Exploration of safety risks in remote controlled sailing

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EXECUTIVE SUMMARY

Introduction

Rijkswaterstaat commissioned MARIN to conduct an exploration of the safety risks associated with remote-controlled navigation in inland shipping. The aim of this assignment was to create an overview of the risks involved in operating a vessel remotely, whether or not in combination with crew reduction and/ or the support by means of Track Pilot-automation (TGAIN) onboard. Additionally, the objective was to obtain an overview of the measures that need to be taken to ensure safe and efficient navigation.

MARIN approached the research with the perspective of an unattended wheelhouse during remote navigation operation commenced from a shore based Remote Control Centre. This perspective allowed us to identify risks, by projecting goals and goal related tasks on a Remote Control-operator, instead of the Wheelhouse-operator. An at MARIN developed Goal Based Task Analysis was used as a fundament to identify risks.

Furthermore, as a starting point we adopted several guiding principles and assumptions that serve as a framework:

- The responsibility remains with the Boatmaster onboard the vessel as long as there is remaining crew onboard and even when the Boatmaster is not attending the wheelhouse. Mainly for the matter of responding to emergency situations, the Boatmaster must have the opportunity and mandate to take back control to the vessel at any given time;
- The responsible Boatmaster onboard and the ROC-operator hold a relevant *Certificate of qualification in inland navigation as Boatmaster*, in accordance with the European Standard for Qualifications in Inland Navigation (ES-QIN). This means that both have received relevant education, training and gained relevant experience to navigate from the wheelhouse on board the vessel;
- MARIN assumes Boatmaster and ROC-operator to be fit for performance of relevant tasks, not suffering from disease, fatigue or mental health issues or occupied with conflicting goals and tasks besides navigation and vessel safety;
- Although a majority of technical and operational regulations are originating from international laws and directives, there might be some national relevant regulations applicable. In those cases, the Dutch laws, regulations or directives prevail in the assessments;
- MARIN assumes all large inland vessels[1] to be equipped with Inland AIS and Inland ECDIS in accordance with the European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN). Although Inland AIS and Inland ECDIS are not mandatory for all Dutch inland waters[2], this equipment is mandatory for large vessels navigating the river Rhine, including the Dutch sections of the river[3]. We assume that all inland vessels sometimes navigate the Rhine, and therefore are equipped as prescribed in applicable regulations. In addition, Inland-AIS is mandatory on all Dutch inland waters of CEMT-class I and up;
- MARIN also assumes that all large inland vessels use electronic books and internet services to provide for operational information.

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1 Ships with a length of 20 metres or more

2 In accordance with the Inland Navigation Police Regulations (Binnenvaart politiereglement)

3 In accordance with the Rhine Navigation Police Regulations (Rijnvaart politiereglement)

Results and conclusions

This research has provided a detailed assessment of the safety risks associated with remote navigation of inland vessels. Using a Goal-Based Task Analysis (GBTA) and MARIN socio-technical model integrated in the IMO Formal Safety Assessment (FSA) methodology, MARIN identified 11 key risk areas and developed corresponding Risk Control Options (RCOs) to support safe and efficient remote operations.

The findings show that while remote navigation offers clear potential for improving efficiency, flexibility, and sustainability in inland shipping, its safe implementation is not yet feasible without significant safeguards. At this moment, the risk of total data connection failure between the vessel and the Remote Operation Centre (ROC) remains a critical concern unless proven otherwise. Without a reliable fallback—such as an autonomous mode capable of maintaining a safe position or track—a competent operator must remain in the wheelhouse to ensure control can be regained in time.

The research also highlights a gap in the current qualification framework. While Boatmasters are formally certified, other crewmembers may lack the formal education needed to support remote operations. MARIN recommends further research into a secondary qualification standard—a formalized level of training below that of a Boatmaster but sufficient to ensure safe task performance during remote operations.
Several other risks were also identified and addressed:

- Unsuccessful voyage planning when delegated to the ROC operator, requiring structured procedures, accurate information exchange, and validation by the onboard Boatmaster.
- Inadequate briefing of ROC or wheelhouse operators during control handovers, mitigated through formalized communication protocols.
- Unsuccessful changeover of control between the wheelhouse and ROC, both in planned and emergency scenarios, requiring detailed procedures, training, and safeguards.
- Failures in environmental monitoring, including under keel clearance, traffic, obstacles, weather, and vessel position, addressed through equipment redundancy and compliance with ES-TRIN standards.
- Inadequate monitoring and control of propulsion and steering systems, which must be fully operable from the ROC.
- Emergency detection systems (e.g., fire and flooding alarms), which must be visible and actionable from the ROC to ensure crew safety.

While the study identifies opportunities for manning reduction, these are conditional. Tasks that are limited in complexity or frequency may not require a fully certified Boatmaster, but the ability to reduce crew safely depends on the vessel’s technical capabilities and the presence of fallback procedures. Until autonomous fallback modes are fully developed and validated, a competent operator must remain onboard.

Remote navigation is a technically promising development for the inland shipping sector. However, its implementation must be approached with caution, grounded in robust technical systems, clear operational procedures, and appropriate crew qualifications. This research provides a foundation for further development, standardization, and safe adoption of remote navigation technologies.

MANAGEMENTSAMENVATTING

Introductie

Rijkswaterstaat heeft MARIN opdracht gegeven om een verkenning uit te voeren naar de veiligheidsrisico's die gepaard gaan met op afstand bestuurde navigatie in de binnenvaart. Het doel van deze opdracht was om een overzicht te creëren van de risico's die verbonden zijn aan het op afstand bedienen van een vaartuig, al dan niet in combinatie met bemanningsreductie en/of ondersteuning door middel van Track Pilot-automatisering (TGAIN) aan boord. Daarnaast was het doel om een overzicht te verkrijgen van de maatregelen die genomen moeten worden om veilige en efficiënte navigatie te waarborgen.

MARIN heeft het onderzoek benaderd vanuit het perspectief van een onbemande stuurhut tijdens op afstand bestuurde navigatie, uitgevoerd vanuit een Remote Control Centre op de wal. Dit perspectief stelde ons in staat om risico's te identificeren door doelen en daaraan gerelateerde taken te projecteren op een Remote Control-operator in plaats van op de schipper aan boord. Een bij MARIN ontwikkelde Goal Based Task Analysis werd als fundament gebruikt om risico's te identificeren.

Verder hebben we als uitgangspunt een aantal leidende principes en aannames gehanteerd die als kader dienen:

- De verantwoordelijkheid blijft bij de schipper aan boord van het vaartuig zolang er bemanning aan boord is, zelfs wanneer de schipper zich niet in de stuurhut bevindt. Met name om te kunnen reageren op noodsituaties moet de schipper te allen tijde en zonder vertraging de mogelijkheid en het mandaat hebben om de controle over het vaartuig terug te nemen.
- De verantwoordelijke schipper aan boord en de ROC-operator beschikken over een relevant kwalificatiecertificaat voor de binnenvaart als schipper, in overeenstemming met de Europese Standaard voor Kwalificaties in de Binnenvaart (ES-QIN). Dit betekent dat beiden relevante opleiding, training en ervaring hebben opgedaan om vanuit de stuurhut aan boord te navigeren.
- MARIN gaat ervan uit dat de schipper en de ROC-operator geschikt zijn voor het uitvoeren van de relevante taken, niet lijden aan ziekte, vermoeidheid of mentale gezondheidsproblemen, en niet bezig zijn met conflicterende doelen en taken naast navigatie en scheepsveiligheid.
- Hoewel een meerderheid van de technische en operationele regelgeving voortkomt uit internationale wetten en richtlijnen, kunnen er ook relevante nationale regels van toepassing zijn. In die gevallen prevaleren de Nederlandse wetten, regels of richtlijnen in de beoordelingen.
- MARIN gaat ervan uit dat alle grote binnenvaartschepen zijn uitgerust met Inland AIS en Inland ECDIS in overeenstemming met de Europese Standaard voor Technische Eisen aan Binnenvaartschepen (ES-TRIN). Hoewel Inland AIS en Inland ECDIS niet verplicht zijn voor alle Nederlandse binnenwateren, is deze uitrusting wel verplicht voor grote schepen die op de Rijn varen, inclusief de Nederlandse delen van de rivier. We gaan ervan uit dat alle binnenvaartschepen soms op de Rijn varen en daarom zijn uitgerust zoals voorgeschreven in de toepasselijke regelgeving. Daarnaast is Inland AIS verplicht op alle Nederlandse binnenwateren van CEMT-klasse I en hoger.
- MARIN gaat er ook van uit dat alle grote binnenvaartschepen gebruikmaken van elektronische boeken en internetdiensten om operationele informatie te verkrijgen.

Resultaten en conclusies

Dit onderzoek heeft een gedetailleerde beoordeling opgeleverd van de veiligheidsrisico's die gepaard gaan met op afstand bestuurde navigatie van binnenvaartschepen. Door gebruik te maken van een Goal-Based Task Analysis (GBTA) en de IMO Formal Safety Assessment (FSA)-methodologie heeft MARIN elf belangrijke risicogebieden geïdentificeerd en bijbehorende Risk Control Options (RCO's) ontwikkeld ter ondersteuning van veilige en efficiënte afstandsbediening.

Uit de bevindingen blijkt dat op afstand bestuurde navigatie duidelijke potentie biedt voor het verbeteren van efficiëntie, flexibiliteit en duurzaamheid in de binnenvaart. Echter, een veilige implementatie is momenteel nog niet haalbaar zonder aanzienlijke waarborgen. Op dit moment vormt het risico op een volledige uitval van de dataverbinding tussen het schip en het Remote Operation Centre (ROC) een kritieke zorg tenzij het tegendeel bewezen is. Zonder een betrouwbare noodprocedure—zoals een autonome modus die een veilige positie of koers kan handhaven—moet een competente operator in de stuurhut aanwezig blijven om de controle tijdig te kunnen hernemen.

Het onderzoek wijst ook op een lacune in het huidige kwalificatiekader. Hoewel schippers formeel gecertificeerd zijn, kunnen andere bemanningsleden de formele opleiding missen die nodig is om afstandsbediening te ondersteunen. MARIN adviseert nader onderzoek naar een secundaire kwalificatiestandaard—een geformaliseerd opleidingsniveau onder dat van schipper, maar voldoende om veilige taakuitvoering tijdens afstandsbediening te waarborgen.

Daarnaast zijn verschillende andere risico's geïdentificeerd en geadresseerd:

- **Onvoldoende reisplanning** wanneer deze wordt gedelegeerd aan de ROC-operator, wat gestructureerde procedures, nauwkeurige informatie-uitwisseling en validatie door de schipper aan boord vereist.
- **Onvoldoende briefing** van ROC- of stuurhutoperators bij overdracht van controle, te mitigeren via geformaliseerde communicatieprotocollen.
- **Onsuccesvolle controleoverdracht** tussen stuurhut en ROC, zowel in geplande als noodscenario's, waarvoor gedetailleerde procedures, training en waarborgen nodig zijn.
- **Falen in omgevingsmonitoring**, waaronder de ruimte onder de kiel, verkeer, obstakels, weersomstandigheden en scheepspositie, aan te pakken via redundantie in apparatuur en naleving van ES-TRIN-standaarden.
- **Onvoldoende monitoring en controle** van voortstuwings- en stuursystemen, die volledig bedienbaar moeten zijn vanuit het ROC.
- **Detectiesystemen voor noodsituaties** (zoals brand- en waterinstroom melders), die zichtbaar en bedienbaar moeten zijn vanuit het ROC om de veiligheid van de bemanning te waarborgen.

Hoewel het onderzoek mogelijkheden voor bemanningsreductie identificeert, zijn deze voorwaardelijk. Taken die beperkt zijn in complexiteit of frequentie vereisen mogelijk geen volledig gecertificeerde schipper, maar de mogelijkheid om bemanning veilig te reduceren hangt af van de technische capaciteiten van het schip en de aanwezigheid van noodprocedures. Totdat autonome noodmodi volledig zijn ontwikkeld en gevalideerd, moet een competente operator aan boord blijven.

Op afstand bestuurde navigatie is een technisch veelbelovende ontwikkeling voor de binnenvaartsector. De implementatie moet echter met de nodige voorzichtigheid worden benaderd, gebaseerd op robuuste technische systemen, duidelijke operationele procedures en passende kwalificaties van de bemanning. Dit onderzoek biedt een fundament voor verdere ontwikkeling, standaardisatie en veilige toepassing van technologieën voor afstandsbediening.

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1 INTRODUCTION AND RESEARCH OBJECTIVE

At the end of 2024, Rijkswaterstaat commissioned MARIN to conduct an exploration of the safety risks associated with remote-controlled navigation in inland shipping. The aim of this assignment was to create an overview of the risks involved in operating a vessel remotely, whether or not in combination with crew reduction on board and/ or the support by means of Track Pilot-automation (TGAIN) on board. Additionally, the objective was to obtain an overview of the measures that need to be taken to ensure safe and efficient navigation.

1.1 Benefits of Remotely Operated Inland ships

New technologies for automated navigation in inland waterways can promote safer and more sustainable shipping and create economic opportunities. This research is intended to ensure readiness for the implementation of these new technologies but also to enable safe implementation of these technologies.

Since these technologies are new, the effects of their application are not always immediately clear. Therefore, building knowledge is essential. This is crucial to assess under which conditions these new technologies can be applied safely and sustainably, and what their impact is on the efficiency of traffic flow. As such, the current research contributes to the safe implementation of this technology.

1.2 Research Objective

This explorative research is intended to be used in, for example, the development of an assessment framework for permitting navigation with reduced crew. It may also serve as a starting point for establishing industry standards regarding the safe and efficient implementation of remote control in inland shipping.

1.3 Scope & Focus

The focus of the study is on the potential risks arising from the use of remote control, although the combination of remote control and automation (such as track-pilot automation) is not excluded. The guiding principle throughout is that the risks to the remaining crew, other waterway users, the waterway itself, and its infrastructure shall not exceed those posed by a conventionally operated vessel of comparable size and type. Furthermore, a remotely controlled vessel shall not impede the flow of traffic on the waterway. Therefore, besides the technical, operational, and organizational aspects of remote control, also the identification of Risk Control Options (RCO) is part of the study.

Legal issues, cost-benefit assessment of RCO or exploration of a viable economic business case fall outside the scope of this research.

In other words, this research focuses primarily on the high level goal of maintaining safe and efficient navigation in inland waters with the adoption of remotely operated vessels. Although in the current practice a completely unmanned wheelhouse on board vessels under remote operation is not yet foreseen, MARIN focuses on the perspective that in the future there will be no operator in the wheelhouse when the vessel is remotely operated. In this way, we are able to identify all critical tasks that need to be performed in the Remote Operation Centre (ROC) for the purpose of safe and efficient navigation.

This perspective also provides for the identification of other vessel-related goals that are observed to be normally performed by the operator in the wheelhouse. Examples are the monitoring of the engine room, alarms, respond to emergencies, keeping administration and accept and/or negotiate about cargo assignments. Only safety related tasks that involves the wheelhouse operator are considered within the scope of this research.

Finally, MARIN explicitly points out that an evaluation of the remote control operation developed by a specific supplier of a remote control concept such as SEAFAR is outside scope of this research. This is also applicable for the few companies that have equipped vessels with such technology and started to gain experience with remotely controlled vessel. As will be addressed later on, in terms of literature study and observations regarding actual implementation of remote control operations of inland vessels, only specific supplier developments are available for the purpose of risk identification and assessment. MARIN translated the results of this literature study and observations to generic risks concerning remote operation of inland vessels, meaning that the results cannot be projected on the development and implementation of specific supplier technology and risk mitigating solutions.

1.4 Acknowledgements

Along the project MARIN was supported by several companies. By supplying operational data and procedures, provide access to the ROC and on board of a remotely operated vessel MARIN obtained valuable insights in the remote navigation operation of inland vessels.

As such, MARIN wants to express her gratitude to Seafar, Bosman, Dari, Danser, Shipping Technology, Dutch Pilot Association and Koninklijke Binnenvaart Nederland for their support.

Additionally, MARIN wants to express her gratitude to Thomas Hornig (Aachen University), Igor Bačkalov (Development Centre for Ship Technology and Transport Systems) and Marvin Glomsda (University of Duisburg-Essen) for their involvement in the reviewing process of the present report.

1.5 Document Structure

Chapter 2 and Chapter 3 address the theoretical framework and research methodology, followed by the risk assessment and analysis in Chapter 4 and the research results in Chapter 5.

2 THEORETICAL FRAMEWORK

In recent years MARIN had foreseen increasing demands for fast, adequate and cost-efficient risk assessment of socio-technical operations within the globally functioning highly volatile, complex, uncertain and ambiguous socio-technical maritime system. More specific, MARIN expected demands in providing accurate descriptions of maritime operational scenarios, predictions of the merging of safety and unsafety within the maritime system and the ability to account for human performance reliability.

These demands served as objectives in MARIN toolbox research around two specific research goals [Ref 1.].

- Identify a risk management methodology that sustains the research objectives described above;
- Adopt, adapt or develop models and tools to describe, assess and mitigate risks in the maritime system, accounting for Human Performance as a key element in the achievement of system goals.

Literature showed that the concepts of *Risk* and of *Human Performance* are strongly connected in socio-technical systems like the maritime domain, meaning that Human Performance is a key element in the achievement of system goals.

At the same time, the volatile, complex, uncertain and ambiguous nature of the maritime domain will provide for an infinite number of possible scenarios, with highly unpredictable outcomes in terms of accidents and consequences of accidents. The significant capacity of humans to adapt to developing scenarios makes it even more difficult to predict Human Performance failures.

Therefore, we concluded that effective and efficient risk management in the complex and dynamic maritime domain should focus on the probability of unsuccessful human task performance as an unwanted event, with the probability of unsuccessful goal achievement as consequence(s) of such events. This conclusion changes the more traditional way of defining and addressing *risk* as a (quantified) measure of probability and consequences of *accidents*.

To be more specific; for the purpose of proper identification, classification, analyzation and mitigation of risks in the highly volatile, complex, uncertain and ambiguous socio-technical maritime domain, MARIN developed an additional definition of “RISK”:

Risk = a unique sequence of system events (scenario) that has a (uncertain) probability to end up in unsuccessful task performance, leading to the possible failure of the achievement of system-goals.

The MARIN toolbox research resulted in the identification of a risk management methodology and into adapted and developed models and tools. More specific, MARIN developed a Hierarchical Goal-Based Task Analysis methodology and a MARIN socio-technical system model. The MARIN toolbox research therefore serves as a theoretical framework in the present research, as summarized in APPENDIX A.

All references accompanying the MARIN toolbox research are left out in APPENDIX A, but can be found in the original paper.

3 RESEARCH METHOD

3.1 General

This research focusses on an overall high level goal of *safe and efficient* navigation with inland vessels, while being remotely operated from a shore based Remote Operation Centre (ROC). It can be expected that remote operation of an inland vessel involves new and sophisticated hardware and software, sensors and reliable data-communication between vessel and ROC. In addition, this has consequences for the human performance and reliability, where humans are involved in the operation. It changes the tasks performed by the crew on board and it is adding a new operational perspective, being the Remote Operator (RO) perspective in the ROC.

These consequences also involve new or changed risks that threatens the overall goal of safe and effective navigation. Risks must be mitigated either to maintain an equivalent level of safety compared to not remotely operated vessel, or to reach a higher level of safety resulting in opportunities to enhance efficiency by manning reduction.

Furthermore, we included the achievement of other goals in the assessment. Safe and efficient navigation might not be the only goal that needs achievement by task performance of the operator in the wheelhouse. Some of these goals are related to safety, others are not. Therefore, we will also consider safety related goals and associated tasks other than safe and efficient navigation and normally performed by the operator in the wheelhouse.

The objective of this research involves the identification and classification of these new or changed risks. It also seeks for mitigating measures, called Risk Control Options. To arrive at a satisfactory and robust set of risks and mitigating measures regarding design and implementation of Remote Control in inland shipping, MARIN has followed a 9-stage research process as depicted in Figure 3-1 and further described in this chapter.

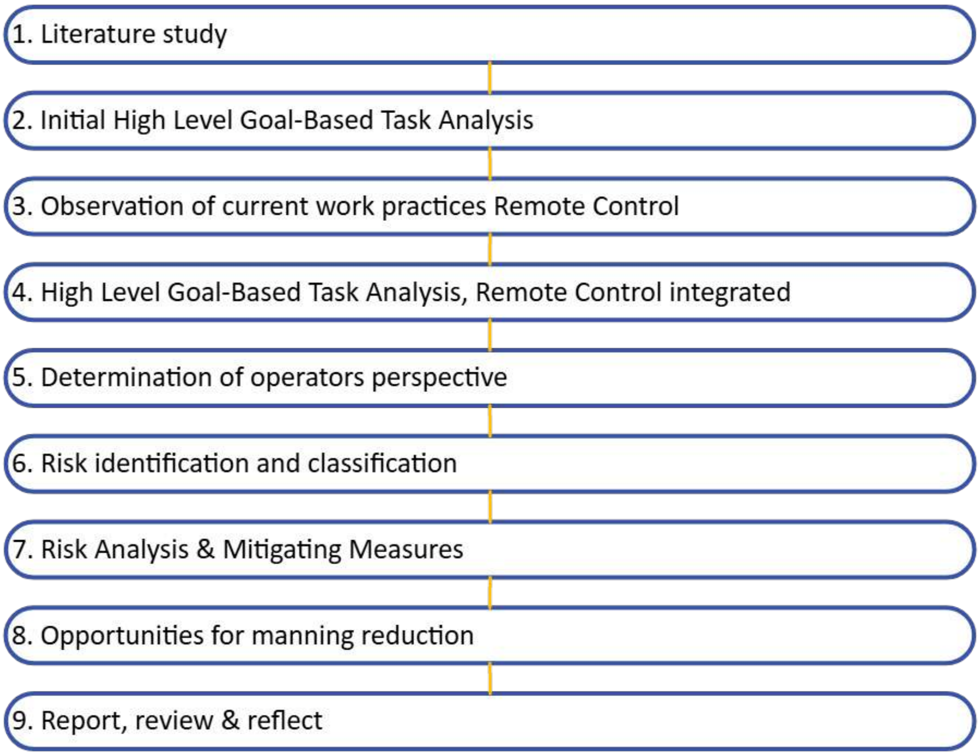

Figure 3-1 MARIN Research process.

3.2 Literature Study

First, the literature review focused on existing documentation with regard to remote control and autonomy on board vessels. As expected, formal documentation such as laws and regulations is mostly in a conceptual stage of development, since the maritime industry has is still in the early stages of implementing of remote control or autonomy for navigation on inland waterway vessels. It shows that, in general, the development of remote control technology is taken forward through learning by doing and step-by-step implementation, allowing for experimental remote control operations with high levels of risk mitigating measures.

secondly, the literature review addresses the navigational tasks on inland waterway vessels from a Remote Operation Centre compared with the operation from the wheelhouse on board. This part of the literature study was limited by the fact that, in inland shipping in the Netherlands, only one company is currently able to provide implemented remote control operations, with only a limited number of ships having permission, as experiments, to sail in Dutch inland waters. Nevertheless, their documentation regarding operational procedures, instructions, risk assessment and training requirements has been helpful in the identification of risks involved in remotely operating inland vessels and possible measures to mitigate the risks.

3.3 Initial generic Hierarchical Goal-Based Task Analysis

MARIN uses a generic Hierarchical Goal-Based Task Analysis (HGBTA) for shipboard operations based on both inland vessels as well as seagoing vessels. This generic HGBTA has been developed over years of research and observation, literature studies and personal knowledge/ experience of researchers with a history in shipboard operations. At this time, the HGBTA is providing for Safe & Efficient Navigation and Maintaining Emergency Preparedness as high level goals, but it is still expanding to other elements of the shipboard operation.

In the present research, the generic HGBTA served as a blueprint to address and project changes and additions to the HGBTA as a consequence of adding remote operation as a way to navigate the vessel from a shore based ROC.

3.4 Observation of current work practices remote operation

The current practice of remotely navigating an inland vessel in the port of Rotterdam has been observed on two separate occasions.

The first time this observation was conducted on board a remotely navigated vessel. Change-over of control to and from the ROC was observed during normal operation, as well as emergency change-over back to the wheelhouse of the vessel. Navigating a stretch of the fairway has also been observed. Manoeuvring and mooring were not part of the observation.

The second observation took place at the ROC, including manoeuvring and mooring operations. In both cases, eye-tracking glasses were used to record the operations. The recordings served only as a reference during the research.

3.5 Hierarchical Goal-Based Task Analysis, remote operation integrated

The observations both on board and at the ROC provided input for the integration of remote operation into the generic GBTA, together with the literature study. In addition, during the Risk Identification and Classification stage in the research (stage 6), an expert meeting was held in which some parts of the GBTA were validated, specifically regarding the equipment (hardware) necessary for performing safe navigation in a ROC.

3.6 Determination of operators' perspective

In the present research, MARIN needs to identify and classify changing or additional risks that comes with remotely navigating a ship from a ROC. In this case, it is possible to take both the ROC-operator perspective as well as the perspective of the remaining on board crew as a primary viewpoint.

Both perspectives are relevant. The perspective of the ROC-operator is completely new and the perspective of the remaining crew on board is expected to change dramatically because of the remote control operation. We decided on the prevailing perspective based on which was assumed to be most beneficial for effective and efficient identification and classification of risks and the determination of mitigating measures, as the criterions.

3.7 Risk Identification, Classification, Analysis and mitigation

3.7.1 Risk Identification

The key part in the present research is the identification and classification of risks involved in remote navigation operation of inland vessels. As explained in Chapter 2, MARIN adopted a definition of risk that identifies *unsuccessful goal achievement* as the main consequence of *unsuccessful Task Performance:*

> *Risk = a unique sequence of system events (scenario) that has a (uncertain) probability to end up in unsuccessful task performance, leading to the possible failure of the achievement of system-goals.*

Risks can therefore be identified by assessing the Hierarchical Goal-Based Task Analysis, in terms of safety goals related to remote navigating inland vessels under the assumption that the on board wheelhouse is unmanned.

3.7.2 Risk Classification and analysis

3.7.2.1 Failure Mode and Effect Analyses (FMEA)

In our approach, we follow the Failure Mode and Effect Analyses (FMEA) methodology [Ref 2.]. In this methodology risks are assessed by the identification and probability of *failure modes*, the *severity* of failure consequences and the probability of *detection*.

To assess risks, we were forced to take a qualitative approach. Remotely operated vessels are still not commonly used, with only a few vessels equipped and in operation. This means there is insufficient data available for a quantitative approach, for example, on accidents, reliability, and robustness. This also affects how the FMEA methodology can be applied.

3.7.2.2 Failure Modes

As per the theoretical framework addressed in Chapter 2, there is a focus on the failure of resources related to relevant Task Performance of the Human Operator involved in the remote operation. These failures can be either system component *functional failures* or system component *interaction failures*, since system components serve as resources for the tasks performed. Because of our qualitative approach, we consider the possibility of failure rather than the probability.

Table 3-1 provides an overview of possible functional failures and interaction failures of system components in the MARIN socio-technical system model for the maritime domain (Figure A-4), extracted from literature as described in Chapter 2.

Table 3-1 Failure modes in the MARIN Socio-technical system model for the maritime domain.

Failure Modes			
Functional Failures		Interaction Failures	
System Component Category	Failure Mode	System Interface Category	Failure Mode
Human Operator	Lack of Experience	Operational Information	Inaccurate
	Lack of Knowledge		Outdated
	Lack of Training		Missing
	Workload (high/low)		Information Saliency
	Conflicting tasks	Communication	Unclear
	Overstretching Physical and Mental limits		Inaccurate
	Lack of Engagement		Outdated
	Distraction		Missing or disturbed
	Fatigue		Contradictory
	Trust (high/low		Wrong language
	Lack of Attitude		Complicated
Organization	Conflicting goals (ETTO)		Attitude
	Too Dynamic	Human Machine Interface	Inconvenient Information Presentation
	Overambitious		Inconvenient Information Saliency
	Lack of governance/management		Lack of intuitive Mode Transition Support
Environment	Physical conditions		Lack of Transparency
	Infrastructure		Lack of Understandability
	Dynamic Traffic		Lack of Predictability
Hardware	Unreliable		Too Complicated
	Robustness		Missing/complicated Controls
	Operability	Documentation	Lack of adequate laws & regulations
	Job-Suitability		Lack of adequate procedures
	Availability		Lack of adequate orders/instructions
			Contradictory documentation
			Lack of relevant policies
			Missing or unclear contract
			Lack of adequate manuals
		Observation	Blocked or disturbed views
			Blocked or disturbed sounds
			Blocked or disturbed taste
			Blocked or disturbed feel
			Blocked or disturbed scent
		Actions	Lack of education, training and exercise availability
			Lack of surveys, audits and inspections

3.7.2.3 Severity

As addressed in Chapter 2 and based on the adopted definition of risk, this study considers unsuccessful task performance as the primary undesired event, with unsuccessful goal achievement as its main consequence. Within the FMEA methodology, however, the concept of severity can be interpreted in two ways: it may refer either to the likelihood that a failed task will lead to unsuccessful goal achievement, or to the impact of that failure—such as the potential severity of resulting accidents.

In this research we only consider *severity* as a measure to assess the likelihood of unsuccessful goal achievement.

During the research, we found that in many scenarios the achievement of higher level goals is depending on the successful completion of multiple interrelated lower level goals, including their associated tasks. In these type of scenarios, a failure of Task Performance does not automatically mean that the higher level goal is not achieved. We also learned that some goals are associated with multiple (partly) overlapping tasks. These tasks are then performed with different resources, meaning there is some kind of task redundancy related to the achievement of a single goal. It also means that in these type of scenarios multiple tasks need to fail in concurrence, before it might lead to unsuccessful goal achievement.

In those cases, we consider it irrelevant to assess the possible failure of a single task. We argued that a scenario driven task failure assessment would be more convenient.

3.7.2.4 Detection

The third element of the FMEA-methodology concerns assessing the likelihood that a resource failure will be detected in time, allowing the human operator to respond and adapt to the evolving situation. As with *severity,* task redundancy is also a beneficial factor. This means that different tasks use different resources, but all independently with the capacity to serve the achievement of one similar goal. This gives the operator the opportunity to detect the failure of one resource, since the result of the associated task is different than the other performed tasks.

3.7.3 Mitigating Measures

Depending on the resource failed, the failure mode, the severity and detectability, risks can be mitigated by taking appropriate measures. In the present research, we identified mitigating measures using mainly the criteria of effectiveness and, to some extent, efficiency. Organizational, administrative and legal aspects have been ignored. The identification process can be considered as a 2-step process:

1. First we focused on mitigating measures except for measures related to onboard wheelhouse attendance during remote navigation from a ROC;
2. If measures could not be identified, or as an alternative measure, we focused on onboard wheelhouse attendance as a mitigating measure.

3.7.4 Operational Data-analysis

We consider the failure of resources as causes to risks involved. Possibility of occurrence and the opportunities for operators to detect such failures are both relevant elements that need to be examined in the process of Risk Classification. For that reason, we conducted data-research on available information regarding alarms, change-over events and navigation accuracy and manageability in short periods just before and after the change-over events. In this way, we were able to verify the occurrence and detectability of some resource failures. At the same time, a quantification of the probability and severity of those failures could not be extracted from the data-analysis, since the data-set was expected to be way too small.

As part of the research, MARIN analysed available operational data as provided by a specific supplier. The analyses is performed on actual remote and onboard operations and alarm notifications. This paragraph provides insights in the analysis approach of the data analysis.

3.7.4.1 Operational data

For the data analysis, MARIN made use of the operational data obtained from a specific supplier. The table below provides insight in the content of the data.

Table 3-2 Description of available operational data.

Description	Content	Units
Vessel type	Motor Freighter	
Vessel dimensions	95.6 x 11.5 x 3.45	metre
Operational area	Rhine (to Karlsruhe)	
Operational period	26-09-2024 / 01-03-2025	
Number of handovers of vessel control	14	
Total duration remote control	7:01	hours
Average time interval data points	10 (alarm), 1 (actuator/control/motion)	seconds
Control location data	Date-/ Timestamp	
	ROC (not) in control	
Actuator data sources	Date-/ Timestamp	
	2x Stern engine speed + power	rpm / %
	1x Stern rudder angle	%
	2x rotational bow thruster power + angle	%
	1x rotational stern thruster power + angle	%
Vessel motions data	Date-/ Timestamp	
	Surge-, sway velocity	m/s
	Yaw angle	deg
Vessel location data	Latitude + Longitude	°
Alarm data	Date-/ Timestamp	
	Alarm message	

The received data contained raw data sets. As such, these data sets which existed of thousands of unique data points, had to be organized and structured in such a way that the content could be easily and automatically analysed. The timestamp at which a handover of control of the vessel took place between the ROC and the navigation bridge is displayed in the time series of the actuator and motion data. The observed time series can be found in APPENDIX B. Six instances of handing over the control are not further discussed since these appeared to be only short term tests of the system and as such not deemed relevant for the purpose of this research.

From the alarm notification data set, an overview was generated with unique alarm notifications. This overview can be found in APPENDIX C.

3.7.4.2 Data analysis

Based on the time series of the data, including the timestamp at which control of the vessel was handed over between the ROC and the Wheelhouse (and vice versa), the data is analysed. The analysis is based on the following criteria, in chronological order:

1. A time frame of 3 minutes before and 3 minutes after handover of controls;
2. The timeseries are checked for a potential emergency handover where the specific supplier procedures (idle engines, rudder at 0 degrees at timestamp of handover) were not in place or alternatively an alarm related to an unplanned handover was present;

3. The time series of the actuators are checked for sudden alterations in the power- or angular settings shortly after the handover of controls. Especially a combination of multiple actuators with sudden alterations might show a deviation in situation awareness between the different control stations, where as a consequence significant manoeuvring actions could be required;
4. Once significant manoeuvring actions are observed, the vessels location would be retrieved via the LAT/LON data at that particular timestamp. By the vessels location an impression of the vessels surroundings (i.e. bends in fairway, bridges, infrastructure, mountains etc.), could lead towards the reasoning for the manoeuvre or to potential risks;
5. Based on the outcomes of the former procedure potential risks could be identified.

3.7.5 Expert Meeting

In addition to observations, literature study and data-analysis, also qualitative data-collection regarding resource failures, severity, detectability and possible mitigating measures has been obtained through an Expert Meeting. This Expert Meeting has been attended by representatives of various shipping companies operating remotely navigated vessels, of SEAFAR as a developing, manufacturing and operating company for ROCs and onboard RC-technology, of Rijkswaterstaat and the Netherlands Shipping Inspectorate on behalf of the client, by pilots of the Dutch Pilot Association and a telecommunication specialist. The meeting was held at the MARIN-complex in Wageningen.

3.8 Opportunities for manning reduction

In this extension of the present research, we explored the opportunities for formal manning reduction on board ships. In the present research, “manning reduction” can be defined as both the reduction of the number of crewmembers on board and the reduction of capacities of the remaining crew.

However, results are strongly dependent on the situation that is related to the combination of a specific ship and a specific Remote Operation Centre, in terms of the actual risks present and the mitigating measures available and implemented.

Part of the exploration is the necessity to maintain wheelhouse attendance during remote navigation and the specific tasks the operator in the wheelhouse then needs to perform. This is because the wheelhouse operator’s tasks defines the level of knowledge, experience and training they need to possess.

3.9 Reporting

The client was given the opportunity to review the draft version of the present report. Finally, the results of the study were reviewed by three subject matter experts from the University of Duisburg, University of Aachen and Development Centre for Ship Technology and Transport Systems in Duisburg who were involved with a similar study at the time.

4 RISK ASSESSMENT AND ANALYSIS

4.1 Introduction

In this chapter the results of the present research are reported in terms of risks identified, classified and analysed, including the identification of Risk Control Options.

To be effective, MARIN needed to stay as close as possible to the objectives of this research. This resulted in the setting of strict boundaries regarding the assessment of navigation goals on inland vessels. The objective specifically concerns the implementation of remote navigation and not the assessment of navigation in general. This means that we only assess low level goals and tasks that are unique for, directly connected to or altered by remote navigation operation.

In addition, MARIN adopted some guiding principles and assumptions that serve as a framework for the research conducted:

- The Boatmaster remains responsible for the vessel as long as there is crew onboard—even if not physically present in the wheelhouse. In particular, the Boatmaster must always have the authority and means to immediately regain control of the vessel's navigation in case of an emergency.
- The responsible Boatmaster onboard and the ROC-operator hold a relevant *Certificate of qualification in inland navigation as Boatmaster*, in accordance with the European Standard for Qualifications in Inland Navigation (ES-QIN). This means that both have received relevant education, training and gained relevant experience to navigate from the wheelhouse on board the vessel.
- MARIN assumes Boatmaster and ROC-operator to be fit for performance of relevant tasks, not suffering from disease, fatigue or mental health issues or occupied with conflicting goals and tasks besides navigation and vessel safety.
- Although a majority of technical and operational regulations are originating from international laws and directives, there might be some national relevant regulations applicable. In those cases, the Dutch laws, regulations or directives prevail in the assessments.
- MARIN assumes all large inland vessels[4] to be equipped with Inland AIS and Inland ECDIS in accordance with the European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN). Although Inland AIS and Inland ECDIS are not mandatory for all Dutch inland waters[5], this equipment is mandatory for large vessels navigating the river Rhine, including the Dutch sections of the river[6]. We assume that all inland vessels sometimes navigate the Rhine, and therefore are equipped as prescribed in applicable regulations. In addition, Inland-AIS is mandatory on all Dutch inland waters of CEMT-class I and up.
- MARIN also assumes that all large inland vessels use electronic books and internet services to provide for operational information.

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4 Ships with a length of 20 metres or more
5 In accordance with the Inland Navigation Police Regulations (Binnenvaart politiereglement)
6 In accordance with the Rhine Navigation Police Regulations (Rijnvaart politiereglement)

4.2 Determination of operators' perspective

One of the objectives of the present research is the determination of opportunities to reduce the number of and/or capacity of the remaining on board crew as a positive effect of safe navigation from a ROC. This could mean:

- allowing for the onboard wheelhouse to remain unmanned during remote operations, or
- allowing for the onboard wheelhouse to be manned by crew with lower certification requirements.

In this case, the potential for reducing onboard crew depends on the accuracy, controllability, robustness, and reliability of remote navigation executed from a shore based ROC. These factors determine what, to what extend and with what competences tasks have to be performed in the wheelhouse during remote navigation and at what frequency. It is therefore convenient to conduct the present research primary from the ROC-operator perspective with regards to risks and mitigating measures, as it also reveals to what level on board crew reduction is possible.

4.3 Goal Based Task Analysis

In the present research we used a generic Goal-Based Task Analysis (GBTA) method to plot changes in the safety related operation that will be transferred from the on board wheelhouse to a Remote Operation Centre (ROC).

Throughout this Chapter the adapted GBTA will be depicted at different levels of detail, depending on the research step that is performed. They all show both the generic GBTA as well as the integrated elements regarding remotely performed navigation and other safety related operations. Figure 4-1 shows the legenda that is valid of all GBTA-diagrams displaying elements and details of the integrated GBTA.

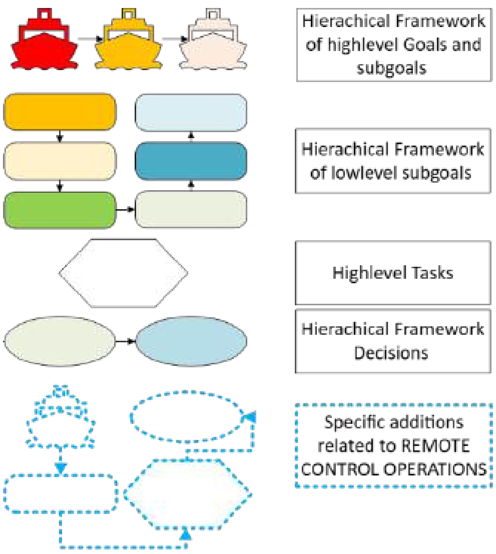

Figure 4-1 Legenda valid for all displayed GBTA-diagrams in this report.

4.3.1 Risk Identification

Since we consider unsuccessful achievement of system goal(s) as the consequence in the definition of Risk, the objective of this step is the identification of new and changing risks using the GBTA. Figure 4-2 shows the GBTA on high level and low level goals, without any details concerning specific tasks.

As a result of the performed research, we consider 11 new or changing risks that need to be analysed and classified. We consider *Voyage Planning* and *Execute Voyage Plan* as high level goals that need to be achieved in order to achieve the higher level goal of Safe and Efficient Navigation. As can be extracted from the high level GBTA- diagram in Figure 4-2:

- Voyage Planning needs to be successfully performed. Unsuccessful achievement can be considered as a risk;
- Unsuccessful briefing of the (updated) Voyage Plan might directly threaten the successful achievement of Voyage Plan Execution. We consider this as a second risk;
- Unsuccessful safe changeover from onboard wheelhouse to ROC and vice versa might directly threaten the achievement of Voyage Plan Execution, after a decision to changeover was made. We consider this as a third risk;
- During execution of the voyage plan and while engaged in remote navigation operation, unsuccessful maintaining Situation Awareness (SA) regarding the Status of the Environment, together with unsuccessful maintaining SA regarding the Status of onboard relevant equipment and Status of the ROC, threatens the maintaining of SA regarding navigation;

  Six lower level goals are directly linked to both the Status of the Environment and the Status of the Navigation. We extract six additional risks out of them, with due regard to the fact that maintaining SA about the Status of the environment also involves onboard equipment, as will be shown later in this chapter;
- To be able to navigate the vessel, the onboard machinery must be controlled and the Status of machinery to be monitored and maintained. We consider unsuccessful achievement of this goal as the 10^{th} risk;
- Finally, SA regarding Emergency warning systems must be maintained. This goal is directly related to the 11^{th} identified risk.

Table 4-1 holds the identified Risks based on brief descriptions connected to the GBTA pictured in Figure 4-2. Table 4-1 also holds brief descriptions of involved categories of system components and categories of system component interfaces that are providing for Task Performance, in accordance with Table 3-1.

More detailed information of any specific risk, including detailed GBTA-diagrams of goals and related Tasks, will be given in the next section (Risk Analysis, Classification, Risk Control Options and opportunities for manning reduction).

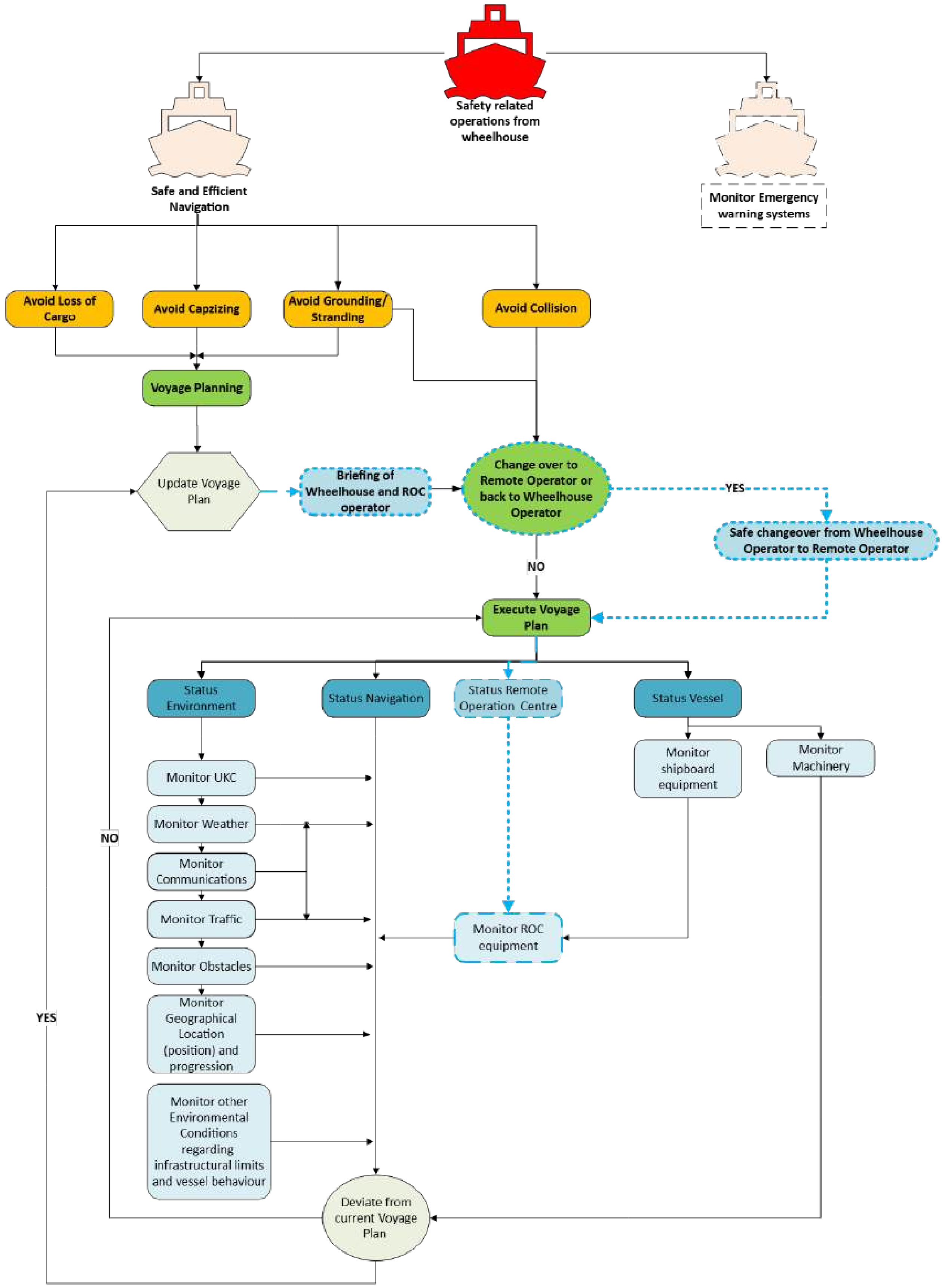

Figure 4-2 Goal-Based Task Analysis for safety related operations that are transferred from wheelhouse to ROC.

Table 4-1 Identified risks, involved System Components (categories) and Interfaces (categories).

Nr.	Identified Risk	Involved System Components (categories) and Interfaces (categories), conform Table 3-1	
		System components	Interfaces
1	Unsuccessful voyage planning by the ROC operator, as a result of unsuccessful task performance related to voyage planning.	Hardware Human Organization Environment	Operational Information Communication Human Machine Interface Documentation Actions
2	Unsuccessful voyage plan execution, as a result of inadequate briefing of the ROC-operator and wheelhouse operator regarding the (updated) Voyage Plan.	Human Organization Hardware	Communication Documentation
3	Unsuccessful changeover of control between Wheelhouse and ROC.	Human Organization Hardware	Communication Human Machine Interface Documentation Actions
4	Unsuccessful voyage plan execution, as a result of unsuccessful task performance related to Under Keel Clearance Monitoring.	Human Hardware Physical environment	Human Machine Interface Communication Observation Actions
5	Unsuccessful voyage plan execution, as a result of unsuccessful task performance related to Traffic Monitoring,	Human Hardware Physical environment	Human Machine Interface Communication Observation Actions
6	Unsuccessful voyage plan execution, as a result of unsuccessful task performance related to Obstacle and Object Monitoring.	Human Hardware Physical environment	Human Machine Interface Communication Observation Actions
7	Unsuccessful voyage plan execution, as a result of unsuccessful task performance related to Monitoring of the Geographical Location and progression of the vessel.	Human Hardware Physical environment	Human Machine Interface Communication Observation Actions
8	Unsuccessful voyage plan execution as a result of unsuccessful task performance related to Weather Monitoring.	Human Hardware Physical environment	Human Machine Interface Communication Observation Actions
9	Unsuccessful voyage plan execution, as a result of unsuccessful task performance related to assessment of Other Environmental Conditions regarding to infrastructural limits and vessel behaviour	Human Hardware Physical environment	Human Machine Interface Communication Observation Actions
10	Unsuccessful voyage plan execution, as a result of unsuccessful task performance related to machinery control and assessment of shipboard machinery status	Human Hardware	Human Machine Interface Communication Observation Actions
11	Unsuccessful monitoring of emergency warning systems	Human Hardware	Human Machine Interface Communication Observation Actions

4.4 Risk Analysis, Risk Classification, Risk Control Options and Opportunities for manning reduction

For every Risk Assessment we report in this Chapter, we start with a detailed GBTA-diagram, followed by a description of the risk. This includes the identification of relevant risk scenarios and the identification of Risk Control Options (RCO) and opportunities for manning reduction.

RCOs and opportunities for manning reduction can be considered as the result of fully performed Risk Assessments for every identified scenario. These assessments are reported in APPENDIX D and consists of a risk analysis section (table) and a risk classification, RCO identification and manning reduction opportunities section (table) for every identified risk scenario.

In our approach, we followed the Failure Mode and Effect Analyses (FMEA) methodology. In this methodology risks are assessed by the identification and possibility of failure modes, the severity of failure consequences and the probability of detection. In this section of the report we describe, analyse and classify every risk:

- The risk analysis is performed based on the identification of Functional or Interaction Failure Modes as results of literature study, observations, data-analysis and input from experts, as described in Chapter 3;
- The risk classification is based on assessments of severity and detectability of Failure Mode as results of literature study, observations, data-analysis and input from experts, as described in Chapter 3.

In addition, we extracted Risk Control Options and indicative opportunities for manning reduction following a 2-step methodology:

1. First we focused on mitigating measures except from measures related to onboard wheelhouse attendance during remote navigation from a ROC;
2. If measures could not be identified, or as an alternative measure, we focused on onboard wheelhouse attendance as a mitigating measure.

4.4.1 Visual monitoring of the vessel's environment using cameras

An important "source" of information for Wheelhouse-operators onboard an inland vessel is their sense of eye-vision. Eye-vision is used to monitor the environment in relation to detection and assessment of objects, obstacles, other traffic, shallow waters, weather, sea state and currents, bridge heights, signs and own vessel behaviour.

In a Remote Operating Centre (ROC) the operator has no opportunity to use direct eye-vision for monitoring the environment. Nor can the operator hear noises and sounds or feel vibrations or how the vessel behaves. Instead, the operator is dependent on multiple high quality cameras on board and monitors in the ROC to get a visual image of the vessels environment.

For the purpose of safe and efficient navigation, two main questions are relevant:

1. How many cameras are, as a minimum, needed to provide for an equivalent visual image compared to that of the Wheelhouse-operator on board?
2. What kind of risks occur when camera footage is not instantly available in the ROC?

The first question will be answered in this paragraph. The answer to the second question is dependent on the task performed and the level of redundancy that is provided by other resources in the ROC, and is therefore part of the assessments of risks in a later stage of this report.

4.4.1.1 Number of cameras required for outside view from the wheelhouse

ES-TRIN (article 7.02), Inland Navigation Police Regulations (BPR, article 1.09, clause 4) and Rhine Navigation Police Regulations (RPR, article 1.09, clause 3) require some levels of unobstructed view from the steering position and a direct or indirect adequate surround view from the wheelhouse.

In terms of safe and efficient navigation, we consider the ROC as a fully operational but separate steering position where, as defined in ES-TRIN, BPR and RPR, the outside view from the ROC must meet the same standards as the view from the onboard wheelhouse.

For the assessment of the number of cameras required, we also refer to the *Aspects of navigation section: visual navigation* in the April 2025 CESNI/EDINNA TGAIN brochure [Ref 3.]. This section outlines a continuous cycle of steps for visual navigation in inland shipping. The first step is the monitoring of the operational, tactical and strategic zones around the own vessel, as depicted in Figure 4-3.

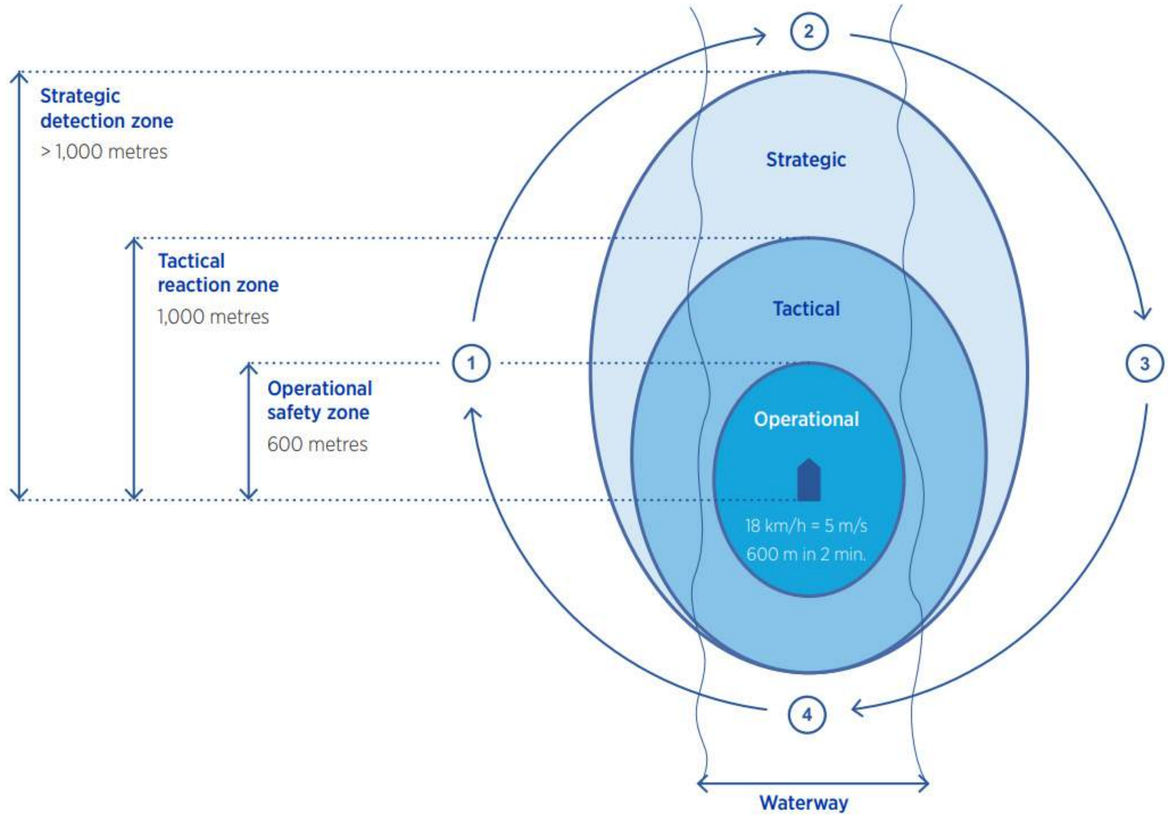

Figure 4-3 Operational safety zone, tactical reaction zone and strategic detection zone around the vessel, according to CESNI/EDINNA [Ref 3.].

Both BPR and RPR require RADAR-navigation in circumstances of reduced visibility, but neither regulation clearly defines what constitutes “reduced visibility”. MARIN found no other applicable laws or regulations that provide a specific definition.

To resolve this matter, the Dutch authorities adopted a Law Enforcement Policy, requiring RADAR-navigation on main fairways if the visibility is reduced to 1000 metres or less. Consequently if visibility exceeds 1,000 metres, vessels are not legally required to continue a voyage based on mandatory RADAR-navigation. In other words, the Strategic detection zone in Figure 4-3 is not relevant according to the Dutch Law Enforcement Policy and can therefore, in terms of the outside view from the Wheelhouse, be left out of scope for the present research.

To ensure an adequate view of the Tactical reaction zone and the Operational safety zone, MARIN considers the use of a high-quality camera system. This system should be capable of maintaining a continuous view of these zones in a *preset* mode. The number of cameras required will depend on the vessel’s size, as well as the quality and placement of the cameras. Additionally, the system should provide:

- Overlapping fields of view to eliminate blind spots, or an equivalent arrangement;
- Zoom and focus capabilities on each camera, allowing temporary use as “binoculars” to focus on specific objects. For applications during transit, it is recommended to employ separate, dedicated zoom cameras;
- An easy and quick method to restore the camera positions to the *preset mode* without any focus and zoom on a specific object.

4.4.2 Risk 1: Unsuccessful Voyage Planning

4.4.2.1 Goal Based Task Analysis

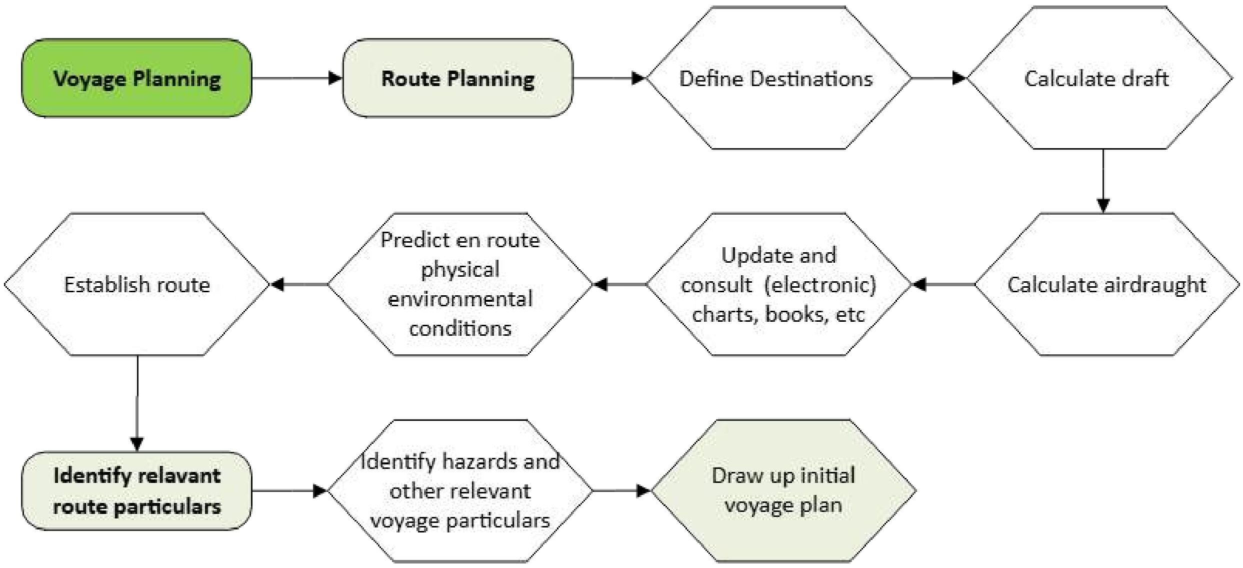

Figure 4-4 Detailed GBTA-diagram Voyage Planning Inland Shipping.

4.4.2.2 Risk Description

The preparation of the voyage remains an essential task performed before the beginning of each journey. Although, unlike on seagoing vessels, inland voyage planning is not strictly regulated, several key steps are still required—such as preparing a loading plan, evaluating available routes, and completing other essential preparatory tasks.

Traditionally, the Boatmaster is responsible for assessing route viability and monitoring the vessel's progress during the voyage. In practice, Boatmasters often plan routes independently, relying on their experience and memory to anticipate challenges, obstructions, and other relevant factors.

The risk addressed here concerns the extent to which the Remote Operation Centre (ROC) operator can and should be involved in voyage planning. This question is particularly relevant because, as highlighted during the expert meeting, ROC operators are expected to play a supporting role in this process.

We considered two different Risk Scenarios:

- Risk scenario 1-1: Unsuccessful Task Performance related to Voyage Planning, assessed in APPENDIX D, Table D-2 and Table D-3;
- Risk scenario 1-2: Unsuccessful updating of the Voyage Plan, assessed in APPENDIX D, Table D-4 and Table D-5.

4.4.2.3 Risk Control Options

Scenario 1-1

Objective: Delegation of the Voyage Planning to the ROC-operator.

To develop a reliable voyage plan, all preceding tasks outlined in the detailed Goal-Based Task Analysis (GBTA) must be successfully completed. Traditionally, this process is carried out almost intuitively by the Boatmaster, drawing on personal experience and knowledge.

In this scenario, the responsibility for voyage planning is transferred to the ROC operator. This shift requires the ROC operator to be provided with accurate and up-to-date information from various sources, including the Boatmaster onboard.

Unlike traditional practice, these tasks cannot be performed intuitively and must therefore be formalized in documented procedures. Organizations involved must recognize that both the Boatmaster and the ROC operator need sufficient time and focus to carry out these tasks effectively—free from high workloads, conflicting duties, or distractions. Additionally, the ROC operator must have prior onboard experience with the specific vessel to ensure adequate familiarity and engagement.

Currently, there are no formal mechanisms to detect flaws in the initial voyage plan. As a result, there is a risk that the Boatmaster may depart with an inadequate plan, despite being ultimately responsible.

We consider the following Risk Control Options to be valid:

1. Establish a mandatory procedure that clearly defines the tasks involved and specifies the information that must be provided to the ROC operator. Ensure both the Boatmaster and ROC operator are given sufficient time and opportunity to perform their tasks.
2. Select ROC operators with prior onboard experience operating the specific vessel.
3. Include a validation step in the procedure, requiring the onboard Boatmaster to review and, if necessary, correct the initial voyage plan before departure.

Scenario 1-2

Objective: Update of the Voyage Planning by the ROC-operator, in consultancy with the Boatmaster

1. Implement a formalized mandatory instruction to the ROC-operator, requiring the ROC operator to immediately inform and consult the onboard Boatmaster whenever an update to the voyage plan is necessary.

4.4.2.4 Opportunities for manning reduction

- Both the responsible Boatmaster onboard the vessel as the ROC-operator need to be involved. In addition, since this task is typically performed once before the start of a voyage and does not require continuous attention, it does not present opportunities for reducing onboard crew. Therefore, there are no opportunities for manning reduction related to the specific goal of successful Voyage Planning.

4.4.3 Risk 2: Inadequate briefing ROC-operator and Wheelhouse-operator regarding the Voyage Plan

4.4.3.1 Goal Based Task Analysis

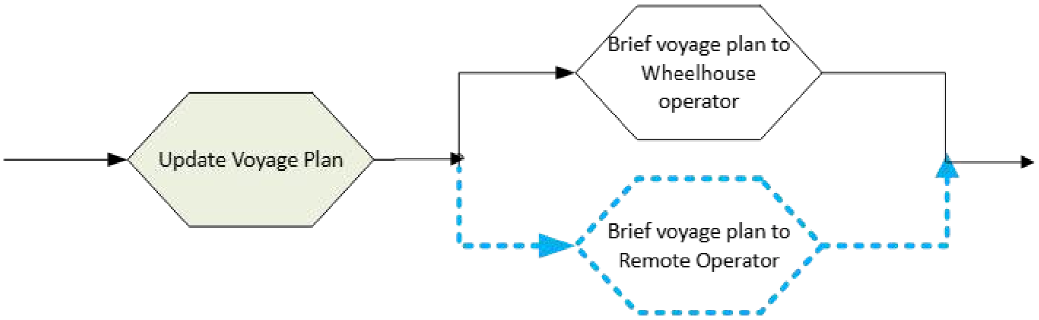

Figure 4-5 Detailed GBTA-diagram Briefing ROC-operator and Wheelhouse operator.

4.4.3.2 Risk Description

Anyone taking over the navigation of a vessel, should be aware of the validated Voyage Plan before taking over. This section focuses specifically on the changeover of control between Boatmaster and ROC-operator in case the ROC-operator was not involved in the original process of Voyage Planning. If the ROC operator was involved, it is assumed that a validation or consultation step with the Boatmaster has already occurred, as outlined in the Risk Control Options for Scenario 1-1 and Scenario 1-2.

We considered two different Risk Scenarios:

- Risk scenario 2-1: The ROC-operator needs to be informed about the content of the Voyage Plan before taking over control, assessed in APPENDIX D, Table D-6 and Table D-7.
- Risk scenario 2-2: The Wheelhouse-operator needs to be informed about the content of the Voyage Plan before taking over control, in case the Wheelhouse-operator is not the Boatmaster.

  Scenario 2-2 was not analysed in detail, as briefing the wheelhouse operator is standard practice and not a new or altered requirement introduced by remote navigation. However, the Risk Control Options identified for Scenario 2-1 may also be applicable to onboard briefing procedures.

4.4.3.3 Risk Control Options

Objective: Timely, adequately and accurately communicating the (updated) Voyage Plan with the Remote Operator.

We consider the following Risk Control Option to be valid:

1. Implement a formalized mandatory procedure to facilitate timely, adequate and accurate communication of the Voyage Plan to the ROC-operator, also addressing the obligation to immediately inform the ROC-operator in case of any updates of the Voyage Plan.

   The purpose of a formalized mandatory procedure is to assure that any crucial part of the Voyage Plan is communicated with the ROC-operator. As a starting point for any design of such a procedure, we refer to the IMO recommendations regarding *master-pilot information exchange*[7]*:*

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[7] Statutory Documents - IMO Publications and Documents - Resolutions - Assembly - IMO Resolution A.960(23) – Recommendations on Training and Certification and on Operational Procedures for Maritime Pilots other than Deep-Sea Pilots - (Adopted on 5 December 2003) - Annex 2 - Recommendation on Operational Procedures for Maritime Pilots other than Deep-Sea Pilots - 5 Master - pilot information exchange:

- *The master and the pilot should exchange information regarding navigational procedures, local conditions and rules and the ship's characteristics. This information exchange should be a continuous process that generally continues for the duration of the pilotage;*

- *Each assignment should begin with an information exchange between the pilot and the master. The amount and subject matter of the information to be exchanged should be determined by the specific navigation demands of the pilotage operation. Additional information can be exchanged as the operation proceeds;*

- *Each competent pilotage authority should develop a standard exchange of information practice, taking into account regulatory requirements and best practices in the pilotage area. Pilots should consider using an information card, form, checklist or other memory aid to ensure that essential exchange items are covered. If an information card or standard form is used by pilots locally regarding the anticipated passage, the layout of such a card or form should be easy to understand. The card or form should supplement and assist, not substitute for, the verbal information exchange.*

- *This exchange of information should include at least:*

    - *presentation of a completed standard Pilot Card. In addition, information should be provided on rate of turn at different speeds, turning circles, stopping distances and, if available, other appropriate data;*

    - *general agreement on plans and procedures, including contingency plans, for the anticipated passage;*

    - *discussion of any special conditions such as weather, depth of water, tidal currents and marine traffic that may be expected during the passage;*

    - *discussion of any unusual ship-handling characteristics, machinery difficulties, navigational equipment problems or crew limitations that could affect the operation, handling or safe manoeuvring of the ship;*

    - *information on berthing arrangements; use, characteristics and number of tugs; mooring boats and other external facilities;*

    - *information on mooring arrangements; and confirmation of the language to be used on the bridge and with external parties.*

4.4.3.4 Opportunities for manning reduction

Both the responsible Boatmaster onboard the vessel as the ROC-operator need to be involved. In addition, it mainly concerns a series of tasks that need single performance before a voyage is commenced. Therefore, there are no opportunities for manning reduction related to the specific goal of successful briefing the Voyage Plan to the ROC-operator.

4.4.4 Risk 3: Unsuccessful changeover of control between onboard wheelhouse and ROC

4.4.4.1 Goal Based Task Analysis

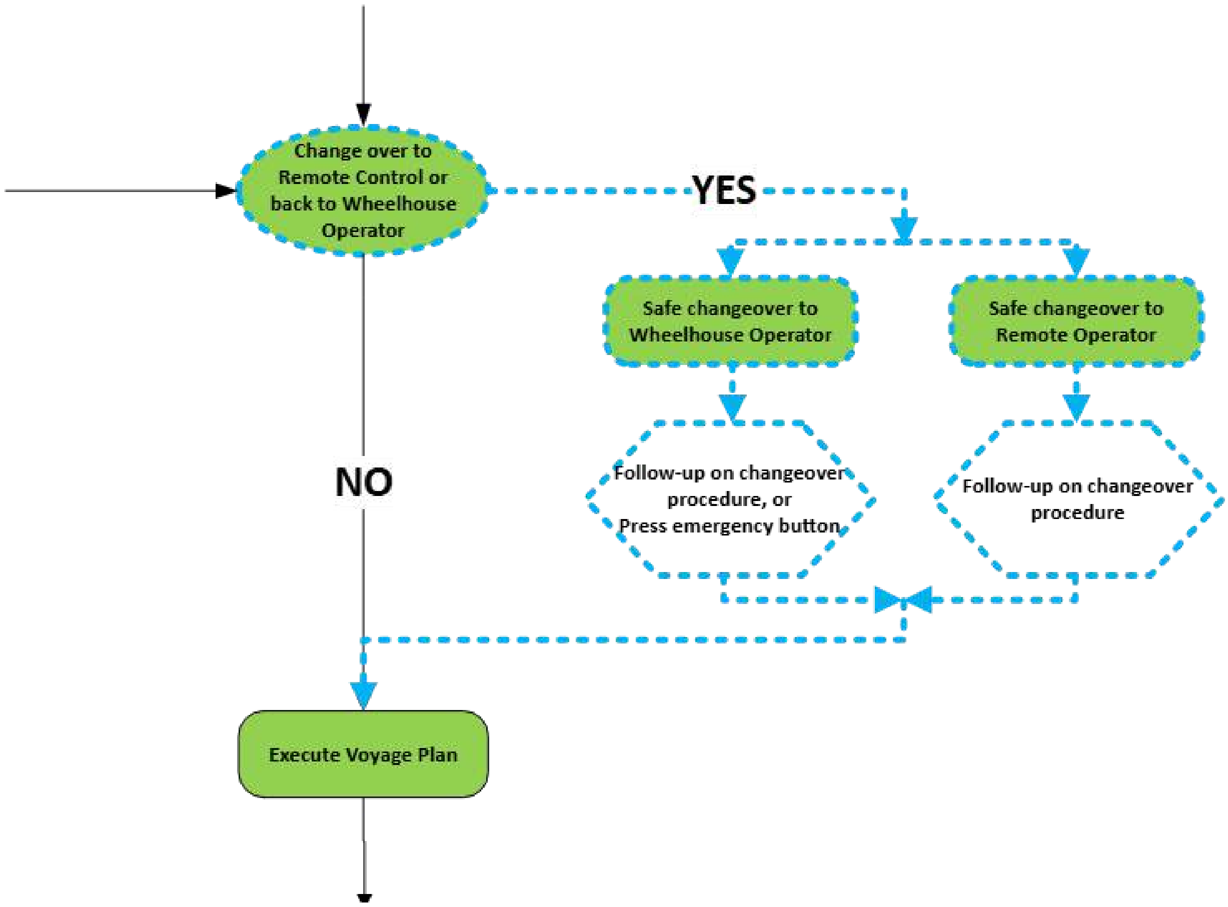

Figure 4-6 Detailed GBTA-diagram transfer of control between wheelhouse and ROC.

4.4.4.2 Risk Description

Control of the ship needs to be transferred to the Remote Operating Centre (ROC) before the Remote Operator (RO) can commence navigating the vessel. Transferring control back to the onboard wheelhouse will also be a common action for remotely operated vessels.

We consider the safe changeover of control to the RO a separate goal compared to the safe changeover back to the wheelhouse. That is because we expect the changeover to the RO being a highly manageable process, only performed under low workload, in safe and mild environmental conditions, at a convenient moment in time and with the wheelhouse attended.

The changeover back to the wheelhouse might occur in different circumstances. Under normal circumstances, we expect this changeover to also be a manageable process, including the attendance of a wheelhouse operator. In addition, in some occasions we expect emergency changeover back to the wheelhouse, initiated by the Boatmaster or Wheelhouse-operator, or triggered by an unexpected malfunction of hardware or data-connection in the ROC. In such cases, the wheelhouse might be not attended at all.

Multiple types of hardware failures could trigger an emergency changeover. These malfunctions are addressed under other identified risks related to the termination of remote navigation. In this specific scenario, we focus solely on the loss of data connection between the vessel and/or ROC, or failure of the hardware responsible for maintaining that connection.

We considered three different scenarios:

- Scenario 3-1: Managed change over between Wheelhouse and ROC, assessed in APPENDIX D, Table D-8 and Table D-9;
- Scenario 3-2: Emergency changeover from ROC back to wheelhouse, assessed in APPENDIX D, Table D-10 and Table D-11;
- Scenario 3-3: Failure of data-connection, causing immediate inability to maintain control over and monitoring of the vessel from the ROC, assessed in APPENDIX D, Table D-12 and Table D-13.

4.4.4.3 Risk Control Options

Scenario 3-1

Objective: Provide for manageable, safe and efficient changeovers between wheelhouse and ROC.

Managing changeover between wheelhouse and ROC to prevent unsafe (remote) navigation, is a complicated procedure with multiple subtasks to be performed in coordination between a competent wheelhouse operator and the ROC operator. Equipment and data-feed verification need to be performed during the changeover, which in turn causes levels of distraction from the navigation task. Furthermore, the necessity to manage changeover and the necessity to gain substantial situation awareness just before commencing changeover, highlights the importance of preventing unexpected changeover.

As being observed during the research, we consider the way forward to be the implementation of detailed changeover-procedures, adequate changeover-equipment transparency[8] and, because of the complexity of the procedure, providing for adequate training both for the involved crew on board as well as the operator in the ROC.

Data-analyses, as performed in the research, proved the validity of sufficient changeover-procedures. The data was obtained from a specific supplier and showed multiple managed changeovers on an inland vessel, without indications of navigational emergencies just before or after the actual changeover (APPENDIX 3). The specific supplier has implemented procedures to facilitate the changeover from wheelhouse to ROC and vice versa.

We consider the following Risk Control Options to be valid:

1. Implement a formalized, mandatory *changeover-procedure*, containing as a minimum:
    - A mandate to the onboard Boatmaster to *decide* on commencing remote navigation from ROC;
    - A mandate to ROC-operator, Boatmaster or competent Wheelhouse operator to *decide* on ending remote navigation from ROC;
    - Checking functionality, accuracy, robustness and reliability of data-connection between vessel and ROC;
    - Checking functionality, accuracy, robustness and reliability of all navigation equipment, communication equipment and monitoring equipment that serve the remote operation in the ROC before commencing changeover. Also the shipboard equipment should be checked regarding functionality. Readings in ROC and Wheelhouse should be compared and assessed on accuracy and time delay. Any deficiencies should trigger the decision to abort the changeover procedure or terminate remote navigation and operation;
    - Checking functionality of all controls and machinery feedback regarding navigation and operation of the vessel. Any deficiencies should trigger the decision to terminate remote navigation and operation;

[8] Equipment Transparency: clear and intuitive understandability of controls, settings, operational/technical status.

- Operating the changeover equipment, supported by a clear and comprehensive manual;
- Presence of environmental conditions that allow for safe changeover procedure, as to cope with the temporally distraction from navigation tasks. We suggest as a minimum:
  - Adequate stretch of fairway with no bends, bridges or locks;
  - Adequate stretch of fairway with no other traffic or inconvenient floating obstacles;

  Any deficiencies should trigger the decision to abort the changeover procedure;
- Operational conditions that allow for safe changeover procedures, as to cope with the temporally distraction from navigation tasks. Based on the observation and assessment of real-time remote operations, associated operational procedures and data-analyses, we suggest as a minimum:
  - Main propulsion settings to zero;
  - Rate-of-Turn or rudder settings close to zero degrees per minute and remaining during the changeover. This means that, when applicable, a TGAIN should be disengaged as well;
  - Extra lookout present in either wheelhouse or ROC, providing for Situation Awareness when the Wheelhouse-operator and the ROC-operators are occupied with the change-over procedure;

2. Design and implement changeover equipment in a way that, under normal conditions, changeover cannot be performed unexpectedly, for instance accidentally. This means that changeover requires at least handlings in the ROC and in the wheelhouse, in a way that requires coordination between Wheelhouse-operator and Remote Control-Operator;
3. Facilitate direct and reliable communication between Wheelhouse-operator and ROC-operator, while allowing the possibility to receive and respond to VHF communication on mandatory listening channels and to internal communication between crewmembers on board;
4. Facilitate adequate training for involved Wheelhouse-operators and ROC-operators.

Scenario 3-2

Objective: Provide for safe and efficient but unmanaged emergency changeover between ROC and wheelhouse.

Emergency changeover is defined as situations where there is no time and opportunity to follow up on procedures for normal changeover. During the research, we did not identify scenarios in which emergency changeover from wheelhouse to ROC would be convenient. Therefore, we only consider the emergency changeover from ROC back to the Wheelhouse.

In any case, emergency changeover should be avoided when no competent Wheelhouse-operator is attending the wheelhouse, unless the vessel is automatically changing to an autonomous mode in which the vessel is capable of maintaining a _safe_ position or track for as long as a competent Wheelhouse-operator needs time to attend to the bridge, communicate with the ROC-operator about the emergency and gain a minimum required Situation Awareness in respect to functionality of machinery controls and the environment.

In addition, MARIN does not consider Track Pilot-automation (TGAIN) as a system component that can provide for such an autonomous mode, as long as it is not capable of detecting and avoiding collisions with other vessels, infrastructure such as bridges and locks, or other objects and obstacles.

If the vessel is not capable of automatic change to such an autonomous mode on ROC-initiated emergency termination of the remote operation, it means that the ROC-operator must have no ability to activate emergency changeover back to the wheelhouse by himself.

In addition, we expect that emergency changeover situations also cause attention tunnelling, meaning that the Wheelhouse-operator might be temporarily distracted from navigation goals or other safety related goals and tasks.
We consider the following Risk Control Options to be valid:

1. Install an emergency button in the wheelhouse of the vessel, instantly terminating the remote navigation operation upon activation;
2. Do not provide the ROC-operator with an ability to instantly terminate the remote navigation operation, unless the vessel is automatically changing to an autonomous mode upon activation, in which the vessel is capable of maintaining a safe position or track for as long as the Boatmaster needs time to attend to the bridge, communicate with the ROC-operator about the emergency and gain a minimum required situation awareness and gain control over the vessel. We assume that the required time will be at least 3 minutes;

   In case the vessel is not capable of such an autonomous mode, the ROC-operator needs to be trained to maintain remote navigation until a Wheelhouse-operator activates the emergency button;
3. Design and install a facility that gives the ROC-operator a quick and easy to activate ability to instantly call the Boatmaster to the wheelhouse;
4. Facilitate in the quick attendance to the wheelhouse of a second crewmember or the attendance of a second operator in the ROC, upon activation of emergency changeover-procedure, with the objective to help the Boatmaster in gaining both situation awareness and control over the vessel.

Scenario 3-3

Objective: Provide for safe operation in case of failures in data-connection between vessel and ROC.

Instant termination of the remote navigation operation due to data-connection failure lead to a not under command status of the vessel, most probably with forward propulsion and speed and some rate-of-turn.

In any case, instant changeover should be prevented when no competent wheelhouse-operator is attending the wheelhouse, unless the vessel is automatically switching to an autonomous mode in which the vessel is capable of maintaining a safe position or track for as long as a competent Wheelhouse-operator needs time to attend to the bridge, communicate with the ROC-operator about the emergency and gain a minimum required situation awareness and control over the vessel.

In addition, MARIN does not consider Track Pilot-automation (TGAIN) as a system component that can provide for such an autonomous mode, as long as it is not capable of detecting and avoiding collisions with other vessels, infrastructure such as bridges and locks, or other objects and obstacles.

If the vessel is not capable of automatic switch over to such an autonomous mode, the remote navigation operation should not be performed without a competent operator permanently attending the wheelhouse.

Risk Control Options, beside the autonomous mode capability of the vessel, look for prevention to an instant and unexpected total loss of control over the vessels navigation.

We consider the following Risk Control Options to be valid:

1. Every provider of remote navigation equipment, which includes an ROC, shall do sufficient research of data-connection availability in all fairways where vessels will sail under remote navigation operation. The objective of this Risk Control Option is to gain Situation Awareness regarding local network-coverage and possible disturbances due to obstacles or other causes;
2. Provide for sufficient redundant data-channels and data-connection hardware components;

3. A convenient level of redundancy has been observed during the research, providing for three independent data-channels, with two of them available as a minimum. Furthermore, we suggest a convenient level of redundancy should be effectuated by:
    a. Capability of two channels together to provide for complete, robust and reliable data transfer between vessel and ROC;
    b. Capability of one channel, temporally and only in unexpected occasions, to facilitate the most critical equipment necessary to control the vessel and keep her at a safe position or track: (1) GPS position coordinates (2) Rate-of-turn indicator (3) Radar (4) Speed-indicator (5) propulsion controls and (6) steering controls.

    Scenarios in which only one data-channel is available, should trigger the decision to terminate the remote navigation operation;
4. Unless the vessel is capable of automatically changing to an autonomous mode upon loss of data-connection, in which the vessel is capable of maintaining a safe position or track for as long as the Boatmaster needs time to attend to the bridge, gain a minimum required Situation Awareness and gain control over the vessel, a competent Wheelhouse-operator shall be present in the Wheelhouse during remote navigation and operation. We assume that the required time will be at least 3 minutes;
5. In case the vessel is capable of such an autonomous mode, facilitate in instant warning and quick attendance to the wheelhouse of the Boatmaster and a second crewmember with the objective to restore and maintain command over the vessel.

4.4.4.4 Opportunities for manning reduction

At this moment, unless the vessel is capable of automatically changing to an autonomous mode upon loss of data-connection, safe remote navigation operation on Dutch inland waters is not yet possible without a competent Wheelhouse-operator attending the Wheelhouse, since there is a possibility of a *Not Under Command* vessel when all data-connections between ROC and vessel fails. It means that the Wheelhouse-operator needs to be competent to (1) maintain Situation Awareness at all times and (2) navigate the vessel in a safe manner, at least for the time required for a competent Boatmaster to attend to the wheelhouse.

4.4.5 Risk 4: Unsuccessful Under Keel Clearance Monitoring

4.4.5.1 Goal Based Task Analysis

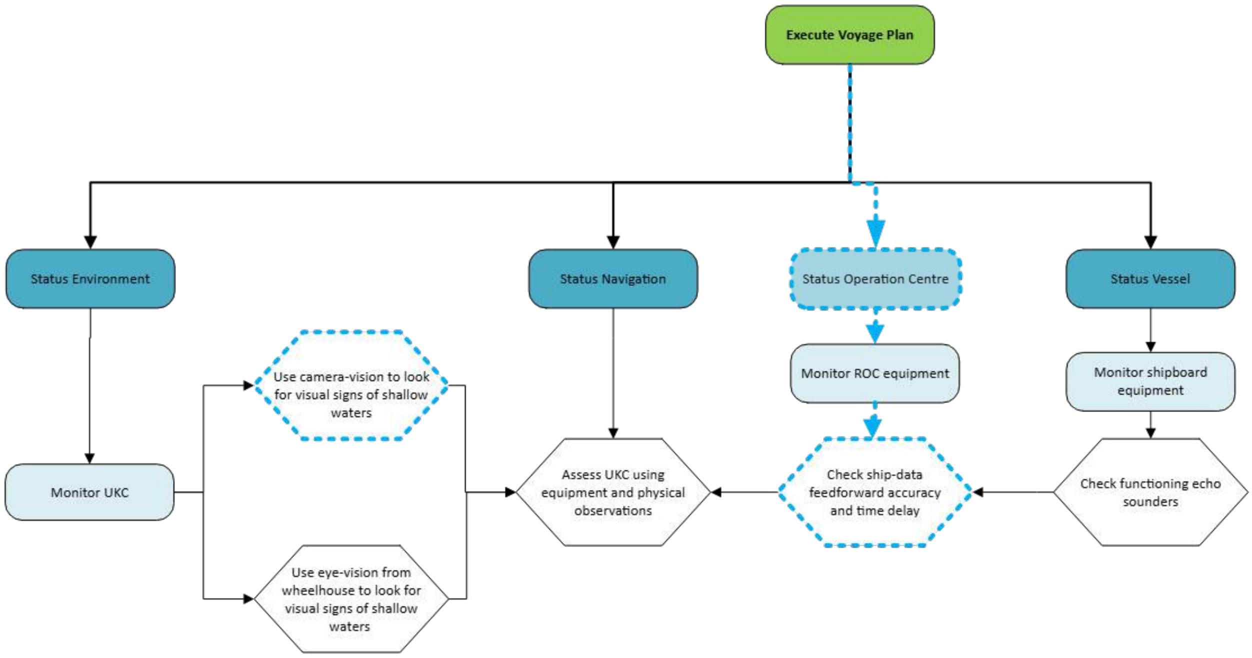

Figure 4-7 Safe and efficient navigation related to monitoring and assessment of Under Keel Clearance.

4.4.5.2 Risk Description

To avoid grounding, stranding or loss of steering capability, the Under Keel Clearance (UKC) needs to be permanently monitored and assessed. For successful achievement of the related goals and perform the related tasks, several resources can provide for information regarding UKC:

- The wheelhouse operator can experience vibrations as an indicator for possible low UKC.
- In daylight conditions, both the wheelhouse operator and an operator in the ROC can visually see the height and angle of the following stern wave, serving as indicators of reduced UKC. Also extreme dropping of the water level at the river banks can be observed.
- The wheelhouse operator and ROC-operator can experience reduced or even failing rudder response.
- The wheelhouse operator and ROC-operator have the availability of an echosounder, showing the UKC at the sensor installation point.

In addition, during voyage planning it is standard practice to calculate the maximum loading condition, using actualized fairway information regarding the (predicted) water level. Nevertheless, monitoring and assessment of the UKC remains standard practice.

The ROC operator does not have the ability to feel vibrations and look at water level drops or the following stern wave during nighttime. Therefore, MARIN considers the availability of echosounder-readings in the ROC as a requirement for remote navigation operations. Monitoring the performance and data-feedforward of the Echosounder(s) is then an additional task to be performed at the ROC.

We considered one scenario:

- Scenario 4-1: Echosounder(s) on board or data-feedforward to ROC are failing, assessed in APPENDIX D, Table D-14 and Table D-15.

4.4.5.3 Risk Control Options

Objective: Provide for detectability of failures of echosounder, data feedforward and data-connection and facilitate safe navigation in case of these failures.

We consider the following Risk Control Options valid:

1. Acknowledge the ROC as a separate “Steering position” from where the ship can be operated independent of the onboard wheelhouse, in a way that ES-TRIN Chapter 7 is applicable on the ROC steering position;

   In addition, acknowledge Echosounders as a required monitoring system in the ROC. The echosounder monitoring is then required to be in accordance with ES-TRIN Article 7.03;
2. If the ROC monitoring of echosounders cannot be compliant to ES-TRIN Article 7.03, a crewmember should be attending the wheelhouse on board and be able to warn the ROC-operator or of a failure, without delay;
3. Formalized Changeover procedures should provide for ending the remote operation during darkness in case of the described failures regarding UKC monitoring and assessment;

   In case of failure during daylight, the procedures should provide for mandatory consultation with the onboard Boatmaster regarding continuation of the remote operation.

4.4.5.4 Opportunities for manning reduction

If the Risk Control Options are implemented, a Wheelhouse-operator’s attendance is not necessary for UKC monitoring and assessment when engaged in remote navigation operation. In the worst-case-scenario, any crewmember with additional training in monitoring the functioning of the echosounder and accurate data-forward to the ROC could attend the wheelhouse for this monitoring task.

4.4.6 Risk 5: Unsuccessful Traffic Monitoring

4.4.6.1 Goal Based Task Analysis

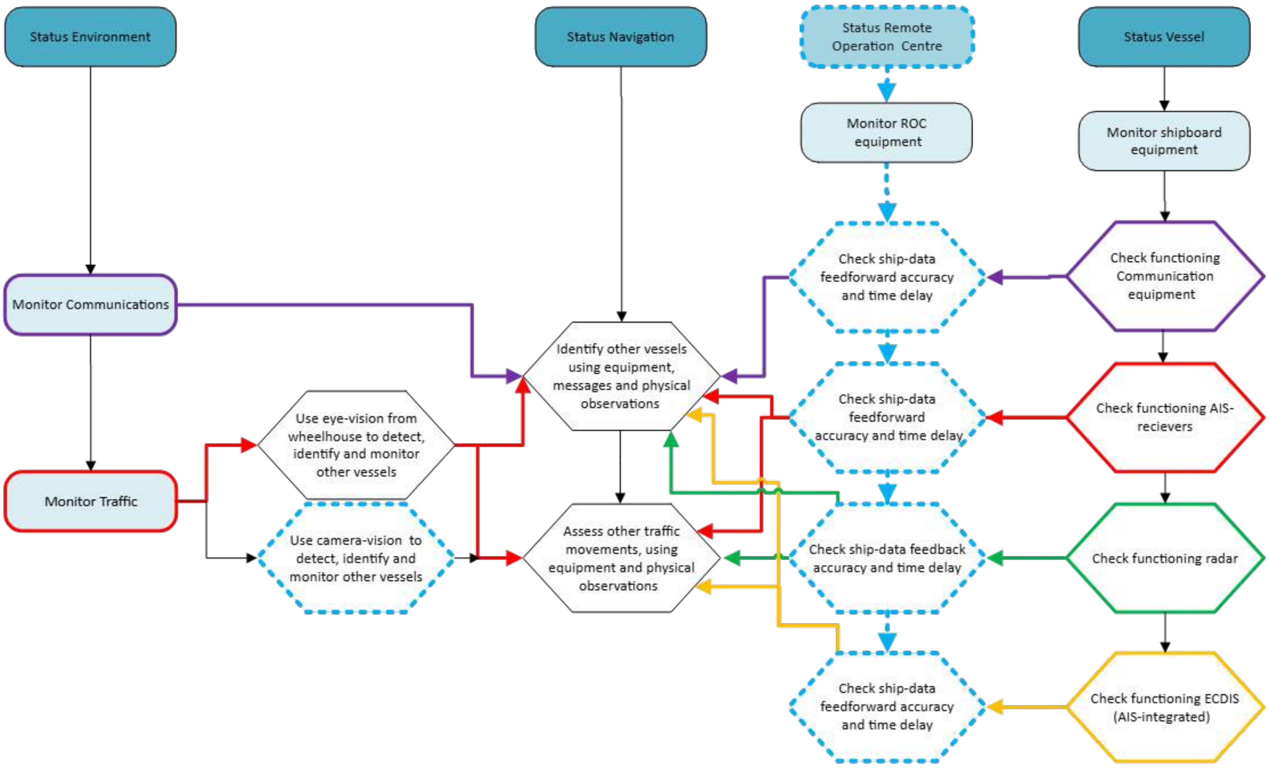

Figure 4-8 GBTA Monitoring, identification and assessment of Traffic.

4.4.6.2 Risk Description

To avoid collisions with other vessels, the traffic needs to be permanently monitored and assessed. For successful achievement of the related goals and perform the related tasks, several resources can provide for information to the ROC-operator regarding detection, identifying and assessment of other traffic:

- Outside view to the Tactical reaction zone and the Operational safety zone using cameras onboard the vessel (referring to Figure 4-3). In addition, navigation lights and other daymarks and signs are being used to communicate intentions to other vessels. The Blue Sign/flickering white light combination on the starboard side of the wheelhouse serves, as an example, to communicate about starboard to starboard passage of vessels on inland waters.
- RADAR for traffic monitoring in the Strategic detection zone, the Tactical reaction zone and the Operational safety zone.
- Inland-AIS in combination with ECDIS to detect, identify and monitor traffic in the Strategic detection zone, the Tactical reaction zone and the Operational safety zone, under the condition that other vessels need to transmit AIS-signals in order to be detectable.
- VHF-communication to listen to or ask for other vessels positions and intentions. VHF communication can also be used to transmit own vessels position and intentions.
- Sound signals on vessels horn are still an accepted or even mandatory way to communicate with other vessels.

The outside view from a wheelhouse is a resource that, except in situation of reduced visibility, provide for a minimum required Situation Awareness, together with the obligation to listen and respond to VHF-radio communications on predetermined VHF-channels. On the Rhine, the obligation to have installed and to use Inland-AIS together with ECDIS (or equivalent) also exists.

On board, the outside view is not to be considered as a technical instrument that can malfunction. It is a primary source of information that can be enforced using RADAR.

In the ROC, the outside view must be considered as a technical instrument. Malfunction leaves the ROC-operator with no view at all, except when also RADAR is used in the operation. Experts during the expert meeting were indicating that, when the camera footage is not available in the ROC, it is just a matter of switching to RADAR-navigation, similar as during periods of reduced visibility. They argue that, in situations of normal visibility, RADAR-navigation in combination with Inland AIS, Inland ECDIS and VHF communication, can be safely performed without having an outside view.

In its essence, this way of arguing is missing an important aspect. In situations of reduced visibility the traffic is changing in a significant manner, meaning that only vessels navigating with radar are allowed. This means that all smaller vessels, that are difficult to detect on radar and are also not equipped with VHF and Inland AIS, are not supposed to be present in the fairway. It is exactly this traffic that is presumed only fully detectable by the outside view from the wheelhouse. In addition, whereas vessels normally might communicate and execute starboard-starboard passage using before mentioned blue sign/flickering white light combination, in reduced visibility vessels are obliged to stay at the starboard side of the fairway, with only port to port passages.

Regarding VHF-communication: Relevant sections of BPR/RPR and ES-TRIN requires reception and response abilities for the person that is steering the vessel.

Regarding ECDIS: There are, in essence, two different ways an ECDIS-screen can be presented in a ROC. The (1) ECDIS-screen of the vessel can be projected on a screen in the ROC or (2) there is a separate ECDIS installed in the ROC that is capable of receiving AIS-signals and own position data from the vessel and projecting that information in the ECDIS-screen.

Finally: Both the reception of all incoming relevant information and the transmission of all outgoing relevant information including VHF-communication and sound signals, is mandatory for the crewmember on the helm, according to RPR and BPR.

We considered one scenario:

- Scenario 5-1: Monitoring of failures in the ROC due to malfunction of hardware or failure of data-connections of the following components:
  - outside view camera footage;
  - RADAR-screen; and/or
  - AIS-signals; and/or
  - ECDIS-screen; and/or
  - and/or VHF-communication;
  - and/or receptions of sound signals.

  This risk scenario is assessed in APPENDIX D, Table D-16 and Table D-17.

4.4.6.3 Risk Control Options

Objectives: Provide for equipment availability, operating ability and detectability of failures, including data feedforward and data-connection failures, of:

- outside view camera footage;
- RADAR;
- INLAND-AIS-equipment;
- INLAND-ECDIS;
- VHF-radio communication equipment;
- Sound reception and transmission equipment;
- Navigation lights and other navigation signs.

including data feedforward and data-connection failures. In addition, facilitate safe navigation in case of failures.

We consider the following Risk Control Option valid:

1. Formalize a requirement that obligates ROC-operators to use both RADAR and outside view camera footage to monitor all the view zones pictured in Figure 4-3;
2. Acknowledge the ROC as a separate “Steering position” from where the vessel can be operated, independent of the onboard wheelhouse, in a way that ES-TRIN Chapter 7 is applicable on the ROC steering position. Also the criteria for vessels with minimum crew, formalized as Standard S1 in Chapter 31 of ES-TRIN and where relevant, should be applicable for the steering position in the ROC;
3. Acknowledge the steering position in the ROC as “*designed for radar navigation by one person*” as defined in ES-TRIN and mentioned in both RPR and BPR in relation to RADAR-Navigation;
4. If the ROC monitoring and operation through controls of:
   - RADAR (monitoring and operation);
   - INLAND-AIS-equipment (monitoring);
   - VHF-radio communication equipment (monitoring and operation);
   - INLAND-ECDIS (monitoring);
   - Sound reception and transmission equipment (monitoring and operation);
   - Navigation lights and other navigation signs (monitoring and operation);

   cannot be compliant to ES-TRIN Chapter 7, a competent crewmember should be attending the wheelhouse on board being able to warn the ROC-operator in case of a failure and/or operate equipment through controls, when requested by the ROC-operator and without delay.

   An exception to ES-TRIN should be made for the requirement to receive VHF-communication through a loudspeaker. We acknowledge that in an ROC, is it much more convenient to use headphones when multiple Remote Operating Stations are active;
5. Formalized Changeover-procedures should provide for ending the remote operation if one or more of the required system components (equipment) fails to provide for adequate monitoring and/or operation through controls;
6. In case of reduced visibility, procedures should provide for mandatory consultation with the onboard Boatmaster regarding continuation of the remote operation;

7. As been observed in practice, if the ROC operator uses the shipboard VHF radio equipment to transmit messages, his messages cannot be heard by anyone in the wheelhouse. This has to be prevented in order to provide wheelhouse-operators and Boatmaster with similar levels of Situation Awareness, if required.

4.4.6.4 Opportunities for manning reduction

The potential for manning reduction depends on the complexity and duration of the tasks that must be performed by a crewmember in the wheelhouse during remote navigation.

4.4.7 Risk 6: Unsuccessful monitoring, identification and assessment of obstacles

4.4.7.1 Goal Based Task Analysis

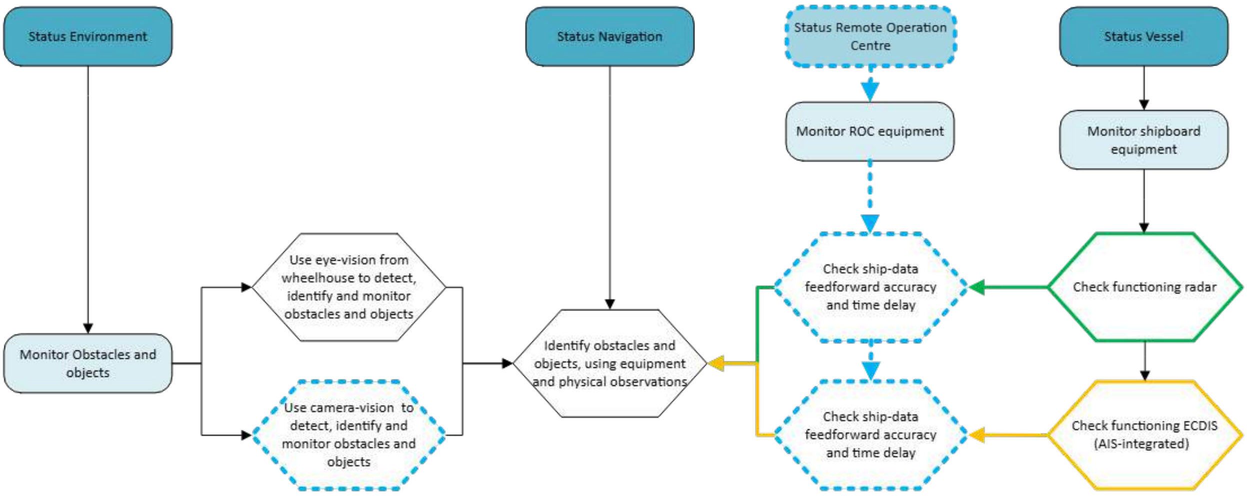

Figure 4-9 GBTA Monitoring, identification and assessment of obstacles and objects.

4.4.7.2 Risk Description

To avoid collisions with obstacles and objects, the environment needs to be permanently monitored and assessed. For successful achievement of the related goals and perform related tasks, several resources can provide for information to the ROC-operator regarding detection, identifying and assessment of other traffic:

- Outside view to the Tactical reaction zone and the Operational safety zone using cameras onboard the vessel (referring to Figure 4-3). Also lights and signs are being used to mark obstacles and objects in the environment;
- RADAR for monitoring in the Strategic detection zone, the Tactical reaction zone and the Operational safety zone;
- ECDIS, for displaying of known and charted obstacles and objects in the electronic navigation charts.

Scenario, Failure Modes, Risk Control Options and opportunities for manning reduction regarding (1) outside view using camera footage, (2) RADAR and (3) ECDIS are similar to those discussed under RISK 5: Unsuccessful monitoring, identification and assessment of traffic.

4.4.8 Risk 7 : unsuccessful monitoring of own vessel geographical location (position) and progression.

4.4.8.1 Goal Based Task Analysis

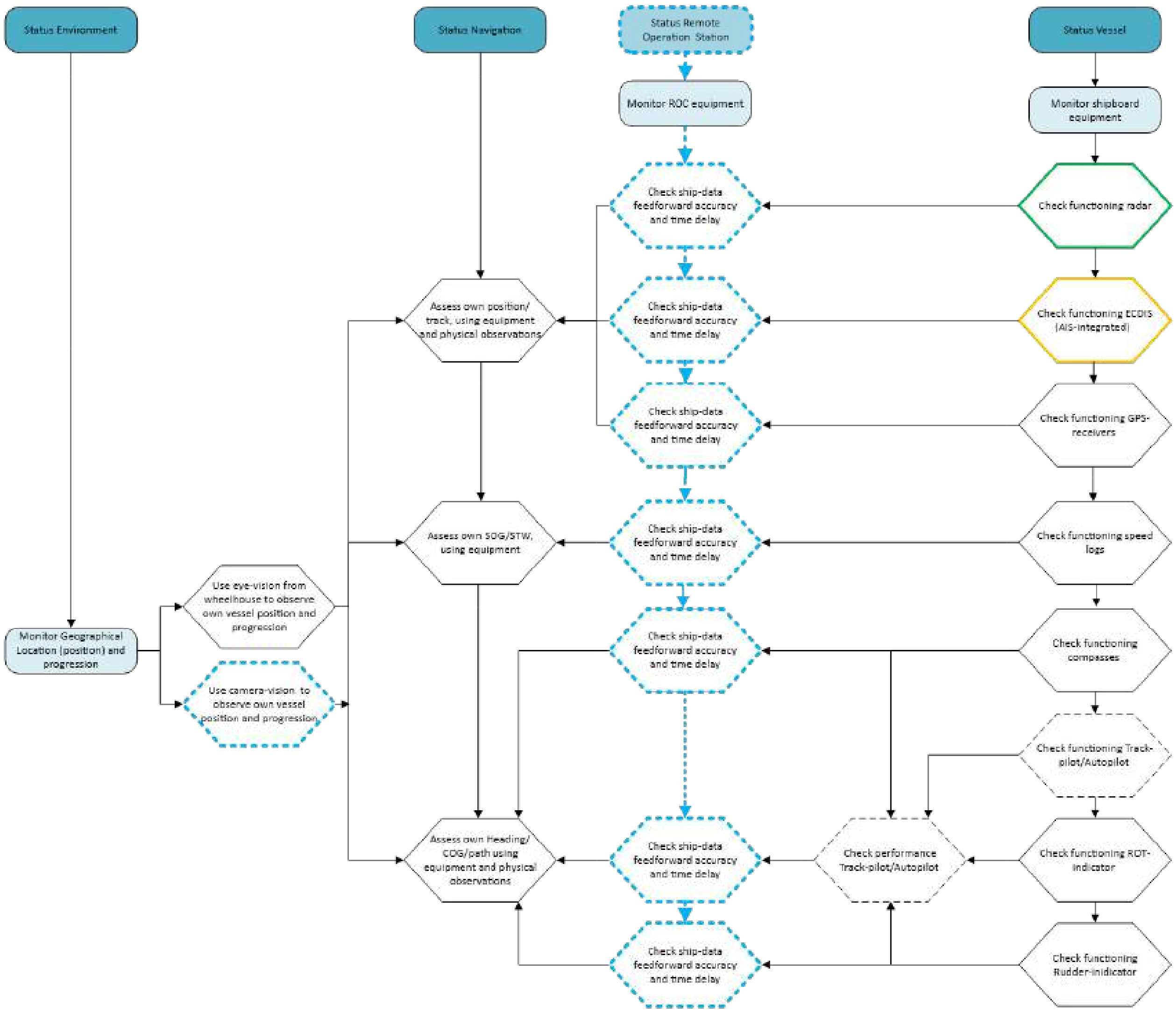

Figure 4-10 GBTA monitoring of own vessel geographical location (position) and progression.

4.4.8.2 Risk Description

Monitor and assess own vessel position and its progress along a route or track is also a key element in safe and efficient navigation. Just like monitoring of traffic, obstacles and objects, it requires sensors on board and equipment to display the sensor data accurate and without significant time delay to the operator in the ROC:

- Outside view using cameras onboard the vessel. Also markings along the fairways are used to monitor own vessel position;
- RADAR images, compared with ECDIS or paper charts, provides information regarding own vessel position;
- GPS-receivers provide for accurate position, course and speed data (course and speed over ground), with the GPS-position projected in the ECDIS;
- Compasses provide information about the heading and the Rate-of-Turn, using a mandatory Rate-of-turn indicator;
- Speed logs provide information about the speed through the water.

In addition, in recent years, Track Pilot-automation (TGAIN) is more and more added to the navigation equipment on board vessels. For the present risk, it means that the track-keeping functioning and accuracy of an activated TGAIN needs to be monitored as well, including track off-set alarms and equipment or sensor (GPS) alarms. For this matter, the track that is set (by the onboard Boatmaster during voyage planning) must be visualized in the ECDIS and the rudders must be monitored to assess TGAIN performance.

Failures and Risk Control options regarding outside view using camera footage, RADAR and ECDIS are similar to those discussed under RISK 5: Unsuccessful monitoring, identification and assessment of traffic.

Also the failure modes that are applicable for equipment assessed in present risk 7, are not significantly different than the failure modes described in RISK 5. Therefore, we pass on to the formulation of Risk Control Options without projecting the analysis and classification steps in separate tables in APPENDIX D.

4.4.8.3 Risk Control Options

Objectives: In the ROC, provide for equipment availability, operating ability and detectability of failures, including data feedforward and data-connection failures, of:

- GPS-receivers, including projecting own vessel position and Course over Ground in the ECDIS;
- Speed logs;
- Compasses;
- Rate-of-turn indicator;
- Route visualization in the ECDIS, in case of steering the vessel using TGAIN;
- TGAIN-performance, if applicable.

In addition, facilitate safe navigation in case of failures.

We consider the following Risk Control Option valid:

1. Acknowledge the ROC as a separate “Steering position” from where the vessel can be operated, independent of the onboard wheelhouse, in a way that ES-TRIN Chapter 7 is applicable on the ROC steering position.

   In addition, acknowledge the steering position in the ROC as “*designed for radar navigation by one person*” as defined in ES-TRIN and mentioned in both RPR and BPR in relation to RADAR-Navigation.

   In addition, acknowledge TGAIN performance monitoring, alarms and mode-selection indicators as a required monitoring systems in the ROC. TGAIN monitoring is then required to be in accordance with ES-TRIN Article 7.03;

2. If in the ROC monitoring and operation through controls of
   - INLAND-ECDIS (monitoring & operation);
   - GPS-receivers, including projecting own vessel position and Course over Ground in the ECDIS (monitoring);
   - Speed logs (monitoring);
   - Heading (monitoring);
   - Rate-of-turn indicator (monitoring);

   cannot be compliant to ES-TRIN Chapter 7, a crewmember should be attending the wheelhouse on board be able to warn the ROC-operator in case of a failure and/or operate equipment through controls, when requested by the ROC-operator and without delay;

3. If in the ROC monitoring of TGAIN-performance cannot be compliant to ES-TRIN Chapter 7 or the route used by the TGAIN is not visible in the ECDIS-screen in the ROC, TGAIN-navigation should be prevented during remote navigation operation;
4. Formalized Changeover-procedures should provide for ending the remote operation if one or more of the required system components (equipment) fails to provide for adequate monitoring and/or operation through controls.

4.4.8.4 Opportunities for manning reduction

The potential for manning reduction depends on the complexity and duration of the tasks that must be performed by a crewmember in the wheelhouse during remote navigation.

4.4.9 Risk 8: Unsuccessful monitoring and assessment of weather.

4.4.9.1 Goal Based Task Analysis

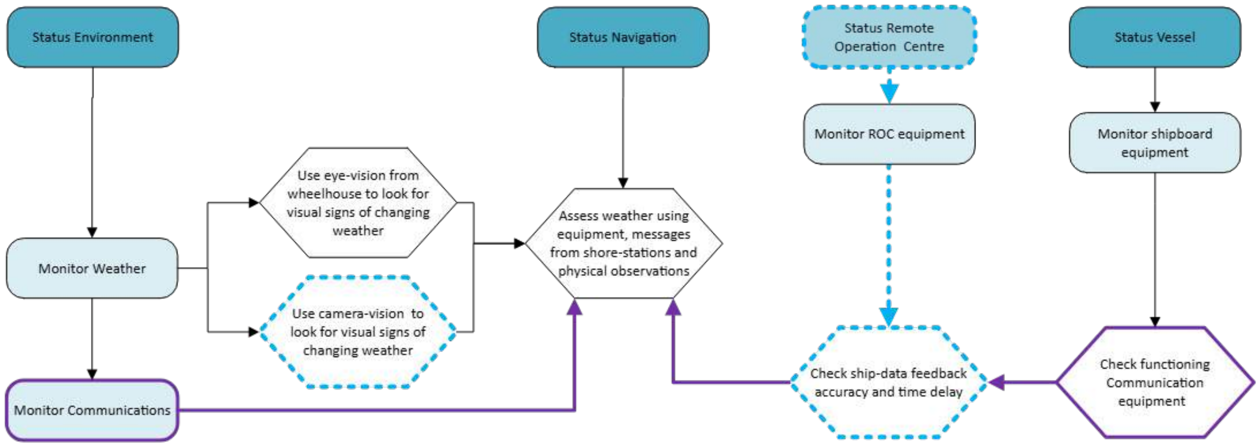

Figure 4-11 GBTA monitoring and assessment of weather.

4.4.9.2 Risk Description

Unexpected, rapidly worsening weather might induce risk to the achievement of safe and efficient navigation from a ROC. Weather monitoring is therefore essential. In the ROC the operator has the ability to monitor the weather through the outside view using cameras onboard the vessel. In addition, weather forecasts using communication equipment and internet services may provide for required information. Rain, hail or snow may also be detected as disturbances on the radar.

Failure modes that are applicable for equipment assessed in present RISK 8, are not significantly different than the failure modes described in RISK 5 (Traffic monitoring). Therefore, we pass on to the formulation of additional Risk Control Options without projecting the analysis and classification steps in separate tables in APPENDIX D.

4.4.9.3 Risk Control Options

Objectives: In the ROC, provide for equipment availability, operating ability and detectability of failures, including data feedforward and data-connection failures, of weather information provider services.

In addition, facilitate safe navigation in case of failures

We consider the following Risk Control Options valid:

1. Provide for information services in the ROC;
2. Formalized Changeover-procedures should provide for warning the ROC-operator if any crewmember onboard starts being aware of unexpected, rapidly worsening weather.

4.4.9.4 Opportunities for manning reduction

If the Risk Control Options are implemented, the presence of a Boatmaster in the wheelhouse is not required solely for weather monitoring during remote navigation. In the worst-case-scenario, any crewmember could attend the wheelhouse to warn the ROC-operator in case of worsening weather conditions.

4.4.10 Risk 9: Unsuccessful monitoring and assessment of Other Environmental Conditions

4.4.10.1 Goal Based Task Analysis

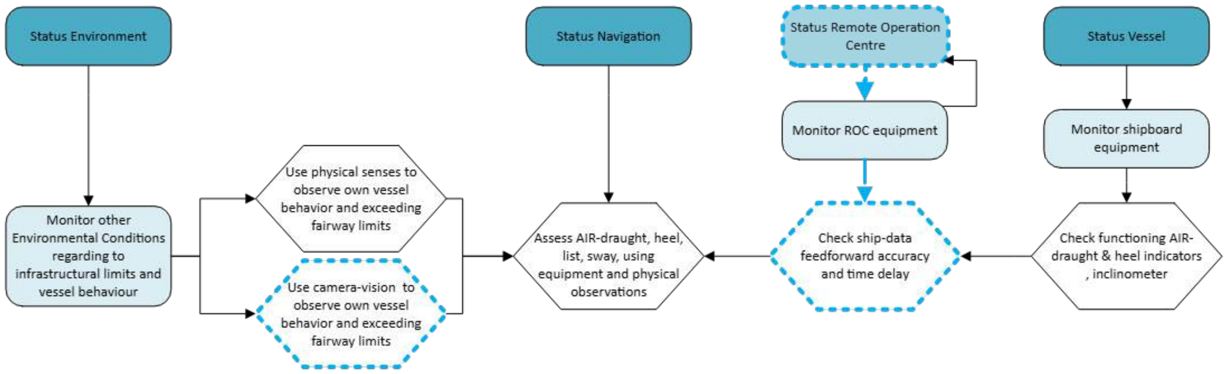

Figure 4-12 GBTA Unsuccessful monitoring and assessment of Other Environmental Conditions regarding to infrastructural limits and vessel behaviour.

4.4.10.2 Risk Description

Besides weather, traffic, obstacles, objects, and UKC, there are also other relevant navigational threats that endanger the vessel while on passage. For the purpose of this research we consider two major threats in one risk scenario 9-1, assessed in APPENDIX D, Table D-18 and Table D-19:

- Reduction or loss of stability due to heavy rolling of the vessel in severe swell conditions (lakes and other open waters). Also water ingress can be a cause to the reduction of stability.

  This threat is relevant because experienced wheelhouse-operators and Boatmasters can feel the vessels motions. A decreasing stability may therefore be sensed by the changes in the way the vessel rolls. The ROC-operator does not have the ability to sense the vessels motions;

- Wheelhouse and (radar)mast elevation related to bridge heights.

  It is a common event that masts and wheelhouse need to be lowered to allow for safe passage under bridges. In these situations the ROC-operator needs to have control over both the masts and wheelhouse lifting mechanisms. In addition, the ROC-operator needs accurate information about the elevation height of masts and wheelhouse related to the water level, before and after every change in elevation, as to be able to assess future bridge passages.

4.4.10.3 Risk Control Options

Objectives: Provide for accurate information, equipment availability, operating ability and detectability of failures, including data feedforward and data-connection failures, regarding:

- Wheelhouse and masts elevation heights above water level;
- Operation controls for lifting mechanisms of masts and wheelhouse.

In addition, facilitate safe navigation in case of failures and in cases of heavy rolling in open water.

We consider the following Risk Control Options valid:

1. Acknowledge the ROC as a separate “Steering position” from where the vessel can be operated, independent of the onboard wheelhouse, in a way that ES-TRIN Article 7.12 (Elevating wheelhouses) is applicable on the ROC steering position;
2. If the ROC monitoring and operation through controls of the elevating wheelhouse cannot be compliant to ES-TRIN Chapter 7, a crewmember should be attending the wheelhouse during bridge passages. This should also be the Risk Control Option in case of missing accurate information regarding the wheelhouse elevation height;

3. Formalized Changeover-procedures should provide for mandatory start of lowering masts and wheelhouse outside vessel stopping distance of a bridge;
4. Formalized Changeover-procedures should provide for mandatory consultation with the onboard Boatmaster regarding continuation of the remote operation in case of possible heavy rolling of the vessel outside the operational (stability) limits of the vessel.

4.4.10.4 Opportunities for manning reduction

The potential for manning reduction depends on the complexity and duration of the tasks that must be performed by a crewmember in the wheelhouse during remote navigation.

4.4.11 Risk 10: Unsuccessful monitoring, assessment and controls of steering systems and propulsion systems

4.4.11.1 Goal Based Task Analysis

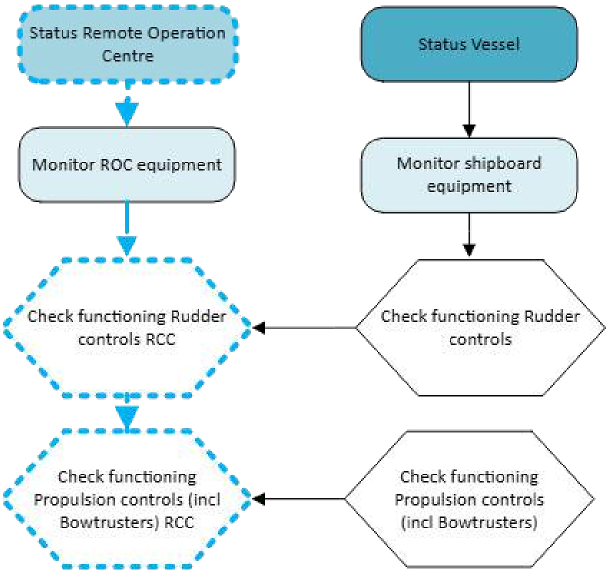

Figure 4-13 GBTA Unsuccessful monitoring, assessment and controls of steering systems and propulsion systems.

4.4.11.2 Risk Description

To navigate a vessel, monitoring, control and emergency response to malfunction of steering systems and propulsion systems should be available at the steering position. The importance of this availability can be traced back to extensive regulation regarding this specific systems.

ES-TRIN provides regulation stretching from monitoring, (emergency) controls and Human Factor Ergonomics in the wheelhouse. Therefore, an unattended wheelhouse during remote navigation operation would by itself comply with the regulation, except that the operator who is designated to perform the associated tasks is missing.

We consider a fully performed risk analysis and reporting unnecessary. For monitoring, adequate control and emergency response related to steering systems and propulsion systems the relevance of operator centred system design is already addressed in ES-TRIN. Risk Control Options therefore primarily focus on the ability of the ROC-operator to perform associated tasks from the steering position in the ROC in compliance with ES-TRIN rules.

Regarding *adequate* controls, we consider that the manoeuvring characteristics of the vessel are the result of certain design criteria for the vessel. It is therefore relevant to acknowledge that the vessel must maintain its manoeuvring characteristics in case of remote navigation operation and through controls in the ROC steering position.

4.4.11.3 Risk Control Options

Objectives: In the ROC, provide for monitoring, adequate controls and emergency response related to steering systems and propulsion systems, including data feedforward and data-connection failures between vessel and ROC. In addition, facilitate safe navigation in case of failures.

We consider the following Risk Control Options valid

1. Acknowledge the ROC as a separate “Steering position” from where the vessel can be operated independent of the onboard wheelhouse.

2. In addition, acknowledge the steering position in the ROC as "*designed for radar navigation by one person*" as defined in ES-TRIN, in a way that ES-TRIN is applicable on the ROC steering position regarding monitoring, controls and emergency response related to steering systems and propulsion systems. Also the criteria for vessels with minimum crew, formalized as Standard S1 in Chapter 31 of ES-TRIN and regarding controls and alarms, should be applicable for the steering position in the ROC.
3. If the ROC steering position cannot be compliant to ES-TRIN, especially regarding applicable regulations in Chapter 6 and Chapter 7, a crewmember should be attending the wheelhouse on board and be able to warn the ROC-operator in case of a failure and/or operate steering systems and propulsion systems through controls, when requested by the ROC-operator and without delay.
4. Formalized Changeover-procedures should provide for ending the remote operation if one or more of the required system components (equipment) fails to provide for adequate monitoring and/or operation of steering systems and propulsion systems through controls.
5. Provide for verification and certification of the vessels manoeuvring characteristics while commenced in remote navigation operation from a ROC. The manoeuvring characteristics as formulated in ES-TRIN Chapter 5 should be validated during a *Navigation Test* in compliance with ES-TRIN Chapter 5. As a minimum criterium, the results of the Navigation Test should be equal to the results obtained from the Navigation Test during navigation from the onboard wheelhouse.

4.4.11.4 Opportunities for manning reduction

If the ROC-operator has the ability to monitor, control and emergency response to malfunctions in accordance with the applicable ES-TRIN rules and regulation, there would be no necessity for a crewmember to attend the onboard wheelhouse.

4.4.12 Risk 11: Unsuccessful monitoring of Fire Detection Systems

4.4.12.1 Goal Based Task Analysis

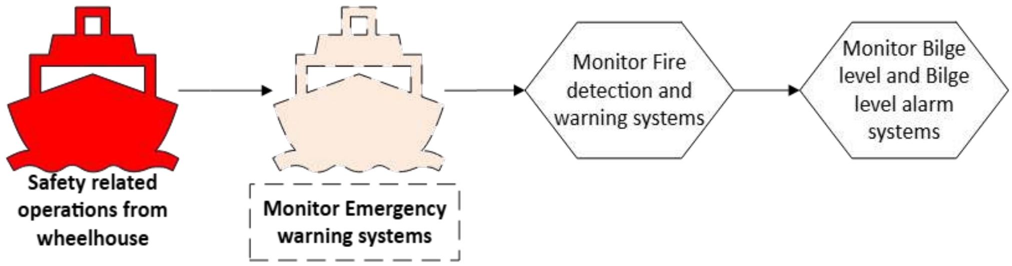

Figure 4-14 GBTA Monitoring Emergency warning systems.

4.4.12.2 Risk Description

ES-TRIN provides for two possible emergency scenarios that require a monitoring and alarm system. The first scenario is fire, which can be life-threatening for the (sleeping) crew onboard. Flooding of the main engine room(s) is also a dangerous emergency situation.

As can be found in ES-TRIN, fire detection systems and bilge alarms in the main engine room(s) onboard should be (also) observable in the Wheelhouse. Without any further assessment, we consider relevant to provide this observability also to the ROC-operator when the wheelhouse is unattended during remote navigation operation. Both for the safety of the crew as well as the necessity to be Situational Awareness of emergency scenarios.

4.4.12.3 Risk Control Options

Objective: Provide for Situation Awareness regarding fire and flooding/excessive leakages in main engine room(s) onboard.

We consider the following Risk Control Options valid:

1. Acknowledge the ROC as a separate “Steering position” from where the vessel can be operated independent of the onboard wheelhouse. In this way, the obligation to receive fire-alarms as addressed in Chapter 13 of ES-TRIN are also applicable for ROCs;
2. In addition, also the criteria for vessels with minimum crew, formalized as Standard S1 in Chapter 31 of ES-TRIN and regarding bilge alarms in main engine room(s), should be applicable for the steering position in the ROC.

4.4.12.4 Opportunities for manning reduction

Since there is no dedicated crewmember assigned with only this task, means that determination of opportunities for manning reduction is not applicable for this specific task.

5 RESULTS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Data-connection between ROC and vessel

A major conclusion of this research concerns the possible failure of all data-connections between ROC and vessel, leaving the ship with an unattended wheelhouse in a status of being *not under command,* possibly with some speed, with propulsion engaged, with some Rate-of-Turn and with some rudder angle present.

MARIN considers this as a major risk that, in case of an unattended wheelhouse, can only be mitigated with the vessel being capable of automatically switching to an autonomous mode upon loss of data-connection. In this fallback mode, the vessel must be able to maintain a safe position or track for at least three minutes—enough time for the onboard Boatmaster to reach the wheelhouse, regain situational awareness, and take control. This requires that the loss of connection immediately triggers an alert to the Boatmaster and a second crewmember, who can assist in restoring command.

In addition, MARIN does not consider Track Pilot-automation (TGAIN) sufficient for this purpose, as it currently lacks the capability to detect and avoid collisions with other vessels, infrastructure (e.g., bridges, locks), or other objects and obstacles.

Nevertheless, MARIN considers a highly reliable and robust data-connection between ROC and vessel an important precondition for safe and efficient implementation and operation of remote navigation. To serve this precondition MARIN considers the following Risk Control Options to be valid:

1. Every provider of remote navigation equipment, which includes an ROC, shall do sufficient research of data-connection availability in all fairways where vessels will sail under remote navigation operation. The objective of this Risk Control Option is to gain Situation Awareness regarding local network-coverage and possible disturbances due to obstacles or other causes.
2. Provide for sufficient redundant data-channels and data-connection hardware components;

   A convenient level of redundancy has been observed during the research, providing for three independent data-channels, with two of them available as a minimum. Furthermore, we suggest a convenient level of redundancy should be effectuated by:

   a. Capability of two channels together to provide for complete, robust and reliable data transfer between vessel and ROC;

   b. Capability of one channel, temporally and only in unexpected occasions, to make available in the ROC of the most critical equipment necessary to control the vessel and keep her at a safe position or track: (1) GPS position coordinates (2) Rate-of-turn indicator (3) Radar (4) Speed-indicator (5) propulsion controls and (6) steering controls.

Scenarios in which only one data-channel is available, should trigger the decision to terminate the remote navigation operation.

5.2 Outside view from the wheelhouse

MARIN considers that an adequate outside view from the wheelhouse shall be facilitated in the ROC. Such an adequate view could be obtained with a high-quality camera-system that is capable of maintaining a permanent view on the Tactical reaction zone and the Operational safety zone [Ref 3.] (Figure 5-1) in a *preset mode*. The number of cameras will be dependent on the quality and placement of the cameras and in respect to the vessels seize. In addition, the camera system should provide for:

- Overlapping fields of view to eliminate blind spots;
- Zoom and focus capabilities on each camera, allowing temporary use as “binoculars” to focus on specific objects. For applications during transit, it is recommended to employ separate dedicated zoom cameras;
- An easy and quick method to restore the camera positions to the *preset mode* without any focus and zoom on a specific object.

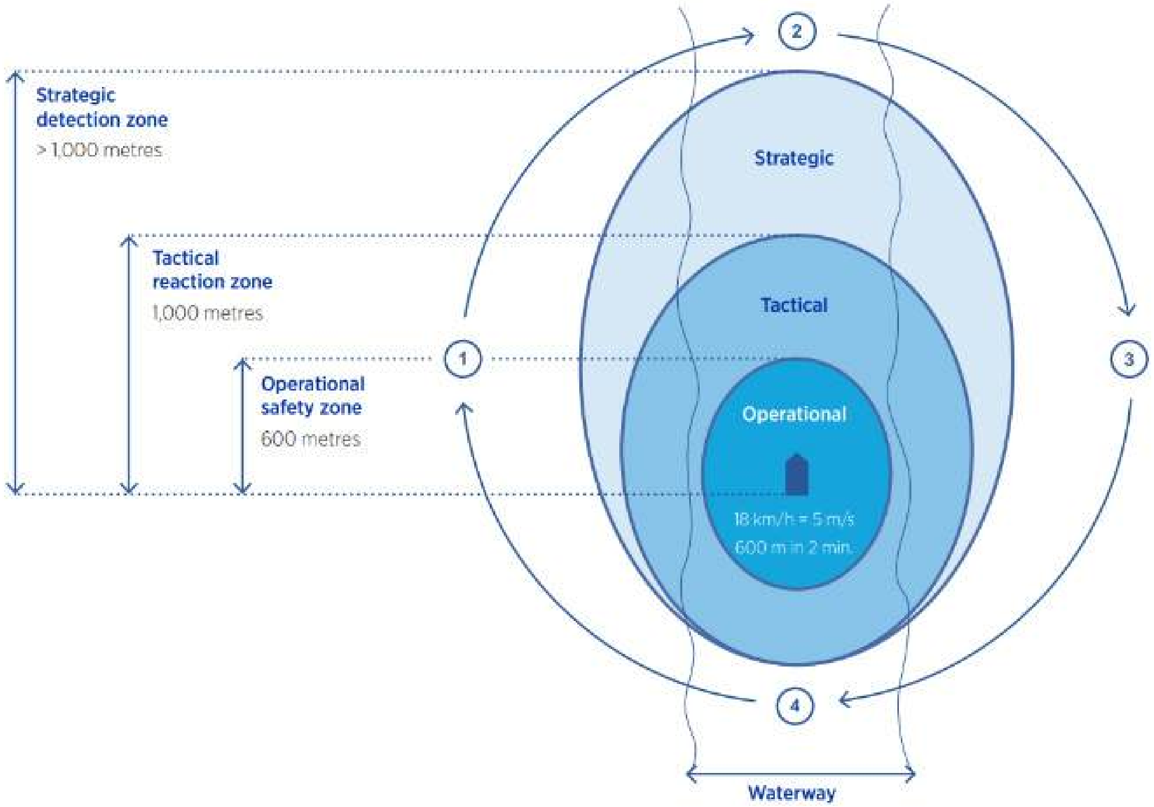

Figure 5-1 Operational safety zone, tactical reaction zone and strategic detection zone around the vessel, according to CESNI/EDINNA [Ref 3.].

5.3 Technical Risk Control Options

The assessment of risks in this study has shown that safe vessel navigation—especially under remote control—requires the ability to monitor, assess, and control a wide range of system components from the steering position. This includes the ability to immediate and effective responses to equipment malfunctions and emergency situations.

MARIN found that the importance of this necessity can be traced back to excessive regulation regarding this specific systems. In particular, ES-TRIN provides for regulation stretching from monitoring, (emergency) controls and, to a certain level, Human Factor Ergonomics in the wheelhouse. For monitoring, adequate control and emergency response the relevance of operator centred system design is already addressed in ES-TRIN.

Unfortunately, in case of an unattended wheelhouse during remote navigation operation, the operator who is designated to perform the associated tasks, is operating from a location ashore. Risk Control Options therefore primarily focus on the ability of the ROC-operator to perform associated tasks from the steering position in the ROC in compliance with ES-TRIN rules:

1. The ROC shall be acknowledged as a separate steering position of the vessel. As such, this steering position will conform to ES-TRIN requirements which mainly refers to Chapters 6 and 7 of ES-TRIN. Also the criteria for vessels with minimum crew, formalized as Standard S1 in Chapter 31 of ES-TRIN and where relevant, should be applicable for the steering position in the ROC.

   An exception to ES-TRIN should be made for the requirement to receive VHF-communication through a loudspeaker. MARIN acknowledges that in a ROC, is it much more convenient to use headphones when multiple Remote Operating Stations are active.

   To summarize; this Risk Control Option concerns navigation equipment, communication equipment, sound reception equipment, lifting of masts and wheelhouse, fire alarm, bilge alarms, steering systems, propulsion systems and cameras providing for the outside view from the onboard wheelhouse.

2. In addition, acknowledge the steering position in the ROC as "*designed for radar navigation by one person*" as defined in ES-TRIN and mentioned in both RPR and BPR in relation to RADAR-Navigation.

3. In addition, acknowledge monitoring, alarms and mode-selection indicators of the following equipment as required monitoring systems in the ROC. The monitoring of this equipment is then required to be in accordance with ES-TRIN Article 7.03:
   - RADAR (monitoring and operation);
   - INLAND-AIS-equipment (monitoring);
   - VHF-radio communication equipment (monitoring and operation);
   - INLAND-ECDIS (monitoring and operation);
   - Sound reception and transmission equipment (monitoring and operation);
   - Navigation lights and other navigation signs (monitoring and operation);
   - Echosounders;
   - GPS-receivers, including projecting own vessel position and Course over Ground in the ECDIS-screen (monitoring);
   - Speed logs (monitoring);
   - Heading (monitoring);
   - Rate-of-turn indicator (monitoring);
   - TGAIN performance (monitoring and operation) and visualization of the selected track in the ECDIS-screen;
   - Wheelhouse elevation (monitoring and control).

4. In addition, every Steering Position in an ROC must be individually certified in compliance with ES-TRIN as a steering position for each individual vessel it supports as being capable to operate. Similarly, each vessel must be certified to ensure that remote operating systems do not interfere with the correct functioning of onboard systems;

5. If the ROC is unable to fully monitor and control all the aforementioned required systems—such as mast and wheelhouse elevation, fire and bilge alarms, steering and propulsion systems, and external camera views—in accordance with ES-TRIN or the Risk Control Options outlined in this research, then a competent crewmember must be present in the onboard wheelhouse. This crewmember must be capable of:
   a. Detecting and reporting any failures to the ROC operator;
   b. Operating the relevant equipment directly when needed; or
   c. Providing the ROC operator with accurate and timely information upon request.

6. In practice, it has been observed that when the ROC operator transmits messages using the ship's VHF radio system, these messages may not be audible in the onboard wheelhouse. This issue should be addressed to ensure that both the wheelhouse operator and the Boatmaster maintain equivalent levels of situational awareness as the ROC-operator, particularly in safety-critical situations;
7. Install an emergency button in the wheelhouse of the vessel, instantly terminating the remote navigation operation upon activation and take over the control to the onboard wheelhouse;
8. Do not enable the ROC-operator to instantly terminate the remote navigation operation in emergency situations, unless the vessel is automatically changing to an autonomous mode upon activation as described before in section 5.1. In case the vessel is not capable of such an autonomous mode, the ROC-operator needs to be trained to maintain remote navigation until a Wheelhouse-operator activates the emergency button;
9. Design and install a facility that gives the ROC-operator a quick and easy to activate ability to alert the Boatmaster and request for the Boatmasters attendance to the wheelhouse;
10. Provide for verification and certification of the vessels manoeuvring characteristics while commenced in remote navigation operation from a ROC. The manoeuvring characteristics as formulated in ES-TRIN Chapter 5 should be validated during a *Navigation Test* in compliance with ES-TRIN Chapter 5. As a minimum criterium, the results of the Navigation Test should be equal to the results obtained from the Navigation Test during navigation from the onboard wheelhouse.

5.4 Operational Risk Control Options

In addition to the technical Risk Control Options addressed in the previous section, MARIN found that the cooperation between ROC-operator, onboard Boatmaster and Wheelhouse-operator, requires formalized operational procedures to facilitate the remote navigation operation:

Regarding to Voyage Planning

1. Establish a mandatory procedure that clearly defines the tasks involved and specifies the information that must be provided to the ROC operator.
2. Ensure both the Boatmaster and ROC operator are given sufficient time and opportunity to perform their tasks.
3. Include a validation step in the procedure, requiring the onboard Boatmaster to review and, if necessary, correct the initial voyage plan before departure.
4. Implement a formalized mandatory instruction to the ROC-operator, addressing the obligation to immediately inform and consult the onboard Boatmaster in case of any necessary update of the Voyage Plan.
5. Implement a formalized mandatory procedure to facilitate timely, adequate and accurate communication of the Voyage Plan to the ROC-operator, also addressing the obligation to immediately inform the ROC-operator in case of any updates of the Voyage Plan.

   The purpose of a formalized mandatory procedure is to assure that any crucial part of the Voyage Plan is communicated with the ROC-operator. As a starting point for any design of such a procedure, we refer to the IMO recommendations regarding *master-pilot information exchange*[9].

Regarding Changeover between wheelhouse operation and remote operation

6. Implement a formalized, mandatory *changeover-procedure*, contenting as a minimum:
   - A mandate to the onboard Boatmaster *to decide on* commencing remote navigation from ROC;
   - A mandate to ROC-operator, Boatmaster or competent Wheelhouse operator *to decide on* ending remote navigation from ROC;
   - Checking functionality, accuracy, robustness and reliability of data-connection between vessel and ROC;
   - Checking functionality, accuracy, robustness and reliability of all navigation equipment, communication equipment and monitoring equipment that serve the remote operation in the ROC before commencing changeover. Also the shipboard equipment should be checked regarding functionality. Readings in ROC and Wheelhouse should be compared and assessed on accuracy and time delay. Any deficiencies should trigger the decision to abort the changeover procedure or terminate remote navigation and operation;
   - Checking functionality of all controls and machinery feedback regarding navigation and operation of the vessel. Any deficiencies should trigger the decision to terminate remote navigation and operation;
   - Operation of the changeover equipment, including a sufficient manual;
   - Environmental conditions that allow for safe changeover procedure, as to cope with the temporally distraction from navigation tasks. We suggest as a minimum:
     - Adequate stretch of fairway with no bends, bridges or lock;
     - Adequate stretch of fairway with no other traffic or inconvenient floating obstacles;

[9] Statutory Documents - IMO Publications and Documents - Resolutions - Assembly - IMO Resolution A.960(23) – Recommendations on Training and Certification and on Operational Procedures for Maritime Pilots other than Deep-Sea Pilots - (Adopted on 5 December 2003) - Annex 2 - Recommendation on Operational Procedures for Maritime Pilots other than Deep-Sea Pilots - 5 Master - pilot information exchange:

        - Visibility over 1000 metres;

        Any deficiencies should trigger the decision to abort the changeover procedure;

    - Operational conditions that allow for safe changeover procedures, as to cope with the temporally distraction from navigation tasks. We suggest as a minimum:
        - Main propulsion settings to zero;
        - Rate-of-Turn or rudder settings close to zero degrees per minute and remaining during the changeover. This means that, when applicable, a TGAIN should be disengaged as well;
        - Extra lookout present in either wheelhouse or ROC;
    - provide for ending the remote operation if one or more of the required system components (equipment) fails to provide for adequate monitoring and/or operation through controls;
    - In case of reduced visibility, provide for mandatory consultation with the onboard Boatmaster regarding continuation of the remote operation, in case of reduced visibility (<1000 metre);
    - provide for alerting the ROC-operator if any crewmember onboard starts being aware of unexpected, rapidly worsening weather.

7. Design and implement changeover equipment in a way that, under normal conditions, changeover cannot be performed unexpectedly, for instance by accident. This means that changeover requires at least handlings in the ROC and in the wheelhouse, in a way that requires coordination between Wheelhouse-operator and Remote Control-Operator;
8. Facilitate direct and reliable communication between Wheelhouse-operator and ROC-operator, without terminating the possibility to receive and respond to VHF communication on mandatory listening channels and to internal communication between crewmembers on board;
9. Facilitate adequate training for involved Wheelhouse-operators and ROC-operators.

5.5 Opportunities for manning reduction

MARIN identified opportunities for manning reduction depending on the tasks to be performed when a crewmember is required in the wheelhouse, in terms of task complexity and duration.

At present, however, safe remote navigation on Dutch inland waters is not feasible without a competent wheelhouse operator, unless the vessel is capable of automatically switching to an autonomous mode in the event of a data-connection failure. In such a scenario, the vessel could become Not Under Command, potentially while still moving if all data-connections between ROC and vessel fail. It means that the Wheelhouse-operator needs to be competent to

1. maintain Situation Awareness at all times; and
2. navigate the vessel safely, at least for the time required for a competent Boatmaster to reach the wheelhouse and take over.

The remaining question is whether a crewmember is competent in performing the required tasks of a Wheelhouse-operator. As far as MARIN has found during research, criteria for navigating inland vessels should consist of:

1. knowledge and education; and
2. experience in serving as sailor or mate.

To enable on board crew reduction by replacing the Boatmaster in the wheelhouse during remote navigation with a Wheelhouse-operator, a careful investigation should take place on the formal level of knowledge and education as well as the on-board experience in navigating the vessel prior to performing the role of Wheelhouse operator.

We therefore recommend to initiate further research as to determine if and what additional qualifications and training are needed for crewmembers replacing the Boatmaster during remote navigation. By those means ensuring that they are able to navigate the vessel safely during the short interval before the Boatmaster has returned to the wheelhouse and has been able to gain situational awareness when communication with the ROC is lost.

5.6 Remotely operated vessel with full on board crew and attended wheelhouse

As can be extracted from previous paragraphs, MARIN considers remote operation of inland vessels safe when the on board wheelhouse is attended by a certified Boatmaster, since a Boatmaster must be recognized as being competent to:

- Maintain Situation Awareness;
- Navigate the vessel safely in scenario's with failing equipment and/or data-connections;
- Operate and monitor on board equipment during remote operation, without delay;
- Detecting and reporting any failures to the ROC operator;
- Providing the ROC operator with accurate and timely information upon request.

A Boatmaster attending the wheelhouse whether the vessel is remotely operated or not, essentially means that the vessel is fully manned according to the present regulations. Remote operation with full on-board crew can therefore be considered safe, as long as the previously described Technical (Section 5.3) and Operational (Section 5.4) Risk Control Options have been implemented and the Boatmaster attends the wheelhouse.

Wageningen, November 2025
MARITIME RESEARCH INSTITUTE NETHERLANDS
Bescherming persoonlijke levenssfeer

Dr. ir. C. Veldhuis
Manager Performance at Sea

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ABBREVIATIONS

Abbreviation	Definition
AIS	Automatic Identification System
BPR	Binnenvaart Politie Reglement
CCR	Central Commission for the Navigation of the Rhine
ECDIS	Electronic Chart Display
ES-TRIN	European Standard on Technical Requirements for Inland Navigation Vessels
GBTA	Goal based task analysis
IMO	International Maritime Organisation
RCO	Risk Control Options
RO	Remote Operator
ROC	Remote operation centre
RPR	Rijnvaart Politie Reglement
SA	Situational awareness
TGAIN	Track Guidance Assistant for Inland Navigation
VHF	Very High Frequency (radio communication signal)

APPENDICES

APPENDIX A THEORETICAL FRAMEWORK

Risk Management methodology

Within MARIN toolbox research a selection was made of a proper risk management methodology that fits both international accepted methodologies in the maritime domain and provide for risk assessment with focus on system goal achievement and human task performance. We concluded that the Formal Safety Assessment (FSA) methodology adopted by the International Maritime Organization (IMO) fits best with our criteria. The FSA methodology, formalized in MSC-MEPC.2-Circ. 12-Rev.2., is described in Figure A-2 and Table A-1. As already mentioned in the introduction, a Cost-Benefit Assessment (step 4) is outside scope of the present research.

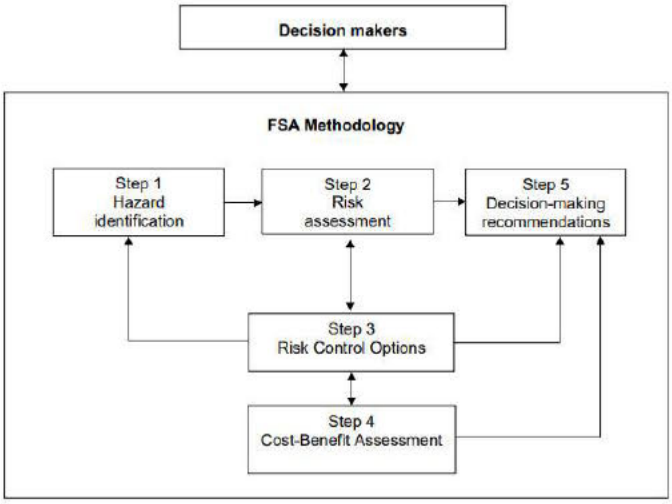

Figure A-2 Flow chart of the FSA methodology.

Table A-1 Formal Safety Assessment methodology.

Formal Safety Assessment (FSA)	
Steps	Description
	The FSA is specifically initiated to address Maritime Safety.
(0)	FSA Preparation: • Problem definition • Setting boundaries (scope) • Develop a generic model of the system under assessment
1	Identification of Hazards concerning selected problem definition; (1) Identify a list of hazards and their associated scenarios and (2) execute an assessment of accident scenarios (prioritized by risk level)
2	Risk Analysis, meaning a detailed investigation of the causes and initiating events and consequences, in order to: (1) Identify the high-risk areas which need to be addressed, and (2) Identify and evaluate the factors which influence the level of risk.
3	Risk Control Options; (1) Identify potential Risk Control Measurements (RCM). RCMs can either preventive on the initiation of accidents or reactive by reducing the severity of effects; (2) Evaluate the effectiveness of the RCMs in reducing risk by re-evaluating step 2, and (3) Grouping RCMs into practical (regulatory) options.
4	Cost-Benefit Assessment[10] (1) Estimate and compare the cost-effectiveness of RCMs as being the cost per unit risk reduction, and (2) Rank RCMs based on the Cost-Benefit Assessment
5	Recommendations for decision-making, meaning recommendations that are based on the assessment and the identification of RCMs that keep risks as low as reasonably practicable. The FSA process should be reported and stored in a prescribed manner.

[10] Out of scope of the present research

Hierarchical Goal-Based Task Analysis
The perception of Risk being defined as unsuccessful goal achievement caused by unsuccessful human task performance, urged us to focus on two more important topics in order to fulfil the research objectives.

First of all we had to find a way to describe at least the shipboard operations in terms of interrelated goals, subgoals and accompanying tasks and subtasks. The main objective of this part of the research was to facilitate in the assessment of probability and severity of unsuccessful goal and subgoal achievement as a result of single or multiple task performance failures. In this case we developed a Hierarchical Goal-Based Task Analysis methodology.

MARIN socio-technical model
Secondly, as we concluded that (Human) Task Performance is highly reliable on the presence and availability of *resources*, we needed to develop a system model that gives us the opportunity to assess Human Task Performance Reliability based on the probability and severity of both *functional* as well as *interaction failures* of relevant resources. Strongly founded on existing models, we succeeded in the development of such a model.

A simplified version of the MARIN socio-technical model is shown in Figure A-3.

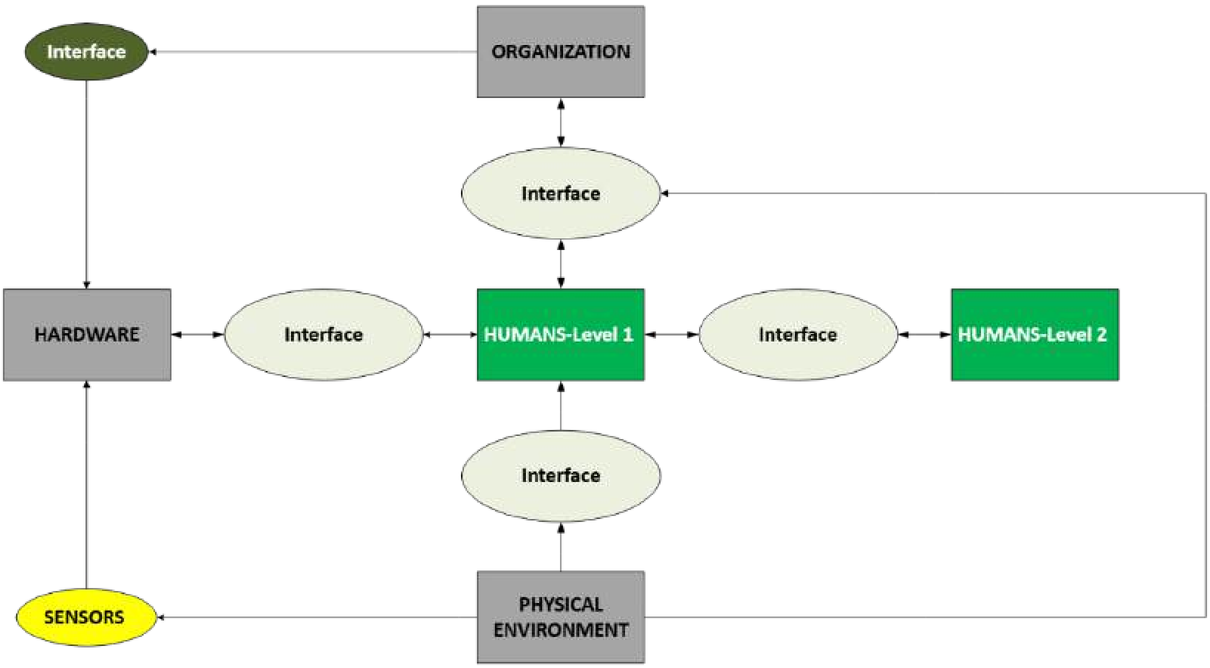

Figure A-3 MARIN socio-technical model developed for research in the maritime domain

The MARIN socio-technical model categorizes (Human) Task Performance resources based on their origin in the maritime system (Hardware, Environment, Organization, Humans) (Figure A-4).

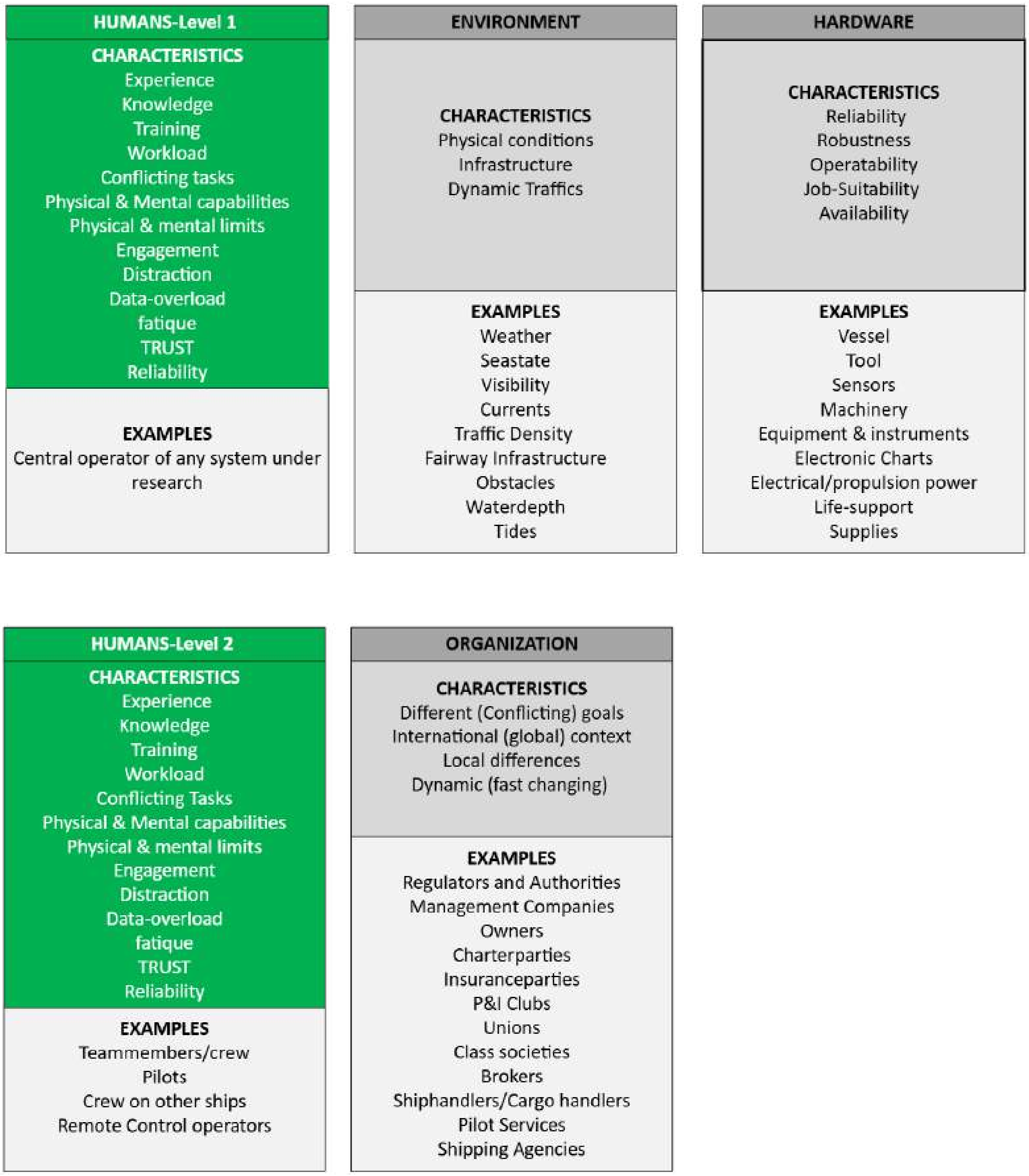

Figure A-4 System component categories, their characteristics and examples within the maritime domain

The model also describes the interfaces providing for resource interaction. These interfaces are described and depicted below in Figure A-6 to Figure A-12. As can be seen, every category of interface is pictured with one or more coloured ovals. These colours are corresponding with the colours in the integrated Natural Decision Model (NDM) showing that a specific interface-category is beneficial to one or more of the five different steps in the integrated NDM-process. The NDM serves as a model to describe the cognitive process of human decision making (Figure A-5).

Figure A-5 Integrated Natural Decision Making model, extracted and adapted from [Ref 4.][Ref 5.][Ref 6.].

Figure A-6 Interaction between Humans through Communication

Figure A-7 Interaction between Hardware and Human through Human-Machine-Interface (HMI)

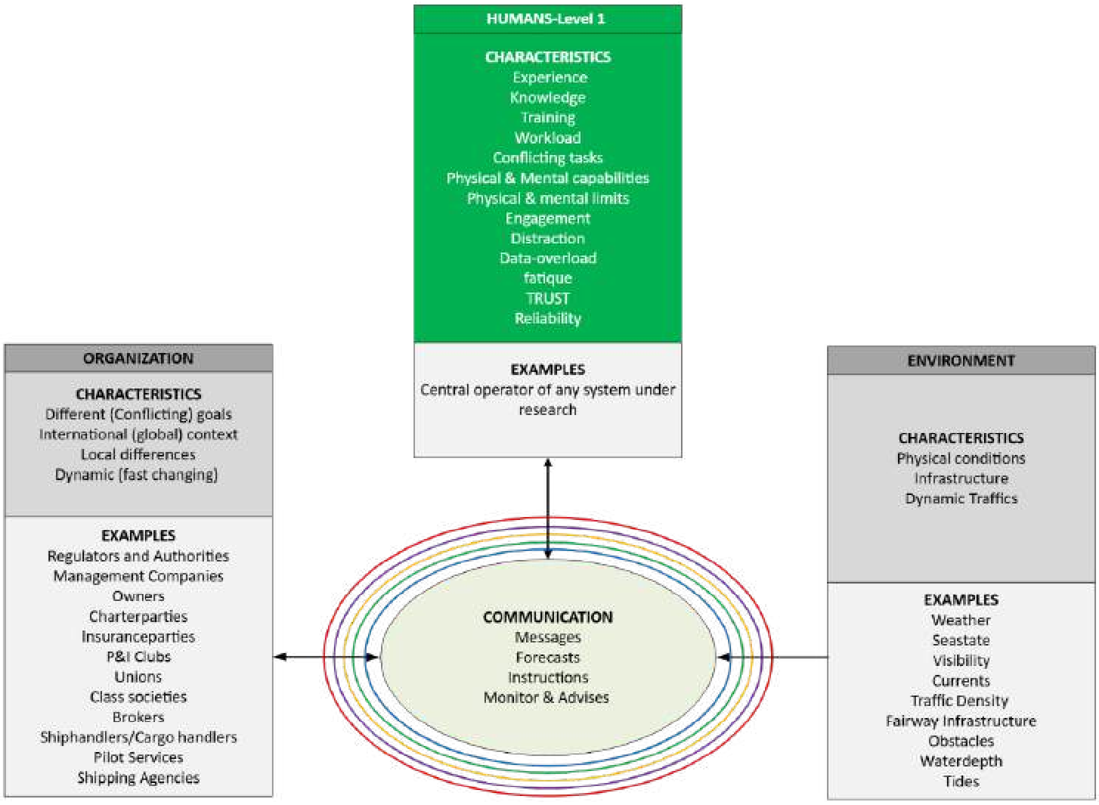

Figure A-8 *Interaction between Organization and Human through Communication, including information from the Physical Environment*

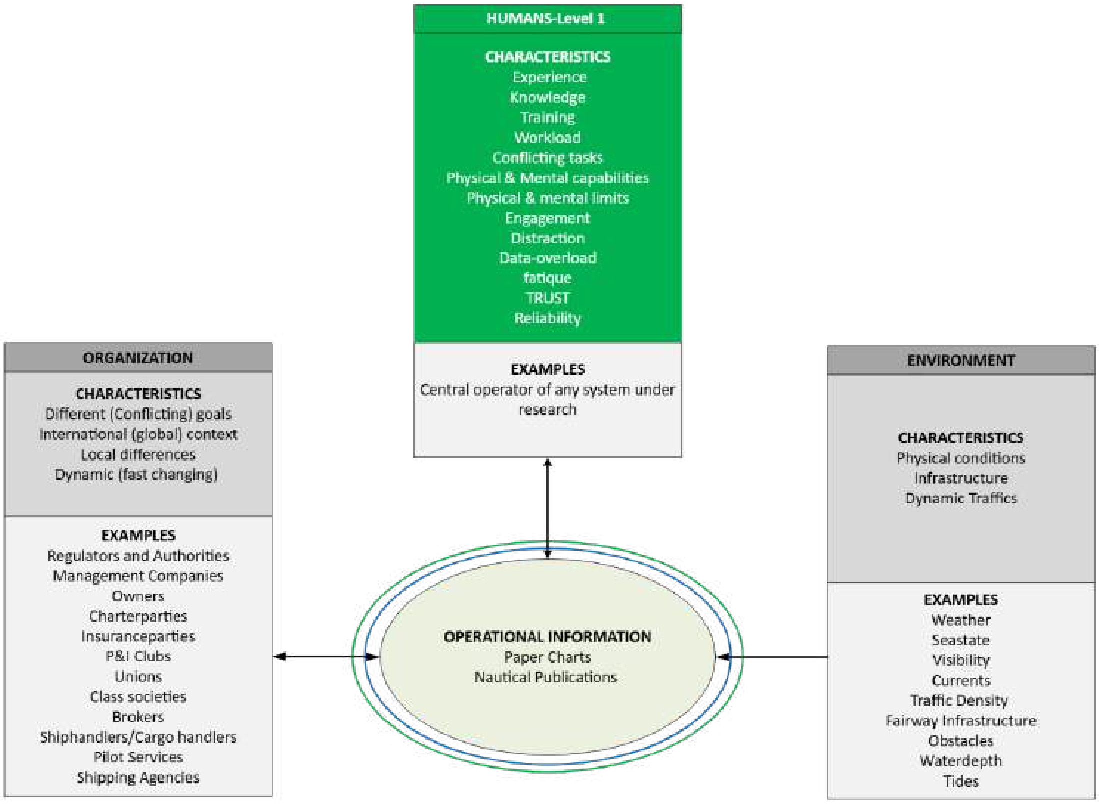

Figure A-9 *Interaction between Organization and Human through Operational Information, including information from the Physical Environment*

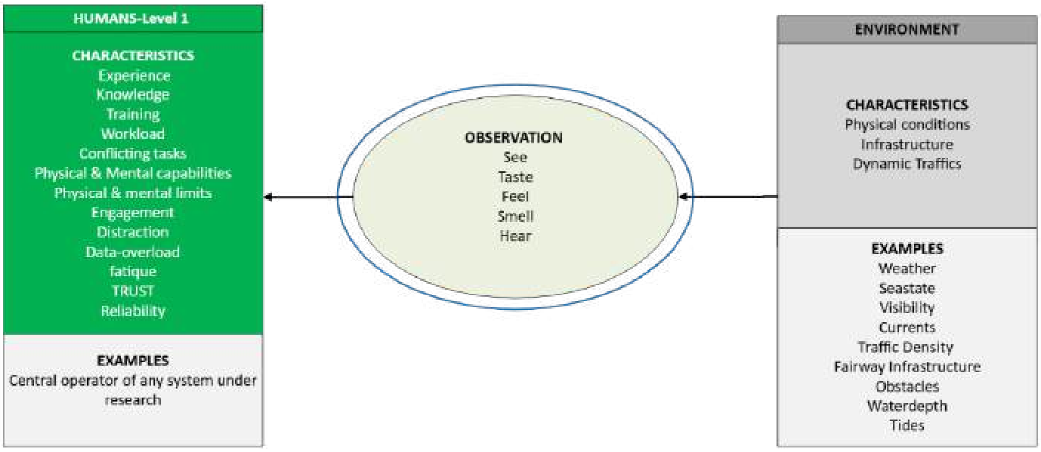

Figure A-10 Interaction between Environment and Human, through observation

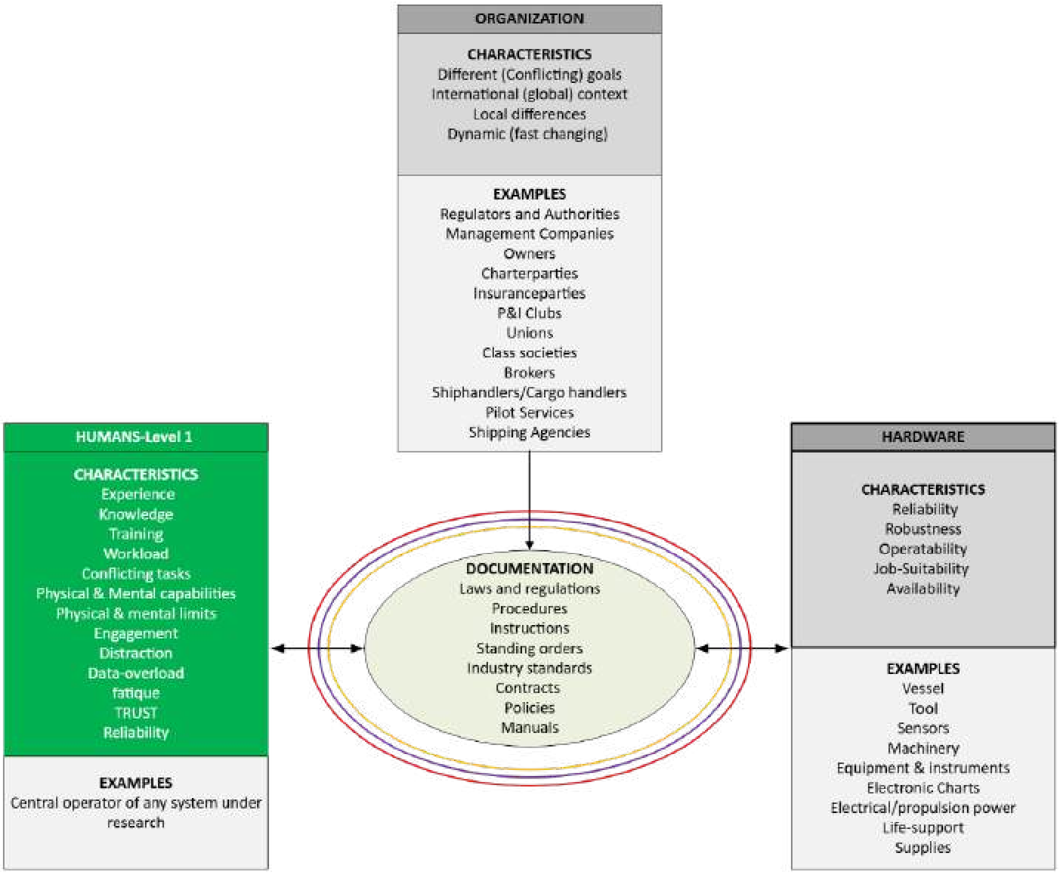

Figure A-11 Interaction between Organization and Hardware and between Organization and Human, through Documentation

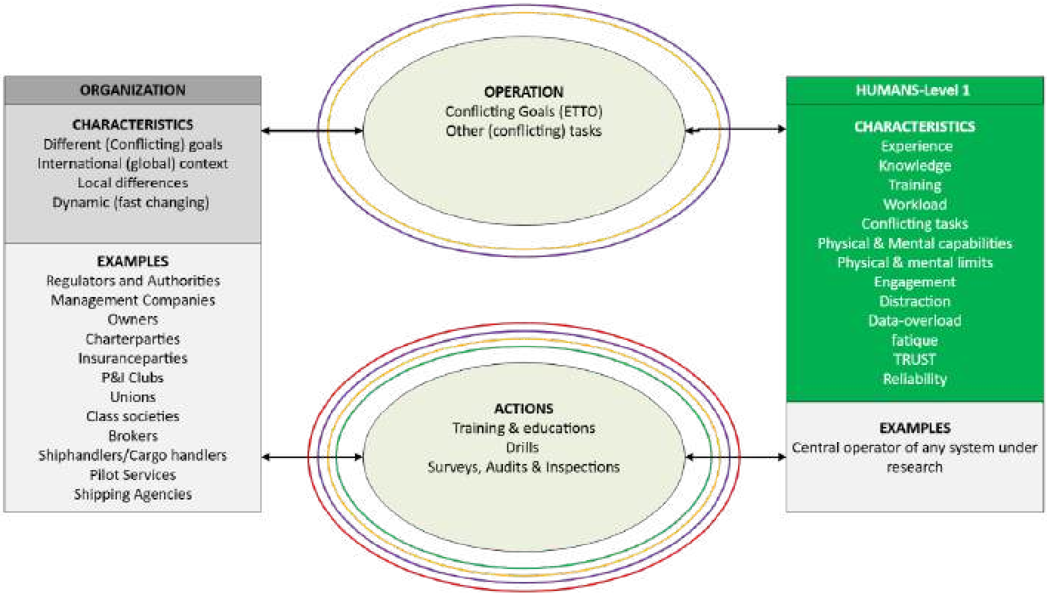

Figure A-12 Interaction between Organization and Human, through Operation and through Actions

As tools for the execution of risk assessment and mitigation within the scope of Formal Safety Assessment as adopted by the IMO, Hierarchical Goal-Based Task Analysis methodology and the MARIN socio-technical model provide for effective Risk Management in the maritime domain. It means that the *probability* and *detectability* of Task Performance failure and the *probability* and *severity* of resulting unsuccessful goal achievement can be assessed. Also an assessment of consequences of failures and/or mitigating measures in distanced system parts might be possible, as long as these parts are integrated in the Hierarchical Goal-Based Task Analysis.

APPENDIX B TIME SERIES OPERATIONAL DATA

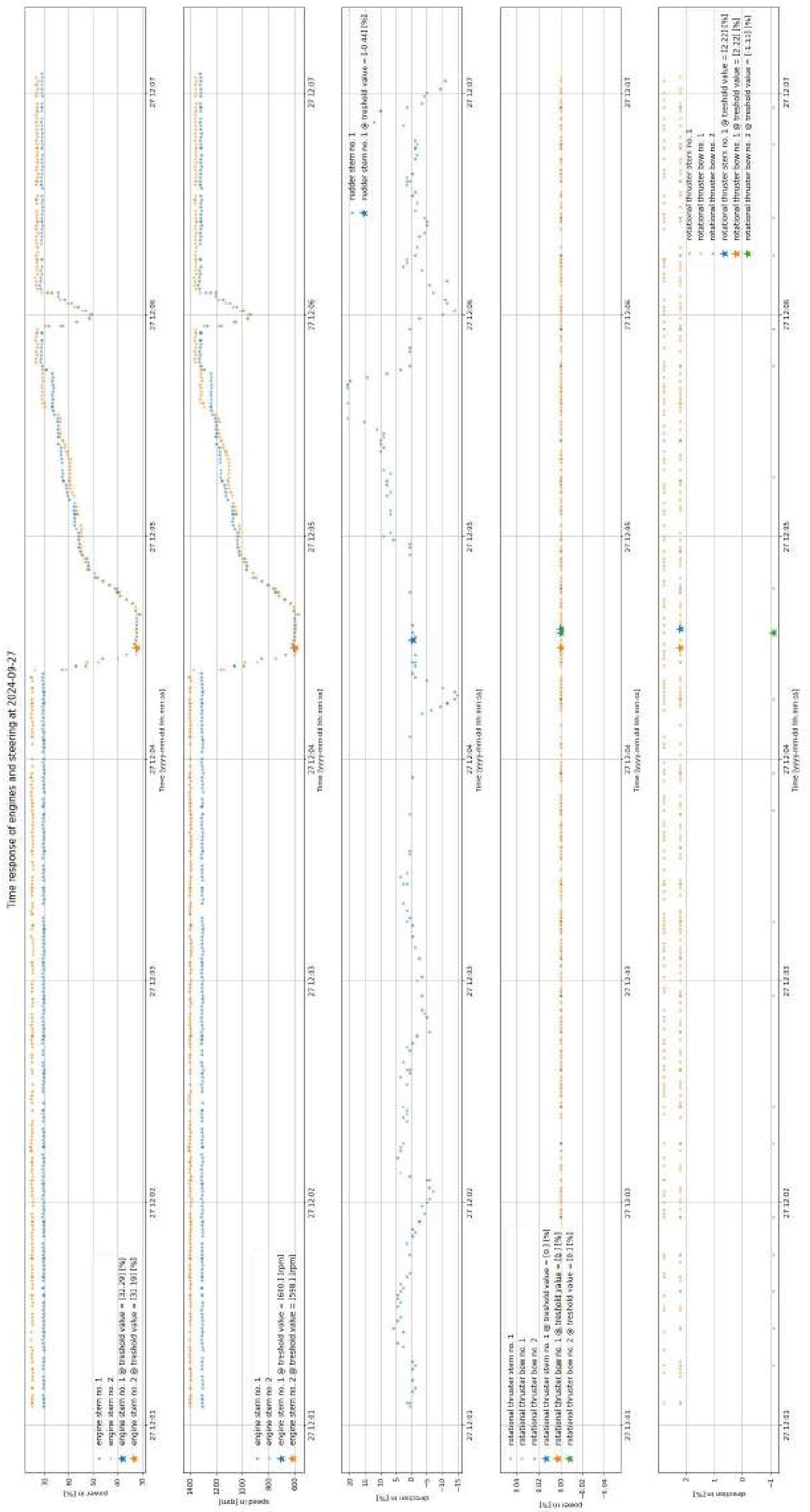

*Figure B-1 Actuators data time series 27-09-2024, 12:04 (the ‘ * ’ indicates the control switch)*

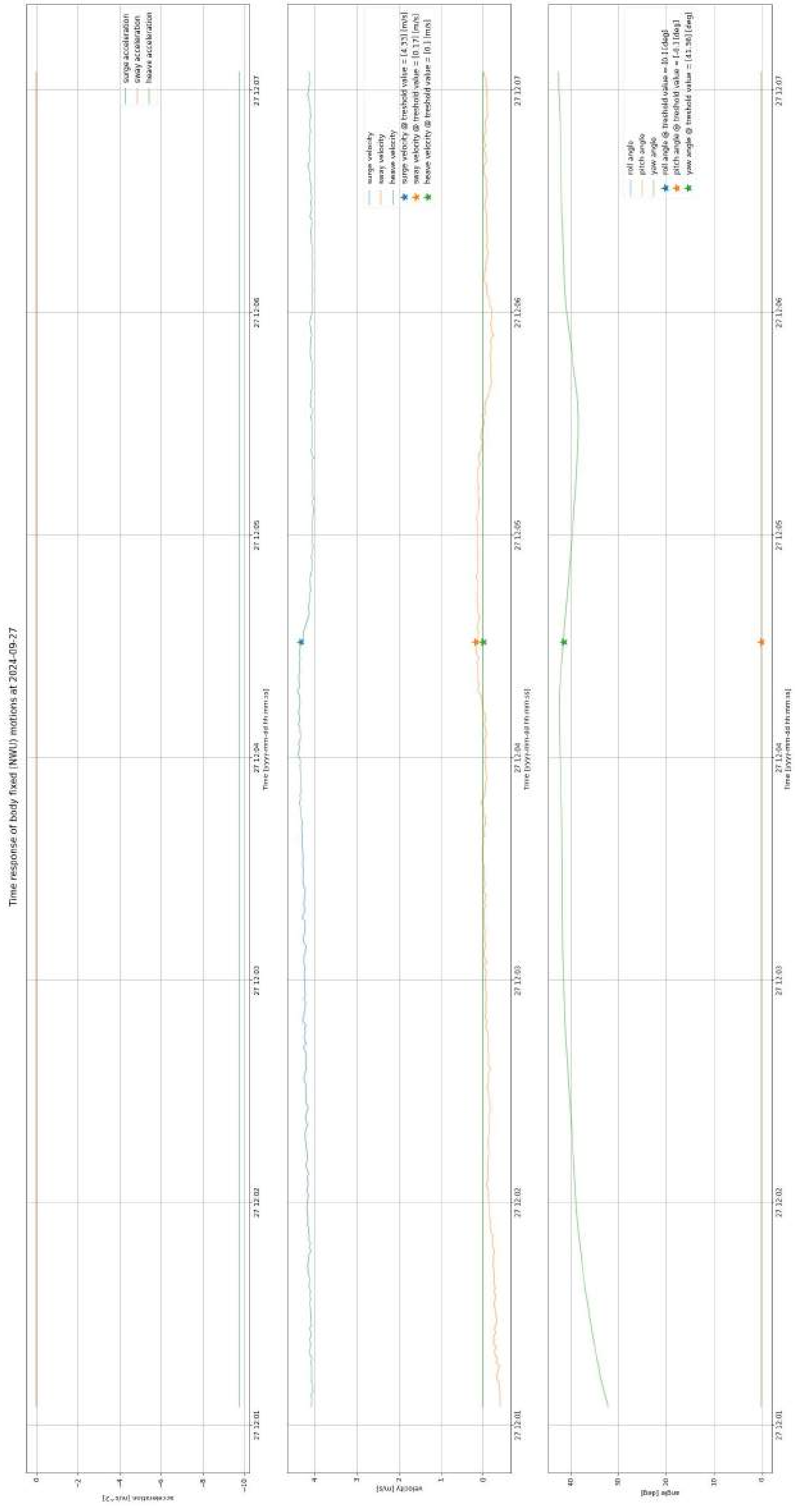

*Figure B-2 Vessel motions data time series 27-09-2024, 12:04 (the ‘ * ’ indicates the control switch).*

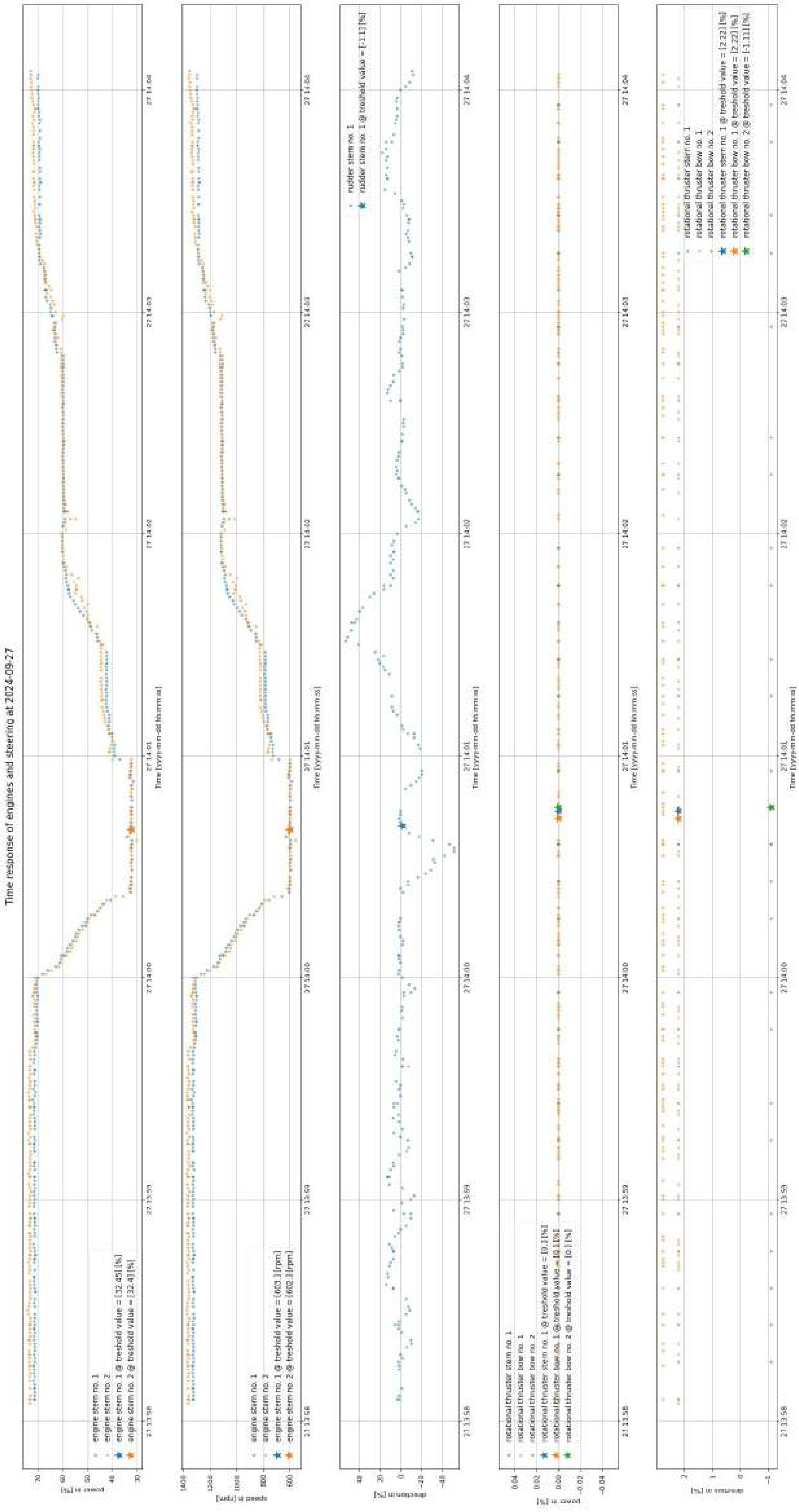

*Figure B-3 Actuators data time series 27-09-2024, 14:00 (the ‘ * ’ indicates the control switch)*

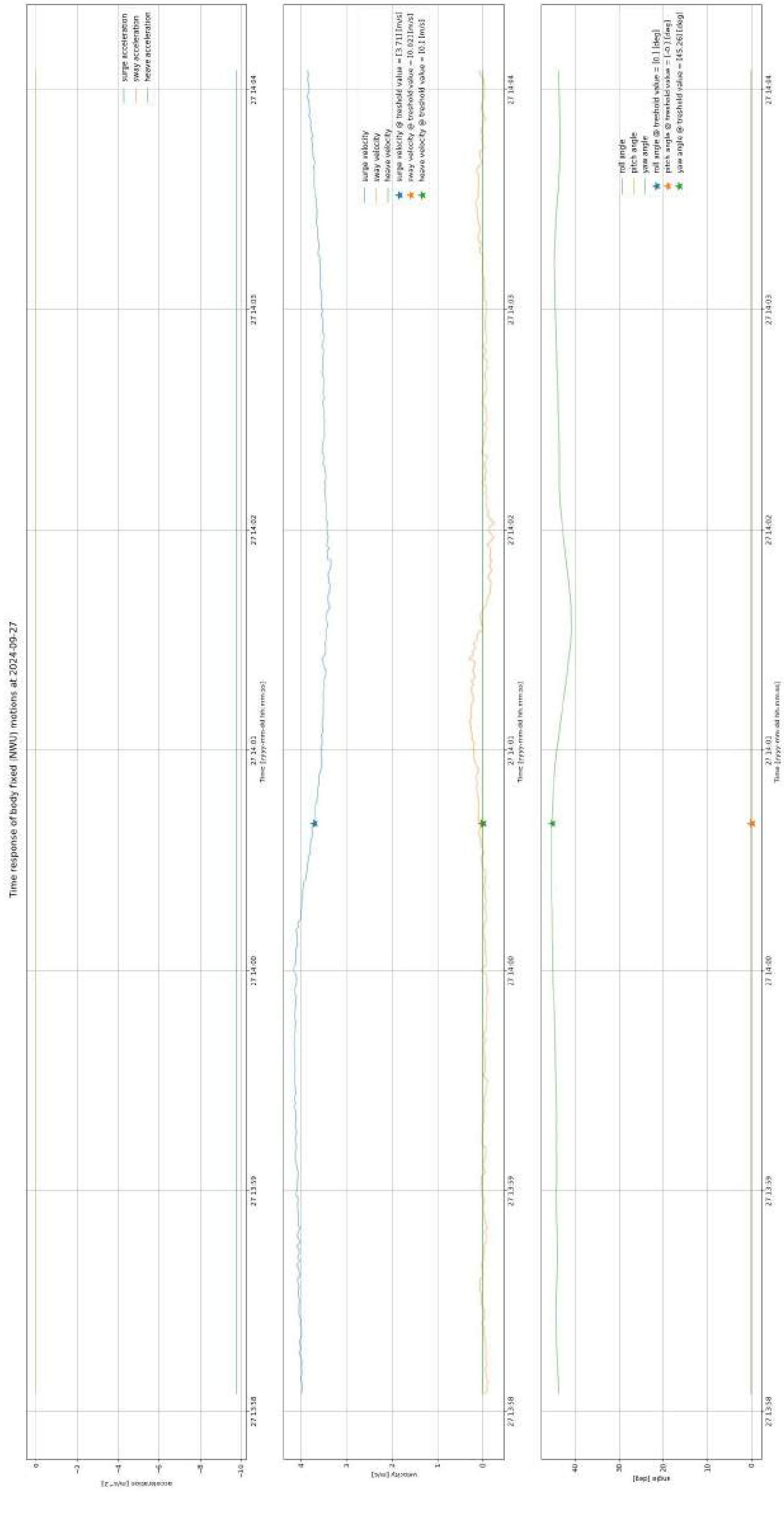

*Figure B-4 Vessel motions data time series 27-09-2024, 14:00 (the ‘ * ’ indicates the control switch).*

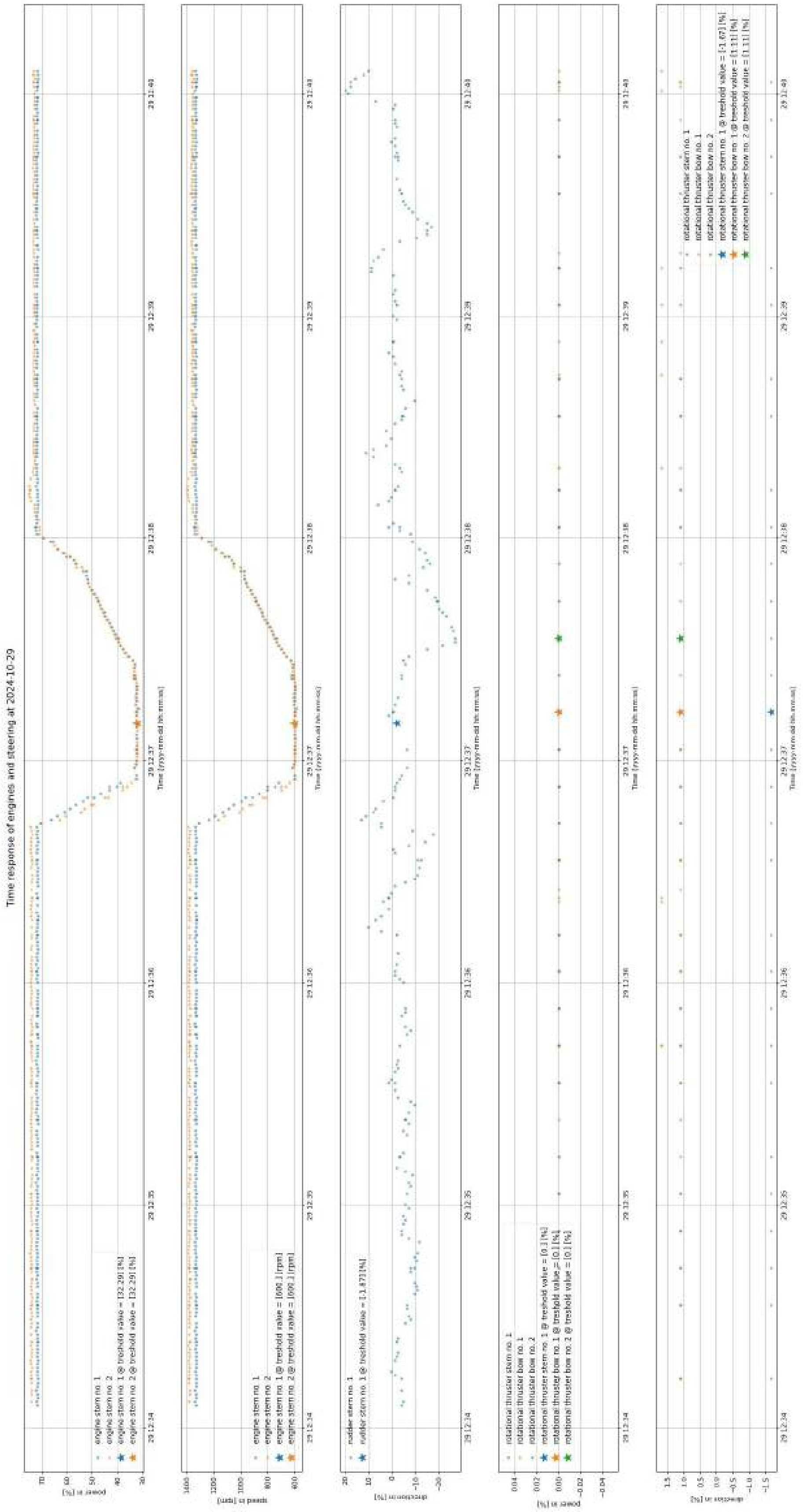

*Figure B-5 Actuators data time series 29-10-2024, 12:37 (the ‘ * ’ indicates the control switch)*

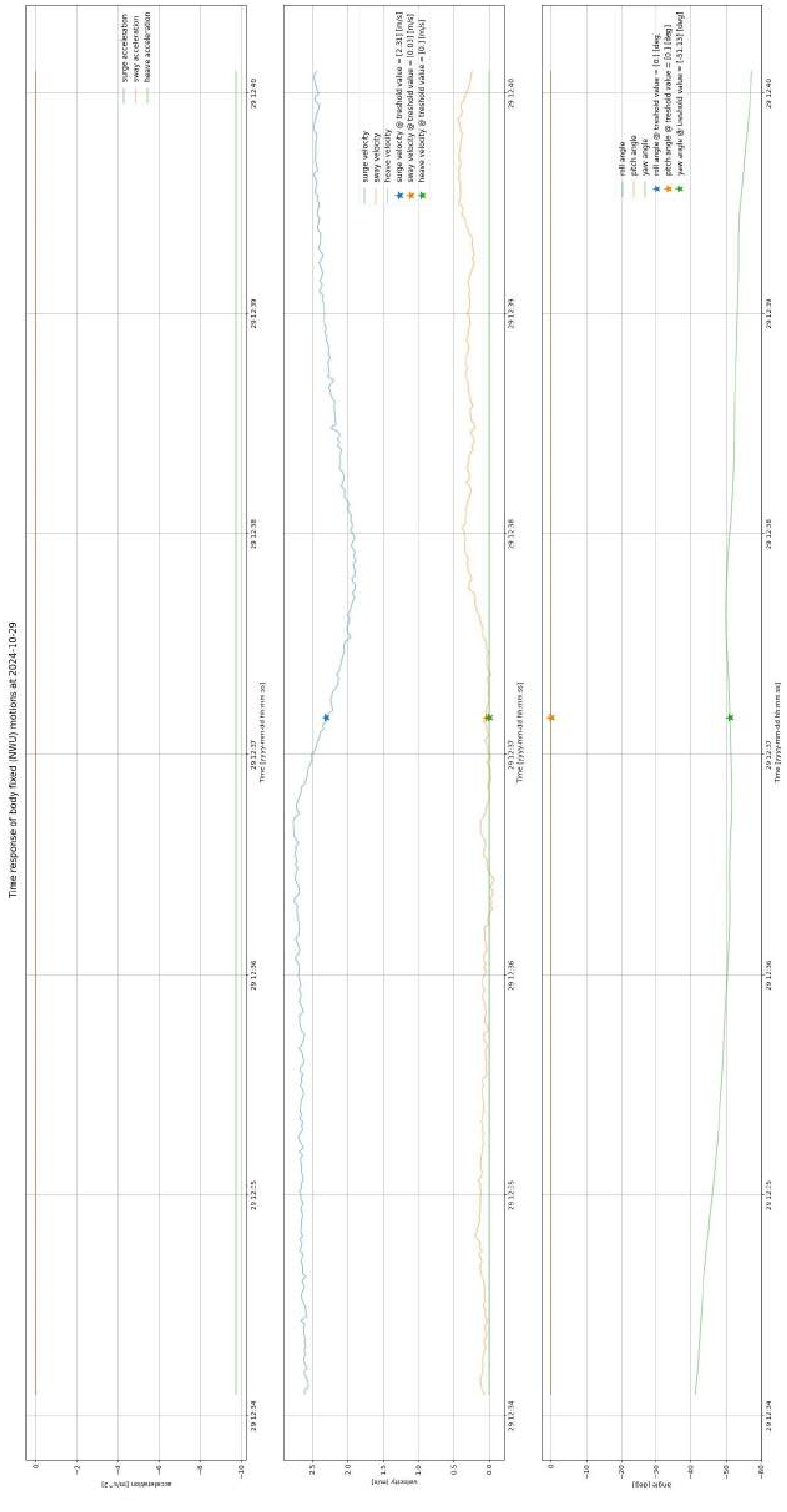

*Figure B-6 Vessel motions data time series 29-10-2024, 12:37 (the ‘ * ’ indicates the control switch).*

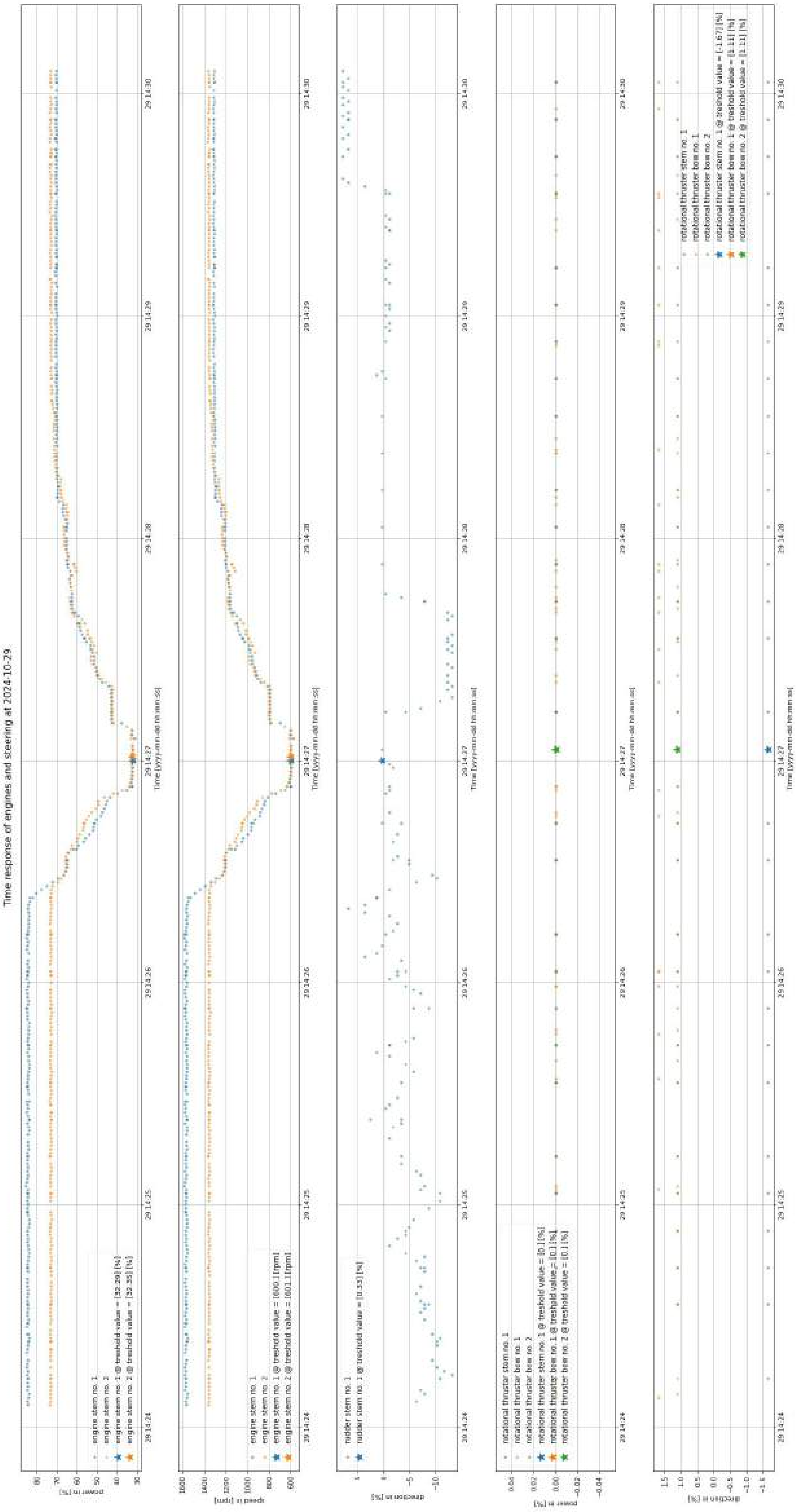

*Figure B-7 Actuators data time series 29-10-2024, 14:27 (the ' * ' indicates the control switch)*

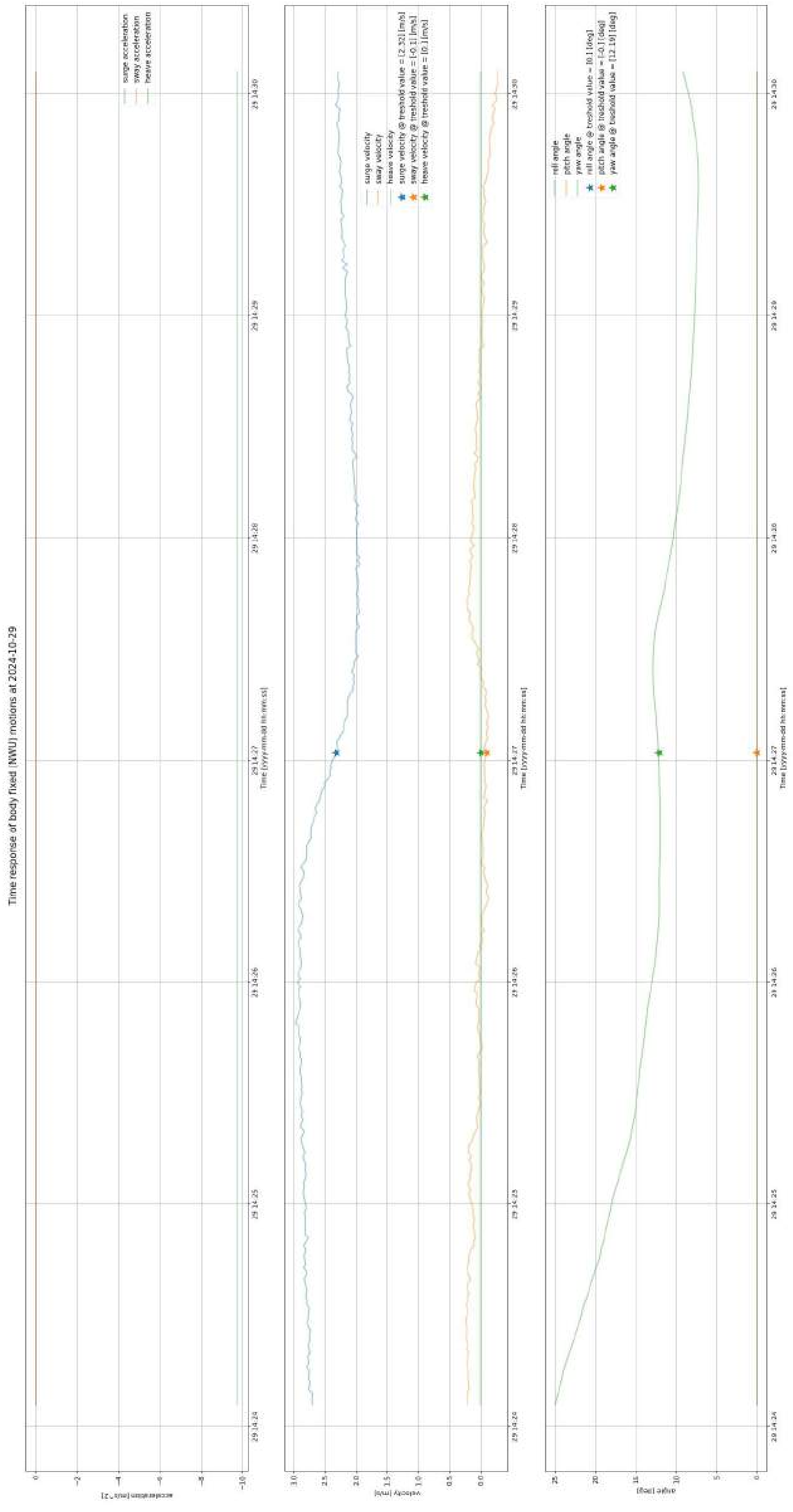

*Figure B-8 Vessel motions data time series 29-10-2024, 14:27 (the ‘ * ’ indicates the control switch).*

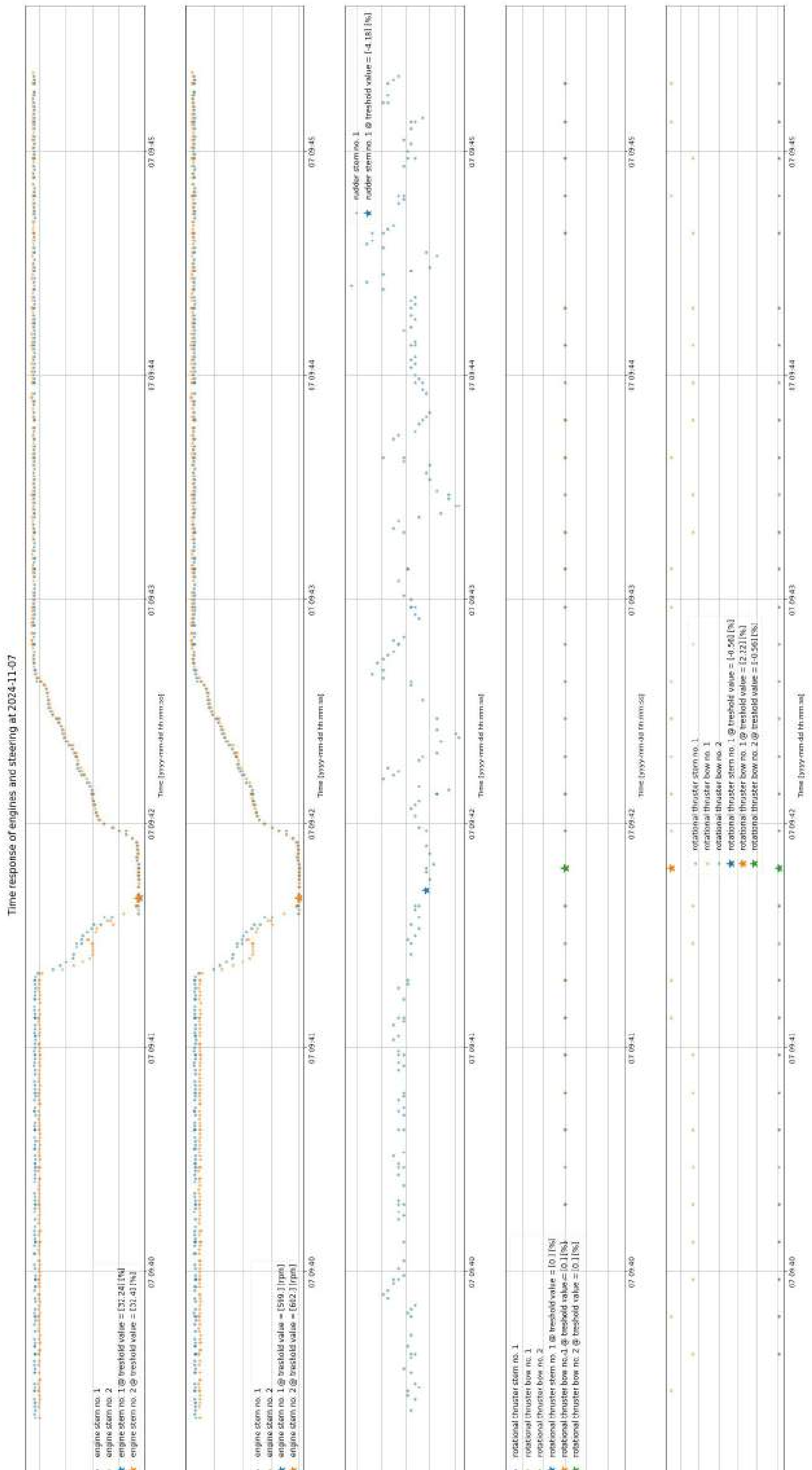

*Figure B-9 Actuators data time series 07-11-2024, 9:41 (the ‘ * ’ indicates the control switch)*

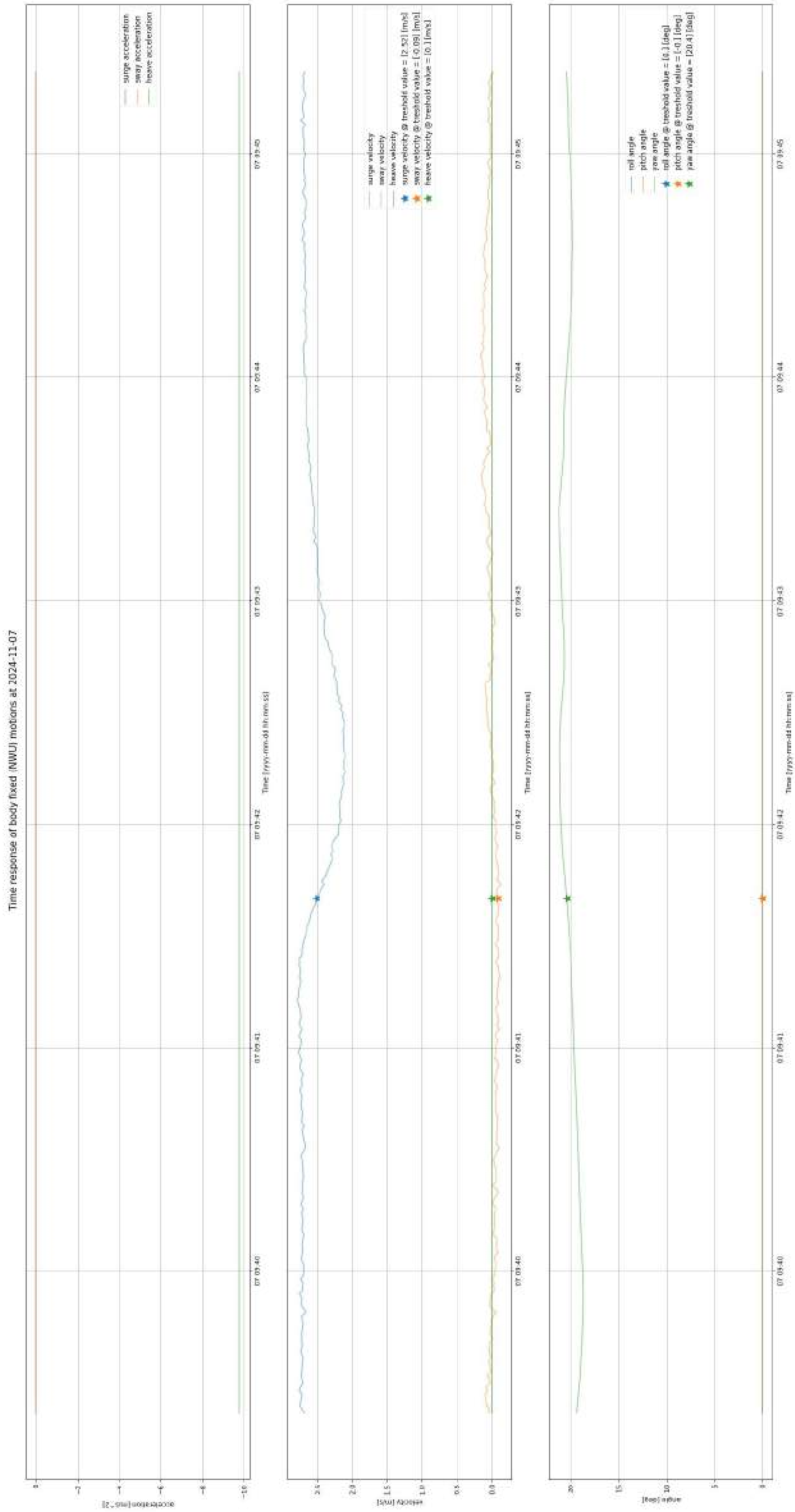

*Figure B-10 Vessel motions data time series 07-11-2024, 9:41 (the ‘ * ’ indicates the control switch).*

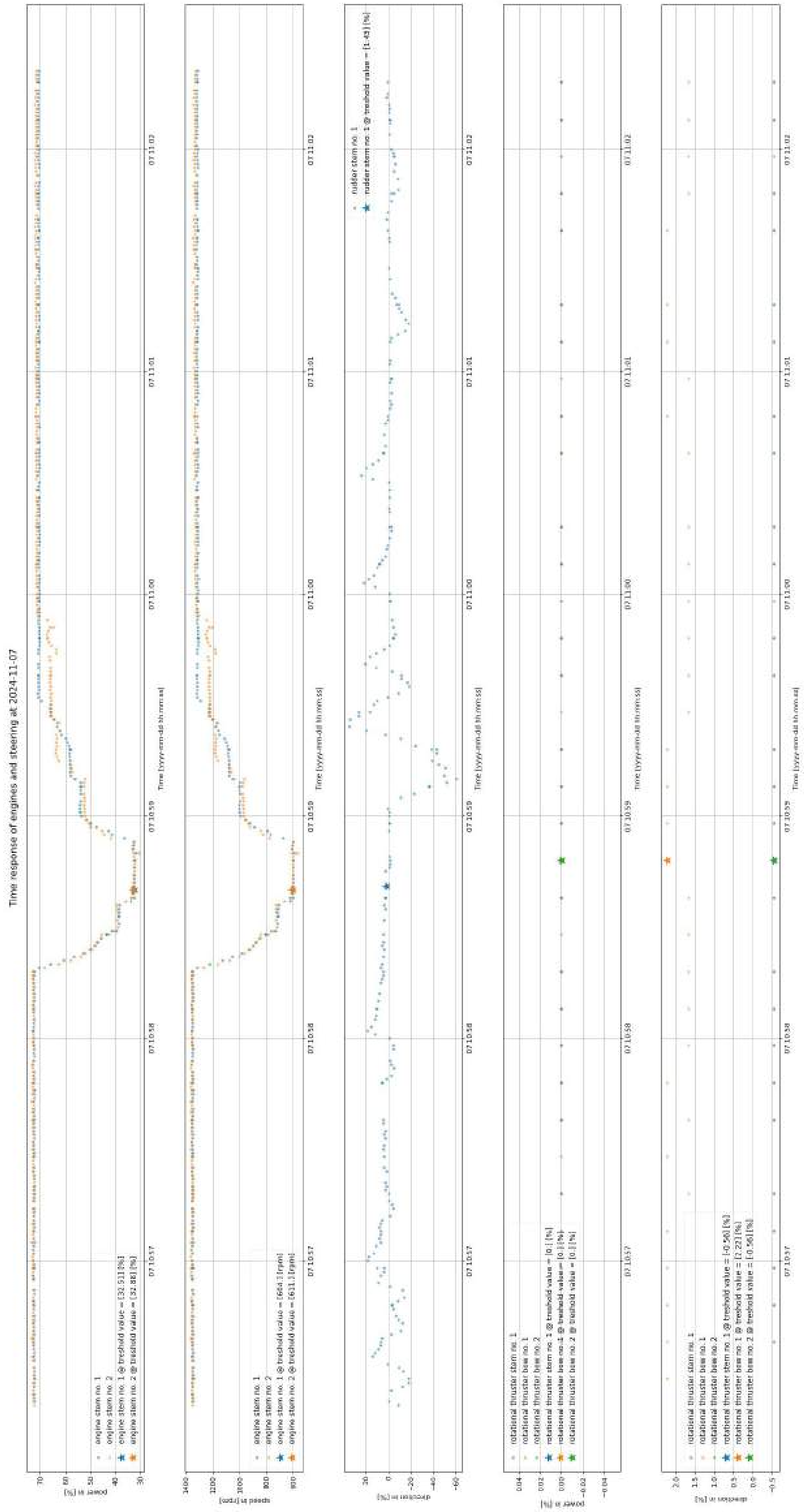

*Figure B-11 Actuators data time series 07-11-2024, 10:58 (the ‘ * ’ indicates the control switch)*

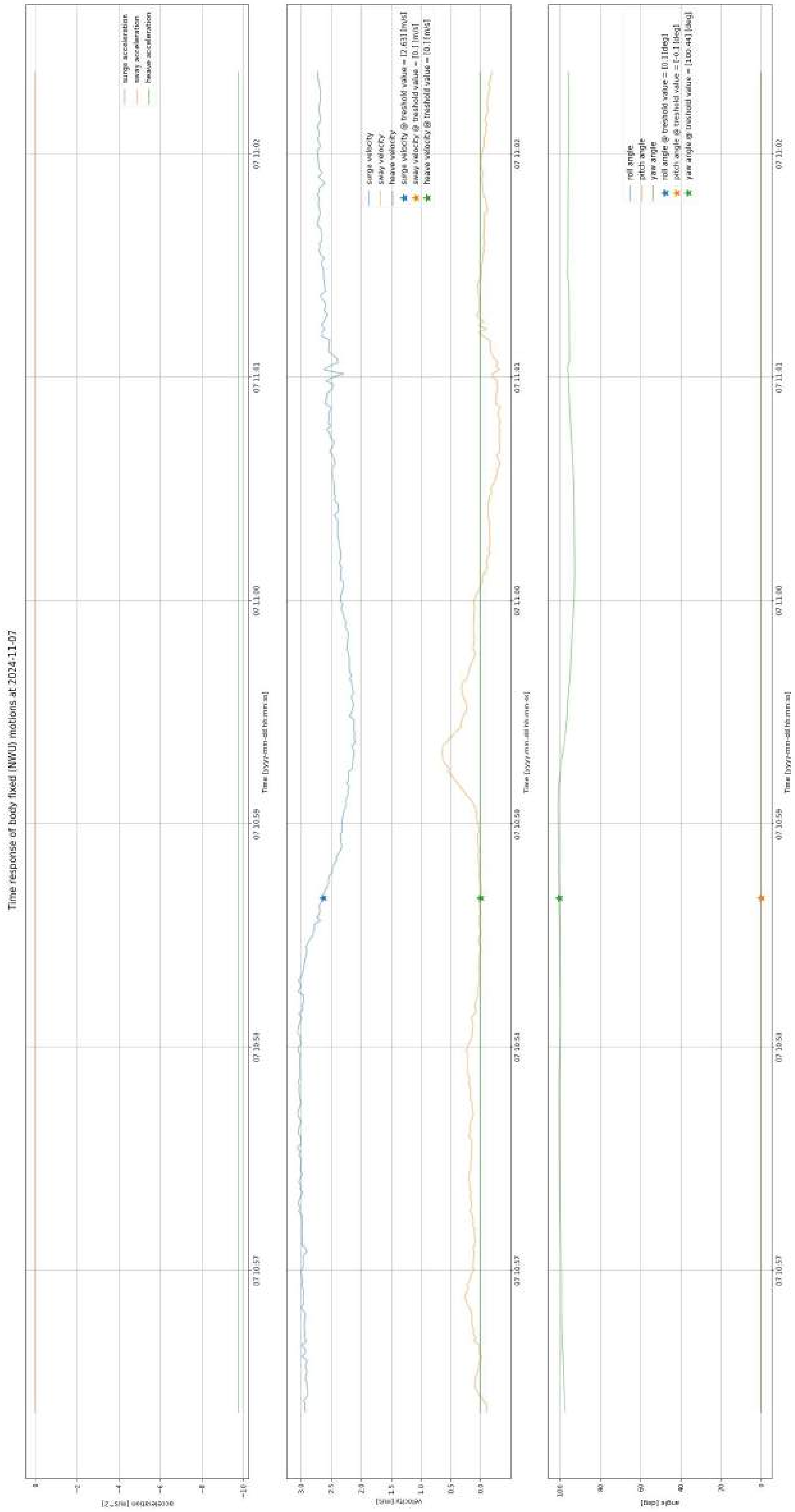

*Figure B-12 Vessel motions data time series 07-11-2024, 10:58 (the ' * ' indicates the control switch).*

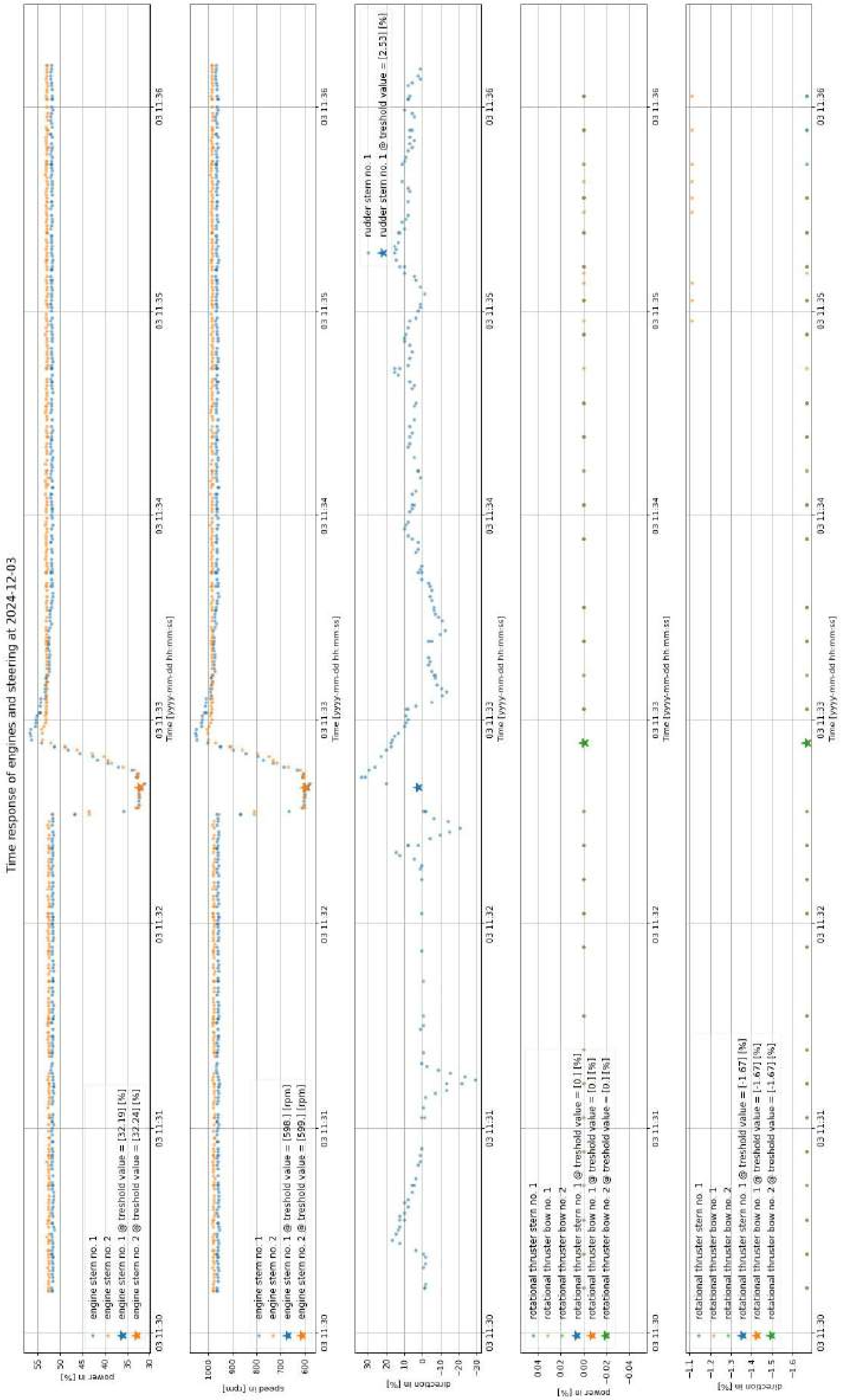

*Figure B-13 Actuators data time series 03-12-2024, 11:32 (the ‘ * ’ indicates the control switch)*

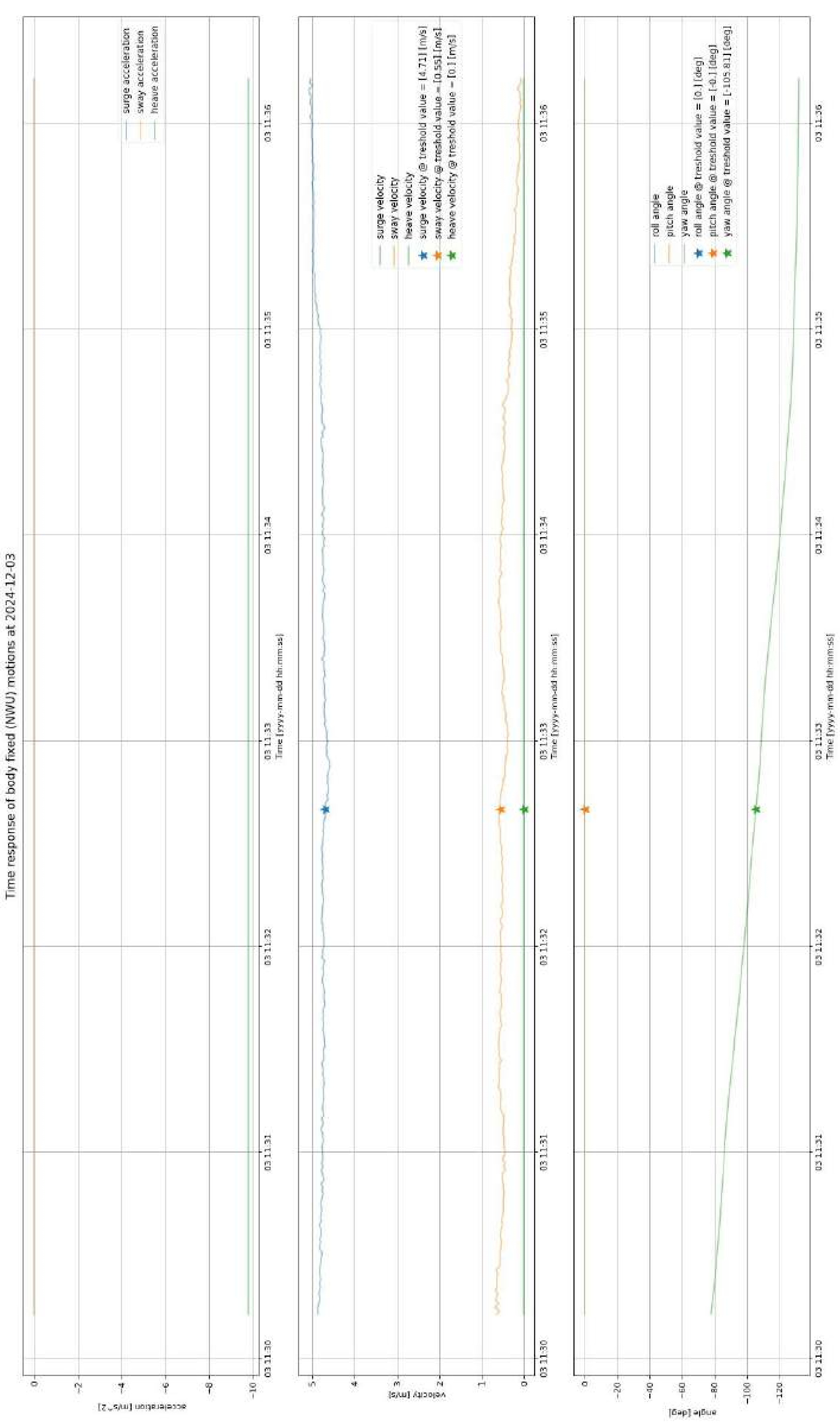

*Figure B-14 Vessel motions data time series 03-12-2024, 11:32 (the ‘ * ’ indicates the control switch).*

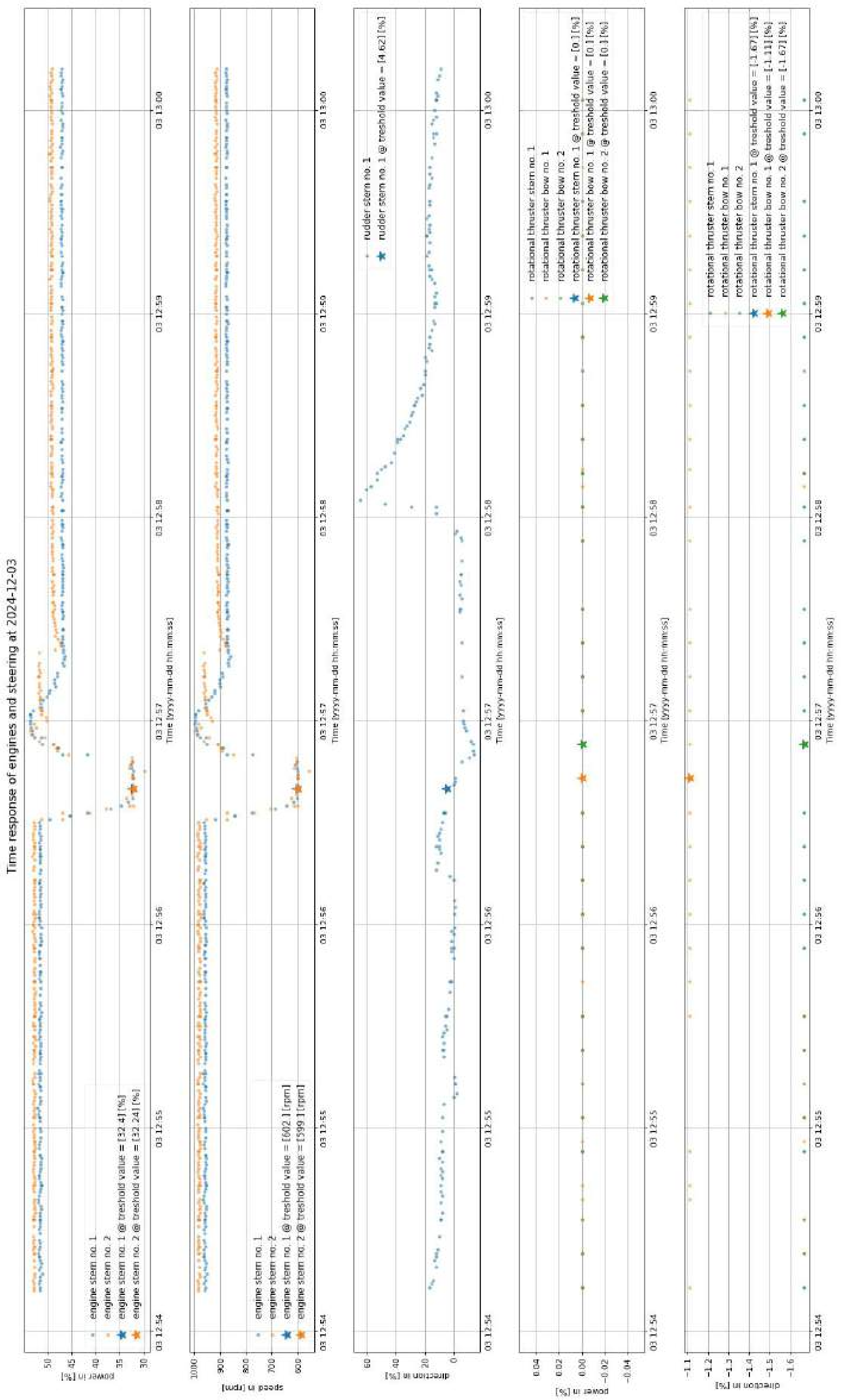

*Figure B-15 Actuators data time series 03-12-2024, 12:56 (the ‘ * ’ indicates the control switch)*

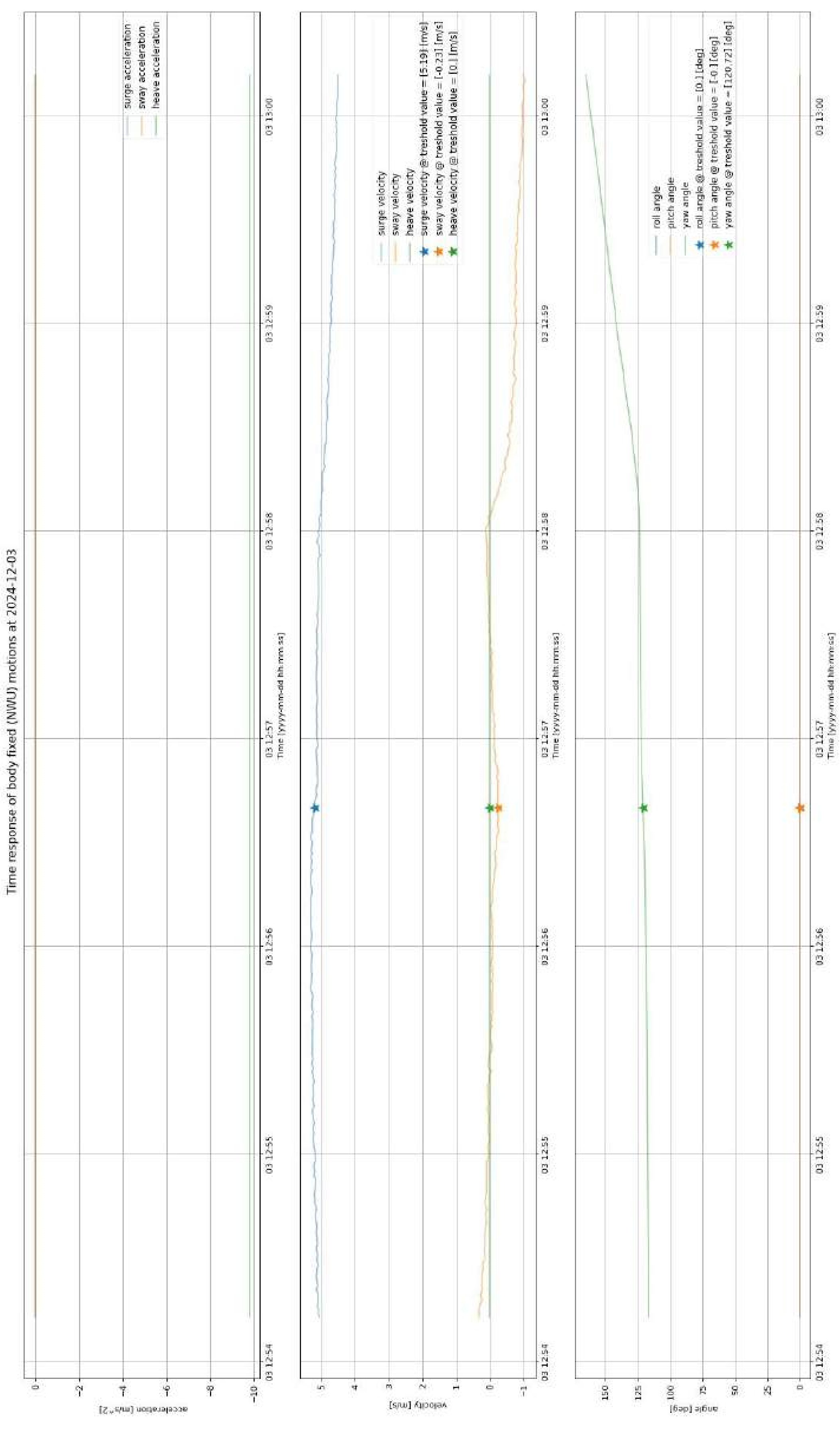

*Figure B-16 Vessel motions data time series 03-12-2024, 12:56 (the ' * ' indicates the control switch).*

APPENDIX C OVERVIEW OF UNIQUE ALARM NOTIFICATIONS

Array of unique alarm messages:	**Number of events:**
'Auto Resolved: Lidar reports an error	3
'Auto Resolved: Lost connection to File Sink gateway of Overall pipeline	557
'Auto Resolved: Lost connection to PLC-SIEMENS 1500 gateway of Overall pipeline	3
'Auto Resolved: Lost connection to Plc gateway of Plc pipeline	3
'Auto Resolved: Lost connection to Scc gateway of Ais pipeline	664
'Auto Resolved: Lost connection to Scc gateway of BridgeWatcher pipeline	661
'Auto Resolved: Lost connection to Scc gateway of Can pipeline	670
'Auto Resolved: Lost connection to Scc gateway of Environment pipeline	685
'Auto Resolved: Lost connection to Scc gateway of Generic pipeline	667
'Auto Resolved: Lost connection to Scc gateway of Gnss pipeline	681
'Auto Resolved: Lost connection to Scc gateway of Imu pipeline	668
'Auto Resolved: Lost connection to Scc gateway of Lidar pipeline	674
'Auto Resolved: Lost connection to Scc gateway of Qos pipeline	607
'Auto Resolved: Lost connection to Scc gateway of Radar pipeline	668
'Auto Resolved: Lost connection to Scc gateway of Reporting pipeline	662
'Auto Resolved: Lost connection to Scc gateway of Scc pipeline	594
'Auto Resolved: Lost connection to device	5996
'Auto Resolved: Lost connection to device	2
'Auto Resolved: Lost connection to device	2
'Auto Resolved: Lost connection to device	1
'Been dead reckoning for longer than 100000 ms without gps fix	7
'CPA warning not accurate.	19
'Cannot process received DIM sentence	6
'Connection to network device restored	992982
'Did not receive any sensor update for 5000.0 ms	736
'Did not yet receive a first sensor signal. Sensor monitor inactive	1
'E-STOP ACTIVE	556
'Incomplete sensor information inside the controller module	5
'Lost connection to File Sink gateway of Overall pipeline	5
'Lost connection to Scc gateway of Ais pipeline	717
'Lost connection to Scc gateway of BridgeWatcher pipeline	741
'Lost connection to Scc gateway of Can pipeline	712
'Lost connection to Scc gateway of Environment pipeline	719
'Lost connection to Scc gateway of Generic pipeline	735
'Lost connection to Scc gateway of Gnss pipeline	736
'Lost connection to Scc gateway of Imu pipeline	715
'Lost connection to Scc gateway of Lidar pipeline	729
'Lost connection to Scc gateway of Qos pipeline	736
'Lost connection to Scc gateway of Radar pipeline	733
'Lost connection to Scc gateway of Reporting pipeline	739
'Lost connection to Scc gateway of Scc pipeline	746
'Lost connection to SensorProcessor gateway of SensorProcessor pipeline	6
'Lost connection to device	888
'Lost connection to network device	987335

Array of unique alarm messages:	Number of events:
'Lost connection to trackpilot	191
'Lost gps updates. Deadreckoning using the last obtained data	31
'Lost heartbeat for module with name SF_HB_AIS_OIP_GENERATOR. Notify the technical team	3
'Lost heartbeat for module with name SF_HB_DEAD_RECKONING_MANAGER. Notify the technical team	5
'Lost heartbeat for module with name SF_HB_FUSION_CACHE. Notify the technical team	6
'Lost heartbeat for module with name SF_HB_OIP_AIS_CACHE. Notify the technical team	3
'Lost heartbeat for module with name SF_HB_PERIODIC_VAR_POSTER. Notify the technical team	5
'No route available at the current moment	2
'Not all data is yet received to do waypoint following	8
'Noticed an autonomy messages delay of 500.4935 ms	1
'Noticed an autonomy messages delay of 537.4444 ms	1
'Resolved: Been deadreckoning for longer than 100000 ms without gps fix	665
'Resolved: CPA warning not accurate.	149
'Resolved: Cannot process received DIM sentence	343
'Resolved: Did not receive any sensor update for 5000.0 ms	2795
'Resolved: Entered dangerous zone due to nearby bridge	3
'Resolved: Inside dangerous zone due to nearby bridge	3
'Resolved: Lost connection to trackpilot	891
'Resolved: Lost gps updates. Deadreckoning using the last obtained data	601
'Resolved: Lost heartbeat for module with name SF_HB_DEAD_RECKONING_MANAGER. Notify the technical team	1
'Resolved: Lost heartbeat for module with name SF_HB_FUSION_CACHE. Notify the technical team	603
'Resolved: Lost heartbeat for module with name SF_HB_PERIODIC_VAR_POSTER. Notify the technical team	1
'Resolved: No route available at the current moment	91
'Resolved: Not all data is yet received to do waypoint following	131
'Resolved: Noticed an autonomy messages delay of 500.4935 ms	1
'Resolved: Noticed an autonomy messages delay of 537.4444 ms	578
'Resolved: The route is loaded into the wrong direction	3
'Resolved: Vessel is currently too far from the loaded route	708
'Resolved: Vessel is moving too slow for track keeping	127
'TEMPERATURE ENGINE ROOM A2 BACK @ NORMAL LEVEL	3
'TEMPERATURE ENGINE ROOM A2 BACK BELOW ALARM LEVEL	3
'TEMPERATURE INSIDE A2 BACK @ NORMAL LEVEL	3
'VESSEL - BILGE ALARM	447
'VESSEL CONTROLLER - ALARM	951
'VESSEL CONTROLLER - ALARM CLEARED	828
'Vessel is currently too far from the loaded route	13
'Vessel is moving too slow for track keeping	9

APPENDIX D RISK ASSESSMENTS

Risk 1

Risk Scenario 1-1

The GBTA shows various low level goals and associated tasks in a series circuit, meaning that failure of a single tasks has a direct consequence on the level of successful achievement of low level goals and the higher level goal of Voyage Planning.'

Table D-1 Unsuccessful Voyage Planning - Risk Scenario 1-1 - Risk analyses

RISK SCENARIO 1-1 - RISK ANALYSES		
Low Level System Goal	Route Planning	
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Define destinations	**Functional Failure**: Organization; Too dynamic **Interaction Failure**: Communication of information inaccurate, outdated or missing.	In Inland Shipping, a voyage can have multiple destinations. Not only in terms of cargo destinations, but also related to fuel and water bunker stations, crew change, car debarkation/embarkation, shopping, small repairs and overnight mooring. This information needs to be transferred adequately to the ROC-operator, in case the ROC-operator is performing the Voyage Planning
Calculate draught and calculate air draught	**Functional failure:** Hardware; availability **Interaction Failure:** Communication of information inaccurate, outdated or missing.	Loading condition, trim and (to some extend) list, altogether provide for the information required to calculate minimum/maximum draught and air draught. These calculations are crucial to determine if there is adequate Under Keel Clearance and Bridge Hight throughout the intended voyage. The information is provided by the vessel itself and could be not available. The information needs to be transferred adequately to the ROC-operator, in case the ROC-operator is performing the Voyage Planning
Update and consult electronic charts, books, etc.	**Functional failure:** Hardware; availability **Interaction Failure:** Operational information: inaccurate, or outdated.	Nautical charts, nautical publication, fairway information regarding constrictions and restrictions, bridge heights, bridge and lock availability and expected waiting times, water level, (tidal) currents, etc, is all necessary information in Voyage Planning. We assumed already that this dynamic information is provided through hardware such as ECDIS, electronic Nautical Almanac and through internet services. This hardware must be available in the ROC in order to perform adequate voyage planning, including ECDIS-information. In addition, the information required need to be accurate and updated
Predict en route physical environmental conditions	**Interaction Failure:** Operational information: inaccurate, or outdated.	Some stretches of fairway or areas could be restricted for navigation due to circumstances like weather, visibility and sea state. Also: Check for allowance of the vessel on the different fairways along an intended route (CEMT-classes) Accurate operational information concerning these topics must be available to the ROC-operator, in case the ROC-operator is performing the Voyage Planning.
Establish route	N/A	The task can be performed by ROC-operators holding a Boatmaster license.
Low Level System Goal	Identify relevant route particulars	
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Identify hazards and other relevant route particulars	N/A	The task can be performed by ROC-operators holding a Boatmaster license.
Draw up initial Voyage Plan	**Functional Failures**:	The tasks requires availability of time and opportunity for both the Boatmaster and the ROC-operator to perform

	Human; High Workload, Conflicting tasks, Distraction and Lack of Engagement	without being exposed to High Workloads, Conflicting Tasks and distraction. It also requires a level of engagement with the vessel, meaning that the ROC-operator has on-board experience with operating the vessel.

Table D-2 Unsuccessful Voyage Planning - Risk Scenario 1-1, Risk Classification, Risk Control Options, Opportunities for manning reduction

Risk Scenario 1-1- Risk Classification, Risk Control Options and Opportunities for manning reduction				
Relevant Associated tasks	Severity	Arguments	Failure Detectability	Explanation
Define destinations	Medium	Only safety related destinations are relevant. In this case on board fuel and water availability and timely arrival at overnight moorings might be safety relevant.	Low	If the Boatmaster onboard does not inform the ROC-operator about all the destinations, the ROC-operator has no opportunity to be aware of the missing or inaccurate information
Calculate draught and calculate air draught	High	Inaccurate calculations can lead to failure of voyage planning in terms of possible groundings or collision with bridges.	Low	If the Boatmaster onboard does not inform the ROC-operator about dynamic features of the vessel, the ROC-operator has no opportunity to be aware of the missing or inaccurate information. This information contains maximum draught, maximum air-draught, trim, list loading condition and wheelhouse elevation
Update and consult electronic charts, books, etc.	High	The information provided by electronic charts, books, etc. is essential when related to planning of a safe and efficient passage to destinations.	Medium	Electronic information providers should normally contain information of the latest update/version etc. This only works in situations de ROC operator has direct access to the electronic provider, instead of indirect information that is extracted from the provider by someone else.
Predict en route physical environmental conditions	High	The associated task is highly relevant because, in case of an unexpected occasions with unsafe weather, visibility and/or sea state conditions, there is a possibility that unsafe situation are hard to escape from. Such occasions must be avoided.	High	It is expected that weather and fairway information can be accessed directly from the ROC by the ROC-operator
Draw up initial Voyage Plan	High	If this task cannot be performed adequately, the goal of successful voyage planning will be not achieved, sending the vessel on an inadequately prepared voyage, possibly leading to unsafe or inefficient navigation.	Low	If there is enough trust in the ROC-operator to perform the task, and the ROC-operator has not detected any failures in the accuracy of the information he has provided with in preceding tasks, nor the Boatmaster or the ROC-operator have the opportunity to detect unsuccessful drawing up the initial voyage plan.

Risk Scenario 1-2

Table D-3 Unsuccessful Voyage Planning - Risk Scenario 1-2 - Risk analyses

RISK SCENARIO 1-2 - RISK ANALYSES		
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Update Voyage Plan	**Interaction Failure**: Communication missing.	There are many operational reasons why a vessel need to deviate from the initial Voyage Plan. This can happen during Remote Operation from a ROC while the Boatmaster is not in the Wheelhouse. Although, based on the assessment of Risk Scenario 1-1, the ROC-operator should have the capacity and the required information to update the Voyage Plan, the Boatmaster remains responsible a should therefore be consulted immediately.

Table D-4 Unsuccessful Voyage Planning - Risk Scenario 1-2, Risk Classification, Risk Control Options, Opportunities for manning reduction

Risk Scenario 1-2- Risk Classification, Risk Control Options and Opportunities for manning reduction				
Relevant Associated tasks	Severity	Arguments	Failure Detectability	Explanation
Update Voyage plan	High	If this task cannot be performed adequately and after consultation with the Boatmaster, the goal of successful voyage planning will be not achieved, sending the vessel on an inadequately prepared voyage possibly leading to unsafe or inefficient navigation.	Low	If the ROC-operator does not consult the Boatmaster about updating the Voyage Plan, the Boatmaster has no opportunity to be aware of the update

Risk 2

Risk Scenario 2-1

Table D-5 Unsuccessful Voyage Planning - Risk Scenario 2-1 - Risk analyses

RISK SCENARIO 2-1 - RISK ANALYSES		
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Brief Voyage Plan to Remote Operator	**Interaction Failure**: Communication missing.	The (updated) Voyage Plan is not timely, adequately and accurately communicated with the Remote Operator

Table D-6 Unsuccessful Voyage Planning - Risk Scenario 2-1, Risk Classification, Risk Control Options, Opportunities for manning reduction

Risk Scenario 2-1 - Risk Classification, Risk Control Options and Opportunities for manning reduction				
Relevant Associated tasks	Severity	Arguments	Failure Detectability	Explanation
Brief Voyage Plan to Remote Operator	High	The goal of successful Voyage Plan Execution will not be achieved when the ROC-operator is not fully aware of the (updated) Voyage Plan, possibly leading to unsafe or inefficient navigation.	Low	If the Boatmaster does not timely, adequately and accurately inform the ROC-operator about the (updated) Voyage Plan, the ROC-operator has no opportunity to be aware of missing crucial parts of the (updated) Voyage Plan.

RISK 3

Scenario 3-1

Table D-7 Unsuccessful transfer of control - Risk Scenario 3-1 - Risk analyses

RISK SCENARIO 3-1 - RISK ANALYSES		
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Follow up on changeover procedures	**Functional failures:** Hardware: Availability, Robustness and Reliability Human: Lack of training and knowledge, conflicting tasks, distraction Organization: Lack of Governance **Interaction failures:** Human-machine interface: Lack of transparency, Inconvenient Information presentation, Complicated controls Communication: unclear, missing Organization: Lack of adequate procedures and manuals Actions: Lack of training availability	Changeover of control can fail due to several causes. First of all the initial decision to initiate remote navigation should be taken by a responsible person on board the vessel. More important, the initial decision to end remote navigation should be taken either by the remote operator or a responsible person on board, without any discussion as to prevent possible continuation of remote navigation in unsafe circumstances. Secondly, changeover should be prevented when no competent wheelhouse-operator and ROC-operator are available at the controls. It means that the operator that will be handed over control over the vessels navigation, also must have had the opportunity to gain situation awareness before commencing control. Thirdly, changeover from wheelhouse to ROC should be prevented when hardware and data-connections are not set, verified and stable: • The remote control related hardware both onboard the vessel and in the ROC must be running and verified to be free of errors; • Sensor-data (e.g. GPS, echosounder, speed indicator, camera images), equipment-data (e.g. radar, rate-of-turn (RoT) indicator, VHF, steering mode selection), machinery feedback-data (rudder angle, main propulsion and bow thruster settings) need to be validated regarding accuracy and presentation without inconvenient time delays. • Data-connections must be verified to be reliable and robust, meaning it is expected to be stable and capable of streaming all the necessary data-exchange between vessel and ROC for the period of time that the ship will be navigated from the ROC. Fourthly, immediately after changeover controls to the ROC, the response and feedback of controls regarding cameras, rudder and/or RoT settings, steering mode settings, main propulsion settings, navigation lights and day-signs, wheelhouse elevation, mast elevation, VHF, horn and, if applicable, bow thruster controls, all need to be verified in cooperation with the competent wheelhouse operator. Finaly, as being observed both on board and in the ROC, changeover-procedures cause attention tunnelling, meaning that operators are temporarily distracted from navigation goals and related tasks, especially the monitoring of the environment.

Table D-8 Unsuccessful transfer of control - Risk Scenario 3-1, Risk Classification, Risk Control Options, Opportunities for manning reduction

Risk Scenario 3-1 - Risk Classification, Risk Control Options and Opportunities for manning reduction				
Relevant Associated tasks	Severity	Arguments	Failure Detectability	Explanation
Follow up on changeover procedures	High	Unsuccessful changeover can easily lead to unsafe navigation because of : • Operators do not have sufficient situation awareness • ROC-operator does not have required levels of control	Low	Without verifying functionality of hardware, availability and situation awareness of the involved operators and verifying data-feedback accuracy, the involved operators have no or less opportunity to detect the existence of failures.

Risk scenario 3-2

Table D-9 Unsuccessful emergency transfer of control - Risk Scenario 3-2 - Risk analyses

RISK SCENARIO 3-2 - RISK ANALYSES		
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Follow up on changeover procedures by pressing emergency button	**Functional failures:** Hardware: Availability, Robustness and Reliability Human: Lack of training and knowledge, conflicting tasks, distraction **Interaction failures**: Human-machine interface: Lack of transparency, Inconvenient Information presentation, Complicated controls Communication: unclear, missing Documentation: Lack of adequate procedures and manuals Actions: Lack of training availability	Emergency changeover of control can fail due to several causes. First of all, most of the procedures that are applicable for “normal” changeover, as addressed in scenario 3-1, cannot be performed. Secondly, because of the possible situation that the wheelhouse is not attended during remote control, any emergency changeover initiated from the ROC would leave the vessel possibly not under command, with forward propulsion and speed and some rate-of-turn. Thirdly, emergency changeover might take place with no or reduced situation awareness of the wheelhouse-operator and under inconvenient environmental conditions regarding to traffic, fairway and fairway infrastructure.

Table D-10 Unsuccessful emergency transfer of control - Risk Scenario 3-2, Risk Classification, Risk Control Options, Opportunities for manning reduction

Risk Scenario 3-2 - Risk Classification, Risk Control Options and Opportunities for manning reduction				
Relevant Associated tasks	Severity	Arguments	Failure Detectability	Explanation
Follow up on changeover procedures	High	Unsuccessful changeover can easily lead to unsafe navigation because of : • Operators not available in the wheelhouse or ROC • Operators not heaving sufficient situation awareness • ROC-operator does not have required levels of control	Low	Without verifying functionality of hardware, availability and situation awareness of the involved operators and verifying data-feedback accuracy, the involved operators have no or less opportunity to detect the existence of failures.

Risk scenario 3-3

Table D-11 Failure of data-connection - Risk Scenario 3-3 - Risk analyses

RISK SCENARIO 3-3 - RISK ANALYSES		
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Follow up on changeover procedures by pressing emergency button	**Functional failures:** Hardware: Availability **Interaction failures**: Human-machine interface: Disturbed	Emergency changeover of control can fail due to several causes. Hardware, such as transmitters and receivers may malfunction or the connection fails. Connections might fail due to failure of telecommunication networks. Also a temporally disturbance caused by obstacles in the environment (bridges, buildings) or jamming on purpose can be a cause to connection failures. The result will probably the same in all situations, being a disruption in the ability of the ROC-operator to control and monitor the vessel and its environment and leave the vessel possibly not under command, with forward propulsion and some rate-of-turn.

Table D-12 Failure of data-connection - Risk Scenario 3-3, Risk Classification, Risk Control Options, Opportunities for manning reduction

Risk Scenario 3-1 - Risk Classification, Risk Control Options and Opportunities for manning reduction				
Relevant Associated tasks	Severity	Arguments	Failure Detectability	Explanation
Follow up on changeover procedures	High	Unexpected and instantly failure of data-connection between vessel and ROC can easily lead to unsafe navigation because of : • Operators not available in the wheelhouse • Operators not heaving sufficient situation awareness • ROC-operator does not have required levels of control	Medium	Without warning involved operators, especially on board the vessel, the operators are not aware of instant termination of the remote navigation operation. On the other hand, the ROC-operator most likely will be immediately aware of the situation.

Risk 4

Risk scenario 4-1

Table D-13 Unsuccessful UKC monitoring and assessment - Risk Scenario 4-1 - Risk analyses

RISK SCENARIO 4-1 - RISK ANALYSES		
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Check ship-data feedforward accuracy and time delay Check functioning echo sounders	**Functional failures:** Hardware: Availability, Robustness and Reliability **Interaction failures**: Human-machine interface: Lack of transparency; disturbed	The echosounder or the data feedforward to the ROC or the data-connection is failing, leaving the ROC operator with no UKC information.

Table D-14 Unsuccessful transfer of control - Risk Scenario 4-1, Risk Classification, Risk Control Options, Opportunities for manning reduction

Risk Scenario 4-1 - Risk Classification, Risk Control Options and Opportunities for manning reduction				
Relevant Associated tasks	Severity	Arguments	Failure Detectability	Explanation
Check ship-data feedforward accuracy and time delay Check functioning echo sounders	Medium	Failures as described are less severe during daylight than in darkness.	Low	If the echosounder or the data feedforward to the ROC or the data-connection is failing without the ROC-operator able to detect the failure, leading to a possible scenario in which the vessel is continuing her voyage without accurate UKC-information in ROC.

RISK 5

Risk Scenario 5-1

Table D-15 Unsuccessful Traffic monitoring, Identification and assessment - Risk Scenario 5-1 - Risk analyses

RISK SCENARIO 5-1 - RISK ANALYSES		
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Check ship-data feedforward accuracy and time delay Check functioning RADAR, ECDIS, INLAND AIS-receivers, VHF radio-equipment, sound reception facilities Monitor, identify and assess other traffic	**Functional failures:** Hardware: Availability, Robustness and Reliability **Interaction failures**: Human-machine interface: Lack of transparency; disturbed; Missing controls	1. Equipment or the data feedforward and feedback to the ROC or the data-connection is failing, leaving the ROC operator with incomplete traffic information. 2. Missing controls: Some equipment require operating controls to facilitate the monitoring tasks. Examples are RADAR, ECDIS, navigation lights and other navigation signs, VHF-radios, Sound signals.

Table D-16 Unsuccessful monitoring, identifying and assessment of traffic - Risk Scenario 5-1, Risk Classification, Risk Control Options, Opportunities for manning reduction

Risk Scenario 5-1 - Risk Classification, Risk Control Options and Opportunities for manning reduction				
Relevant Associated tasks	Severity	Arguments	Failure Detectability	Explanation
Check functioning and use of outside view camera footage and RADAR to monitor, identify and assess other traffic Check ship-data feedforward accuracy and time delay	Medium to high	Outside view and RADAR serve as primary system components for traffic monitoring. Especially in remote navigation operation and due to the fact that camera footage of the outside view from the wheelhouse can fail, RADAR and Camera footage are complementary to each other, meaning that they not only provide together for situation awareness in all view zones around the vessel (Figure 4-3), but also, in practice, serve as each other's backup.	Medium	Comparing radar-image with outside view and/or ECDIS should provide for detection if one of the systems fail. In case of disturbances in multiple systems, the possibility of failure detection decreases.
Check functioning and use of ECDIS, INLAND AIS-receivers to monitor, identify and assess other traffic Check ship-data feedforward accuracy and time delay	Low	ECDIS and Inland-AIS serve as secondary system components for traffic monitoring. This means that failure does not lead to unsuccessful traffic monitoring. It also means that both systems cannot provide for successful traffic monitoring in case of failure of primary system components.	Medium	Failure of ECDIS can be detected by comparing the ECDIS-screen with RADAR and Camera footage. The same works for AIS-receivers; Detecting other large vessels by RADAR or Camera footage and not receiving AIS-data might indicate a failure of the AIS equipment.
Check functioning and use of VHF radio-equipment, sound reception facilities to monitor, identify and assess other traffic. Check ship-data feedforward accuracy and time delay	High	All equipment is mandatory as being part of the navigation task performed by the helmsman, both in the wheelhouse as in the ROC. Malfunction leads to unsuccessful traffic monitoring, identification and assessment	Low	Malfunction is not easy to detect. If the equipment fails , the situation is comparable with "normal" situations in which no other vessels or traffic service is transmitting. The operator does not know if sounds and radio-transmissions fails to be forwarded to the ROC.

RISK 9

Risk Scenario 9-1

Table D-17 Unsuccessful monitoring and assessment of Other Environmental Conditions - Risk Scenario 9-1 - Risk analyses

RISK SCENARIO 9-1 - RISK ANALYSES		
Associated Tasks (grouped)	Identified Task Failure mode(s)	Failure mode description
Use physical senses and camera-vision to observe own vessel behaviour and exceeding fairway limits Assess AIR-draught and roll using equipment and physical observations Check functioning and use of relevant equipment, if applicable Check ship-data feedforward accuracy and time delay	**Functional failures:** Hardware: Availability **Interaction failures**: Human-machine interface: Lack of transparency; disturbed; Missing controls; Observation: Disturbed feel	1. The opportunity to feel the vessels motion is disturbed, because the ROC-operator is not on board the vessel; 2. Accurate elevation height information regarding adjustable masts and wheelhouse missing.; 3. Missing controls: Some equipment require operating controls to facilitate the monitoring tasks.

Table D-18 Unsuccessful monitoring and assessment of Other Environmental Conditions - Risk Scenario 9-1, Risk Classification, Risk Control Options, Opportunities for manning reduction

Risk Scenario 9-1 - Risk Classification, Risk Control Options and Opportunities for manning reduction				
Relevant Associated tasks	Severity	Arguments	Failure Detectability	Explanation
Use physical senses and camera-vision to observe own vessel behaviour and exceeding fairway limits Assess AIR-draught and roll using equipment and physical observations	Medium to high	Mis-interpretation of wheelhouse and masts elevation heights can have a serious impact of navigation safety. Also heavy rolling, due to swell in open waters, can lead to reduced stability (and possible capsizing) and cause unsafe situations for navigation, vessel and crew	Medium to heigh	The ROC-operator has no options to feel the vessels motion. We consider also that the outside view using camera-footage will by itself not provide sufficient Situation Awareness. The ROC-operator might have an indication of elevation heights of masts and wheelhouse using camera-footage. This might not be accurate enough.
Check functioning and use of relevant lifting mechanisms of mast and wheelhouse, if applicable Check ship-data feedforward accuracy and time dela	High	If the lifting mechanisms are failing within vessels stopping distance to bridge, a collision with the bridge deck will be eminent.	High	Malfunction is easy to detect, by try and error. The remaining question is if the malfunction will be detected in time to stop the vessel from passing under the bridge

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