiring or their installation cause fires or cause fires to spread more rapidly than normally > Information used in the planning stage does not correlate with the use of the system > Testing is poorly planned and done
23. Appropriate cooling and heating for electrical systems	By providing appropriate cooling and heating for electrical systems, the overheating and problems caused by humidity can be prevented	> Overheating of the equipment breaks the equipment or causes a fire > Condensation causes a short circuit in electrical equipment

24. Preventive maintenance programs	Preventive maintenance programs are the best way to prevent ignition of electrical equipment and wiring. By checking the cleanliness, connections and proper function of the protection equipment regularly, the risk of ignition of electrical equipment and wiring can be reduced	> Dust in the equipment may result in overheating and ignition > Loose connections may result in overheating and ignition > Malfunction of the circuit breakers or other protection components e.g. arc protection system
16. Circuit breakers and fault current protection	Circuit breakers and fault current protection protect equipment and prevent the risk of ignition of the electrical equipment and wiring	> Circuit breakers do not open or cut off the power
1. Automatic fire extinguishing systems inside electrical cabinets	Automatic fire extinguishing systems inside electrical cabinets prevent spreading of fire to the surrounding spaces and reduce damage to equipment. Attention should be paid to defining the capacity of the extinguishing system.	> Without extinguishing systems inside cabinets, fires can spread to surrounding spaces > Capacity of the extinguishing system is too small to extinguish the fire > Too large capacity of the aerosol or gas extinguishing system builds up pressure and increases the fire instead of extinguishing it.
2. Automatic fire detection, alarm and extinguishing systems in engine spaces	Automatic and effective fire detection and alarm systems provide ship systems and remote operation centres information about the situation without delay. Detector locations, types and number of detectors should be planned carefully. Automatic extinguishing systems are the quickest and safest way to extinguish engine room fires in autonomous vessels. Firefighters may not be able to enter the engine spaces physically at all. Attention should be paid to choosing the right type of extinguishing systems and defining the right capacity for the space.	> Fire in engine spaces cannot be detected > Alarm systems are not connected directly to the remote monitoring centres; the information about the situation is not forwarded > Fire fighters may not be able to enter or extinguish the fire in the engine room > Extinguishing systems are not capable to extinguish the fire
11. Passengers starting a fire		
Safety Control (SC)	**Control logic principle**	**Risks mitigated**
10. Smoke detectors and automatic fire extinguishing systems in passenger spaces	Smoke detectors are the most suitable devices to detect fires in passenger spaces. However, the use of flame detectors additionally could also be considered. It is essential to get the information about fires immediately. Delays in this information endanger the whole rescue operation. When choosing extinguishing systems for passenger spaces the safety of the passenger should be priority number one. For example, low pressure water mist systems with concealed nozzles is a safe and reliable option in an unmanned vessel	> Fire in passenger spaces is not detected > Extinguishing systems are not capable to extinguish the fire
25. No smoking signs on piers and vessels	No smoking signs inform the passengers that smoking on board is not allowed. Smoking is one of the most likely reasons for having fires in passenger spaces	> Passengers smoke on-board and starts a fire
11. Video surveillance systems	Existence of video surveillance can prevent erratic behaviour. With active monitoring dangerous situations can also be identified in real-time and intervened. Reliable real-time data transfer ashore is an essential part of the system, if a human does the monitoring. Appropriate technical specifications of systems should be planned and implemented efficiently. Video surveillance systems have to be efficiently monitored.	> Without active video surveillance the preventive factor cannot be achieved > Video material is not transferred ashore from the vessel in real time. > There is no reaction to situations captured by the video surveillance system > Video surveillance does not perform properly
12. Both automatic and manual fire alarm systems in passenger spaces with direct access to remote monitoring centres	It is essential to get information about fires immediately to remote monitoring centres. Delays in this information endanger the whole rescue operation. In some cases, passengers may notice fires earlier than automatic systems and need to be able to send alarms manually. Passengers need to be informed about activated alarms	> Passengers on board have no easy and quick way to send an alarm about fires in passenger spaces > Smoke detectors are activated but there is no alarm for passengers > Alarm systems are not connected directly to the remote monitoring centres, the information about the situation is not forwarded

26. Use of inflammable and fire resistant materials in passenger spaces	The material used in passenger spaces has significant effect on passenger safety in case of fires. The amount of plastic should be kept low	> Flammable and non-fire resistant materials allow the fire to spread quickly
3. Possibility for the passengers to extinguish fires	Firefighting equipment on board should be easily available, simple, safe and easy to use for untrained persons. The equipment should be placed so that it cannot be easily tampered with, e.g. inside a cabinet with an alarm if opened	> Firefighting equipment available are too complicated to be used for untrained people > Firefighting equipment are not properly located, missing or not ready for use.
12. Unintended falling over board + 13. Intended jumping over board		
Safety Control (SC)	**Control logic principle**	**Risks mitigated**
17. Vessel design with closed and "unclimbable" reeling e.g. transparent inward curved plastic.	The best way to prevent mob situations is to design vessels from the beginning so that it is impossible or at least very difficult to jump or fall overboard from them. Emergency situations have to be taken into account already in the initial design phase.	> Vessels have an open reeling structure (e.g. horizontal bars with large gaps in between) that allow for falling overboard. > The reeling structure is easy to climb over
18. Vessel design with automated sliding door type passenger gates which don't open unless the vessel is firmly ,moored	Well-designed door structures with pressure sensors etc. is an effective way to control the movement of passengers and prevent man over board situations. Passenger safety in case of door malfunction has to be taken into account.	> Vessel design with open ends like in cable ferries allows for passengers to fall/jump overboard > If the doors open at the wrong time, passengers may fall or jump over board
4. Manual alarm systems in passenger spaces and piers with direct contact to remote monitoring centres	It is essential to get the information about man over board situations immediately to the rescuers when someone falls or jumps into the water. Delays in this information endanger the whole rescue operation.	> Passengers on board have no easy and quick way to send alarms about man over board situations > Alarm systems are not connected directly to the remote monitoring centres, the information about the situation is not forwarded
27. Video surveillance systems	If a person travels alone or falls over board without other passengers noticing, the situation can only be detected by technical means. Reliable real-time data transfer ashore is an essential part of the system if monitoring is done by a human. Existence of video surveillance can prevent erratic behaviour. With active monitoring a person can also interfere with situations. Appropriate technical specifications of the systems should be planned and implemented efficiently. The video surveillance systems have to be monitored continuously	> Man over board situations are not noticed, because there is no video surveillance system to monitor passenger safety onboard > Video material from vessels is not monitored continuously automatically or manually > Video material is not transferred ashore from vessels in real time > There is no reaction to situations captured by video surveillance systems > Without active video surveillance the preventive factor cannot be achieved > Video surveillance does not perform properly
28. Passenger instructions on piers and on board for man over board situation	Other passengers on board are the best available resource in emergency situations, if they know what to do. Good passenger information is clear, simple and doesn't leave place for misunderstandings. If the information is visually interesting and the means for providing it are correct, people are more likely to read, listen to or watch it.	> Passenger instructions are poor or not easy enough to understand > Passengers do not familiarize themselves with the instructions
5. Remote monitoring centre to calm down and instruct people by voice after the alarm	Calming passengers if necessary in order to keep them functional and prevent irrational actions that make the situation worse. With detailed instructions, untrained people are able to perform operations they would not be able to do on their own. Persons giving instructions have to be well trained in LSA functions as well as in crowd and crisis management. Connections between vessels and shore have to be reliable and there have to be redundancies.	> People on board panic, don't know what to do or act irrationally, because there is no system for instructing people by voice > Connections between vessels and monitoring centres do not work > The way of giving instructions is not suitable and they are not followed onboard
6. Vessels to stop automatically in case of man over board alarms	Stopping vessels without delay after an alarm protects persons in the water and ensures that they can get all available help. The propeller of the vessels should be properly covered if the engines are running at the man over board scene	> Vessels are not programmed to stop in case of mob alarms and persons in the water get into the moving vessel's propeller > Persons cannot be found in the water and/or passengers are not able to assist because the vessel has continued on her route.

7. Well planned and rehearsed procedures, suitable equipment and clear roles between authorities for recovering persons from the water	In man over board situations there is no time for planning, only for well-rehearsed action. Man over board situations may happen in areas where help is not close by. Co-operation between authorities increases the amount of available resources and speeds up the rescuing.	> Assistance for recovering persons from the water takes too long to arrive.
8. Possibility for other passengers or the vessel to assist or recover a person in the water	Even if vessels are designed to protect people and keep them inside, there must be emergency exits and devices that can be used to pull a person on board from the water. All LSA-equipment on board should be easily available, simple, safe and easy to use for an untrained person. Automatic LSA equipment such as lifebuoys, ladders, slides, ramps, or emergency lighting should be automatically activated.	> Vessels' hull and structure are designed so "safe" that the passengers on board cannot assist or rescue anyone from the water > LSA equipment available are too complicated to be used by untrained people > Without automatic LSA equipment operated by the vessel, persons in the water may not get help
9. Automatic warning messages to be sent to surrounding vessels	Other vessels in the area are most likely the fastest available assistance, but only if they know the situation. Without information about the situation, they are an imminent danger to persons in the water.	> Autonomous vessels do not inform surrounding vessels about man over board situations and therefore other vessels cannot assist. > Autonomous vessels do not inform surrounding vessels about the man over board situation and another vessel runs over the person in the water
14. Persons getting injured + 15. Medical conditions		
Safety Control (SC)	**Control logic principle**	**Risks mitigated**
29. Good lighting and air conditioning	Good lighting ensures that passengers can move safely. With proper temperature on board, passengers remain calm and alert, and it reduces the risk of seizures and medical conditions	> Persons cannot see an obstruction and fall accidentally > High temperatures can trigger seizures or medical conditions
19. Unobstructed access and non-slippery floor materials in piers and vessels	Unobstructed access and non-slippery floor materials in piers and vessels ensure that passengers can move safely in all weather conditions	> Entrance to vessels is not level > Vessel or pier floors are made with slippery coating and passengers fall
4. Manual alarm systems in the passenger spaces and piers with direct contact to remote monitoring centres	It is essential to get the information about medical emergencies immediately to the authorities. Delays in this information endanger the safety of the patient	> Passengers on board have no easy and quick way to send alarms about medical emergencies > Alarm systems are not connected directly to remote monitoring centres, information about the situation is not forwarded
10. Vessels re-route to closest medical evacuation pier and transmits position to the authorities	Patient safety has to be prioritized and medical attention reached as soon as possible. Special attention should be paid to the information flow and the planning of the emergency harbours.	> Vessels continue to next planned pier and there is a delay for the patient to get the medical attention needed. > The information about the emergency does not reach the authorities or it is incorrect
27. Video surveillance systems	If persons travel alone, situations can only be detected by technical means. Reliable real-time data transfer ashore is an essential part of the system if a human does the monitoring. Technical specifications of systems should be planned and implemented efficiently. Video surveillance systems have to be monitored continuously.	> Medical emergencies are not noticed, because there is no video surveillance system to monitor passenger safety on board > Video material from vessels is not monitored continuously automatically or manually > Video material is not transferred ashore from vessels in real time > There is no reaction to situations captured by video surveillance systems > Video surveillance does not perform properly
11. Passenger instructions on quay and on board for medical emergencies	Other passengers on board are the best available resource in emergencies, if they know what to do. Good passenger information is clear, simple and does not leave place for misunderstandings. If the information is visually interesting and the means for providing it are correct, people are more likely to read, listen to or watch it.	> Passenger instructions are poor or not easy enough to understand > Passengers do not familiarize themselves with the instructions
5. Remote monitoring centres to calm down and instruct people by voice after alarms	Calming of passengers if necessary in order to keep them functional and prevent irrational actions that make situations worse. With detailed instructions, untrained people are able to perform operations they would not be able to do on their own. Persons giving instructions have to be well trained in medical first aid as well as in crowd and crisis management. Connections between vessel and shore have to be reliable and there have to be redundancies.	> People on board panic, don't know what to do or act irrationally, because the system for instructing people by voice does not exist > Connections between vessels and monitoring centres do not work > The way of giving instructions is not suitable and the instructions are not followed on board

12. Well planned and rehearsed procedure for medical evacuation	In medical emergencies, there is no time for planning, only for well-rehearsed action. Medical emergencies may happen in areas where help is not close by. Co-operation between authorities increases the amount of available resources and speed up the process.	> Medical assistance takes too long to arrive
13. Possibility for other passengers to give first aid to injured persons	First aid equipment on board should be easily available, simple, safe and easy to use for untrained persons. First aid equipment should be placed so that it cannot be easily tampered with, e.g. inside cabinets with alarms if opened	> There is no first aid equipment available > First aid equipment available is too complicated to be used for untrained people.

Figure 1 below presents the types of safety controls utilized for the prevention and response to the defined accidents shown on the top of the table. The types of safety controls are marked with the same color codes as in Table 2. Each coded square represents a single safety control and the codes H1-H14 show which hazard these controls are connected to in each accident. By connecting the hazard number and the safety control number on the left-hand side column, details of the safety control in question can be found in Table 2.

Figure 1. Safety control types utilized for prevention and response to defined accidents

Safety Control (SC)	Accident 1	2,1	2,2	3	4	5	6	7	8	9	10
1	H1 H1 H1	H1 H1 H1	H1 H1 H1	H1 H1 H1	H1	H1		H10			
2	H2 H1 H4	H2 H1	H2 H1	H2 H1 H4	H2 H4	H2 H4		H10			
3	H2 H1 H4	H2 H1	H2 H1	H2 H1 H4	H2 H4	H2 H4		H11			
4	H3 H1 H4	H3 H1	H3 H1	H3 H1 H4	H3 H4	H3 H4			H12	H12	H12
5	H3 H1 H4	H3 H1	H3 H1	H3 H1 H4	H3 H4	H3 H4			H12	H12	H12
6	H4 H2 H4	H2	H2	H4 H2 H4	H4 H2 H4	H4 H2 H4			H12		
7	H6 H2	H2	H2	H6 H2	H4 H2	H4 H2	H8		H12		
8	H2	H2	H2	H2	H2	H2	H7 H9		H12		
9	H3	H3	H3	H3	H3	H3	H7 H9		H12		
10	H3	H3	H3	H3	H3	H3	H7	H11		H14	H14
11	H4			H4	H4	H4	H7	H11		H14	H14
12	H4			H4	H4	H4	H8	H11		H14	H14
13	H6			H6	H6	H6	H8			H14	H14
14	H6			H6	H6	H6	H9				
15	H6			H6	H6	H6	H9				
16	H6			H6	H6	H6		H10			
17	H6			H6	H6	H6			H12		
18							H8		H12		
19							H8			H14	H14
20							H9				
21							H9				
22								H10			
23								H10			
24								H10			
25								H11			
26								H11			
27									H12	H14	H14
28									H12		
29									H12	H14	H14
Total SC	30	16	16	30	24	24	15	12	10	9	9

SC control strategy:

- Attempt to eliminate the hazard
- Reduce the likelihood that the hazard will occur
- Reduce the likelihood that the hazard results in an accident
- Reduce the damage if the accident occur

Distribution of the safety control types based on the mitigation approach in the initial safety management strategy for ferry A and B is presented in table 3. 27 % of the controls focus on implementing actions, which attempt to eliminate the hazard. 18 % of the safety controls focus on implementing actions to reduce the likelihood that the hazard will result in an accident. 18 % of the controls focus on implementing actions to reduce the damage if the accident occurs.

Table 3. Distribution of the safety control types used

Safety control mitigation approach	Safety controls defined
Attempt to completely eliminate the hazard	19
Attempt to reduce the likelihood that the hazard will occur	29
Attempt to reduce the likelihood that the hazard results in an accident	12
Attempt to reduce the damage if the accident occurs	13

5. Conclusions

This report presents a systematic hazard analysis prior to the concept design phase of an autonomous vessel. The process consists of five different steps to elaborate a systematic analysis of hazards and to define safety controls for mitigating and preventing the identified hazards. These safety controls are the basis of the initial safety management strategy of autonomous vessels and their operational system.

The process is suitable for analysing hazards and proposing safety controls with a systematic approach that covers the operational context of autonomous vessels. The process was applied to analyse two concepts of autonomous ferries operating in urban waterways in Finland. As an outcome of the process, ten accidents were defined and fifteen hazards identified. The result of the analysis is an initial safety management strategy composed of 73 safety controls. The controls provide itemized information that is relevant for planning, designing and constructing autonomous vessels and their entire operational system.

The process application promotes an anticipated involvement of different key stakeholders for planning the management of safety for autonomous vessels and their operational system. The implementation of the process produces initial itemized information, which can guide the initial design process of autonomous vessels and their entire operational system. The aim is to initiate the design of safety in the earliest conceptual design phase for engineering more efficient and safer autonomous ferries and systems.

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References

Chatzimichailidou, M., and Dokas, I. 2015. “The Risk Situation Awareness Provision Capability and Its Degradation in the Überlingen Accident over Time.” Procedia Engineering 128 (January):44–53.

Chen, J., Zhang, S., Lu, Y. and Tang P. 2015. “STPA-Based Hazard Analysis of a Complex UAV System in Take-Off.” In 2015 International Conference on Transportation Information and Safety (ICTIS), 774–79.

Fleming, C., Spencer M., Thomas, J., Leveson, N. and Wilkinson, C. 2013. “Safety Assurance in NextGen and Complex Transportation Systems.” Safety Science 55 (June):173–87

Hinchman, J., Clark, M., Hoffman, J., Hullbert, B., Snyder, C. 2012. Towards safety assurance of trusted autonomy in air force flight critical systems. In Computer Security Applications Conference, Layered Assurance Workshop

Jalonen, R., Tuominen, R. and Wahlström, M. 2017. Safety of Unmanned Ships - Safe Shipping with Autonomous and Remote Controlled Ships. Aalto University. https://aaltodoc.aalto.fi:443/handle/123456789/28061.

Leveson, N. 2011. Engineering a Safer World: Systems Thinking Applied to Safety. MIT Press.

Leveson, N., Dulac, N., Marais, K. and Carroll, J. 2009. “Moving Beyond Normal Accidents and High Reliability Organizations: A Systems Approach to Safety in Complex Systems.” Organization Studies 30 (2–3):227–49

Oscarsson, J., Stolz-Sundnes, M., Mohan, N. and Izosimov, V. 2016. “Applying Systems-Theoretic Process Analysis in the Context of Cooperative Driving.” In 2016 11th IEEE Symposium on Industrial Embedded Systems (SIES), 1–5

Rødseth, O.J., and Burmeister, H.C. 2015. “Risk Assessment for an Unmanned Merchant Ship.” TransNav, International Journal on Marine Navigation and Safety Od Sea Transportation 9 (3).http://www.transnav.eu/Article_Risk_Assessment_for_an_Unmanned_Rødseth,35,593.html

Teivainen A. 2017. Rolls-Royce to set up R&D centre in Turku, Finland. Helsinki Times. March 2017

Valdez Banda, O.A and Goerlandt, F. 2017. A STAMP-based approach for designing maritime safety management systems. Submitted to Safety Science. December 2016

Vermesan, O. and Friess, P. 2013. *Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems*. River Publish

Appendix 1

The background and expertise areas for each participating expert

A: Master mariner and master of marine technology with over 14 years of seagoing experience as marine officer, and about 5 years of experience from maritime administration as senior inspector and marine safety investigator.

B: Senior researcher with about 4 years of practical experience in quality and safety management of maritime traffic and port logistics, and over 5 years of experience in the research of safety and risk management practices implemented in the maritime industry.

C: Shipbuilding engineer with over 14 years of experience in ship design and technical management in the maritime industry and about six years of experience from classification societies.

D: Design and production engineer with over six years of experience as project manager and director in smart mobility and transport automation projects.

E: Sea captain with ten years of seagoing experience as marine officer and shipmaster, and 20 years of experience in the maritime simulator training and simulator environment development in a maritime college.

F: Doctor of technology, specialized in control engineering, automation and system identification. The expert has over six years of experience in the marine electric and automation industry and is currently a manager of intelligent shipping in one of the leading technology companies in the field.

G: Doctor of philosophy specialized in positioning technologies. The expert has over ten years of experience in the development of GNNS products and over four years of experience in researching geodesy, geoinformatics, navigation, remote sensing and spatial data infrastructure.

H: Software engineer with over ten years of experience as designer of software and algorithms for automation and energy domains. Specialized in critical and high-reliability systems.

I: Naval architect with 14 years of experience in ship design and construction, and works currently as managing director of a shipyard. The expert also has over 9 years of technical ship management experience from a shipping company.

J: Coast guard officer with a total of 28 years of experience of maritime search and rescue work, of which seven years as a search and rescue mission coordinator.

K: Fire engineer with about ten years of rescue service experience specialized in fire inspections and contingency planning in chemical sites and ports. Currently the expert works as leading fire inspector in charge of developing control activities for the South West Finland rescue area.

L: Ship owner with over 20 years of experience in ship management and practical ship operations, and 12 years of experience as ferry captain in the Finnish archipelago. The expert also acts as safety manager (DPA) of a shipping company.

M: City risk manager with a master's degree in engineering. This expert is in charge of the safety and security strategies and their implementation in one the largest cities of Finland.

N: Master mariner with five years of seagoing experience as marine officer and 11 years of experience as survival instructor in a maritime safety training centre. The expert also has experience in development and evaluation of marine lifesaving equipment.

O: Master mariner with three years of seagoing experience as marine officer and 10 years of experience as simulator instructor and training manager in a maritime college.

P: Master mariner with five years of experience in developing maritime on-board solutions. The expert currently works as CEO of a company focusing on maritime IT/ICT/IoT/telematics and safety systems.

Q: Naval architect with over five years of experience in the implementation of maritime safety regulations for ship design and construction. The expert also has over 3 years of experience in researching the interaction between sea ice and ship structures.

R: Chief engineer with 18 years of seagoing experience as marine engineer. The expert is also the safety manager (DPA) in a shipping company specialized in operating public transportation routes in a city area.

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