Project title	Safe, Efficient and Autonomous: Multimodal Library of European Shortsea and inland Solutions		
Project acronym	SEAMLESS		
Project number	101096923		
Project start date	01/01/2023	**Duration**	48 months

D2.3 – CONCEPT OF OPERATIONS AND REQUIREMENTS FOR SEAMLESS BUILDING BLOCKS

Due date	31/08/2024	**Delivery date**	31/08/2024
Work package	WP2		
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Version	1.0		
Dissemination level	Public		

VERSION AND AMENDMENTS HISTORY

Version	Date (MM/DD/YYYY)	Created/Amended by	Changes
0.1	07.19.2024	Håvard Nordahl	First draft for review
1.0	27.08.2024	Håvard Nordahl	Final, review incorporated

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LIST OF ABBREVIATIONS

Abbreviation	Description
ACC	Autonomous Cargo Crane
AIS	Automatic Identification System
AMS	Autonomous Mooring System
AO	Automatic Operations (autonomy level, see section 1.3.3)
API	Application Programming Interface
AT all fast	Actual Time all mooring lines fastened
ATA	Actual Time of Arrival
ATA berth	Actual Time of Arrival at berth
ATA bridge	Actual Time of Arrival at bridge
ATA lock	Actual Time of Arrival at lock
ATC cargo ops	Actual Time Completion cargo operations
ATD	Actual Time of Departure
ATS cargo ops	Actual Time Start cargo operations
AVSPM	Advanced Vessels' Smart Port Manager
BBx	Build Block number x
CA	Constrained Autonomous (autonomy level, see section 1.3.3)
CONOPS	Concept Of Operations
CD	Continuous Development
CI	Continuous Integration
CRUD	Create, Read, Update and Delete
CS	Connectivity System
DC	Direct Control (autonomy level, see section 1.3.3)
DUC1	Demonstration Use Case 1 (the demonstration scope of the Northern European use case)
DUC2	Demonstration Use Case 2 (the demonstration scope of the Central European use case)
Dx.y	SEAMLESS project Deliverable number x.y where x denotes work package number and y is a sequence number
EDIFACT	Electronic Data Interchange For Administration, Commerce and Transport
EMSWe	European Maritime Single Window environment
EOSP	End Of Sea Passage
eRIBa	electronic Reporting for Inland Barges
ETA	Estimated Time of Arrival
ETA bridge	Estimated Time of Arrival at bridge
ETA lock	Estimated Time of Arrival at lock
ETC cargo ops	Estimated Time Completion cargo operations
ETD	Estimated Time of Departure
ETD berth	Estimated Time of Departure from berth
ETS cargo ops	Estimated Time Start of cargo operations
F	Functional Requirement (used in Functional Requirement ID tag)
GNC	Guidance Navigation and Control
GSM	Global System for Mobile
HTTP	Hypertext Transfer Protocol
JSON	JavaScript Object Notation
JWT	JSON Web Token

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ID	Identification
MNET	ModalNET
NCA	Norwegian Coastal Authority
NF	Non-Functional Requirement (used in Non-Functional Requirement ID tag)
NFR	Non-Functional Requirement
PA	Phase A: Plan shipment (defined in section 0)
PB	Phase B: Early port call planning (defined in section 3.3)
P1	Phase 1: Plan port call (defined in section 3.4
P2	Phase 2: Approach location (defined in section 3.5
P3	Phase 3: Activities at location (defined in section 3.6
P4	Phase 4: Plan departure (defined in section 3.7
P5	Phase 5: Depart location (defined in section 3.8
P6	Phase 6: Navigate (defined in section 3.9
P7	Phase 7: Pass lock (defined in section 3.10
P8	Phase 8: Pass bridge (defined in section 3.11)
PNR	Position Navigation Route
PTA	Planned Time of Arrival
PTA berth	Planned Time of Arrival at berth
PTC cargo ops	Planned Time Completion cargo operations
PTD berth	Planned Time of Departure from berth
PTS cargo ops	Planned Time Start of cargo operations
Q1	Quarter 1 (January to March)
Q2	Quarter 2 (April to June)
Q3	Quarter 3 (July to September)
Q4	Quarter 4 (October to December)
REST	Representational state transfer
ROC	Remote Operations Centre
ROW	Remote Operations Workstation
RTD berth	Requested Time of Departure from berth
RTC cargo ops	Requested Time Completion cargo operations
RTS cargo ops	Requested Time Start cargo operations
R&A	Remote and Autonomous
SCT	System Control Task
SOSP	Start Of Sea Passage
TEU	Twenty-foot equivalent unit
TLS	Transport Layer Security
TOS	Terminal Operating System
UC1	Use case 1 (The Northern European use case, full scope for concept development and impact studies)
UC2	Use case 2 (The Central European use case, full scope for concept development and impact studies)
UI	User Interface
VC	Voice Communication
VCOP	Voyage Container Optimisation Platform
VHF	Very High Frequency
VPN	Virtual Private Network
VSL	Vessel
VTS	Vessel Traffic Service
XML	Extensible Markup Language

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LIST OF PARTNER ABBREVIATIONS

Abbreviation	Company name
ISL	Institut fur Seeverkehrswirtschaft und Logistik
KMNO	Kongsberg Maritime Norway
KMFI	Kongsberg Maritime Finland
MCGNO	MacGregor Norway
MCGFI	MacGregor Finland
NTUA	National Technical University Athens
PNO	PNO CiaoTech
SO	SINTEF Ocean
VPF	Valencia Port Foundation

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EXECUTIVE SUMMARY

This report documents the outcome of the work related to SEAMLESS task 2.5 "Concept of Operations and requirements to building blocks". The task was to identify the requirements for the building blocks within the context of the use cases and logistic system architecture. Requirements shall cover functional, and non-functional requirements for the building blocks. The purpose is to provide the basis for development within the work packages developing SEAMLESS building blocks, and for the integration of the SEAMLESS building blocks.

This report constitutes the concept of operations document and defines the SEAMLESS building blocks by their subsystems, how the subsystems are intended to work, and by functional requirements for each subsystem. The SEAMLESS concept is then defined as the system constructed by combining the building blocks, defining the SEAMLESS concept architecture, and by defining the operational phases for the SEAMLESS concept and how each subsystem interacts in each phase. Non-functional requirements (NFRs) are then identified as the conditions that must be satisfied for the SEAMLESS concept to function as intended. This includes pre-conditions that needs to be satisfied per design, and conditions that may change due to external factors, e.g., weather or traffic, or internal factors such as system status. Non-functional requirements are proposed for each building block subsystem, including a mapping between NFRs and the phases they apply to.

The contexts of the two project use cases are described by the geographical areas, the transport problem that needs to be solved, the SEAMLESS concept architecture applied to the use cases, and the involved actors. Furthermore, the scenario is described by the voyage definition, which consists of the route and the operational phase that the system will be in along the route, and by the system processes. The system processes are all the tasks that must be executed during operations, such as navigation, nautical communication, or logistics management.

Then, the state space is defined per use case, i.e., a set of variables defining the conditions (NFRs) that the system will operate under. And finally, the system control tasks are proposed. System control tasks are the realisation of the system processes, per voyage phase, and can either be automated or executed by human operators. The state space and system control tasks combined, provides a definition of intended autonomy level per system control task and the conditions that must be satisfied.

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REFERENCES TO THIS DOCUMENT – ACKNOWLEDGMENTS

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Håvard Nordahl, Lars Andreas Lien Wennersberg, Jan Karsten, Patrick Specht, Janne Suominen…et.al.: “SEAMLESS deliverable D2.3: Concept of Operations and requirements for SEAMLESS building blocks”, August 2024.

The authors listed in the above citation have contributed material that has been included (more or less) verbatim in this report. The editor and contributors also acknowledge all other comments and inputs to this document from all participants in the SEAMLESS project.

1 INTRODUCTION

This report represents deliverable D2.3 – Concept of operations and requirements for SEAMLESS building blocks, based on Task 2.5 with the same name. SO was task lead and participating partners were NTUA, VPF, ISL, MCGFI, MCGNO, KMNO, and KMFI. The task description was as follows:

This task will identify the requirements for the SEAMLESS technology building blocks within the context of the use cases (T2.1) and the logistics system architecture (T2.3). SEAMLESS will implement a system's engineering approach, where requirements are given as formal and structured statements that may be verified and validated. The scope of this task will include functional (i.e., what the building blocks will be able to do) and non-functional (e.g., ergonomic requirements for ROC operators) requirements. The methodology that will be implemented for each building block consists of the following steps:

1) *defining the Concept of Operations (ConOps),*
2) *identifying stakeholder requirements to ensure relevance to stakeholder needs through engagement activities,*
3) *formally stating requirements,*
4) *validation of requirements from stakeholders, incl. the SEAMLESS Advisory Board and Reference Group.*

The engagement activities will include workshops, focus groups, surveys, and interviews, and will involve stakeholders within the Consortium, as well as external stakeholders (see T2.1). The results of this task will be used to set the scene for the specifications of the SEAMLESS technology building blocks (WPs: 3, 4, 5).

The mentioned building blocks are:

1. Automated Port Interface (DockNLoad) (WP3)
2. Modular Vessel and Operations Concepts (WP4)
3. Integrated supply chain support (ModalNET) (WP5)

This reports answers to the task 2.5 description as follows:

1) The report constitutes the concept of operations document, with specifics per use case in chapters 0 and 6.
2) Requirements have been identified through a series of activities as listed in section 1.5.
3) Functional requirements are stated formally in section 2, non-functional requirements in section 4.
4) Requirements have been validated through the same activities as listed in section 1.5. The most important stakeholders for validation have been the responsible party for each system being developed, being the domain experts.

1.1 LINKS TO OTHER WPS AND DELIVERABLES

This deliverable, documenting the work in Task 2.5, builds on the detailed description and background for the use cases from Task 2.1 [1]. The deliverable is linked to the building blocks

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developed within work packages 3, 4, and 5 by providing requirements to their functionality and outlining how they can be integrated into the SEAMLESS concept. These requirements have been developed through a tight cooperation with the three work packages.

Another link is evident to Task 2.3 which models the SEAMLESS Reference Logistics System Architecture and contains the logistics process and communication flows along a complete “cargo story”, i.e., the planning and execution of a door-to-door transport process from the consignor (origin) to the consignee (destination) via multiple transport legs using various transport modes. Whereas Task 2.3 focuses on the logistics process flow and pertaining communication and interaction patterns between different process participants, Task 2.5 focuses on the *functional and non-functional requirements of the SEAMLESS Building Blocks and their interaction within the considered process.*

The outcome of this deliverable is linked to Task 4.3 which will continue the work through studying simplification of risk-based approval. Task 4.3 will hence do a more extensive deep dive into that topic than the present report, by developing models (e.g. UML). In this respect, D2.3 is a pre-work for task 4.3.

There is also a connection between Task 2.5 and work package 7 as the planning of the demonstrations and the refinement of DUC1 and DUC2 provided inputs to Task 2.5.

1.2 LIMITATIONS

1.2.1 Scope

It should be noted that this report deals with functional and non-functional requirements (see section 1.3.2), and the concept of operations. This means that the scope is focused on how technical systems are intended to work in the operational phase. The scope thus includes the technical systems developed within SEAMLESS, i.e., the systems that are developed for the realisation of a highly automated seamless transport service. This also implies that tools and methods related to improving the design and approval phases are not in scope for this report. Specifically, building block 2 tools *Rapid Prototyping, Green machinery & Propulsion* and *Risk-based Safety Assessment* are not addressed in this report because the functional and non-functional requirements, as well as the concept of operations, are not relevant to these.

1.2.2 Considered use cases in this report

The SEAMLESS project has defined two Demonstration Use Cases named DUC1 and DUC2. These will both be investigated in terms of logistical, cost, emissions, and other socio-economic impacts, and be used to demonstrate the technology developed within SEAMLESS. The outlined scope of each of the two demonstrations, as defined in the Grant Agreement, does not cover all aspects of what is developed within the project. E.g., the autonomous cargo crane will be simulated, and the AVSPM and the autonomous mooring system will be demonstrated in one of the two demonstration use cases only. This means that the scope of each demonstration is slightly smaller compared to the corresponding scope of the application case studies that will be done within the project. This report will address the Concept of Operations and requirements for SEAMLESS building blocks from the perspective of the application case studies. I.e., the full scope of the use cases will be considered. The background for the use cases is provided in [1].

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To make a clear distinction, and to underline that we are not discussing the scope of the full-scale demonstrations, we give the use cases the following definitions for the purpose of this report:

Use case 1: Northern European Feeder-loop

Shorthand notation UC1

The case study will provide the operational conditions for applying the SEAMLESS concept to autonomous small feeder shuttles operating between a container terminal and smaller ports in the Bergen region. The objective is to replace truck transportation with an efficient and cost competitive waterborne option. Detailed definition of the use case is given in section 0. It should be noted that there is an important difference between the UC1 studies done within the SEAMLESS project, and the full-scale demonstration DUC1. While UC1 is centred around a transport problem in the Bergen region in Norway, for practical reasons, the full-scale demonstration DUC1 will be performed in the Horten-Moss area with the ASKO ferries. This report deals with UC1, not the planning and preparation of the full-scale demonstration of DUC1 (which will be handled in SEAMLESS work package 7 at a later stage of the project). The technical conditions for DUC1 and UC1 are similar, the technical concept is the same, and requirements presented in this report are applicable to both DUC1 and UC1.

Use case 2: Central European Waterway Shuttle

Shorthand notation UC2

The case study will provide the operational conditions for applying the SEAMLESS concept to autonomous inland waterways container barges operating on a roundtrip shuttle service between Lille and Duisburg to replace long-haul truck transport. Detailed definition of the use case is given in section 6.

1.3 DEFINITIONS

This section contains some definitions that are important for the correct understanding of the concept of operations and requirements given in this report.

1.3.1 The SEAMLESS concept, building blocks, and subsystems

Subsystem: A technical system automating one or more specific tasks, and which is a subsystem to a building block. Examples are the autonomous mooring system and the Remote Operations Centre (ROC). Detailed definitions are given in chapter 2.

SEAMLESS building block: The combination of subsystems that form a building block. The building blocks are: Automated port interface (DockNLoad), Modular vessel and operations concept, and Integrated supply chain support. Detailed definitions in chapter 2.

SEAMLESS concept: The automated transport system made by integrating the SEAMLESS building blocks. Defined in more detail in chapter 3.

1.3.2 Requirements

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Requirements: Both functional and non-functional requirements proposed in this report shall be understood as requirements for the SEAMLESS concept.

Functional and non-functional requirements are defined for the building block subsystem according to definitions as discussed in [2]. These definitions are:

Functional requirements: "*A function that a system must be able to perform."* Or, "*a requirement that specifies an action that a system must be able to perform, without considering physical constraints; a requirement that specifies input/output behaviour of a system.".* Functional requirements are qualitative.

Non-functional requirements: "…*specifies system properties, such as environmental and implementation constraints, performance, platform dependencies, maintainability, extensibility, and reliability. It can be a requirement that specifies physical constraints on a functional requirement".* Non-functional requirements are qualitative or quantitative. Non-functional requirements are measurable, and qualitative non-functional requirements have values such as on/off, true/false, active/inactive, etc.

As an extension to the above definition, we define non-functional requirements as parameters for which a numeric or Boolean (true/false) value can be set. This makes non-functional requirements (NFRs) quantifiable conditions that must be met to guarantee the specified functionality. For the purposes of this report, NFRs are thus conditions that shall be met to guarantee the correct function of a subsystem when it is an integrated part of the SEAMLESS concept. Further details on the significance of NFRs and how they are used in the definition of the CONOPS are given in section 1.4.

As this report will present identified requirements, it is necessary to define the terms *Shall* and *Should*. These terms are defined as follows, and inspiration is taken from [3].

Shall: verbal form used to indicate requirements strictly to be followed to ensure the correct functionality of the SEAMLESS concept.

Should: verbal form to indicate that among several possibilities one is recommended as particularly suitable, without excluding other possibilities, or that a certain course of action is preferred but not required.

Interpretation shall and should: a *shall* requirement means that it is strictly to be followed to ensure correct function of the SEAMLESS concept, however, it does not mean that it is strictly to be followed in all application of the system for which the *shall* requirement has been identified. As an example, the Remote and autonomous vessel systems (R&A vessels systems) have the following non-functional requirement:

The autonomous mooring system shall handle the mooring process autonomously without any other commands from the R&A vessel system than "connect", "disconnect", "abort", and "commence".

This would not be a strict requirement for applications of R&A vessel systems in general as it is possible that autonomous mooring is not part of the overall system, or that some other actor is responsible for interfacing the autonomous mooring system. Similarly, *should* requirements are

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based on the assumption that the system for which the *should* requirement has been identified is an integrated part of the SEAMLESS concept.

1.3.3 Autonomy level and ROC operator modes

The definitions proposed in [4], and somewhat elaborated in [5], will be the basis for the autonomy levels used in this report.

Direct Control: The operator has full control of the system, e.g., by levels and push buttons, and uses relatively simple automation and decision support systems. This is the normal automation mode on a conventional ship today.

Automatic Operations: The automation system performs the operations under continuous supervision by an operator. Examples are auto-docking, auto-tracking, dynamic positioning. While the automation performs the operation, it is the operator that makes decisions such as when to activate a function or system, what option to choose from proposals generated by decision support, providing setpoints, route, or motion trajectories (e.g., for a crane), or deviating from a plan.

Constrained Autonomous: The automation performs the operations without continuous supervision of a human operator. Decision making is automated such that function and system activation, setpoints and commands to controllers are done by the automation. However, there are clearly defined conditions specifying the decision making capability of the automation (e.g., visibility, environmental conditions, or system status), which must be satisfied. If conditions are not satisfied, the decision making shall be handed over to the ROC operator. Furthermore, the ROC operator creates and uploads a digital mission defining the voyage, cargo operations, and schedule, as well as the conditions and limitations for the automated decision making. Legal responsibility, i.e., the role of the master, remains with the ROC operator.

Autonomous: When used in the discussions within this report, autonomous refers to autonomy level Constrained Autonomous.

The SEAMLESS project is studying ROC operator modes within work package 4. The purpose is to achieve operations of a fleet of three vessels by one ROC operator team. While several modes are likely to result from the research in work package 4, the most important distinction for this report is between low and high operator attention mode.

Low operator attention mode: The operator is presented with a reduced set of information per vessel, providing sufficient information to monitor three vessels operating in Constrained Autonomous mode.

High operator attention mode: For a given vessel operating in Automatic Operations mode, the operator is presented with sufficient information to actively ensure safe operations.

It should be noted that for one given vessel some subsystems, e.g., power distribution and machinery, could be in low operator attention mode while another, e.g., navigation systems, could be in high operator attention mode. In the same way, it is possible to have different autonomy levels for different subsystems.

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R&A vessel: Remote and autonomous vessel. This definition assumes that the vessel is operating without crew onboard, and that the vessel is supported by operators in a Remote Operations Centre. The autonomy level can be Constrained Autonomous or Automatic Operations.

1.3.4 CONOPS related definitions

Simplification of approval of autonomous ship systems by their operational envelope was proposed in [6], and a methodology for defining the CONOPS, based on the ideas in [6], was proposed in [7].

Some important definitions that were first proposed in [7], and which are important for our methodology in section 1.4 and the UC1 and UC2 CONOPS in chapters 0 and 6, are Voyage Phase Patterns, Ship Control Tasks, and the State Space. In addition, our extension of the Ship Control Task to define the System Control Task.

Voyage Phase Patterns: A generalisation of voyage phases covering several voyage phases with the same characteristics. Examples are that "Berthing at port A" and "Berthing at port B" are two voyage phases that can be generalised into the same voyage phase pattern "Berthing".

Ship Control Task: A high-level ship function such as "Navigate during berthing", or "Autonomous cargo handling" [7], which could be automated under pre-defined conditions.

System Control Task: The SEAMLESS scope extends beyond the ship functions. The System Control Tasks hence include all relevant Ship Control Tasks, and control tasks related to logistics operations such as "Manage logistics".

State Space: "The state space for each ship control task is described by a set of variables used to describe the condition under which the ship system will operate in this use case." [7]. I.e., the state space defines the conditions that must be satisfied for operating in a given autonomy mode in a specific application of an SCT, by the application specific variable values. Example state space variables are environmental conditions such as wind, waves, rain or snow, geographic conditions, traffic conditions, or system state (active failures or not).

In our case, this translates to: *The state space for each system control task is described by a set of variables used to describe the conditions under which the SEAMLESS concept will operate in this use case.*

1.4 METHODOLOGY AND STRUCTURE OF THE REPORT

The CONOPS definition and methodology that this report is based on is given in [7]. This is the same methodology that will be further developed in SEAMLESS work package 4 Task 4.3. The methodology is based on formally describing the autonomous ship system through several steps, or levels. First the context is described, then the scenario, and finally the use cases. Several iterations through these steps may be needed before the final CONOPS is ready. An overview of the main steps and sub-steps is given in Figure 1 which is taken from [7].

The idea behind this method is that by formally defining use cases by Ship Control Tasks (equivalent to System Control Tasks, see section 1.3.4) and the state space (see section 1.3.4), it should be possible to simplify the approval for applying an already approved Ship Control Task to another application. A new application would require quantification of the state space variables, and verification that the systems implementing the Ship Control Tasks comply.

To define the system subject to the CONOPS, by System Control Tasks and the state space, it is necessary to define the intended functionality of the system and the conditions for the intended functionality to work. This translates to defining functional and non-functional requirements (defined in section 1.3.4). While non-functional requirements (NFRs) include pre-conditions, some NFRs corresponds to *conditions* in the operational envelope concept proposed in [6], and applied in [7], where the functional distribution between automation and operator depends on *conditions* that must be satisfied to guarantee correct behaviour.

The structure of this report is therefore as follows: the definitions of SEAMLESS building blocks, their subsystems and functional requirements, are given in section 2, the SEAMLESS concept architecture and operational phases (corresponding to voyage phase patterns) are given in section 3, the non-functional requirements, from which state space variables are extracted, are given in section 4, and in sections 0 and 6 we present the Context, Scenario, and Use Cases based on the method in [7], with the modifications as given in Figure 2.

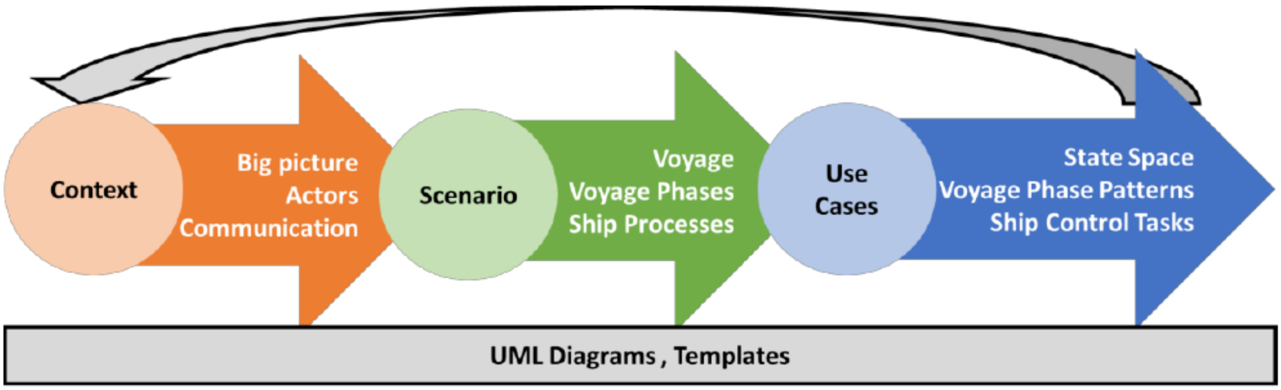

Figure 1: Methodology overview
Source: the figure is taken from [7].

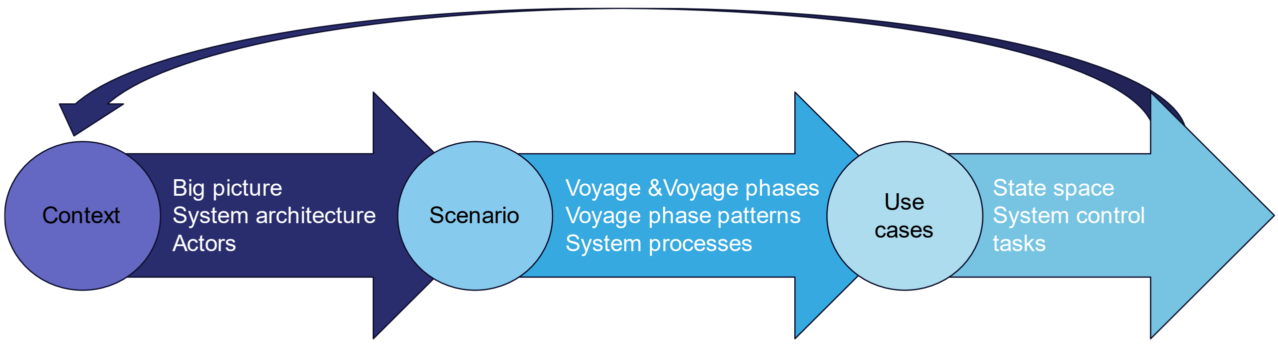

Figure 2: Implemented methodology

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1.5 WORKSHOPS AND FOCUS GROUPS

The development of this report has been in tight cooperation with other work packages, experts both from the project consortium and external to the project. The following is a listing of the main stakeholder engagement activities.

Workshops:

- Bergen Q1 2023 (D2.1 documents the outcome)
- Trondheim Q4 2023 (Section 3 documents the result)
- Antwerp Q1 2024 (Specifying DUC2)
- Lysaker Q1 2024 (Specifying DUC1)
- General Assembly in Duisburg Q2 2024 (workshops further specifying DUC1 and 2)
- Online meeting series Q1-Q2 2024 (refining DUC1)
- Online meeting series Q1-Q2 2024 (refining DUC2)

Focus groups:

- VCOP and Crane – MCGFI and MCGNO online meetings 2024 Q2-Q3 (Sections 2.1, 4.1, 4.2, and 0 documents the results)
- Vessel and ROC – KMNO and KMFI online meetings 2024 Q2 (Section 2.2, 4.5, 4.6, and 4.7, documents the result)
- ModalNET – VPF online meetings 2024 Q2 (Section 2.3 and 4.8 documents the result)

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2 BUILDING BLOCKS

The SEAMLESS project will develop three missing building blocks for realising SEAMLESS cargo transport. Each of these building blocks consist of a set of subsystems. This section will introduce the building blocks, their subsystems, architecture, and main functionality. For each building block, the functional and non-functional requirements will also be presented.

2.1 BUILDING BLOCK 1: AUTOMATED PORT INTERFACE (DOCKNLOAD)

The DockNLoad consist of four main subsystems:

- The autonomous onboard robotic mooring arm and winch, which handles automated mooring by placing conventional mooring lines on conventional bollards.
- The autonomous cargo crane which can be placed both onboard vessels and at quay.
- The Voyage and Container Optimisation Platform (VCOP), which automates stowage and cargo handling sequence planning.
- The Autonomous Vessels' Smart Port Manager (AVSPM), which handles automated port calls for autonomous vessels.

An overview of the DockNLoad building block is given in Figure 3.

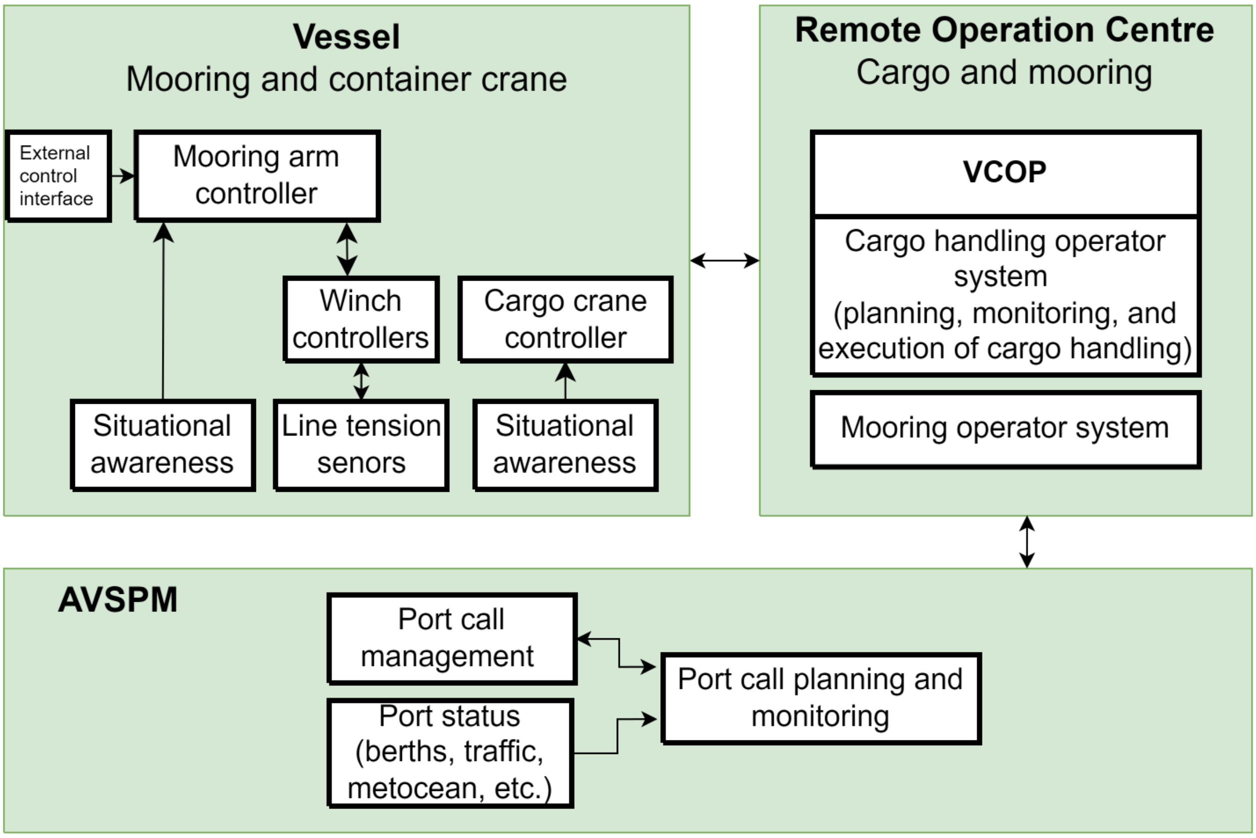

Figure 3: Building Block 1: DockNLoad

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The autonomous mooring system consist of a robotic arm for placing mooring lines on bollards, a winch for controlling line tension, and an autonomous control system. The system is designed to be placed onboard vessels, where one winch per mooring line is needed (typically 4 in total), and more than one robotic arm could be needed depending on vessel size. See Figure 4.

Figure 4: The robotic mooring arm installed on Yara Birkeland
Source: MacGregor

The system has an interface for external command signals enabling integration with the vessel control systems, the ROC, handheld remote controllers, etc., see Figure 5. While the mooring arm and the winches have dedicated controllers, it is the mooring arm controller that serves as the overall system controller, and which is interfaced to external systems. The following will discuss the two subparts: the robotic arm, and the winches.

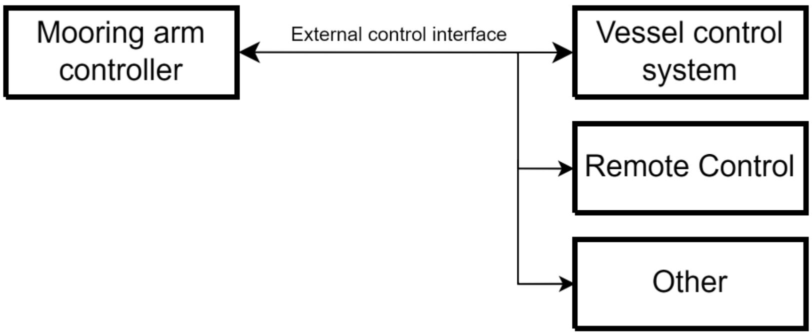

Figure 5: Autonomous mooring system external control interface

The robotic arm executes the mooring or unmooring sequence automatically. The sequence is initiated (or aborted) through command signals over the external interface. The status can be supervised from a ROC, and the ROC operator can abort a mooring sequence if this should be needed.

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The robotic arm depends on its sensory system to detect the quay and bollards, verify that the bollard is not already in use, and calculate trajectories for moving the arm and mooring line to the bollard, and place the line on the bollard. If a digitalized map of the quay side with coordinates for the bollards is available, it can shorten the time used to detect the bollards. While the robotic arm is moving, it is compensating for vessel movements such that relative position and movements between the mooring arm and bollard are not affected by the vessel motions. Object detection and the anti-collision system ensures that the mooring arm does not crash into any object or structure. Once mooring lines are placed, the mooring arm retracts to the parking position, and the line tension is controlled by the winches.

The system also performs automatic unmooring. In this case the robotic arm moves from the resting position on the vessel to above the bollard which it placed a mooring line on. From that position it locates and identifies the mooring line and the gripping position and moves towards the line and grips it. It is recommended that independent bollards are used for the Autonomous mooring system. In case some other mooring line has been placed on a bollard to be used, the system will detect this and abort. This is the case both during mooring and unmooring.

Winches control the line tension automatically according to setpoints given through the control interface to the mooring arm controller. This will add roll stability (needed during cargo handling), as well as release or tighten mooring lines during draft and tide changes. The winch control system also includes the possibility to adjust the vessel position through a hauling feature. The vessel control system (or external controller) can command the mooring system to pull the vessel forward or backwards, through the external control interface. The mooring system controller will then synchronize the (normally) 4 winches to slowly haul the vessel.

The autonomous cargo crane is designed to be placed onboard a vessel. For smaller vessels the crane will be too large, and, in such cases, it can be placed at the quay side. The autonomous cargo crane is designed as a triple joint crane, as illustrated in Figure 6. In the figure, the container is hoisted to the top position such that the load line is not visible, however, the crane does include a winch for hoisting.

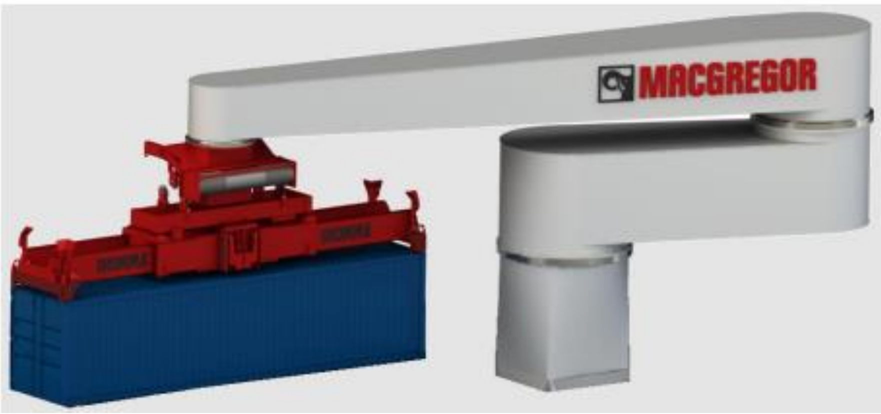

Figure 6: The MacGregor triple joint crane
Source: MacGregor

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The autonomous crane has an interface for receiving work instructions consisting of the cargo to be moved, the location for grabbing it, and the locations for placing it. The autonomous cargo crane also communicates status over this interface, such as “container ID.x has been placed in location[1] y”. In the SEAMLESS building block 1, the autonomous cargo crane is interfaced to the VCOP and to a remote controller (Figure 7).

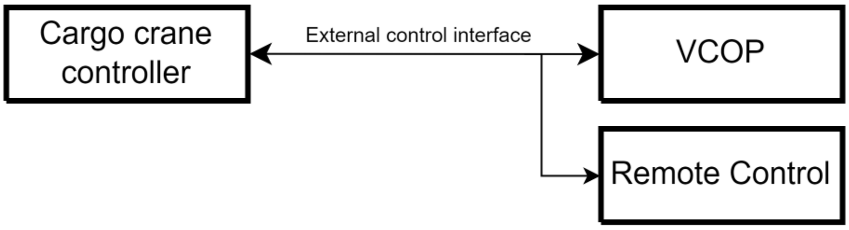

Figure 7: Autonomous cargo crane external control interface.

The autonomous cargo crane has its own situational awareness and autonomous controller. In addition, the system depends on digital maps of the quay side and the vessel, and the real-time vessel position and orientation. The crane system receives it starting command from the ROC and scans the surrounding to ensure secure operations. Once this is done, and the container sequence is received from the VCOP, the autonomous controller moves the crane with its spreader to the vicinity of the container that is to be handled. The situational awareness reads the container markings (e.g. container identification number) to verify that it is the correct container, calculates accurate position, and trajectories for the crane motions. At the same time, object detection and collision avoidance ensure that the crane does not crash with anything during operation. The crane positions the spreader and locks on to the container. It then lifts the container, moves it to the predefined destination location (which could be onboard the vessel or on the quay side), places it securely in the location and releases the container. Once this is done, the autonomous crane controller reports back to the VCOP that container with given ID has been placed in the given location.

A cargo handling operation can be aborted manually from the ROC via the VCOP user interface. Once a cargo handling sequence is completed, the crane moves into parking position.

The VCOP is a logistics and cargo handling planning tool. In SEAMLESS building block 1 its main function is to automatically generate the stowage plan, the loading and unloading sequences, to be the high-level controller for the autonomous cargo crane by sending work instructions, and to monitor the execution of these.

The automated stowage planning is done while considering vessel stability, sailing schedule, cargo source and destination. Based on the generated stowage plan, the VCOP generates loading and unloading sequences. The VCOP thus generates both the workorders for the autonomous container crane (or cargo handling equipment) and is the interface towards the terminal for communicating loading and unloading sequences such that terminal handling can be planned and organized.

[1] A location is a geographical location where a container can be placed. In a digital representation of a vessel, or a terminal, the storage areas are divided into location defined by x, y, z coordinates and an ID.

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The VCOP user interface includes the autonomous crane user interface and will be a tool for the ROC operators that can be integrated to the remote operations workstations. It also includes a logistical interface for the stowage and loading/unloading sequences.

Advanced Vessels' Smart Port Manager (AVSPM) is the final part of DockNLoad (building block 1). AVSPM handles automated port calls for autonomous vessels by conducting port call management and negotiation, digitised port notices, port traffic and metocean data exchange with the autonomous vessels, and real time safety and security monitoring.

The AVSPM is a digital interface between the port and the ROC. The AVSPM handles both long-term and short-term port call planning. For the long term planning (weeks or even months ahead) a pre-reservation of berth can be done. Such pre-reservations can be overridden in rare cases, such as some maintenance activities that must be done. In such cases the ROC will receive a notification message from the AVSPM.

Short term port call planning is executed days, or hours, prior to a port call. This is a negotiation for fixing terminal and berth, exact time of arrival and departure, for a port call. It includes information such as bollards to moor to (id and placement) and the route that the R&A vessel intends to sail within the port area. The AVSPM includes port call change management, which is a re-negotiation of one or more of the agreed resources (terminal, berth, bollards, etc.).

The AVSPM offers transmission of relevant metadata for berths, bollards, terminals, etc.

The AVSPM handles the port call execution. This includes confirmation of the berth readiness for the port call prior to initiating auto-docking, exchanging key information such as traffic with accurate positioning of other ships, objects, etc., port notices and local environmental data such as wind and current conditions, which is used in the port manoeuvring phase. AVSPM also handles event tracking such as registering berth approach about to start (30 minutes to berth arrival), berth manoeuvring activated, actual time of arrival, berth all fast (vessel fully moored), actual time of departure, etc. Such berth events are timestamped and sent from the ROC to the AVSPM.

The AVSPM also monitors the safety state of the R&A vessel by receiving safety pulses and safety events from the ROC. The safety pulses indicate the navigational and communication status of the vessel. The safety event messages inform the AVSPM about events related to safety, such as related to navigation, manoeuvrability, equipment, energy, communication, etc.

The AVSPM offers port call monitoring to the Traffic Managers of the smart port through a user interface (UI). This gives insight into planned port calls, and the status. It includes zone events for an R&A vessels specific port call, which are timestamps for all entry and exit events of predefined zones. It includes position navigation route (PNR) pulses, which contains position, speed, course, draft, AIS status, wind speed and direction, navigational status, and route. It includes R&A vessel behaviour observations such as breaking speed limits, adherence to route, confrontations, overtaking, timeliness, PNR and safety pulse sending requirement fulfilment. And it includes navigational data which is the historical track of the R&A vessel.

The UI also offers insight into the AVSPM system health status and offers the option of chat messaging to manage the port call.

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Sometimes it can happen that the AVSPM must do changes to a port call, inform about some other important information to the ROC, or even cancel the port call. In such cases the AVSPM will notify the ROC by dedicated pre-defined messages.

Finally, the AVSPM handles port call post processing. This is done when the R&A vessel leaves the port area and consists of two main steps: 1) analysis and comments of the R&A vessel navigational behaviour inside the port area 2) Behaviour of conventional vessels when navigation near or near by the R&A vessel. These reports will automatically be sent to pre-configured e-mails, and are intended for learning and improvement processes, both for the port (AVSPM) and the ROC. However, the ROC must request these reports through the unique key created during the port call negotiation.

The following sections present the identified building block 1 requirements resulting from activities as listed in section 1.5, the SEAMLESS report [1], and direct inputs from the responsible partner of this building block.

2.1.1 Autonomous Mooring system functional requirements

The identified functional requirements for the Autonomous Mooring System (AMS), is given in Table 1. The table gives the functional requirement ID (subsystem.Functional.sequence), name, and description.

Table 1: AMS functional requirements

ID	Name	Description
AMS.F.01	**Positioning robotic arm**	The robotic mooring arm controller shall calculate the robotic arm position, and pose, relative to the vessel and its structures, in a digital 3D model, based on the situational awareness.
AMS.F.02	**Situational awareness**	The robotic mooring arm shall have sensors for situational awareness. The situational awareness shall position the robotic arm within the vessel 3D model, detect and position objects.
AMS.F.03	**Auto-mooring sequence**	When a ship is at the dedicated berth position and a start mooring command signal is given to the autonomous mooring system, it shall complete the auto-mooring sequence
AMS.F.03.1	Locate and grab	The AMS shall locate and grab the mooring line from pre-defined resting position in the vessel 3D model
AMS.F.03.2	Move from ship	The AMS shall move arm and mooring line from the vessel, over to the quay in the vicinity of the target bollard
AMS.F.03.3	Detect bollard	The AMS shall, using the situational awareness and digital 3D model, detect the target bollard.
AMS.F.03.4	Calculate trajectory	The AMS shall calculate a motion trajectory for moving the robotic arm with the mooring line to the bollard.
AMS.F.03.5	Detect obstacles	The AMS shall detect any obstacles in conflict with the robotic mooring arm trajectory.
AMS.F.03.6	Collision avoidance	The AMS shall execute collision avoidance and re-calculate trajectories considering any detected obstacles.

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AMS.F.03.7	Detect other mooring lines	The AMS shall determine if a bollard is already in use by other mooring lines, and if so, do not use an occupied bollard
AMS.F.03.8	Place mooring line	The AMS shall move the mooring line onto bollard and release the mooring line
AMS.F.03.9	Retract arm	The AMS shall retract to parking position (or move to next mooring line)
AMS.F.03.10	Adjust line tension	The AMS shall tighten mooring lines for safe mooring with the winch
AMS.F.03.11	Abort	Depending on the situation and cause of the need to abort the mooring sequence, e.g., no collision free trajectory can be calculated, or a bollard is occupied, the AMS should stop and freeze mooring arm pose, or retract to parking position.
AMS.F.04	**Automatic motion compensation**	The mooring arm shall perform automatic ship motion compensation. Compensation of ship motions should be such that arm motions and position are stable (not effected by ship motions) relative to the bollard.
AMS.F.05	**Automatic line tension control**	When the ship is moored the winch shall automatically control line tension
AMS.F.05.1	Vertical displacement	The automatic line tensioning shall handle variation in water height (e.g., tidal changes), and variation in draft
AMS.F.05.2	Ship motion damping	The automatic line tensioning shall dampen ship-motions (specifically roll)
AMS.F.05.3	Line tension setpoint	When the ship is moored the winch system shall be able to take commands from the ship controller, via the mooring arm controller, to set the line tension setpoint
AMS.F.05.4	Hauling ship	When the ship is moored the winch system shall be able to take commands from the ship controller, via the mooring arm controller, to haul the ship forward and backward for adjusting ship position
AMS.F.06	**Auto-unmooring sequence**	When a ship is moored and an unmooring command signal is given to the autonomous mooring system, the AMS shall complete the unmooring sequence.
AMS.F.06.1	Move towards bollard	Arm shall move to an estimated position over the bollard where the mooring line was attached.
AMS.F.06.2	Detect other mooring lines	The AMS shall detect if other mooring line has been placed on bollard. If so, abort unmooring.
AMS.F.06.3	Detect mooring line	The AMS shall detect own mooring line and its gripping point.
AMS.F.06.4	Calculate trajectory	The AMS shall calculate a motion trajectory for moving the robotic arm to the mooring line.
AMS.F.06.5	Detect obstacles	The AMS shall detect any obstacles in conflict with the robotic mooring arm trajectory.
AMS.F.06.6	Collision avoidance	The AMS shall execute collision avoidance and re-calculate trajectories considering any detected obstacles.
AMS.F.06.7	Grab mooring line	The AMS shall move the robotic arm to the mooring line, place gripping mechanism and grip the mooring line.

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AMS.F.06.8	Release line tension	When the mooring line has been gripped, the AMS shall release tension in mooring line as needed.
AMS.F.06.9	Retract mooring line	The Ams shall lift the mooring line off the bollard and retract it to the ship.
AMS.F.06.10	Park mooring line	The AMS shall place mooring line at parking position, retract arm to parking position, or move to next bollard.
AMS.F.06.11	Abort	Depending on the situation and cause of the need to abort the mooring sequence, e.g., no collision free trajectory can be calculated, or a bollard is occupied, the Ams should stop and freeze mooring arm pose, or retract to parking position.
AMS.F.07	**Status messages**	The AMS shall send status messages to its supervising controller. This could be a user interface in a ROC, or it could be that it is controlled by the R&A vessel systems
AMS.F.07.1	First mooring line fastened	The event “first mooring line fastened” shall be notified. This is e.g. used by terminals to determine actual time of arrival.
AMS.F.07.2	Last mooring line fastened	The event “last mooring line fastened” shall be notified. This gives the information that the mooring is completed and the next operation, e.g. cargo operations, can start.
AMS.F.07.3	Status	Sensor and actuator health (detected errors and faults), and system status (idle, mooring, x lines remaining, etc.) shall be notified.
AMS.F.07.4	Exceptions	Exceptions such as object obstructing operation, component and system failures, etc. shall be notified.

2.1.2 Autonomous cargo crane functional requirements

The identified functional requirements for the Autonomous Cargo Crane (ACC) are given in Table 2. The table gives the functional requirement ID (subsystem.Functional.sequence), name, and description.

Table 2: ACC functional requirements

ID	Name	Description
ACC.F.01	**Determine crane position**	The autonomous cargo crane controller shall calculate the crane movable structural parts position, and pose, relative to the vessel and other structures, in a digital 3D model, based on the situational awareness.
ACC.F.02	**Situational awareness**	The autonomous cargo crane shall have sensors for situational awareness. The situational awareness shall determine the position of the crane movable structural parts within the 3D model, detect and determine position of obstacles and containers.
ACC.F.03	**Ship motion compensation**	When installed on a vessel, the crane shall compensate for ship motions such that crane tip and payload motions are unaffected by vessel motions.
ACC.F.04	**Container handling sequence**	The autonomous container crane shall automatically perform container handling, while performing anti-collision

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ACC.F.04.1	Calculate trajectory	The autonomous container crane shall automatically calculate a motion trajectory from current position to target position (location of container to be handled) within the 3D model.
ACC.F.04.2	Collision avoidance	The autonomous container crane shall detect obstacles and structures (ACC.F.02) and avoid collisions while moving towards the target position by re-calculating motion trajectories as needed.
ACC.F.04.3	Locate and ID container	The autonomous cargo crane shall automatically move towards the container to be handled, based on calculated trajectories. Once in the vicinity of the container it shall locate the container and read the container ID.
ACC.F.04.4	Grab container	Once container ID is confirmed, the autonomous cargo crane shall position the spread and grab the container.
ACC.F.04.5	Move to container destination	The autonomous cargo crane shall lift and move the container to its target position by calculating trajectory (ACC.F04.1) and performing anti-collision (ACC.F.04.2).
ACC.F.04.6	Place container	The autonomous cargo crane shall place the container in the designating location, with correct orientation, and release the container.
ACC.F.04.7	Re-position	The autonomous cargo crane shall move to next container, or resting position.
ACC.F.05	**Status to VCOP**	The autonomous container crane shall transmit status signals to the VCOP
ACC.F.05.1	Picked up	When the crane has picked up a container it shall send “Container ID.x picked up” status signal notifying that the container location is now empty. E.g., used to notify the Terminal Operating System (TOS) that the next container to be loaded can be placed in the location.
ACC.F.05.2	Discharged	When the crane has placed a container at a location it shall send “Container ID.x discharged to location with id y” status signal notifying that there is a container in location y. E.g., used to notify TOS that there is a container in location y ready for being picked up by terminal container handling equipment, for transport to storage or the next vehicle in the transport chain.
ACC.F.05.3	Status	Sensor and actuator health (errors and faults), and status (moving container, idle, etc.)
ACC.F.05.4	Exceptions	Exceptions such as object obstructing operation, component and system failures, etc.

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2.1.3 VCOP functional requirements

The identified functional requirements for the VCOP are given in Table 3. The table gives the functional requirement ID (subsystem.Functional.sequence), name, and description.

Table 3: VCOP functional requirements

ID	Name	Description
VCOP.F.01	**Booking interface**	Shall have an interface for receiving shipments (cargo information, source and destination, voyage to be transported on).
VCOP.F.02	**Stowage plan generation**	Shall automatically calculate optimal stowage plan based on stability concerns, cargo (size, weight, source and destination), and voyage plan.
VCOP.F.03	**Handling sequence generation**	Shall generate cargo handling sequences based on the stowage plan: Container id, current location and destination location.
VCOP.F.04	**TOS interface**	Shall have an interface to the Terminal Operating System (TOS).
VCOP.F.04.1	Cargo handling sequence	The interface shall include loading sequence and unloading sequence transfer to TOS.
VCOP.F.04.2	Event and status	The VCOP shall send and receive event and status messages over an interface to the TOS.. Examples: • Initiate unloading/loading sequence • Container handling events (ID.x picked up from location y, ID.x placed in location y) • Reporting on completed loading/unloading
VCOP.F.05	**Crane control**	Shall be the high-level controller for the autonomous container crane and monitor status, generate work orders for the crane, initiate and abort cargo handling sequences.
VCOP.F.06	**User interface**	The VCOP shall include user interfaces for ROC operators and for bay planners.
VCOP.F.06.1	ROC operator	User interface for ROC operators shall at least include the following functions: • Crane controls • Crane status • Cargo handling operation status • View and accept plans • Modify plans
VCOP.F.06.2	Bay planner	User interface for bay planner shall include at least the following functions: • Receive new bookings to be planned • View and accept plans • Modify plans • Cargo handling operation status

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2.1.4 AVSPM functional requirements

The identified functional requirements for the AVSPM are given in Table 4. The table gives the functional requirement ID (subsystem.Functional.sequence), name, and description.

Table 4: AVSPM functional requirements

ID	Name	Description
AVSPM.F.01	**Traffic data**	Shall share precise traffic data observations and short-term route predictions of other vessels to the ROC
AVSPM.F.02	**Metocean**	Shall share metocean data for the port area with the ROC
AVSPM.F.03	**Early port call planning**	Shall automatically respond to ROC requests to initiate an early (long term) port call planning and execute it.
AVSPM.F.04	**Port call planning**	Shall automatically respond to ROC requests to initiate a port call negotiation and execute the port call negotiation.
AVSPM.F.05	**Safety state of R&A vessel**	Shall monitor the safety state of the R&A vessel and determine the safety situation.
AVSPM.F.05.1	Safety pulse	The R&A vessel issues a safety pulse via the ROC which the AVSPM shall receive and interpret.
AVSPM.F.05.2	Safety state	The AVSPM shall determine the safety state based on the safety pulse issued by the R&A vessel. Navigational status and the situation at hand shall be analysed to determine the safety state.
AVSPM.F.06	**Health pulse**	The AVSPM shall issue a health pulse at regular intervals to enable the ROC to determine the status of the AVSPM
AVSPM.F.07	**Port call metadata**	During the port call, the AVSPM shall provide the necessary metadata to the ROC
AVSPM.F.08	**Port call post processing**	The AVSPM shall post process the port call by the R&A vessel. It shall analyse and score the R&A navigational behaviour, as well as the other vessels behaviour around the R&A vessel.
AVSPM.F.09	**UI for VTS/ Port Traffic Management**	The AVSPM shall provide a user interface for the port traffic management to: • Accessing planned port calls • Accessing recorded data for executed port calls • Supervising ongoing port calls • Messaging with ROCs • R&A vessel behaviour during port calls (keeping speed limits and other regulations)

2.2 Building Block 2: Modular vessel and Operation Concept

This building block includes the design phase through a prototyping tool for evaluating the performance of a design, and a method for safety assessment for risk-based approval. These are not within the scope of this report as this report deals with the CONOPS and requirements for the SEAMLESS building blocks, which implies the overall technical system that is the SEAMLESS concept. However, this report will feed into the work related to developing a new method for safety assessment for risk-based approval.

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The building block also includes the operational phase through a Guidance Navigation and Control (GNC) scheme, or the Remote and Autonomous (R&A) vessel systems, and a Remote Operations Centre (ROC) concept. In addition, the connectivity system constituting the interface between the R&A vessel and the ROC is included, see Figure 8. These are central for this deliverable as they are part of the overall SEAMLESS concept and will be discussed in the following.

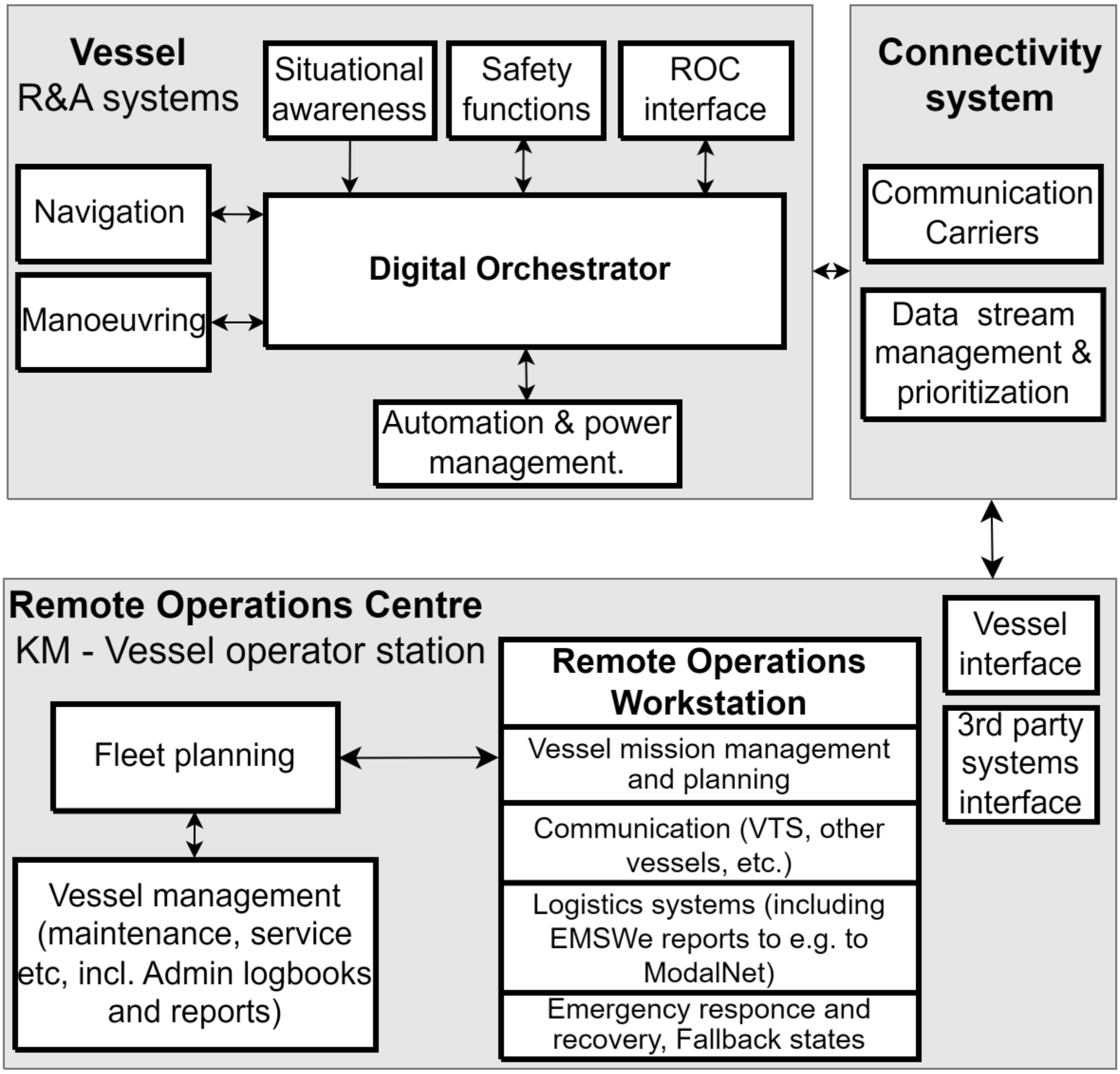

Figure 8: Building block 2: Modular vessel and Operational Concept

The R&A vessel systems include Onboard Systems such as automation and power management systems, navigation and manoeuvring systems, situational awareness systems, safety functions, and communication interface to ROC. In addition, the Digital Orchestrator, which is the system tying everything together, communicates with the ROC, and which manages the execution of the autonomous mission.

The Onboard Systems can be defined as all vessel systems that executes the commands from the Digital Orchestrator, and which provides status signals, sensor data and measurements, that the Digital Orchestrator uses to monitor system status.

The Digital Orchestrator can be defined as the generalized software system performing similar tasks as relevant for the human roles Master, Navigator, and Chief, currently onboard the vessel. The software systems generalized as the Digital Orchestrator are the Digital Chief, The Digital Navigator, and the Digital Master, see Figure 9. The Digital Orchestrator is responsible for communication with the ROC, for supervising the vessel and external conditions and thus the situational awareness, and for the autonomous navigation. It is responsible for monitoring and executing the mission, and for detecting and notifying the ROC of the need for operator attention mode switching. The Digital Orchestrator executes the mission by setting the Onboard Systems in the correct mode, providing the setpoints and commands to initiate, abort or complete the execution of a given task by the Onboard Systems. It should however be noted that it is not the case that the Digital Orchestrator holds the role of the Master, this role will be held by an ROC operator.

The R&A vessel systems will thus handle all vessel processes, watchkeeping, navigation, automation, and the execution of the pre-defined voyage mission. The Digital Orchestrator can, however, take mission update commands from the ROC, and the ROC operator can take over control.

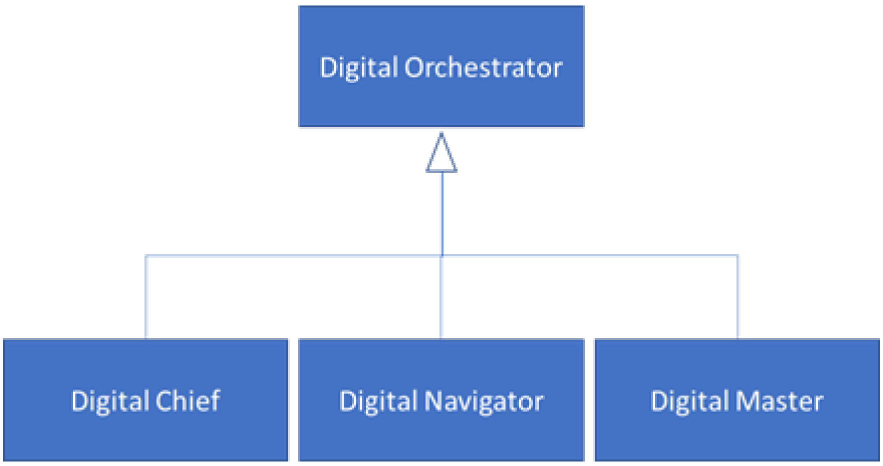

Figure 9: The Digital Orchestrator

The R&A vessel systems are based on the Key Enabling technologies that were developed and demonstrated in the AUTOSHIP[2] project. In AUTOSHIP the technology reached a level where the ROC operator had to monitor the vessels in a one-to-one relationship. Which means that the technology automatically executed navigation and all other vessel processes, however, the operator needed to continuously monitor the R&A vessel and be ready to intervene at a relatively short notice. The ambition of SEAMLESS is to move from this “one-to-one” relationship between the navigational operator and vessel, to a “one-to-many” relationship.

[2] https://www.autoship-project.eu/

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This requires advancing both R&A vessel and ROC technology, and definitions of operational modes, conditions for operating in a given mode, and procedures for switching between modes. In SEAMLESS the R&A vessel technologies will be further advanced to enable low attention operation mode (enabling one-to-many operations). This means that the Digital Orchestrator should manage most situations on board the vessel, and requests for intervention by the remote operator should be reduced. The principle is that the Digital Orchestrator will be aware of certain conditions that needs to be fulfilled to remain in low attention mode. These conditions can be related to traffic, weather, geography, and the R&A vessel system status. If the Digital Orchestrator detects that one or more condition crosses a pre-defined threshold, it notifies the ROC and requests the ROC to be monitored in high attention mode. In the end, it is the operator who decides to switch attention mode or not. This decision can also be made without a request from the Digital Orchestrator.

In a critical situation, the R&A vessel can initiate fallbacks automatically. The remote operations workstation supports the operator in emergency response and fallback recovery.

High attention mode implies that the operator in charge of navigation switches to having dedicated attention to the one vessel, and that the other vessels that the operator was managing might need to be handed over to another operator, or possibly to another ROC, depending on the situation at hand. In situations where the navigating operator needs to be in charge of one R&A vessel only, the engineering operator may still be in charge of more than one vessel, depending on the situation at hand.

The ROC will also be based on the ROC technology developed in AUTOSHIP, and this includes Remote Operations Workstations (ROWS) that provides the information and controls to the operators (user interface), servers and computers for data processing, power and network management systems. In SEAMLESS, advancements will be to define a set of operation modes and corresponding operator views. Specifically, low and high attention modes need to be defined. In addition, it is necessary to define the conditions and requirements that needs to be fulfilled for each mode, as well as procedures for handing over an R&A vessel to another operator or another ROC. The evolution of the ROC from AUTOSHIP to SEAMLESS is illustrated in Figure 10.

In low attention, the ROC operator will monitor three vessels (preliminary target). Presented information will be high-level and needs to give the operator an overview of the R&A vessel navigational status, R&A system health, and indication of detected issues (e.g., traffic) that potentially will lead to an attention mode switch in the near future (e.g., next 30 minutes). It is not expected that the operator will need to actively control R&A vessel systems in low attention mode. However, some controls will be available, such as control of the R&A vessel radio (VHF) or use of PTZ camera. In fact, radio watchkeeping will always be carried out actively by the remote operator, also in low attention mode. Hence, for the point of view of radio watchkeeping the operator will always be in high attention mode.

In high attention mode, the operator will monitor the R&A vessel more closely and the presented information will be quite like the operator workstation setup developed by AUTOSHIP. In this mode, the operator shall have better awareness of the situation, thus being able to react faster if needed. It is expected that the operator might need to give control inputs to the vessel, potentially interact with other vessels, and actively make decisions related to navigation and manoeuvring.

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In all modes, focus will be on providing correct and sufficient information to enable the operator to perform the tasks that are defined for the relevant mode and make safe and sufficiently informed decisions. At the same time, it is important to not overload the operator with redundant or unnecessary information.

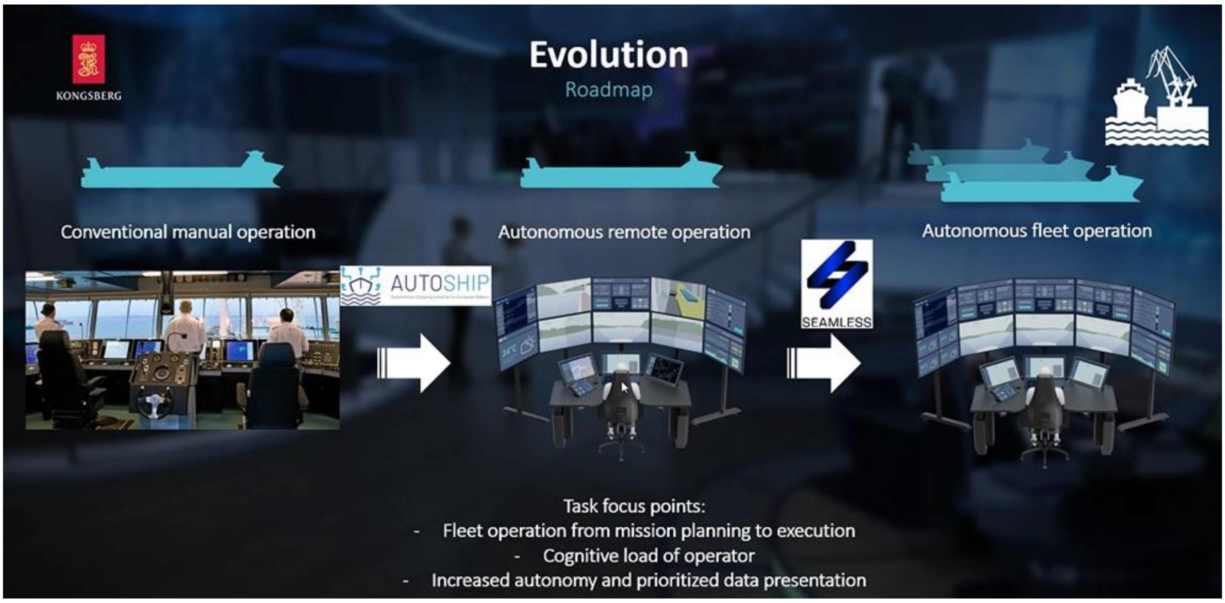

Figure 10: The evolution of ROC of autonomous ships, from AUTOSHIP to SEAMLESS
source: Kongsberg Maritime

The connectivity system is responsible for providing an appropriate communication link between the ROC, vessel, logistics and port systems. It is also responsible to do data transfer prioritisation based on communication link quality, and to alert in case of errors or missing link etc.

The following sections present the identified building block 2 requirements resulting from activities as listed in section 1.5, the SEAMLESS report [1], and direct inputs from the responsible partner of this building block.

2.2.1 R&A vessel systems functional requirements

The R&A vessel systems functional requirements are given in Table 5. The table gives the functional requirement ID (subsystem.Functional.sequence), name, and description.

Table 5: R&A vessel systems functional requirements

ID	Name	Description
R&A.F.01	**Positioning**	Shall be able to perform sufficiently accurate positioning for safe navigation, docking and undocking.
R&A.F.02	**Object detection**	Shall be able to detect all relevant objects (at a reasonable level) that must be avoided.
R&A.F.03	**Object classification**	Shall be able to classify all objects that requires interaction (i.e., vessels need to be detected and classified as such, enabling operators to know what vessel to call, if needed, over VHF).
R&A.F.04	**Light signals**	Shall be able to sense and analyse light signals

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R&A.F.05	**Sound signals**	Shall be able to sense sound signals
R&A.F.06	**Auto-tracking**	Shall be able to perform auto-tracking, while performing anti-collision manoeuvres when necessary. • Limited to situations which actions are clearly defined in COLREGs. • Situations where COLREGs cannot give one defined response requires operator intervention.
R&A.F.07	**Detecting complex traffic**	Situations, or situations with potential to develop into situations, where COLREGs do not give one clear action shall be predicted and lead to a request to switch operator mode to high attention, well within time for the operator to make safe actions. As a minimum, this can be solved by handing over when other vessels are within a certain sector of the autonomous vessel, but more advanced methods should be researched.
R&A.F.08	**Autonomous docking**	Shall be able to perform autonomous docking.
R&A.F.09	**Autonomous un-docking**	Shall be able to perform autonomous un-docking.
R&A.F.10	**System status**	Shall be aware of own system status, detect any error or failure leading to degraded performance or capability, and notify the ROC of such.
R&A.F.11	**Fallbacks**	Shall be able to detect the need for and initiate fallbacks in case safety cannot be guaranteed if the mission continues
R&A.F.12	**Efficient operations**	While navigation shall be safe, it should also be efficient, ensuring operational performance satisfying commercial requirements: • Schedule keeping • Energy usage

2.2.2 ROC functional requirements

The Remote Operations Centre functional requirements are given in Table 6. The table gives the functional requirement ID (subsystem.Functional.sequence), name, and description.

Table 6: ROC functional requirements

ID	Name	Description
ROC.F.01	**Operation modes**	Shall have defined operation modes, each with a configuration of information presented to the operator allowing the operator to safely perform their task.
ROC.F.01.1	Presented information	Shall be capable of presenting information based on operational modes, e.g., low, and high attention.
ROC.F.01.2	Level of presented information	Presented information for each operation mode shall be sufficient to ensure that the operator has the information needed to do the actions and make the decisions that are available in the given operation mode. However, presented information should also not be redundant as it is critical that the operator is not overloaded.

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ROC.F.01.3	Multi-vessel scenarios	Shall be capable to distinguish levels of multi-vessel scenarios for safe operation.
ROC.F.02	**Handover of R&A vessel responsibility**	The ROC shall have functionality for handing over an R&A vessel from one ROC operator to another ROC operator.
ROC.F.02.1	Handover between ROWS	Shall provide capability for handing over the responsibility of an R&A vessel operation between the ROWS in one ROC.
ROC.F.02.2	Handover between ROCs	Shall have functionality for handing over R&A vessels between ROWS in different ROCs.
ROC.F.03	**Communication with other vessels**	Shall provide communication means for the operator to engage with other vessels and VTS (VHF).
ROC.F.04	**VTS**	Shall handle VTS sailing clearance and reporting. Message formats for the Fedje VTS are provided in [1] as an example.

2.2.3 Connectivity system functional requirements

The connectivity system (CS) functional requirements are given in Table 7. The table gives the functional requirement ID (subsystem.Functional.sequence), name, and description.

Table 7: CS functional requirements

ID	Name	Description
CS.F.01	**Bandwidth**	Shall provide sufficient bandwidth for the communication link between the ROC, vessel(s), and port systems.
CS.F.02	**Latency**	The provided bandwidth shall be with sufficiently low latency.
CS.F.03	**Data prioritization**	Shall be capable to manage data transfer prioritization based on communication link availability.
CS.F.04	**Link fault detection**	Shall be capable to monitor system status and alert the ROC in case of missing communication link, faults, or insufficient quality of service.

2.2.4 Vessel functional requirements

The vessel (VES) functional requirements are given in Table 8. The table gives the functional requirement ID (subsystem.Functional.sequence), name, and description.

Table 8: VES functional requirements

ID	Name	Description
VES.F.01	**Cargo handling**	Onboard cargo handling: In case of an extended network, it might be too expensive to have dedicated cargo handling equipment at each node. Especially the smaller nodes. Cargo handling equipment onboard the R&A vessel might thus be a better option. This may be the autonomous crane of building block 1, however, its applicability depends on the R&A vessel size due to space and stability issues. Another option for onboard cargo handling is the concept proposed by AEGIS, where a reach stacker is carried onboard [8]. The latter option

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		will probably limit the number of container rows to three due to reach stackers not being able to load or unload from the fourth row [1].
VES.F.02	**Automated mooring**	Onboard automated mooring shall be included in the R&A vessel design.
VES.F.03	**Securing containers**	A concept for securing containers should be developed as part of the R&A vessel design. Details in [1].

2.3 BUILDING BLOCK 3: INTEGRATED SUPPLY CHAIN SUPPORT (MODALNET)

Building block 3 is **the ModalNET building block.** ModalNET is a logistics platform where a transport customer can plan and book multimodal transport from end to end. It also provides reporting to relevant authorities and lets the customer monitor the progress and status through operational data provided by the other building blocks [9].

ModalNET's specifications and architecture are divided into three modules with different components, as seen in Figure 11: The "computational engine for resilient logistics", the "ModalNET platform" and the "Cybersecure communications" [9]. The first part contains the main functionality of ModalNET, where methods and algorithms are provided to optimize multimodal transport schedules, i.e., with combinations of vessels, train, and trucks. The second part is responsible for publishing a set of APIs, and connectors for ModalNET to be used with other platforms, systems, and formalities (e.g., VCOP, ROC, EMSWe). Finally, the third part is concerned with secure access control for users and stakeholders, allowing only authorized access, and providing a framework for secure implementation of the other parts and communication of ModalNET with the other building blocks. The ModalNET modules and components will be developed and deployed in cloud computing solutions and all communications and external access will be performed through secure REST APIs [9].

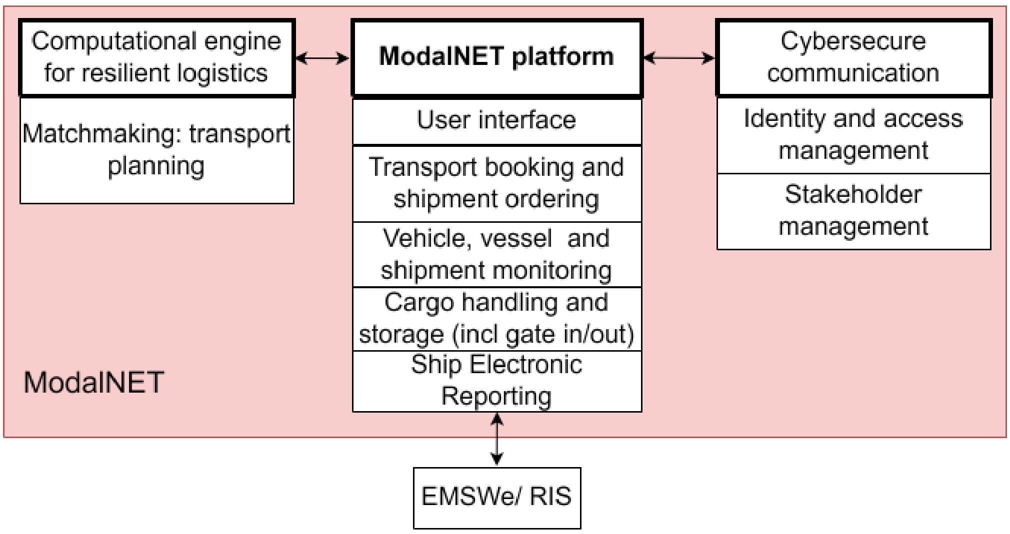

Figure 11: Building block 3 overview

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The **computational engine for resilient logistics** is based on the matchmaking platform developed in the H2020 MOSES project [9], [10]. It lies at the core of ModalNET where, from a transport order, possible transport schedules are automatically obtained, sorted according to user-defined optimization criteria.

The transport planning component is responsible for performing matchmaking using data stored in a database. In the first step, a model of the transport network is built as a graph [6], with data provided by service providers such as carriers, freight forwarders, and ROCs [4]. The data includes, among others, stopping locations (e.g., ports and train terminals), arrival and departure times, cargo capacities and transportation costs. The model can be updated with new data as needed, and filtered with selective pruning, i.e., disregarding part of the graph that does not fit a set of constraints [6]. A user may then submit a transport order in the ModalNET platform module, including information such as origin and destination, cargo amount, and preferred optimalization criteria (e.g., total cost, sailing distance or total emissions) [4]. The order is sent to the computational engine and the transport network graph is filtered according to the provided information (e.g., ignoring ports with insufficient capacity). Search algorithms are then used on the filtered graph to find candidate feasible schedules [4], which are sorted according to the user's preferred criteria and stored in a database for later reuse, saving computing resources [6].

The **ModalNET platform** module presents user interfaces for capturing user inputs and showing information and updates relevant to the matchmaking task [4]. The MODALNET platform provides the screens, menus and information depending on the access rights according to the user roles and the user company branch [6]. The roles available in the platform include cargo owners acting as consignors and consignees, freight forwarders, road hauliers, rail operators, sea and barge carriers and freight terminals. Depending on these access rights, the user can create, read, update, and delete the data of different entities (i.e. CRUD operations over the entities). Its UI shows information such as transport schedules and execution, bookings and consignments, gate-in, gate-out, loading and discharge orders and stored items in terminals and warehouses and traceability events. It offers a dashboard with total shipments per month, daily consignments and completed tasks. Potential customers, e.g., shippers, can provide transport orders with data such as origin and destination, cargo amount and possible date of delivery, as well as their preference for optimization criteria. ModalNET is designed to be generic to any type of cargo, capacity, and work area [4]. The results from the DATAPORTS [12] project will be used to this end, where a data model was developed to support logistics data from any transport mode and any type of data. The computational engine uses the transport order to compute a sorted list of feasible transport options, which are sent back to the platform and presented in the potential customer's UI [4]. This UI shows mainly the sorted feasible routes and notifications, such as cancellation or fulfilment of the transport orders, and operational changes or unexpected events, at which point the customer can request an alternative route.

After the customer selects and confirms one of the transport schedules, the transport booking and shipment ordering component generates individual bookings and consignments for each mode of transportation of the transport plan, which are sent to each carrier in the transport plan, creating a transport chain [4]. The carriers can then complete the information of each consignment and coordinate the transport planning, as well as connecting to ModalNET and receiving updates and new consignments.

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The cargo handling and storage component is responsible for registering cargo/container entries and departures from port terminals and storage facilities [4]. An automated port interface is used here to interface TOS to gate-in and gate-out messages, i.e., connecting VCOP to TOS and TOS to ModalNET. There are two crucial processes between ModalNET and TOS. The first process involves the connection with hinterland transport (e.g., truck or train) through gate-in and gate-out orders. In this case, ModalNET sends notifications of reception and delivery orders to the involved terminals and TOS, and receiving of reports when the operations are completed. The second process involves loading and discharging operations and involves communication between ModalNET and VCOP. VCOP receives a list of bookings for loading and unloading of a particular vessel and will carry out the bay planning and communicate the results to the ROC. Then, loading and unloading orders will be executed between VCOP, TOS and cranes without ModalNET's intervention.

The vehicle, vessel and shipment monitoring component is responsible for the monitoring and traceability of the consignments and vessels, providing status reports to the ModalNET users [4]. It gathers data from the other modules and building blocks, for example, receiving reports from VCOP through the cargo handling and storage component when loading and unloading orders are completed.

The ship electronic reporting component is responsible for complying and reporting formalities of the autonomous ships operated by liner operators when arriving or departing from ports [4]. The formalities can be, for example, the European maritime single window environment (EMSWe), in maritime applications, or river information services (RIS) in inland waterway transport applications.

Finally, the **cyber secure communication** module describes the architecture used in ModalNET overall to achieve cyber secure communications, data exchange and coordination [4]. In general, communications will be performed through REST APIs that implement state-of-the-art cyber security measures, and a zero-trust paradigm will be adopted throughout ModalNET, where each message and resource must be thoroughly verified and authenticated.

The stakeholder management component is responsible for defining the entities of "branch offices" to represent offices of different organizations, companies or public entities that contribute to logistics and transport systems, or that will use ModalNET as customers [4].

The identity and access management component allows for registration and approval of new users to ModalNET. Users will be identified according to their role as well as their branch office. Each branch office will have admin users that can manage user access, i.e., approve new users or deny access as needed [4].

The following sections present the identified building block 3 requirements resulting from activities as listed in section 0, the SEAMLESS report [1], and direct inputs from the responsible partner of this building block.

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2.3.1 ModalNET functional requirements

The ModalNET (MNET) functional requirements are given in Table 9. The table gives the functional requirement ID (subsystem.Functional.sequence), name, and description.

Table 9: MNET functional requirements

ID	Name	Description
MNET.F.01	**Cyber secure communication**	ModalNET shall implement cyber secure communication
MNET.F.01.1	REST API	All modules shall communicate via REST APIs implementing state-of-the-art cybersecurity measures, ensuring secure communication channels.
MNET.F.01.2	Access control	All communication shall follow a zero-trust paradigm, with restrictive access control and message authentication protocols.
MNET.F.01.3	Registration of users	Shall allow for the registration of stakeholders in the form of branch offices of organizations, companies, or public entities.
MNET.F.01.4	Admin users	Shall allow for admin users in each branch office to manage access control, i.e., registering new users and denying access when needed.
MNET.F.01.5	Data access	Shall only provide access to the data the user is entitled to access.
MNET.F.02	**Computational engine for resilient logistics**	ModalNET shall include a computational engine for resilient logistics which proposes multimodal transport options.
MNET.F.02.1	Network graph	Shall receive and use service provider data (e.g., vessel capacity, transport costs) to build the transport network graph model and update it with new data from service providers.
MNET.F.02.2	Candidate schedules	Shall use search algorithms to find a list of candidate feasible schedules based on the customer's transport order.
MNET.F.02.3	Schedule sorting	Shall sort the list of feasible schedules according to the customer's preferred criteria (e.g., total cost, ETA) and store it in the database for later referencing and reuse.
MNET.F.03	**ModalNET platform**	The ModalNET platform shall function as the user application where transport bookings can be made, and where monitoring of booked transport can be done.
MNET.F.03.1	User interface	Shall implement a responsive human-machine user interface to effectively obtain user information and present status updates and notifications.
MNET.F.03.2	Cargo types	Shall be generic to accept any type of cargo, capacity, and work area.
MNET.F.03.3	Cargo data	Shall be the entry point for cargo data (ID, dimensions, weight, special or dangerous cargo information, origin and destination, etc.)
MNET.F.03.4	Transport requests	Shall facilitate input of transport requests from authorized users.
MNET.F.03.5	Transport options	Shall provide the vessel schedules and the transport requests to the computational engine and in return receive the transport plan options. The transport plan options shall be

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		presented to the users, allowing them to choose the most suitable transport option.
MNET.F.03.6	Booking	Shall generate bookings and consignments from the chosen transport option, communicating with the other modules and building blocks to report these bookings.
MNET.F.03.7	Monitoring transport	Shall continuously obtain data from the other modules and building blocks to monitor operations, shipments, and vessel statuses.
MNET.F.03.7	TOS	Shall interact with TOS by sending notifications of reception and gate-in/gate-out or delivery events, receiving reports when the operations are completed.
MNET.F.03.8	VCOP	Shall receive reports of completed loading and unloading operations through VCOP.
MNET.F.03.9	Formalities	Shall report formalities to the relevant authorities, e.g., EMSWe and RIS
MNET.F.03.10	Vessel schedule changes	The vessel route is fixed in the sense that the sequence of ports does not change. There can, however, be changes in timing. The vessel schedule should be managed by the ROC and shall be transferred to ModalNET whenever it is needed

3 THE SEAMLESS CONCEPT

The SEAMLESS concept is the combination of the three SEAMLESS building blocks into a highly automated, green and efficient, transport system. The SEAMLESS concept architecture is given in Figure 12. As the building blocks were described in more detail in the previous section, a simplified representation of the building blocks is shown in Figure 12 to better illustrate how they are interconnected. In the figure, the SEAMLESS building blocks are colour coded as follows: Firstly, all building blocks are placed within the blue box. Building block 1 (BB1) are the green boxes, building block 2 (BB2) are the grey boxes, and building block 3 (BB3) is the red box. Some important external systems are also included in the figure to indicate which main external systems need to be interfaced for a realisation of the SEAMLESS concept.

As can be seen in Figure 12 some building blocks are distributed. Building block 1 and 2 both include R&A vessel and ROC systems. In addition, BB2 includes the connectivity systems providing the interface between the vessel, the ROC, and external stakeholders like the VTS and other vessels. And BB1 includes the AVSPM, which is the interface between the ROC (R&A vessels) and the port.

In the following sections, the interfaces between the building block subsystems and their main functions will be presented and discussed in more detail by dividing the operations into 10 distinct planning and execution phases.

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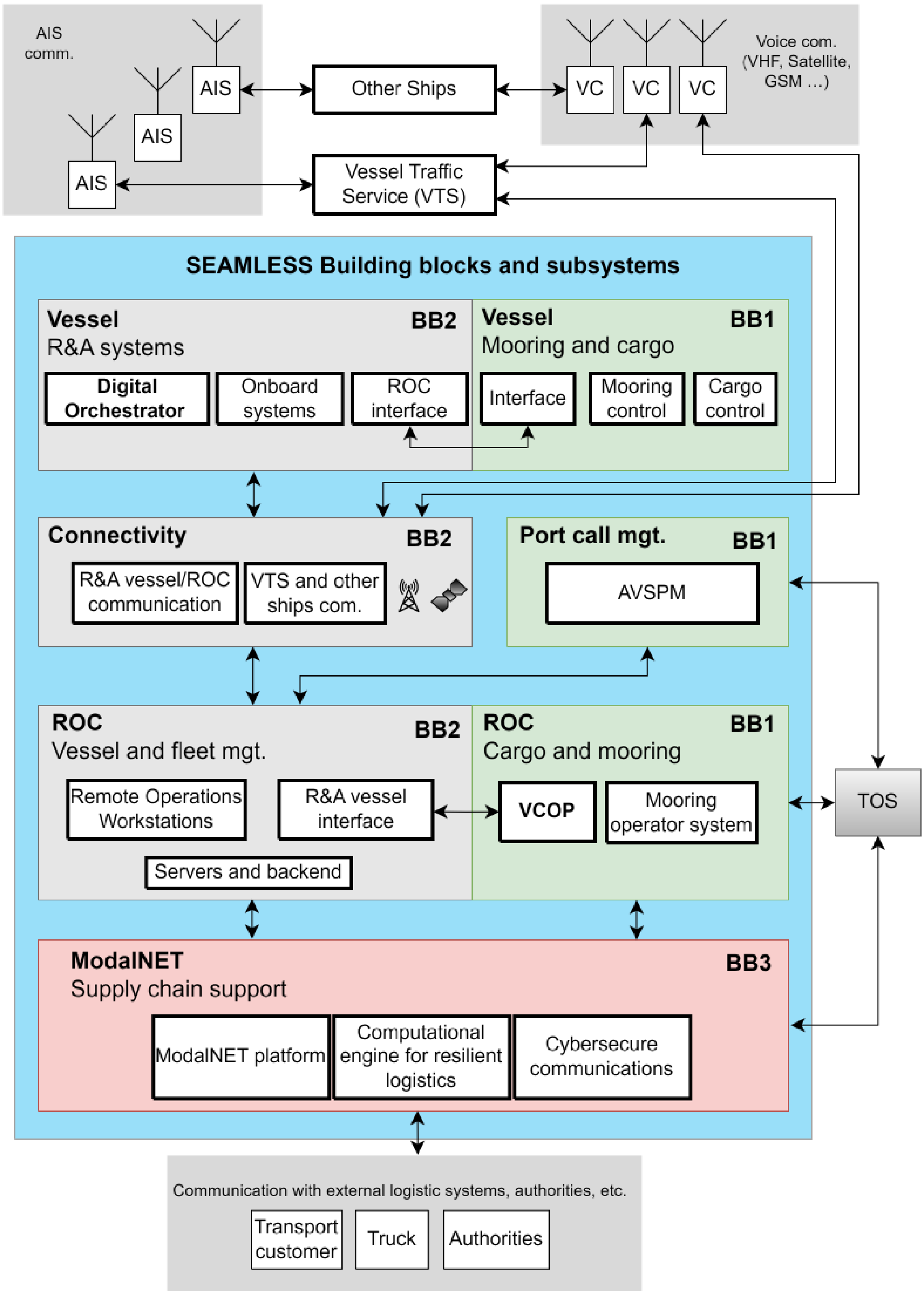

Figure 12: The SEAMLESS concept high-level architecture.

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3.1 THE SEAMLESS CONCEPT OPERATIONAL PHASES

The SEAMLESS operation phases corresponds to voyage phase patterns as proposed in [7] (see also definition in section 1.3.4). The descriptions of all phases are given in Table 10.

Table 10: The SEAMLESS concept operational phases

Phase name	Description
A. **Plan shipment**	Shipment planning occurs every time a customer initiates a transport booking process. This is synchronous to the vessel operations. The phase deals with the process of booking a shipment from a to b, by organising a sequence of transportation legs. With the R&A vessel at the centre of the SEAMLESS concept, the stowage planning for a voyage is also part of this phase.
B. Early port call planning	Early port call planning occurs at a low frequency and is done when the preliminary schedule for a longer period has been set. Typically, it will be done one or more months ahead of the port call. It deals with a pre-allocation for the R&A vessel port call, but a final port call planning needs to be done approximately 48 hours prior to the port call (see phase 1. Plan port call).
1. Plan port call	In this phase the navigation in the port area is planned, negotiation with port for port resources like berth allocation and time of arrival, and the terminal activities are planned. This phase is indicated as being executed in between the “6. Navigate” and “2. Approach location” phases, however, in practice it will happen during the “Navigate” phase, about two days ahead of the port call.
2. Approach location	This phase is when the R&A vessel ends its sea passage (or canal navigation) and approaches a certain location (i.e., port). It includes the navigation into berth and mooring.
3. Activities at location	This phase starts once the R&A vessel is moored. This phase includes all activities at a location, such as cargo handling, charging, etc.
4. Plan departure	Before departing, this phase is executed to plan and prepare for the vessel departure. It includes the completion of cargo operations and related reporting.
5. Depart location	This phase is initiated once the terminal and R&A vessel are ready for departure. This phase includes releasing mooring and navigating out of the port area and ends at the start of the sea passage (or start of canal navigation).
6. Navigate	This phase is initiated at the start of sea passage. The phase includes the navigation between port areas and ends once the next port area is reached and the next “2. Approach location” phase starts. During navigation, the R&A vessel can encounter locks and bridges. If the R&A vessel encounters a lock, it enters the “7. Pass lock” phase, if it encounters a bridge, it enters the “8. Pass bridge" phase. Once either of these phases are completed, the “6. Navigation” phase is commenced.
7. Pass lock	This phase is when the R&A vessel needs to pass a lock. It includes the communication with the lock operator for booking a time slot, navigation into the lock, mooring within the lock, and navigation out of the lock.
8. Pass bridge	This phase is when the R&A vessel needs to pass a movable bridge. It includes communication with the bridge operator for booking a time for when the bridge will open, waiting for the bridge to open if needed, and passing the bridge.

The SEAMLESS operational phases include planning phases and execution phases. While some planning phases have a natural place in a sequence of events, the shipment planning and early port call planning phases are asynchronous to the vessel operations and are as such placed outside the

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operational phases. The typical sequence of the SEAMLESS operational phases is given in Figure 13. The 4 planning phases are marked by green, and the 6 execution phases are marked by blue.

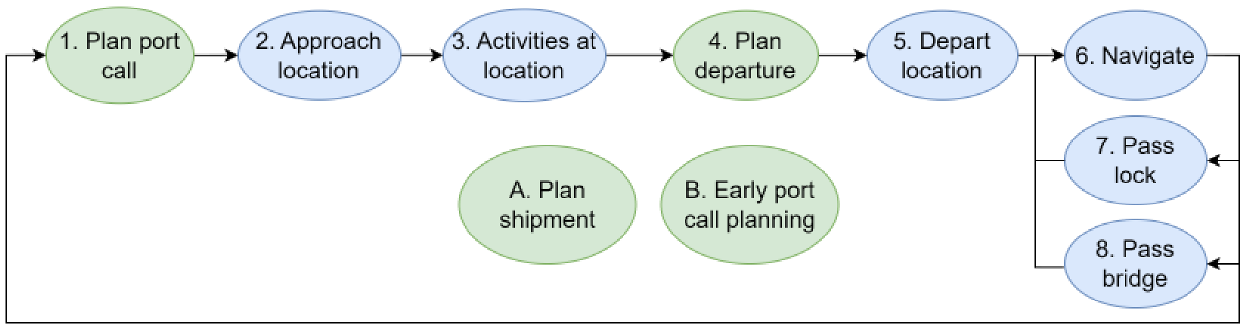

Figure 13: Operational phases

3.2 PHASE A: PLAN SHIPMENT

Shipment planning can occur at any time during operations. The *Plan shipment* phase is initiated every time a transport customer accesses ModalNET for booking transport of a shipment. This is done by entering a transport job via the ModalNET user interface. This job is then formed into a transport request that is sent to the ModalNET matchmaking platform, see Figure 14. The ModalNET matchmaking platform knows the schedule of all vessels, which are provided by the ROC[3]. The matchmaking platform finds a suitable combination of vessel and truck (or train) transportation legs and proposes one or more transport options. These are presented to the customer in the ModalNET UI, which lets the customer choose the preferred option. Once the customer chooses the preferred option and confirms, a booking request is sent back to ModalNET.

If the customer chooses an option that includes waterborne transportation, the booking for waterborne transport is forwarded to the VCOP as a stowage request, which initiates the stowage planning process. The stowage planning depends on static vessel data, which is transferred from the ROC (once or once for any modification work having been done on the vessel impacting stability and stowage). The stowage planning also depends on the berth map. The berth map includes berth and bollard position, as well as any static objects, to be used in the operational phase for mooring, and for the stowage planning it includes the quay logical positions for placement of containers. The stowage planning process includes the ROC as a ROC operator will hold the role of the master and will be responsible for the R&A vessel safety. The VCOP makes an initial stowage plan, loading, and unloading sequences, where R&A vessel stability is considered as part of the planning. The plan is reviewed by the master, who may send it back with requested changes. Once the final stowage plan is agreed between the VCOP and the ROC, a confirmation that the booking is accepted is sent to the ROC. The ROC also makes a draft port call reservation and sends to the AVSPM. This is an update to the scheduled port call reservations for the effected port calls (not indicated in Figure 14 as it is

[3] It is assumed that the vessel schedules, in terms of port visit sequence, is fixed for the planning horizon, while port call timings can change.

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covered by the *Early port call planning* diagram). Every time a booking is planned and accepted by the stowage planner, the VCOP transmits the loading and unloading sequence to the TOS for terminal planning, and a confirmation of the stowage to the ModalNET. The booking confirmation is then sent to the ModalNET UI such that the transport customer is informed.

ModalNET also books truck or train transport, whenever this is required. However, the details of this booking process are not scope for SEAMLESS.

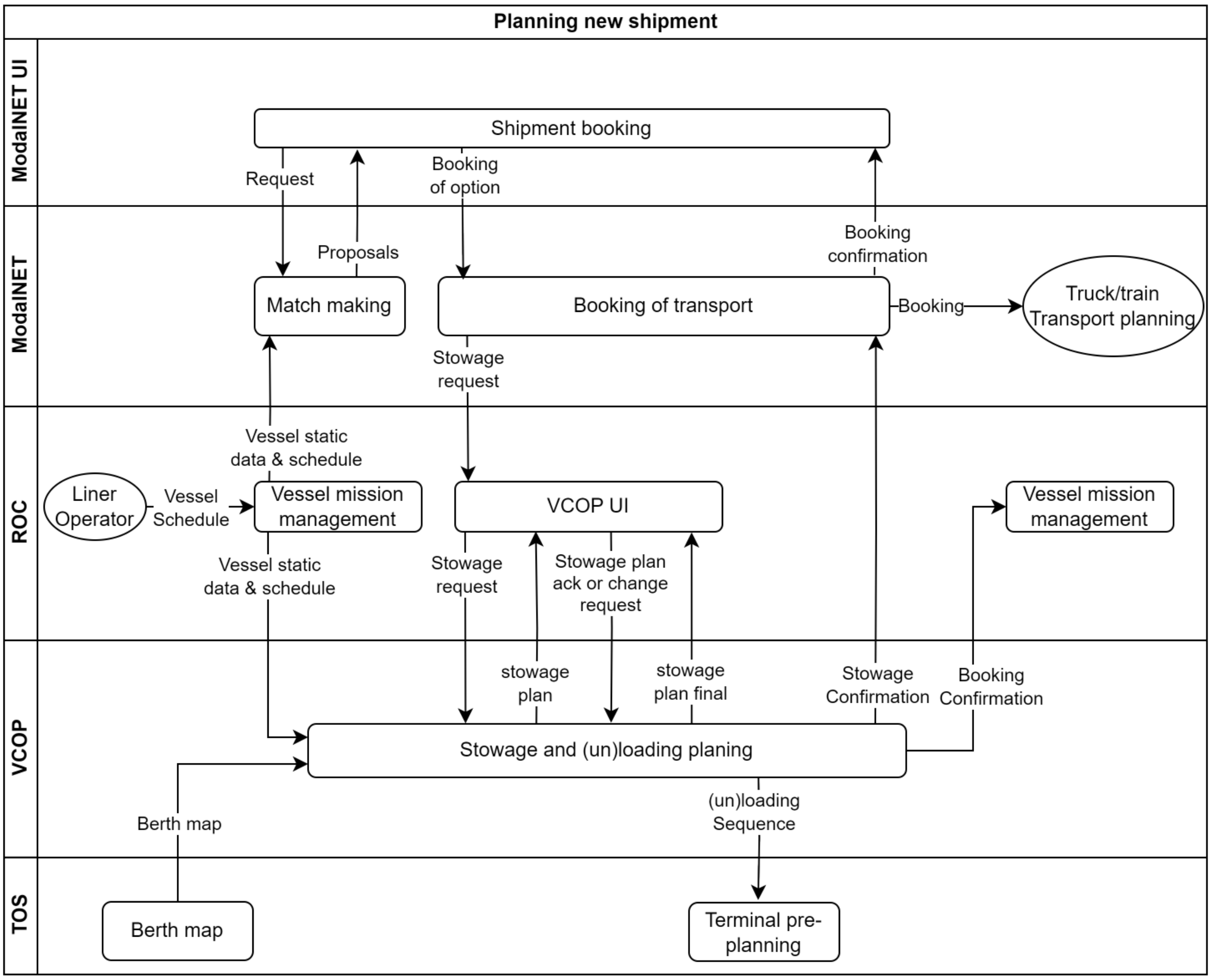

Figure 14: Phase A - Plan shipment

3.3 PHASE B: EARLY PORT CALL PLANNING

Early port call planning can be done at any time during operations but is performed for future operations. Typically, about a month prior to the port call, or as a consequence of a new shipment being planned (see phase *Plan shipment*). The *Early port call planning* is done to create a draft port call reservation. A reduced set of planning data is exchanged, compared to the final port call planning (see 3.4 for details on the *Plan port call* phase). The AVSPM can then confirm that the port call can be accepted at this time, but a final port call negotiation and verification needs to be done closer to the actual port call.

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The process starts with the ROC operator sending an *initiate planning* message to the AVSPM, followed by a *pre-plan basic data* message. The pre-plan data includes items such as expected cargo (types, amounts, units, loading and unloading), operator, vessel and voyage ID, as well as the purpose of the visit. The AVSPM then responds with a confirmation to start the negotiations by issuing the *confirm start plan* message. This triggers an iterative message exchange where the ROC sends an early port call *reservation request* message to the AVSPM containing planned time window for the port call, the terminal that it is planned to visit, and optionally the berth ID, berth meter marked, and bollard ID. The AVSPM then responds with a *proposed changes* message if changes are needed. The ROC then re-plans, if necessary, and sends the amended port call plan through a new *reservation request* message to the AVSPM. Finally, once the iterative message exchange has resulted in an agreement, the AVSPM sends a *confirmed* message.

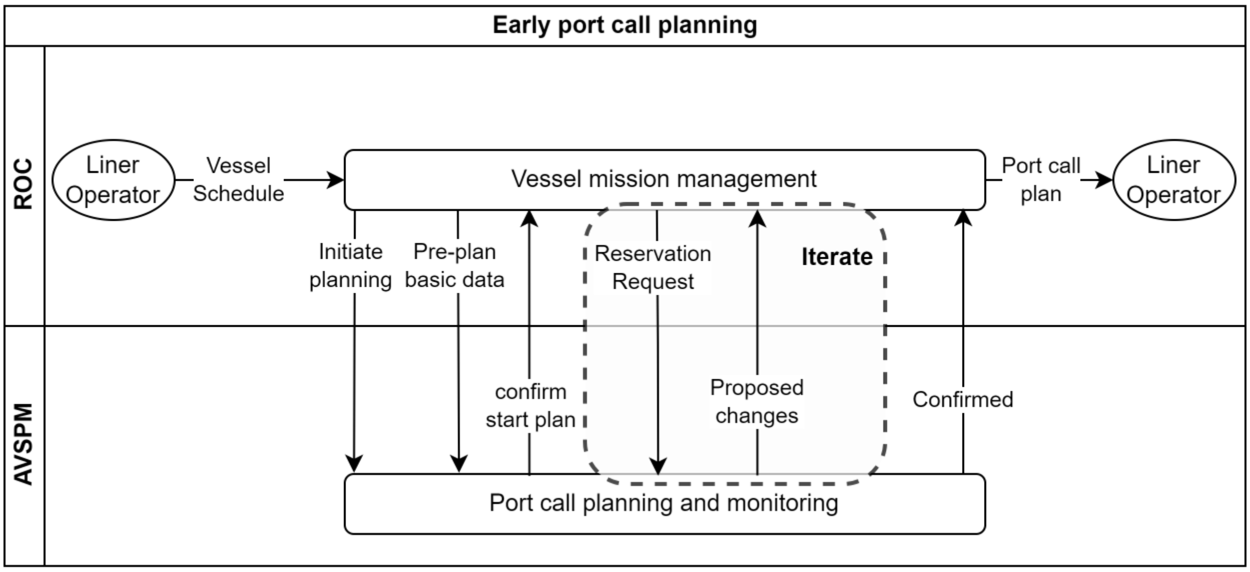

Figure 15: Phase B - Long term port call planning

3.4 PHASE 1: PLAN PORT CALL

The *Plan port call* phase covers the last planning and port call negotiations before the port call starts. The phase is executed shortly before the port call during the final part of the *Navigation* phase, before the *Approach location* phase starts (see Figure 13). The port call planning is initiated by the Remote Operations Centre (ROC) by sending an *initiate port call planning* request to the AVSPM. The ROC also transmits the planned *Route* and the *ETA Berth*. The AVSPM responds with a *RTA Berth*, and the ROC confirms with a *PTA berth* (Planned Time of Arrival) message. Next the AVSPM transmits the *Allocated berth* and *Port notices* to the ROC. The AVSPM also sends the *Allocated berth* and *PTA berth* to the Port management system.

The R&A vessel regularly sends *Status & position* updates to the ROC, which is input to planning and triggering startup of phases, such as the *Plan port call* phase. Once the port call negotiation between the AVSPM and the ROC is completed, the ROC sends an updated *Mission* to the R&A vessel. The ROC also sends the updated *Schedule & voyage data* to the ModalNET.

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The last part of the *Plan port call* phase is to plan the cargo operations. This is also initiated by the ROC by sending the *PTA Berth* and *RTS cargo ops* messages to the TOS. The TOS responds with *ETS cargo ops*, and then later, the *PTS cargo ops* message. The ROC forwards the *PTS cargo ops* message to the ModalNET, which performs the Vessel reporting and sends the electronic repots (e.g., EMSWe report to the RIM).

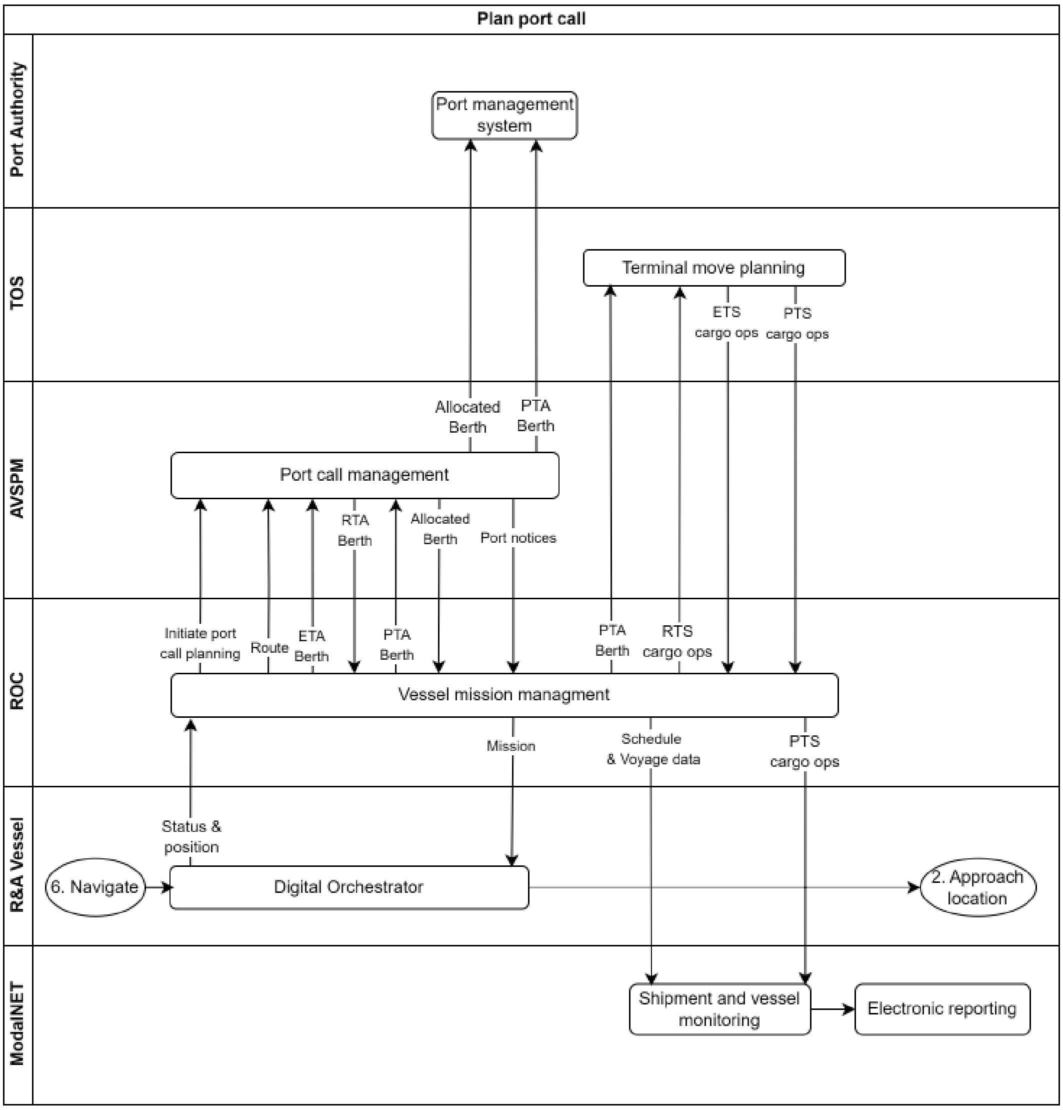

Figure 16: Phase 1 – Plan port call

3.5 PHASE 2: APPROACH LOCATION

While the *Plan port call* phase is completed before the *Approach Location* phase, the transition into the *Approach location* is from the *Navigate* phase, see Figure 17. Once the R&A vessel gets to the point where it is to move from the *Navigation* phase to the *Approach location* phase, the Digital Navigator issues an End Of Sea Passage (*EOSP)* message to the ROC, via the Digital Master. This message is relayed to the AVSPM to give notification that the R&A vessel is now entering the port area and is approaching the berth. The AVSPM responds with updated *port notices* and *Metocean*

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& traffic data. If deemed necessary, based on the information sent by the AVSPM, the ROC will send an updated *mission* to the R&A vessel. Upon ending the sea passage, the R&A vessel will do a mode switch to approach mode. The Digital Master will send a *mode switch* command to the Digital Chief, which confirms with a *mode* message. The Digital Master relays this to the ROC.

Throughout the phase the Digital Navigator will issue regular position and status reports *Pos&status* to the ROC, via the Digital Master. When the vessel reaches a certain point near the berth the Digital Master will issue an *initiate berthing* command to the Digital Navigator. The Digital Navigator executes the berthing process and issues a *moor* command to the autonomous mooring system once the R&A vessel is at the berth. The autonomous mooring system issues *mooring status* to the Digital Master, via the Digital Navigator, such as first mooring line fastened, and last mooring line fastened. These are used to define the Actual Time of Arrival *ATA Berth* and Actual Time *AT all fast* messages, which are sent from the Digital Master to the ROC and relayed by the ROC to the AVSPM and ModalNET.

Once the R&A vessel is moored, the charging or energy container replacement process is initiated by the ROC. The case of charging is illustrated in Figure 17. Energy container replacement would be done by the container crane and follow a similar process as the container loading and unloading described in the *Activities at location* phase in section 3.6.

Initially, for the charging process, the ROC issues the *connect charging* command to the Digital Master, unless this is part of the mission definition. The Digital Master then issues a *mode switch* command to the Digital Chief, which in turn issues a *connect charging* command to the autonomous mooring system. The autonomous mooring system responds with a *charging connected* status message, which is relayed by the Digital Chief to the Digital Master as a *mode change* status message, and from the Digital Master to the ROC as a *charging connected* status message. The Digital Chief also reconfigures the vessel power grid according to the correct mode, however these details are out of scope for this report.

Finally, when the R&A vessel is moored and charging, or energy container replacement has started, the ROC initiates a move to the next phase, which is *Activities at location.*

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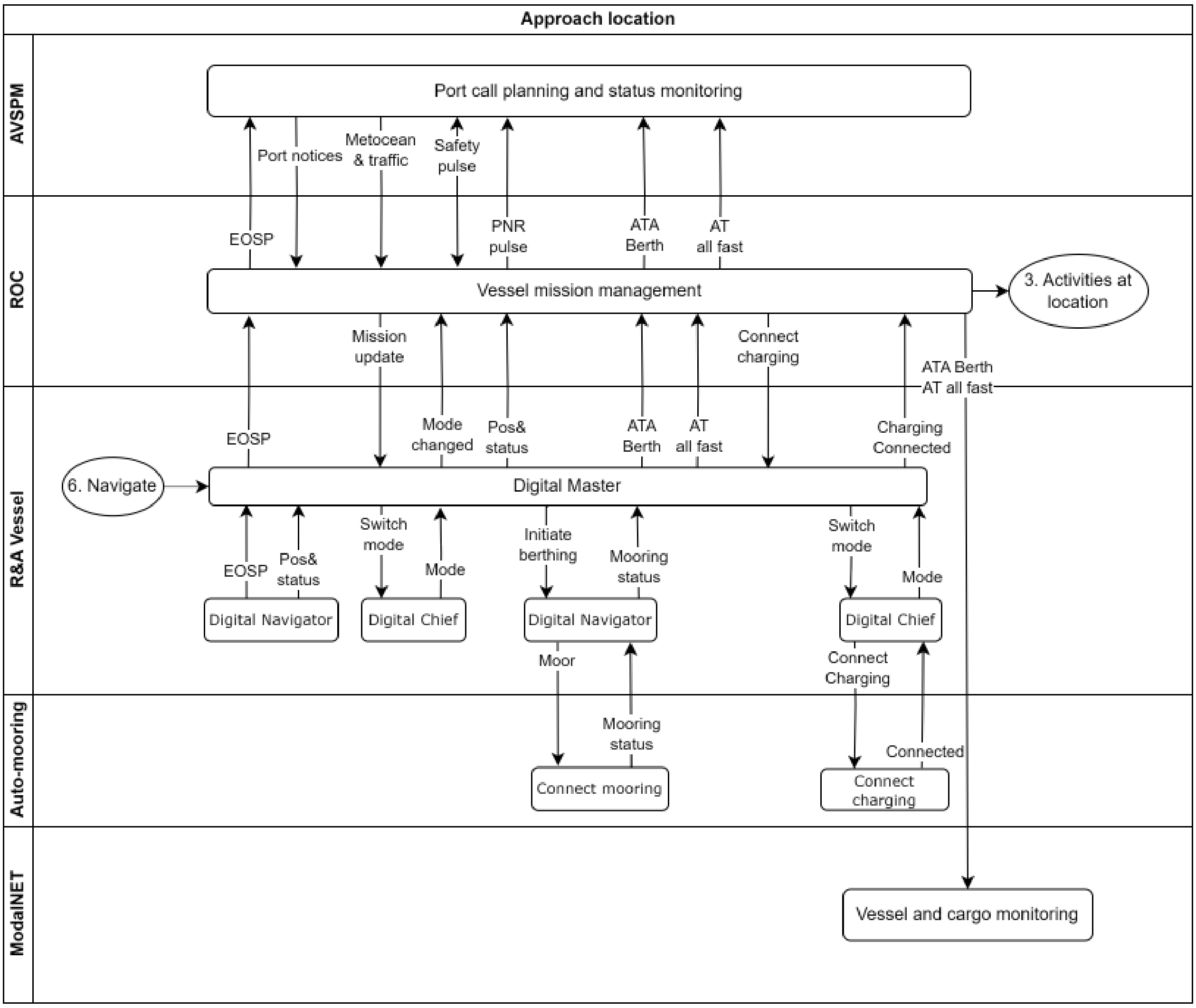

Figure 17: Phase 2 - Approach Location

3.6 PHASE 3: ACTIVITIES AT LOCATION

For the seamless concept as given in Figure 12, the *activities at a location* (e.g. a port), are unloading and loading of containers. Given the small size of the SEAMLESS concept vessel, it is assumed that unloading is always completed prior to loading. Larger vessels could perform both loading and unloading at the same time, especially when only parts of the load is to be unloaded, however, such processes are not included in the SEAMLESS concept.

The VCOP, crane, and TOS need a definition of the logical position of a container at the quay side such that it is clearly defined where a container is to be placed, and where it is to be picked up. This logical position is called a “location”. The location can mean the designated space on the quay side ground, but it can also mean a trolley or trailer placed at the quay side in case of direct transfer between vessel and vehicle. Whichever situation, the location is a physical location, defined by coordinates, where one container can be placed or picked up from. The location data is transferred as part of the Berth map in the *Plan shipment* phase.

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In case of changes, such as a container not being ready at the terminal, or a container delivery being aborted or re-routed, the *Plan shipment* phase is repeated to updated stowage and cargo handling plans. There will always be a cut-off time, after which it is not possible to make changes. This cut-off will be case specific.

3.6.1 Unloading containers

The *activities at location* phase therefore starts with unloading, as given in Figure 18. The phase is initiated by the ROC by sending a *Vessel ready for cargo operations* signal to the TOS, via the VCOP. The TOS responds by sending an *ATS cargo operations* signal to the VCOP, as a confirmation that cargo operations have started. The signal is forwarded to the ROC by the VCOP. The ROC then sends an *initiate* signal to the VCOP. The VCOP then sends the unloading plan to the the crane. The VCOP sends an *Unload next container to location y* message to the crane, and the crane unloads the next container to location y and issues a status update message to the VCOP *Container ID-x unloaded.* The VCOP sends the *container ID-x discharged to location y* message to the TOS to notify that the container ID-x can be picked up at location y. The TOS organises terminal moves and notifies the VCOP when the container has been picked up and the location y is free for another container by sending the *Container ID.x moved from location y* message. This repeats until all containers are unloaded.

After the unloading is completed, the VCOP issues an *Unloading completed* message to the ROC and TOS, and a *discharge status report* to the ModalNET. ModalNET also handles the gate out process by issuing *Container ID-x gate out order* messages to the TOS, which responds with *Container ID-x gate out report* messages once the process is completed for container ID-x. The details of this process are out of scope for the SEAMLESS project.

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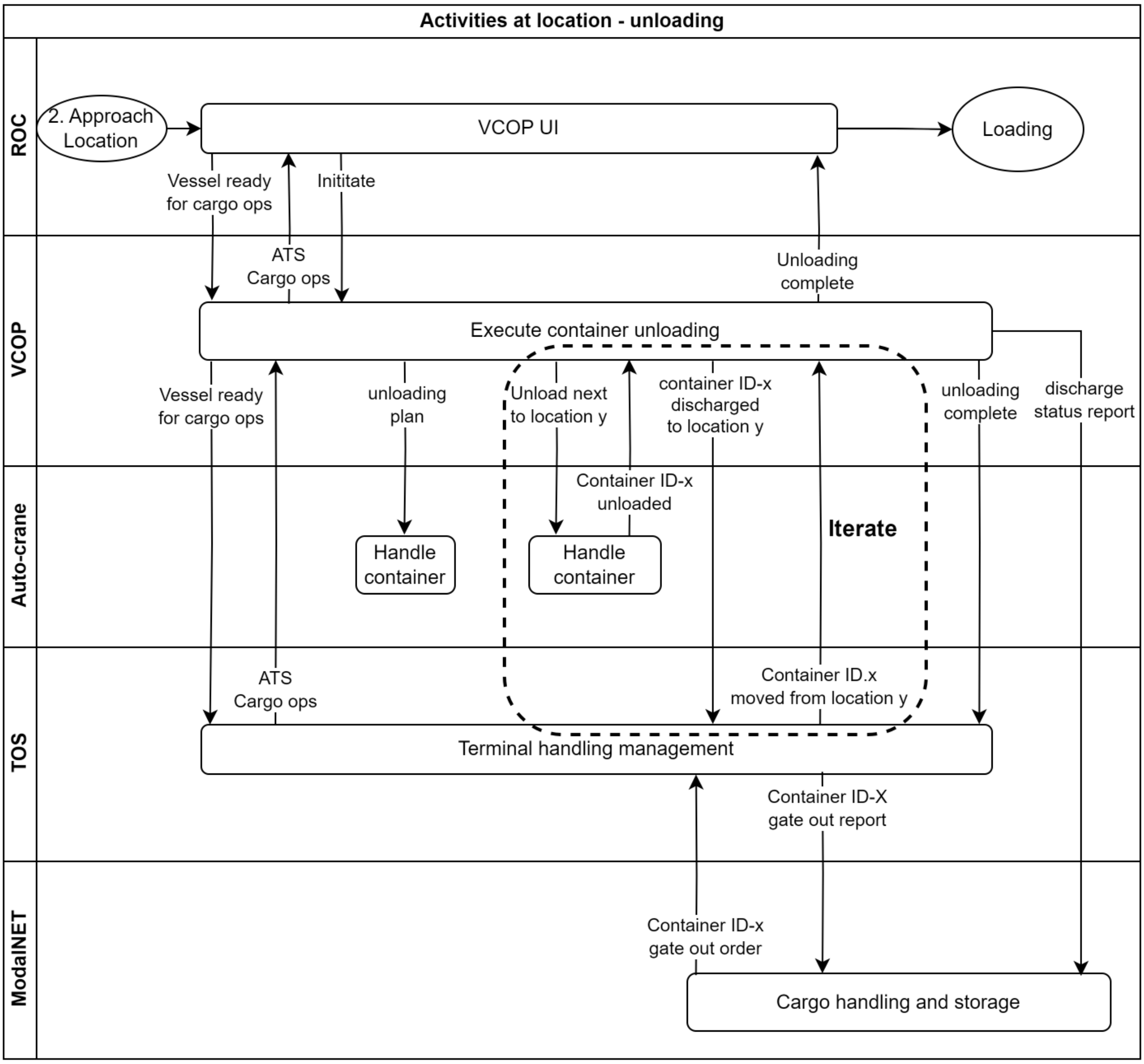

Figure 18: Phase 3 - Activities at Location, unloading

3.6.2 Loading containers

As for the gate out process, the gate in process is not covered in detail as it is out of scope. However, the ModalNET handles the gate in ordering and status tracking by sending *Gate in order* messages to the TOS and receiving *Gate in report* messages from the TOS, as indicated in Figure 19.

Once the ROC receives the confirmation from the VCOP that the unloading has been completed, it is ready to start the loading process. This is initiated by the ROC by sending an *initiate* message to the VCOP, via the VCOP UI. At his time, the VCOP will have received the *Gate in report* from the ModalNET, making it able to do re-planning if any containers planned for loading are not available at the terminal (replanning is done by running the Plan shipment phase). The VCOP then sends the final loading sequence to the crane, and once a container is ready in the location the TOS issues a

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Container ID-x ready in location y message to the VCOP which notifies the crane with the *container ID-x in location y*. Then the crane picks up the container and places it on board the vessel according to the loading plan. Then it issues a *Container ID-x loaded* message to the VCOP, which relays this to the TOS as a *Container ID-x loaded* status message. This process repeats itself until all containers are loaded.

When the last container is loaded, the TOS issues an *ATC Cargo ops* message to the VCOP, which relays this message to the ROC (VCOP UI). The VCOP also sends a *Loading status report* message to the ModalNET.

Finally, the *Plan departure* phase is initiated by the ROC (which would be initiated prior to completion of the Activities at location).

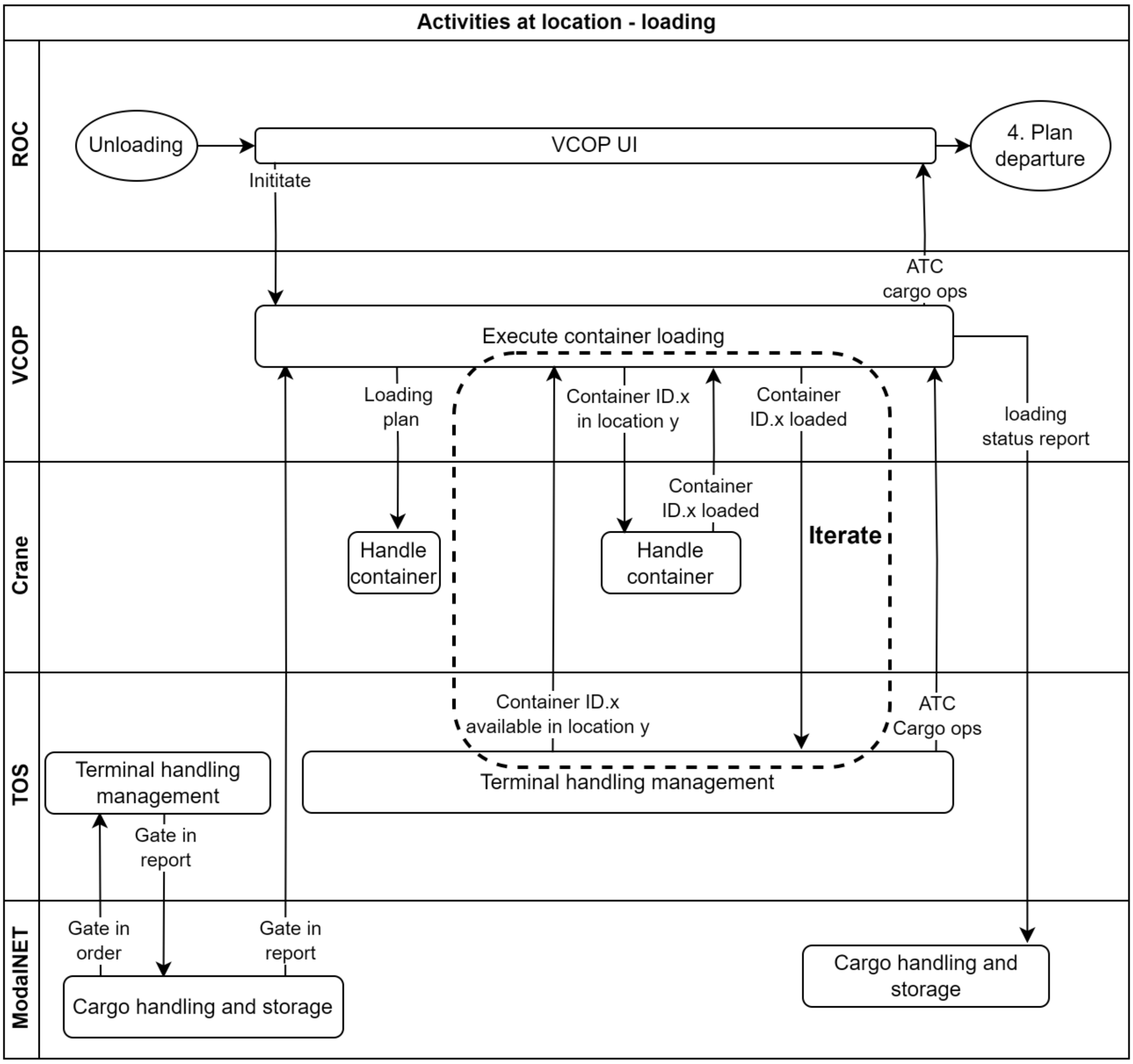

Figure 19: Phase 3 - Activities at location, loading

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3.7 PHASE 4: PLAN DEPARTURE

While the *Plan departure* phase is illustrated as being executed sequentially after the *Activities at location* phase, it will start during the *Activities at location* phase as it includes the message exchange related to planning the completion of cargo operations and departure from the terminal.

The *Plan departure* phase starts with the TOS, it sends the *ETC cargo ops* message, and then the *PTC cargo ops* (Planned Time Completion cargo operations) message to the VCOP and AVSPM. The AVSPM relays the *PTC cargo ops* message to the ROC. The ROC then sends the *ETD berth* message to the AVSPM, which responds with an *RTD berth* (Requested Time Departure from berth) message to the ROC. The *RTD berth* message could be different from the *ETD berth* message as there could be port local conditions making it desirable to change the departure time. The ROC confirms by issuing the *PTD berth* (Planned Time Departure from berth) message, and then the planned *Route*. The ROC also issues the *Schedule and voyage data* message to the ModalNET, and the *Mission update* message to the Digital Orchestrator onboard the vessel. ModalNET then issues the electronic reports, such as the *EMSWe* in maritime applications.

The phase is completed when the AVSPM issues the *Terminal ready for VSL departure* (Terminal ready for vessel departure) message to the ROC (the message is indicated as the transition to the next phase, *Depart location*, in Figure 20, while the message exchange with the ROC is given in the next section).

VTS clearance might have to be done prior to, or during departure, as it needs to be done a certain time before entering the VTS area. However, for convenience, it is only included in the *Navigate* phase diagrams as the process and related messages are the same independently from when it is executed.

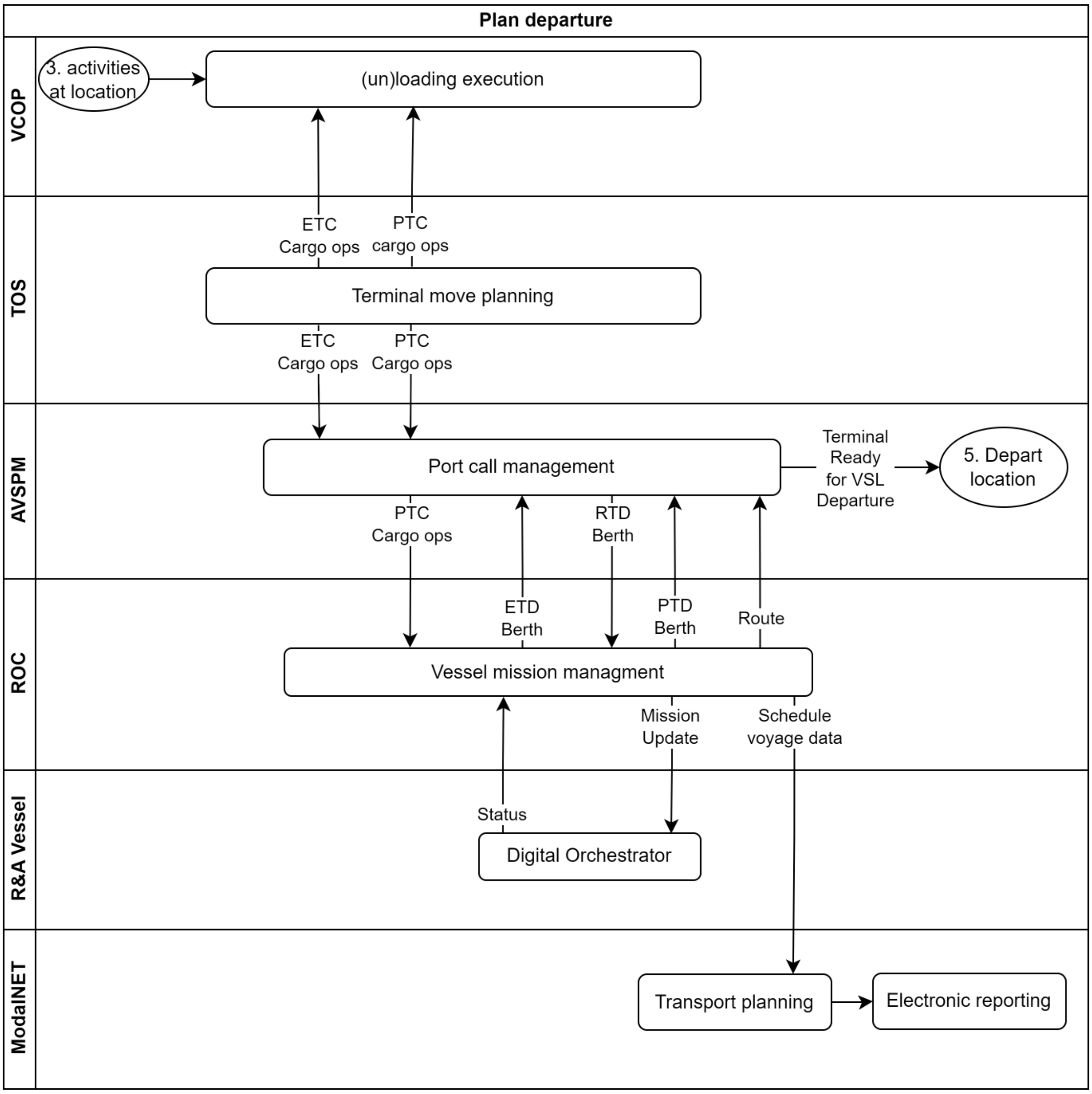

Figure 20: Phase 4 - Plan departure

3.8 PHASE 5: DEPART LOCATION

The *Depart location* phase is initiated by the *Terminal ready for VSL departure* signal being issued by the AVSPM to the ROC. The AVSPM will also send a *MetOcean & traffic* message to the ROC, containing weather, wave, current and traffic data for the port area. Based on this, the ROC updates the R&A vessel mission and sends the *Mission* message to the vessels Digital Master. The Digital Master sends the *Change mode* message to the Digital Chief, which confirms with the *Mode* message once the R&A vessel propulsion and power system has entered the given mode. As part of the mode change, the Digital Chief sends the *Disconnect command* message to the autonomous

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mooring system, in case the R&A vessel is charging. The autonomous mooring system responds with a *Charging disconnected* message once the disconnection is completed. The Digital Master then sends the *Vessel ready to sail* message to the ROC, which relays the message to the AVSPM. When ready, the ROC issues a *Start mission* message to the Digital Master.

The estimate time of departure and arrival messages, *ETD* and *ETA*, are issued with regular intervals to the ModalNET.

When the Digital Master receives the *Start mission* message, the Digital Master sends the *Initiate voyage* message to the Digital Navigator. This message includes the voyage definition. The Digital navigator then initiates the voyage by sending the *Release command* to the autonomous mooring system, which then starts the process of releasing all mooring lines. During this process the autonomous mooring system issues *Mooring released* messages for each mooring line. The Digital Navigator supervises the process and issues *Mooring status* messages to the Digital Master until the mooring is completed. During this process, the Digital Master issues *AT First line released* when the first mooring line has been released, and *ATD* (Actual Time of Departure) when the last mooring line has been released, to the ROC which relays these messages to the AVSPM. The ROC also sends the *ATD* message to the ModalNET.

Once the R&A vessel is un-moored, the Digital Navigator manoeuvres the vessel out of berth and towards the boarder of the port area (to the start of the sea passage or canal navigation). If there are any changes in the *MetOcean&traffic* messages sent from the AVSPM to the ROC, the ROC may send a *Mission update* message to the Digital Master. The Digital Master will then send a *Voyage update* message to the Digital Navigator. Throughout this process the *Pos&status* messages are issued from the Digital Navigator, via the Digital Master, to the ROC at regular intervals. The ROC and the AVSPM exchanges *Safety pulse* messages to supervise the communication link, and the ROC regularly issues *PNR pulse* messages, based on the *Pos&status* messages from the Digital Master. Once the R&A vessel reaches the end of the port area, the digital Navigator issues the *SOSP* (Start Of Sea Passage) message to the ROC, via the Digital Master, and moves to the next phase *Navigate.* The *SOSP* message is relayed by the ROC to the AVSPM.

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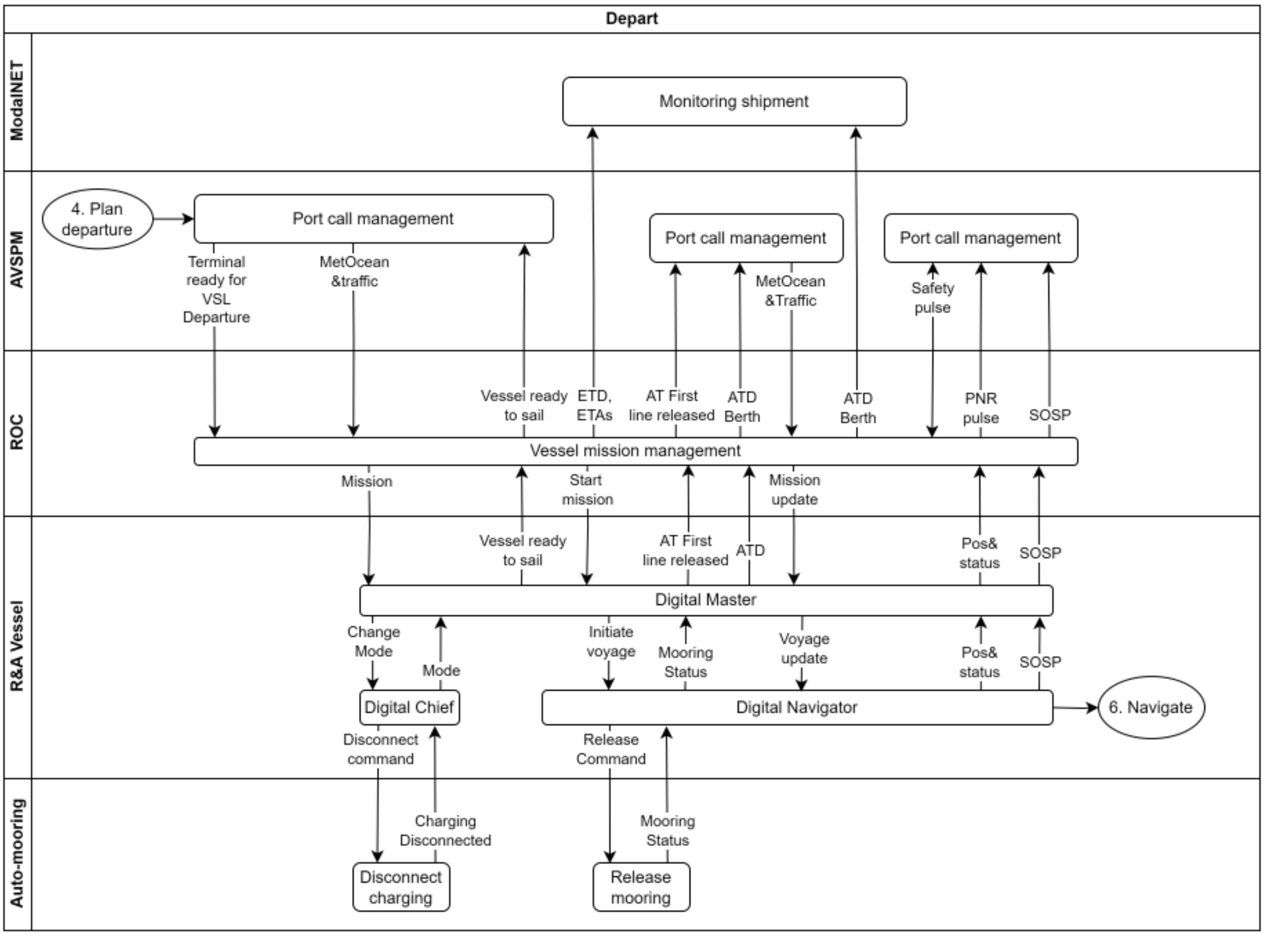

Figure 21: Phase 5 - Depart location.

3.9 PHASE 6: NAVIGATE

The *Navigate* phase is where the R&A vessel navigates from one port to the next port in the voyage schedule. The phase starts with the *SOSP* message being issued from the ROC to the AVSPM, notifying the AVSPM that the R&A vessel no longer needs to be monitored as it has left the port area. Unless the phase is entered from the *Pass lock* or *Pass bridge* phases. Throughout this phase, as with all phases where the R&A vessel is moving, the Digital Orchestrator issues *Position&status* messages at regular intervals, and, if deemed necessary, the ROC sends *Mission update,* messages to the Digital Orchestrator. The ROC also regularly sends *ETA* and *ETD* messages to the AVSPM for the upcoming port calls, and *ETA* messages to the ModalNET.

In case the R&A vessel will enter a VTS area as part of the *Navigate* phase, the ROC will do the necessary sailing clearance and reporting to the VTS. In some cases, this might happen before entering the *Navigate* phase, such as in the SEAMLESS UC1 where one of the ports resides within the VTS area, meaning, VTS clearance must be done prior to leaving the port. In such cases, VTS negotiation is done before the *Navigate* phase, but in the same way as given in Figure 22. The ROC initiates the process by issuing a *Request sailing clearance* message to the VTS. This message includes time window and route, etc. The VTS will respond with a *Sailing clearance* message that

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could include a change in time window and route, etc. While the R&A vessel is within the VTS area, the ROC regularly issues *Position report* messages to the VTS. This process is simplified a bit in this report as the VTS is not within the SEAMLESS scope of work.

When the R&A vessel reaches the end of its sea passage (or canal navigation), and the border of the next port area, the Digital Orchetratior issues the *EOSP* message, and the *Approach location* phase is entered. Once more, the port call planning is executed during the *Navigate* phase.

The *Navigation* phase can also transition to the *Pass lock* or *Pass bridge* phases.

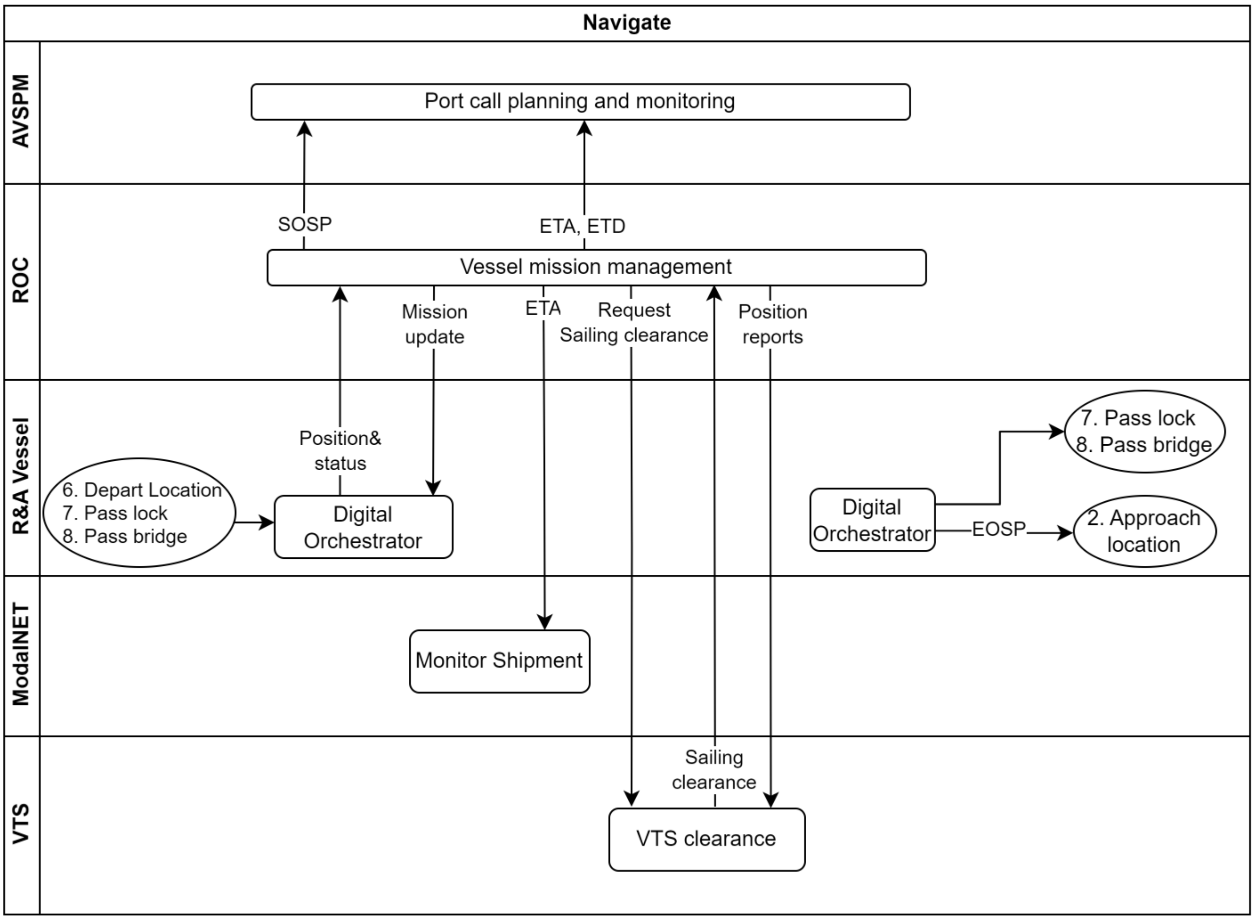

Figure 22: Phase 6 - Navigate

3.10 PHASE 7: PASS LOCK

The phase starts while the R&A vessel is in the *Navigate* phase and has a certain ETA to the next lock. It is initiated by the ROC which sends a *request time slot* message for booking time in the lock, by VHF (unless the lock has a digital interface, such as in [13]), to the lock operator (typically VTS), and an Estimated Time of Arrival message *ETA lock*. The VTS assigns the R&A vessel to a certain time and communicates the *Time slot* for entering the lock to the ROC. The R&A vessel issues position and status messages to the ROC at regular intervals throughout the phase. When the vessel arrives at the lock, the ROC informs the VTS (lock operator) about having arrived (Actual Time of

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Arrival) by the *ATA lock* message. When the time comes for the R&A vessel to enter the lock, the VTS informs the ROC that it can enter by the *Initiate enter lock* message. The ROC initiates the lock passing procedure by sending a *Enter lock* command to the Digital Orchestrator. The Digital Orchestrator navigates the R&A vessel into the lock, and to the designated place for mooring, and then initiates the mooring procedure by sending the *Start mooring* command to the auto-mooring system. When the last mooring line is fastened, the auto-mooring controller sends a *Moored* notification to the Digital Orchestrator, which the Digital Orchestrator passes on to the ROC by the *All fast* message, and which the ROC passes on the VTS. When the lock procedure is completed and the VTS is ready for the R&A vessel to leave the lock, it sends an *initiate leave lock* message to the ROC. The ROC sends a *Leave lock* command to the Digital Orchestrator for starting the procedure for leaving the lock. The Digital Orchestrator sends a *Release mooring* command to the auto-mooring system, which responds with a *Mooring released* message when the last mooring line is released, and the mooring arm is in the parking position. The R&A vessel leaves the lock, and finally the ROC sends an updated *ETA* to the ModalNET. The system then enters back into the *Navigate* phase.

Note that the details of the R&A vessel internal messaging between the Digital Navigator and Digital Master have been left out in Figure 23 as the abstraction Digital Orchestrator has been used for simplicity (see section 2.2 for definition of Digital Orchestrator, while Figure 20 and Figure 21 gives the details on messaging for mooring).

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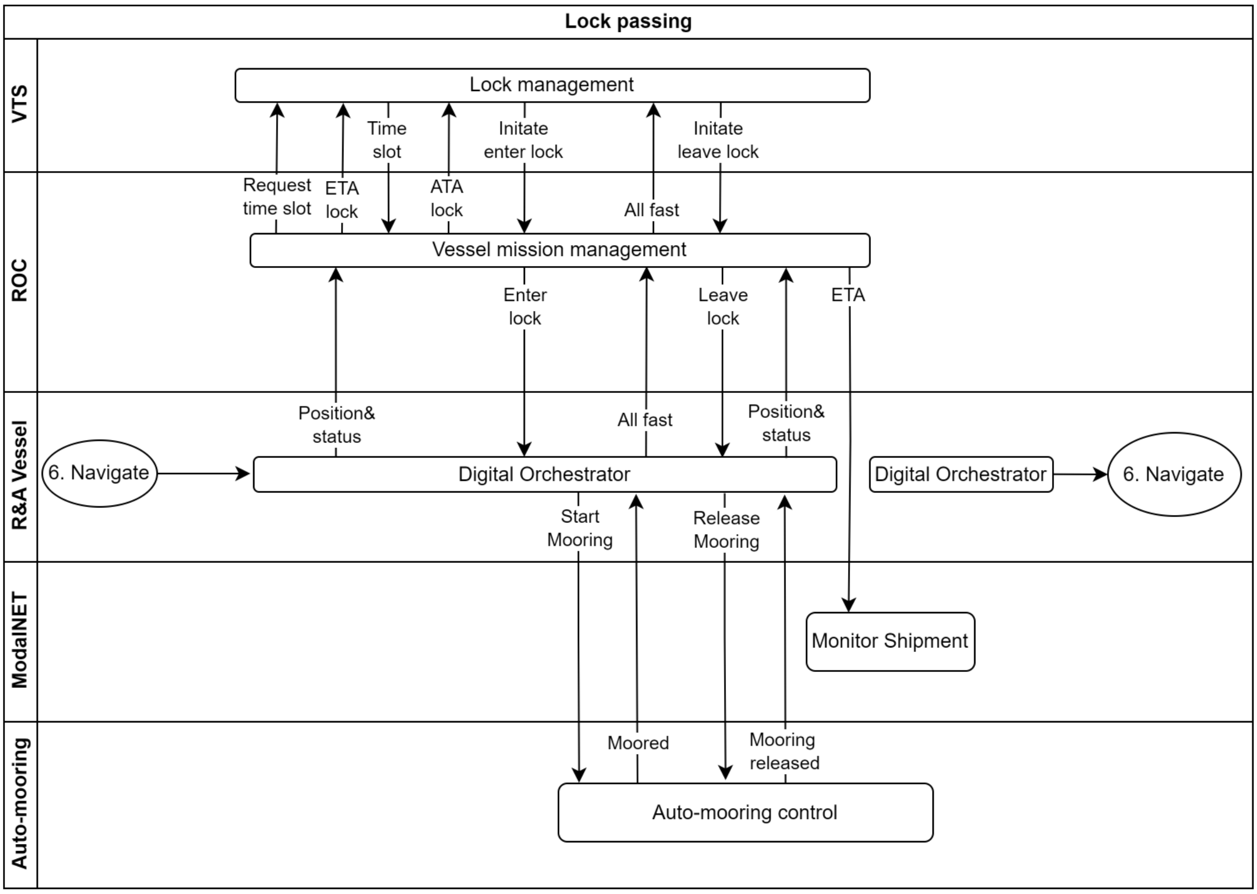

Figure 23: Phase 7 - Pass lock

3.11 Phase 8: Pass bridge

The phase starts while the R&A vessel is in the *Navigate* phase and has a certain ETA to the next bridge. For bridges that must open, it is initiated by the ROC by sending a *Request bridge opening* message to the VTS via VHF, along with an *ETA bridge*. The VTS responds with the *Time opening* message to indicate the time that the bridge will open. When the R&A vessel arrives at the bridge, it notifies the VTS about its arrival by the *ATA bridge* message and waits for the bridge to open. The ROC gives a *Hold position* command to the Digital Orchestrator to set it in the correct mode. Once the bridge has been opened the VTS notifies the ROC by the *Clear to pass* message. The ROC sends a *Continue navigation* command to the Digital Orchestrator to commence navigation. Any changes to *ETA* are notified by ROC to ModalNET.

For bridges that does not have to be opened, the vessel might have to lower masts where sensors such as radar and cameras are mounted, to stay clear of the bridge. The only involved systems in this case are the ROC and the R&A vessel, and message exchanges are Position & status messages from the R&A vessel to the ROC.

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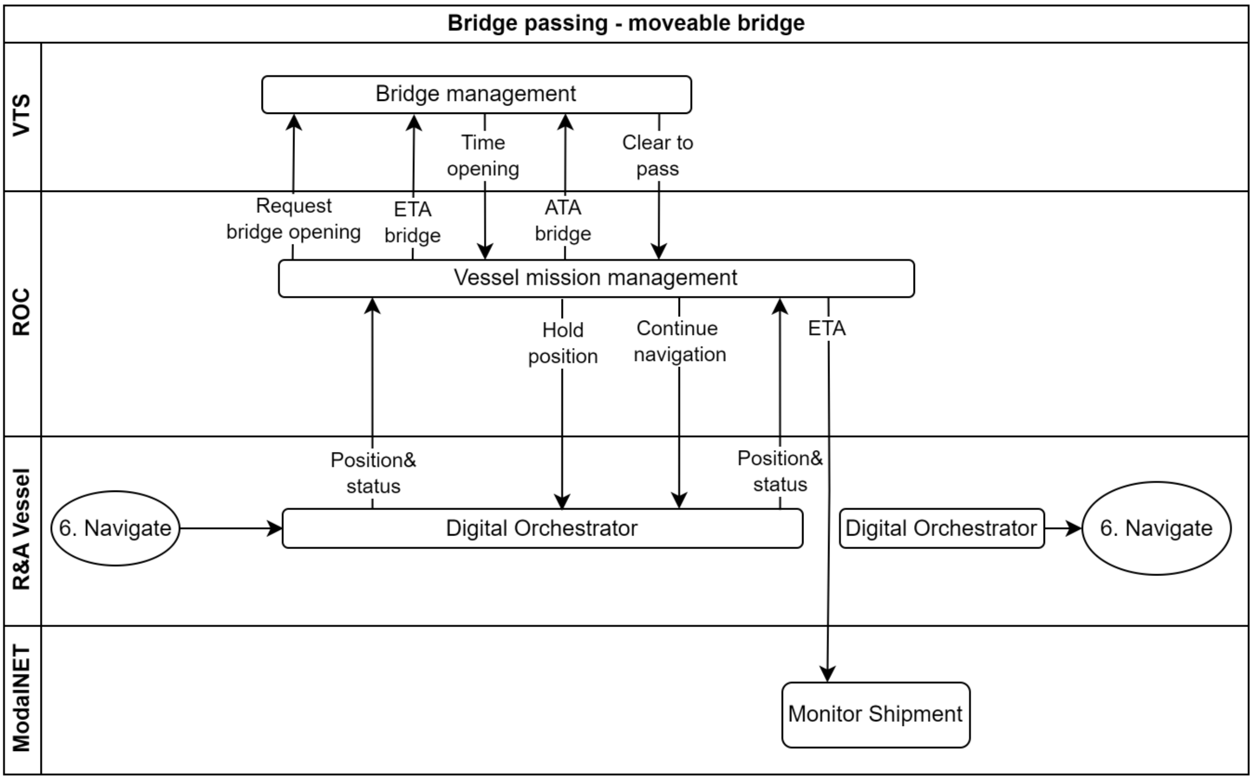

Figure 24: Phase 8 - Pass bridge

4 NON-FUNCTIONAL REQUIREMENTS

Based on what has been presented in the preceding chapters, and discussions with the building block work package leaders, this chapter presents the identified non-functional requirements for the building block subsystems. The following sections will go through building block subsystems defined in chapter 2 and present the identified non-functional requirements in tables. The tables give the non-functional requirement ID (subsystem.NonFunctional.sequence), name, and description, e.g.:

ID	Name	Description
R&A.NF.03	**Position fix**	Position fix of own vessel, other vessels or objects, should be within accuracy of x cm
R&A.NF.03.1	Own vessel	Position fix of own vessel should be within accuracy of x cm

In some cases, the same parameter (NFR) will be relevant for the same system in different operational phases. However, the value can differ. E.g., for the R&A vessel system an NFR related to positioning accuracy will be relevant for the *Navigation*, *Approach location*, *Depart location,* and *Pass obstacle* phases. But the position accuracy requirement (the value of the parameter) is likely more stringent for *Approach location* than for *Navigation.* Therefore, the following section will also include a table mapping the NFRs to planning and operational phases where “-“ means that the NFR is not relevant or applicable to the given phase, and “x” means that a value should be assigned to the NFR for that phase, e.g.:

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ID	PA	PB	P1	P2	P3	P4	P5	P6	P7
R&A.NF.01	-	-	-	X	-	-	X	X	X
R&A.NF.01.1	-	-	-	X	-	-	X	X	X

Which means that R&A.NF.01 (non-functional requirement number 1 for the R&A vessel system) is applicable to phase 2: Approach location, phase 5: Depart location, etc., but not to phase A: plan shipment, and so on.

Clarifications and limitations:

- In addition to the proposed NFRs, equipment, sensors, and systems, will need to comply with relevant regulatory and class rules, and standards.
- NFRs are defined with the perspective of the correct functionality of the SEAMLESS concept. This means that some NFRs might not be relevant if the subsystem is applied in an autonomous ship system not implementing the SEAMLESS concept.
- Operation modes for the ROC operator (such as high and low attention modes) are being studied within work package 4 and will be finalised after the completion of this report. Hence, the NFRs proposed in this report are not differentiated with respect to operation mode. However, while NFR values are likely to be influenced by operator modes, NFR parameter definitions should be the same.
- Assigning NFR parameter values is beyond the scope of this report.

4.1 AUTONOMOUS MOORING SYSTEM

The identified non-functional requirements for the autonomous mooring system (AMS) are listed in Table 11. The NFR ID for the Autonomous Mooring System is AMS.NF.sequence. The mapping of the AMS NFRs to the planning and operational phases are given in Table 12.

Table 11: AMS identified non-functional requirements

ID	Name	Description
AMS.NF.01	**Visibility**	Visibility conditions need to be within pre-defined thresholds for each sensor providing input to the situational awareness. The visibility conditions, for which thresholds should be defined, include fog, light (from full dark to intense light), rain, snow, and other objects creating blind spots. For each sensor, predefined values for either minimum, maximum, or both minimum and maximum levels measuring the relevant condition, needs to be specified.
AMS.NF.02	**Sensor status**	For sensors for positioning (e.g., joint encoders), object detection and positioning (e.g., Lidar), and for load (e.g., line tension), the fault status shall be within tolerable limits. This could be that no sensor faults are present, or a predefined matrix of minimum number of, and/or combination of, sensors that are not in a fault condition should be defined. Fault conditions include equipment failures, external noise or jamming, and external conditions outside the sensor validity range (e.g., as specified in AMS.NF.01).

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AMS.NF.03	**Actuator status**	No active actuator faults can be present
AMS.NF.04	**Environment**	Environmental conditions shall be within the threshold for safe and efficient operations
AMS.NF.04.1	Waves	Significant wave height shall be below threshold
AMS.NF.04.2	Wind	Wind speed shall be below threshold
AMS.NF.04.3	Ice	No ice on the mooring line connection point
AMS.NF.05	**Bollard**	The bollard shall be within reach, of a type and size that is supported, and the relative height difference within tolerable limits.
AMS.NF.05.1	Distance	Bollard shall be within maximum distance from the mooring arm base.
AMS.NF.05.2	Height mooring arm	The height difference between the bollard and the mooring arm should be within + x and – y meters
AMS.NF.05.3	Height winch	The height difference between the bollard and the mooring winch should be within + x and – y meters and cm
AMS.NF.05.4	Type	The bollard type and geometry shall be known and supported by the mooring system
AMS.NF.05.5	Occupied	Other mooring lines above line thickness threshold shall be detected. If the bollard is occupied, the mooring sequence shall be aborted.
AMS.NF.06	**Safety**	No humans shall be within the operational area.
AMS.NF.06.1	ROC	The ROC operator shall confirm that the area is clear prior to initiating the mooring sequence
AMS.NF.07	**Anti-collision**	Objects and surroundings shall be detected, and a motion trajectory to be calculated with a safe clearance.
AMS.NF.07.1	Vessel model	A vessel 3D geometry model is needed and shall be of an accuracy above a threshold ensuring that a trajectory with a sufficient safety zone can be calculated.
AMS.NF.07.2	No-go zones	The 3D model shall include no-go zones ensuring that all occupied space, or potentially occupied space, is avoided. This could be cargo hold or other areas of the vessel where objects might be placed temporarily.
AMS.NF.07.3	Object size	Objects above a size threshold shall be detected
AMS.NF.07.4	Object detection	Objects causing a collision risk shall be detected. The object detection sensor distance resolution and precision shall be within a pre-defined threshold, horizontal and vertical field of view shall be within minimal thresholds, and point density at a defined distance shall be above x points/10cm^3
AMS.NF.07.5	Trajectory	Generated trajectories shall ensure a minimum clearance (safety zone) to other objects (if this is not possible, the robotic arm shall stop)
AMS.NF.08	**Connectivity**	Connectivity shall be of sufficient quality to provide operators with enough data at low enough latency.
AMS.NF.08.1	Bandwidth	Connectivity bandwidth shall be above threshold
AMS.NF.08.2	Latency	Connectivity latency shall be below threshold

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AMS.NF.9	**Line tension and position adjustment**	Automatic line tension control and automatic position adjustment shall be within safe limits regarding line forces and back-up line on the winch drum.
AMS.NF.9.1	Line forces	The mooring line forces, e.g., caused by vessel motions or during hauling, shall be below threshold.
AMS.NF.9.2	Line length on winch	The remaining line length on the winch drum shall be above threshold for safe auto tensioning. This limits the operational distance between the winch and the bollard to ensure auto-tension functionality, and the distance forward and aft that the vessel can be hauled by the winching system.
AMS.NF.10	**External commands**	The autonomous mooring system shall take start and abort commands from an external interface.
AMS.NF.10.1	Mooring	The autonomous mooring system shall take start mooring command as input and complete the mooring sequence.
AMS.NF.10.2	unmooring	The autonomous mooring system shall take start unmooring command as input and complete the unmooring sequence.
AMS.NF.10.3	Abort	The autonomous mooring system shall take abort command as input and abort the current sequence.
AMS.NF.10.4	Adjust position	The autonomous mooring system shall take move forward and aft command as input and complete the repositioning sequence
AMS.NF.10.5	Response to commands	The autonomous mooring system response to commands shall be within a latency threshold of x ms.

Table 12: AMS NFR mapping to planning and operational phases

ID	PA	PB	P1	P2	P3	P4	P5	P6	P7	P8
AMS.NF.01	-	-	-	X	-	-	X	-	X	-
AMS.NF.02	-	-	-	X	-	-	X	-	X	-
AMS.NF.03	-	-	-	X	X	-	X	-	X	-
AMS.NF.04	-	-	-	X	-	-	X	-	X	-
AMS.NF.04.1	-	-	-	X	-	-	X	-	X	-
AMS.NF.04.2	-	-	-	X	-	-	X	-	X	-
AMS.NF.04.3	-	-	-	X	-	-	X	-	X	-
AMS.NF.05	-	-	-	X	-	-	X	-	X	-
AMS.NF.05.1	-	-	-	X	-	-	X	-	X	-
AMS.NF.05.2	-	-	-	X	-	-	X	-	X	-
AMS.NF.05.3	-	-	-	X	X	-	X	-	X	-
AMS.NF.05.4	-	-	-	X	-	-	-	-	X	-
AMS.NF.05.5	-	-	-	X	-	-	X	-	X	-
AMS.NF.06	-	-	-	X	X	-	X	-	X	-
AMS.NF.06.1	-	-	-	X	X	-	X	-	X	-
AMS.NF.07	-	-	-	X	-	-	X	-	X	-
AMS.NF.07.1	-	-	-	X	-	-	X	-	X	-
AMS.NF.07.2	-	-	-	X	-	-	X	-	X	-
AMS.NF.07.3	-	-	-	X	-	-	X	-	X	-
AMS.NF.07.4	-	-	-	X	-	-	X	-	X	-
AMS.NF.07.5	-	-	-	X	-	-	X	-	X	-
AMS.NF.08	-	-	-	X	X	-	X	-	X	-

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AMS.NF.08.1	-	-	-	X	X	-	X	-	X	-
AMS.NF.08.2	-	-	-	X	X	-	X	-	X	-
AMS.NF.9	-	-	-	X	X	-	-	-	X	-
AMS.NF.9.1	-	-	-	X	X	-	-	-	X	-
AMS.NF.9.2	-	-	-	X	X	-	-	-	X	-
AMS.NF.10	-	-	-	X	X	-	X	-	X	-
AMS.NF.10.1	-	-	-	X	-	-	X	-	X	-
AMS.NF.10.2	-	-	-	X	-	-	X	-	X	-
AMS.NF.10.3	-	-	-	X	-	-	X	-	X	-
AMS.NF.10.4	-	-	-	X	X	-	-	-	X	-
AMS.NF.10.5	-	-	-	X	X	-	X	-	X	-

4.2 AUTONOMOUS CARGO CRANE

The identified non-functional requirements for the Autonomous Cargo Crane (ACC) are listed in Table 13. The NFR ID for the Autonomous Cargo Crane is ACC.NF.sequence. The mapping of the ACC NFRs to the planning and operational phases are given in Table 14.

Table 13: ACC identified non-functional requirements

ID	Name	Description
ACC.NF.01	**Visibility**	Visibility conditions shall be within pre-defined thresholds for each sensor providing input to the situational awareness. The visibility conditions, for which thresholds should be defined, include fog, light (from full dark to intense light), rain, snow, and other objects creating blind spots. For each sensor, predefined values for either minimum, maximum, or both minimum and maximum levels measuring the relevant condition, needs to be specified.
ACC.NF.02	**Sensor status**	Sensor fault status (sensors for positioning and object detection). A predefined matrix of minimum number of, and/or combination of, sensors that are not in a fault condition should be defined. Fault conditions include equipment failures, external noise or jamming, and external conditions outside the sensor validity range (as specified in ACC.NF.01).
ACC.NF.03	**Actuator status**	No active actuator faults can be present
ACC.NF.04	**Environment**	Environmental conditions shall be within the threshold for safe and efficient operations
ACC.NF.04.1	Waves	Significant wave height shall be below threshold
ACC.NF.04.2	Wind	Wind speed shall be below threshold
ACC.NF.04.3	Ice	Ice and snow on container gripping surface below threshold
ACC.NF.05	**Containers**	Container weight and dimension shall be within thresholds
ACC.NF.05.1	Weight	Maximum container weight 30.5MT
ACC.NF.05.2	Dimensions	Container is an ISO container.
ACC.NF.06	**Safety**	No humans can be within the operational area.
ACC.NF.06.1	ROC	The ROC operator shall confirm that the area is clear prior to initiating the cargo handling sequence

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ACC.NF.07	**Anti-collision**	Objects and surroundings need to be detected, and a motion trajectory to be calculated with a safe clearance.
ACC.NF.07.1	Vessel model	A vessel geometry model needs to be of an accuracy of 0.5 cm
ACC.NF.07.2	Object size	Objects above a size threshold shall be detected
ACC.NF.07.3	Trajectory	Generated trajectories shall ensure a minimum clearance of 200 cm to other objects
ACC.NF.07.4	Quay model	Shall have a digital map of the quay which includes all fixed objects and structures, with an accuracy of 10 cm,
ACC.NF.07.5	Container location	Container locations with id and coordinates shall be defined
ACC.NF.08	**Connectivity**	Connectivity shall be of sufficient quality to provide operators with enough data at low enough latency.
ACC.NF.08.1	Bandwidth	Connectivity bandwidth shall be above threshold
ACC.NF.08.2	Latency	Connectivity latency shall be below threshold of 10 secs.
ACC.NF.9	**Distance**	Maximum distance from container crane base to container centre is approximately 28m, however, this will depend on the specific design.

Table 14: ACC NFR mapping to planning and operational phase

ID	PA	PB	P1	P2	P3	P4	P5	P6	P7	P8
ACC.NF.01	-	-	-	-	X	-	-	-	-	-
ACC.NF.02	-	-	-	-	X	-	-	-	-	-
ACC.NF.03	-	-	-	-	X	-	-	-	-	-
ACC.NF.04	-	-	-	-	X	-	-	-	-	-
ACC.NF.04.1	-	-	-	-	X	-	-	-	-	-
ACC.NF.04.2	-	-	-	-	X	-	-	-	-	-
ACC.NF.04.3	-	-	-	-	X	-	-	-	-	-
ACC.NF.05	-	-	-	-	X	-	-	-	-	-
ACC.NF.05.1	-	-	-	-	X	-	-	-	-	-
ACC.NF.05.2	-	-	-	-	X	-	-	-	-	-
ACC.NF.06	-	-	-	-	X	-	-	-	-	-
ACC.NF.06.1	-	-	-	-	X	-	-	-	-	-
ACC.NF.07	-	-	-	-	X	-	-	-	-	-
ACC.NF.07.1	-	-	-	-	X	-	-	-	-	-
ACC.NF.07.2	-	-	-	-	X	-	-	-	-	-
ACC.NF.07.3	-	-	-	-	X	-	-	-	-	-
ACC.NF.07.4	-	-	-	-	X	-	-	-	-	-
ACC.NF.07.5	-	-	-	-	X	-	-	-	-	-
ACC.NF.08	-	-	-	-	X	-	-	-	-	-
ACC.NF.08.1	-	-	-	-	X	-	-	-	-	-
ACC.NF.08.2	-	-	-	-	X	-	-	-	-	-
ACC.NF.9	-	-	-	-	X	-	-	-	-	-

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4.3 VCOP

The identified non-functional requirements for the Voyage and Container Optimisation Platform (VCOP) are listed in Table 15. The NFR ID for the VCOP is VCOP.NF.sequence. The mapping of the VCOP NFRs to the planning and operational phases are given in Table 16.

Table 15: VCOP identified non-functional requirements

ID	Name	Description
VCOP.NF.01	**Decision basis**	To ensure quality and robustness of stowage and cargo handling sequence plans, the decision basis data provided to the VCOP shall be within accuracy thresholds.
VCOP.NF.01.1	Schedule	The vessel schedule shall be transferred to the VCOP. Any change to the schedule, such as adding or removing a port call from the vessel schedule shall be transferred to the VCOP and acknowledged by the VCOP.
VCOP.NF.01.2	Vessel model available	The vessel model has been transferred to the VCOP for each vessel
VCOP.NF.01.3	Vessel model accuracy	The vessel model with all necessary data to perform stability calculations and stowage planning shall be within the accuracy threshold (dimensions, weights, weight distribution, etc.).
VCOP.NF.02	**ModalNET bookings**	To ensure quality and robustness of stowage and cargo handling sequence plans, the booking information sent by ModalNET shall be correct and within thresholds.
VCOP.NF.02.1	Cargo amount	Bookings received from ModalNET shall not exceed remaining vessel capacity
VCOP.NF.02.2	Required cargo unit data	Bookings received from ModalNET shall contain cargo data per cargo unit (id, dangerous cargo, type of ISO container, weight, port of origin, and destination port).
VCOP.NF.02.3	Weight	Cargo data for each unique cargo item: weight accuracy shall be within +/- 250 kg.
VCOP.NF.02.4	Container type	Cargo data for each unique cargo item: ISO container type shall be correct .
VCOP.NF.02.5	Booking transfers	No cargo booking to the vessel shall be done without transferring the booking to the VCOP.
VCOP.NF.02.6	ModalNET and VCOP consistency	If a valid stowage plan cannot be achieved for a given booking, the booking shall be cancelled (also in ModalNET). ModalNET and VCOP booking status per vessel shall be consistent.
VCOP.NF.03	**Terminal and TOS**	Digital communication between the TOS and VCOP shall be consistent and of sufficient accuracy
VCOP.NF.03.1	API available	TOS shall have an API for cargo handling sequence planning and execution
VCOP.NF.03.2	API implemented	VCOP shall implement the TOS API for cargo handling sequence planning and execution
VCOP.NF.03.3	Container locations	There shall be designated areas at the quay front where the autonomous container crane can place or pick-up containers (container locations), defined by coordinates and id.
VCOP.NF.03.4	Location definition Consistency	There shall not be any discrepancy between the TOS and VCOP container location definitions

VCOP.NF.03.5	Terminal container placement accuracy	The terminal cargo handling equipment shall always place containers in locations with accuracy within the thresholds such that the autonomous cargo crane can find and pick-up the correct container.
VCOP.NF.03.6	TOS update frequency	TOS shall update container location status by sending a message to the VCOP within x seconds of having placed or removed a container from a location: ○ Container ID.x moved from location ID.y ○ Container ID.x placed in location
VCOP.NF.03.7	VCOP update frequency	VCOP shall update container location status by sending a message to the TOS within x seconds of having placed or removed a container from a location: ○ Container ID.x moved from location ID.y ○ Container ID.x placed in location
VCOP.NF.04	**Connectivity TOS**	Communication link between TOS and VCOP bandwidth and latency within thresholds.
VCOP.NF.04.1	Bandwidth	Connectivity bandwidth shall be above threshold
VCOP.NF.04.2	Latency	Connectivity latency shall be below threshold
VCOP.NF.05	**Connectivity Crane**	Communication link between the cargo crane and VCOP bandwidth and latency shall be within thresholds.
VCOP.NF.05.1	Bandwidth	Connectivity bandwidth shall be above threshold
VCOP.NF.05.2	Latency	Connectivity latency shall be below threshold
VCOP.NF.06	**User interface**	The VCOP user interface shall provide sufficient situational awareness for the ROC operator to decide if any intervention will be necessary, and all controls needed to intervene.
VCOP.NF.06.1	Presented data	The VCOP user interface shall provide sufficient situational awareness for the stowage, loading and unloading plans, cargo, and cargo operations.
VCOP.NF.06.2	Controls	The VCOP user interface shall include high level controls such as initiate cargo operation, abort cargo operation, accept stowage plan, etc.
VCOP.NF.07	**Container data**	Registered container data shall not deviate from actual metrics by more than threshold limits to ensure stowage plan accuracy and quality.
VCOP.NF.07.1	Weight	Container ID.x weight registered in the VCOP shall not deviate from actual weight by more than +/-250 kg
VCOP.NF.07.2	Type	Container ID.x ISO type registered in the VCOP shall be correct

Table 16: VCOP NFR mapping to planning and operational phase

ID	PA	PB	P1	P2	P3	P4	P5	P6	P7	P8
VCOP.NF.01	X	-	-	-	-	-	-	-	-	-
VCOP.NF.01.1	X	-	-	-	-	-	-	-	-	-
VCOP.NF.01.2	X	-	-	-	-	-	-	-	-	-
VCOP.NF.01.3	X	-	-	-	-	-	-	-	-	-
VCOP.NF.02	X	-	-	-	-	-	-	-	-	-
VCOP.NF.02.1	X	-	-	-	-	-	-	-	-	-
VCOP.NF.02.2	X	-	-	-	-	-	-	-	-	-
VCOP.NF.02.3	X	-	-	-	-	-	-	-	-	-

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VCOP.NF.02.4	X	-	-	-	-	-	-	-	-	-
VCOP.NF.02.5	X	-	-	-	-	-	-	-	-	-
VCOP.NF.02.6	X	-	-	-	-	-	-	-	-	-
VCOP.NF.03	-	-	-	-	X	X	-	-	-	-
VCOP.NF.03.1	-	-	-	-	X	X	-	-	-	-
VCOP.NF.03.2	-	-	-	-	X	X	-	-	-	-
VCOP.NF.03.3	-	-	-	-	X	-	-	-	-	-
VCOP.NF.03.4	-	-	-	-	X	-	-	-	-	-
VCOP.NF.03.5	-	-	-	-	X	-	-	-	-	-
VCOP.NF.03.6	-	-	-	-	X	-	-	-	-	-
VCOP.NF.03.7	-	-	-	-	X	-	-	-	-	-
VCOP.NF.04	-	-	-	-	X	X	-	-	-	-
VCOP.NF.04.1	-	-	-	-	X	X	-	-	-	-
VCOP.NF.04.2	-	-	-	-	X	X	-	-	-	-
VCOP.NF.05	-	-	-	-	X	-	-	-	-	-
VCOP.NF.05.1	-	-	-	-	X	-	-	-	-	-
VCOP.NF.05.2	-	-	-	-	X	-	-	-	-	-
VCOP.NF.06	X	-	-	-	X	-	-	-	-	-
VCOP.NF.06.1	X	-	-	-	X	-	-	-	-	-
VCOP.NF.06.2	X	-	-	-	X	-	-	-	-	-
VCOP.NF.07	X	-	-	-	X	-	-	-	-	-
VCOP.NF.07.1	X	-	-	-	X	-	-	-	-	-
VCOP.NF.07.2	X	-	-	-	X	-	-	-	-	-

4.4 AVSPM

The identified non-functional requirements for the Advanced Vessels' Smart Port Manager (AVSPM) are listed in Table 17. The NFR ID for the AVSPM is AVSPM.NF.sequence. The mapping of the AVSPM NFRs to the planning and operational phases are given in Table 18.

Table 17: AVSPM identified non-functional requirements

ID	Name	Description
AVSPM.NF.01	**API**	The AVSPM shall implement the terminal management API
AVSPM.NF.02	**Training**	The VTS operators shall be trained in the usage of the AVSPM
AVSPM.NF.03	**Port call planning basis**	To ensure that the AVSPM port call planning and negotiations with the ROC is consistent, the port call planning basis shall be within thresholds.
AVSPM.NF.03.1	Terminal booking status	Terminal booking status shall be updated within x minutes of booking a port call for a vessel not within the scope of the AVSPM (e.g., conventional vessels not implementing the AVSPM service).
AVSPM.NF.03.2	Vessel data	Vessel data transmitted by ROC shall be of accuracy above threshold (vessel particulars, type, capabilities etc.)
AVSPM.NF.03.3	Vessel capabilities	Received Vessel type, and capabilities shall be correct
AVSPM.NF.03.4	Cargo data	Cargo data transmitted by ROC to AVSPM shall be of accuracy above threshold (type, weight, size, amount, dangerous cargo, etc.).

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AVSPM.NF.03.5	Vessel schedule arrival	Provided data in the ROC port call planning messages (route, ETA, ETD, vessel data, cargo data) shall be within accuracy thresholds
AVSPM.NF.03.6	Vessel schedule departure	Provided data in the ROC departure planning messages (route, ETD, PTD, vessel data) shall be within accuracy requirements.
AVSPM.NF.04	**Port call execution**	To ensure safe and efficient port call execution, the data sources used by the AVSPM shall comply with accuracy thresholds.
AVSPM.NF.04.1	PNR data	Received PNR pulse position, speed, course, and draft shall be within accuracy thresholds
AVSPM.NF.04.2	PNR status	Received PNR navigational status shall be correct
AVSPM.NF.04.3	Route	Received route shall be an array of at least 90 coordinates with at least 10 second intervals
AVSPM.NF.04.4	Metocean	Metocean data accuracy shall be within threshold
AVSPM.NF.04.5	Traffic	Traffic data (vessel size, heading, speed, and navigational status) shall be within accuracy threshold
AVSPM.NF.05	Schedule update	The AVSPM depends on updated ETA and ETDs from the ROC anytime these changes. Updates should be provided x minutes after having been made.

Table 18: AVSPM NFR mapping to planning and operational phase

ID	PA	PB	P1	P2	P3	P4	P5	P6	P7	P8
AVSPM.NF.01	-	X	X	-	-	X	-	-	-	-
AVSPM.NF.02	-	X	X	-	-	X	-	-	-	-
AVSPM.NF.03	-	X	X	-	-	X	-	-	-	-
AVSPM.NF.03.1	-	X	X	-	-	X	-	-	-	-
AVSPM.NF.03.2	-	X	X	X	-	X	X	-	-	-
AVSPM.NF.03.3	-	X	X	X	-	X	X	-	-	-
AVSPM.NF.03.4	-	X	X	X	-	X	-	-	-	-
AVSPM.NF.03.5	-	X	X	-	-	X	-	-	-	-
AVSPM.NF.03.6	-	X	X	-	-	X	X	-	-	-
AVSPM.NF.04	-	-	-	X	-	-	X	-	-	-
AVSPM.NF.04.1	-	-	-	X	-	-	X	-	-	-
AVSPM.NF.04.2	-	-	-	X	-	-	X	-	-	-
AVSPM.NF.04.3	-	-	X	X	-	X	X	-	-	-
AVSPM.NF.04.4	-	-	X	X	-	X	X	-	-	-
AVSPM.NF.04.5	-	-	X	X	-	X	X	-	-	-
AVSPM.NF.05	-	X	X	X	-	X	X	X	X	X

4.5 R&A VESSEL SYSTEMS

The identified non-functional requirements for the R&A vessel systems are listed in Table 19. The NFR ID for the R&A vessel systems is R&A.NF.sequence. The mapping of the R&A vessel systems NFRs to the planning and operational phases are given in Table 20.

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Table 19: R&A vessel systems identified non-functional requirements

ID	Name	Description
R&A.NF.01	**Visibility**	Visibility conditions shall be within pre-defined thresholds for each sensor providing input to the situational awareness. The visibility conditions, for which thresholds should be defined, include fog, light (from full dark to intense light), rain, snow, and other objects creating blind spots. For each sensor, predefined values for either minimum, maximum, or both minimum and maximum levels measuring the relevant condition, should be specified.
R&A.NF.02	**Sensor status**	Sensor fault status (sensors for positioning and object detection). A predefined matrix of minimum number of, and/or combination of, sensors that are not in a fault condition should be defined. Fault conditions include equipment failures, external noise or jamming, and external conditions outside the sensor validity range (as specified in R&A.NF.01).
R&A.NF.03	**Position fix**	Position fix of own vessel, other vessels or objects, should be within accuracy threshold.
R&A.NF.03.1	Own vessel	Position fix of own vessel should be within accuracy above threshold
R&A.NF.03.2	Other vessel	Position fix of other vessels should be within accuracy above threshold
R&A.NF.03.3	Other object	Position fix of other objects should be within accuracy above threshold
R&A.NF.04	**Object size**	Size estimation of objects and vessels should be within an accuracy above threshold
R&A.NF.05	**Course**	Own and other vessel course should be determined with an accuracy above threshold
R&A.NF.05.1	Own vessel	Own vessel course shall be determined with an accuracy above threshold
R&A.NF.05.2	Other vessel	Other vessel course should be determined with an accuracy above threshold
R&A.NF.06	**Speed over ground**	Own and other vessel or object speed over ground shall be determined with an accuracy above threshold
R&A.NF.06.1	Own vessel	Own vessel speed over ground shall be determined with an accuracy above threshold
R&A.NF.06.2	Other vessel	Other vessel speed over ground shall be determined with an accuracy above threshold
R&A.NF.06.3	Object	Object speed over ground shall be determined with an accuracy above threshold
R&A.NF.07	**Vessel identification**	Correct identification of other vessels requires that the other vessels shall emit AIS messages according to rules.
R&A.NF.08	**Traffic**	Traffic conditions shall be such that the predicted navigational risk is below a given threshold.
R&A.NF.09	**Connectivity**	Connectivity shall be of sufficient quality to provide operators with enough data at low enough latency, given the operation mode.
R&A.NF.09.1	Bandwidth	Connectivity bandwidth shall be above threshold
R&A.NF.09.2	Latency	Connectivity latency shall be below threshold
R&A.NF.10	**Ship system status**	Ship system status (power system, propulsion, equipment, etc.) shall not degrade manoeuvring capabilities below threshold.

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R&A.NF.11	**Mooring**	The R&A vessel system shall interface the autonomous mooring system and give high-level commands to initiate or abort mooring and un-mooring.
R&A.NF.11.1	API	The R&A vessel system "Digital Orchestrator" shall implement the autonomous mooring system API for external control (including forwarding commands from the ROC).
R&A.NF.11.2	Mooring command signals	The autonomous mooring system shall handle the mooring process autonomously without any other commands from the R&A vessel system than "connect", "disconnect", "abort", and "commence".
R&A.NF.11.3	Positioning command signals	The autonomous mooring system shall handle the adjustment of vessel position autonomously without any other commands from the R&A system than "move x cm forward", "move x cm backward", "abort" and "commence".
R&A.NF.11.4	Mooring status	The autonomous mooring system shall provide correct status updates on the autonomous mooring process to ensure correct function of the R&A systems related to mooring.

Table 20: R&A vessel systems NFR mapping to planning and operational phase

ID	PA	PB	P1	P2	P3	P4	P5	P6	P7	P8
R&A.NF.01	-	-	-	X	-	-	X	X	X	X
R&A.NF.01.1	-	-	-	X	-	-	X	X	X	X
R&A.NF.02	-	-	-	X	-	-	X	X	X	X
R&A.NF.03	-	-	-	X	-	-	X	X	X	X
R&A.NF.03.1	-	-	-	X	-	-	X	X	X	X
R&A.NF.03.2	-	-	-	X	-	-	X	X	X	X
R&A.NF.03.3	-	-	-	X	-	-	X	X	X	X
R&A.NF.04	-	-	-	X	-	-	X	X	X	X
R&A.NF.05	-	-	-	X	-	-	X	X	X	X
R&A.NF.05.1	-	-	-	X	-	-	X	X	X	X
R&A.NF.05.2	-	-	-	X	-	-	X	X	X	X
R&A.NF.06	-	-	-	X	-	-	X	X	X	X
R&A.NF.06.1	-	-	-	X	-	-	X	X	X	X
R&A.NF.06.2	-	-	-	X	-	-	X	X	X	X
R&A.NF.06.3	-	-	-	X	-	-	X	X	X	X
R&A.NF.07	-	-	-	X	-	-	X	X	X	X
R&A.NF.08	-	-	-	X	-	-	X	X	X	X
R&A.NF.08.1	-	-	-	X	-	-	X	X	X	X
R&A.NF.08.2	-	-	-	X	-	-	X	X	X	X
R&A.NF.08.3	-	-	-	X	-	-	X	X	X	X
R&A.NF.08.4	-	-	-	X	-	-	X	X	X	X
R&A.NF.09	-	-	-	X	-	-	X	X	X	X
R&A.NF.09.1	-	-	-	X	-	-	X	X	X	X
R&A.NF.09.2	-	-	-	X	-	-	X	X	X	X
R&A.NF.10	-	-	-	X	-	-	X	X	X	X
R&A.NF.11	-	-	-	X	-	-	X	-	X	-
R&A.NF.11.1	-	-	-	X	X	-	X	-	X	-
R&A.NF.11.2	-	-	-	X	-	-	X	-	X	-

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R&A.NF.11.3	-	-	-	X	X	-	-	-	X	-
R&A.NF.11.4	-	-	-	X	X	-	X	-	X	-

4.6 ROC

The identified non-functional requirements for the Remote Operations Centre (ROC) are listed in Table 21. The NFR ID for the ROC is ROC.NF.sequence. The mapping of the ROC NFRs to the planning and operational phases are given in Table 22.

Table 21: ROC identified non-functional requirements

ID	Name	Description
ROC.NF.01	**ROWS**	Remote operations workstation shall provide the operator with the information and controls needed to safely operate the autonomous vessel, and to interact with the SEAMLESS building blocks.
ROC.NF.01.1	ModalNET API	Remote operations workstations shall implement the ModalNET ROC API
ROC.NF.01.2	VCOP UI	Remote operations workstations shall include the VCOP user interface (UI). The VCOP UI is responsible for providing all information and controls that are needed for the safe and efficient cargo operations.
ROC.NF.01.3	AVSPM API	Remote operations workstations shall implement the AVSPM ROC API
ROC.NF.01.4	R&A vessel situational awareness	ROC operators shall be presented with sufficient information to determine the navigational and manoeuvring capability of the R&A vessel, the traffic situation including geography, and weather conditions, facilitating safe and efficient decision making.
ROC.NF.01.5	Modes of operation	Presented information for ROC operator situational awareness shall be configurable to facilitate different operation modes. Pre-sets per mode should also be available.
ROC.NF.01.6	R&A vessel status updates	Position and status reports from the R&A vessel shall be sent with a refresh rate of x seconds to facilitate sufficient situational awareness.
ROC.NF.01.7	Controls	The ROWS shall include all relevant controls for ensuring safe and efficient operations.
ROC.NF.01.8	System status	There shall be no active faults in the ROWS technical systems that degrades the ROC operator situational awareness below thresholds, or their capability to perform necessary actions.
ROC.NF.02	**Vessel data**	Vessel owner shall provide the vessel data to the ROC (main particulars, cargo hold capacity, design speed, capabilities, systems and equipment etc.).
ROC.NF.03	**Schedule keeping**	Vessel schedule shall be managed by the ROC and transferred to the VCOP and ModalNET whenever it is needed (within x minutes of a change to the schedule).
ROC.NF.04	**Training**	Operators need training in the SEAMLESS concept
ROC.NF.04.1	VCOP	Operators shall be trained in the usage of VCOP, including autonomous cargo operations where the VCOP controls the autonomous cargo crane.

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ROC.NF.04.2	ModalNET	Operators shall be trained in digital communication with ModalNET
ROC.NF.04.3	AVSPM	Operators shall be trained in digital communication with the AVSPM; digital port call planning and execution.
ROC.NF.04.4	Operating modes	Operator shall be trained in different operational modes (e.g., different number of vessels in the fleet, different levels of attention such as high and low).
ROC.NF.04.5	Handover R&A vessel	Operator shall be trained in handing over R&A vessel responsibility between operators, and between ROCs.
ROC.NF.05	**Connectivity**	Communication link to the R&A vessel bandwidth and latency within thresholds
ROC.NF.05.1	R&A vessel link bandwidth	The R&A vessel link bandwidth shall be above threshold
ROC.NF.05.2	R&A vessel link latency	The R&A vessel link latency shall be below threshold
ROC.NF.05.3	Security	A secure connection to the other building blocks and their subsystems shall be available.
ROC.NF.06	**AVSPM port call**	Safety pulse and PNR to be transmitted to the AVSPM at fixed intervals
ROC.NF.06.1	Safety pulse	Safety pulse shall be transmitted every x second
ROC.NF.06.2	PNR	PNR to be transmitted every x second
ROC.NF.07	**Auto-Mooring**	Auto-mooring shall be supervised from the ROC, including initiation of automatic mooring and unmooring sequences.
ROC.NF.07.1	interface	ROC interface to the R&A vessel systems shall include “abort” and “commence” commands for the autonomous mooring system, as well as “remote control on/off” and setpoint signals for the mooring arm and winch actuators. This can be implemented by a dedicated control station.
ROC.NF.07.2	Situational awareness	Sufficient situational awareness for the autonomous mooring system operational area shall be provided to the ROC operators (e.g., video feed etc from the Auto-mooring system).
ROC.NF.07.3	Response to commands	The autonomous mooring system response to commands shall be within a latency threshold of x ms to facilitate safe operations from the ROC.

Table 22: ROC NFR mapping to planning and operational phase

ID	PA	PB	P1	P2	P3	P4	P5	P6	P7	P8
ROC.NF.01	X	-	-	X	-	X	X	X	X	X
ROC.NF.01.1	X	-	X	X	-	X	X	X	X	X
ROC.NF.01.2	X	-	-	-	X	-	-	-	-	-
ROC.NF.01.3	-	X	X	X	-	X	X	X	X	X
ROC.NF.01.4	-	-	-	X	-	X	X	X	X	X
ROC.NF.01.5	X	X	X	X	X	X	X	X	X	X
ROC.NF.01.6	X	X	X	X	X	X	X	X	X	X
ROC.NF.01.7	-	-	-	X	X	-	X	X	X	X
ROC.NF.01.8	X	X	X	X	X	X	X	X	X	X
ROC.NF.02	X	-	-	X	-	-	X	X	X	X

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ROC.NF.03	X	-	-	X	-	X	X	X	X	X
ROC.NF.04	X	-	-	-	-	-	X	X	X	X
ROC.NF.04.1	X	-	-	-	X	-	-	-	-	-
ROC.NF.04.2	X	-	X	X	-	X	X	X	X	X
ROC.NF.04.3	-	X	X	X	-	X	X	X	X	X
ROC.NF.04.4	X	X	X	X	X	X	X	X	X	X
ROC.NF.04.5	-	-	-	X	-	-	X	X	X	X
ROC.NF.05	X	-	-	X	X	X	X	X	X	X
ROC.NF.05.1	X	-	-	X	X	X	X	X	X	X
ROC.NF.05.2	X	-	-	X	X	X	X	X	X	X
ROC.NF.05.3	X	X	X	X	X	X	X	X	X	X
ROC.NF.06	-	-	-	X	-	-	X	-	-	-
ROC.NF.06.1	-	-	-	X	X	X	X	-	-	-
ROC.NF.06.2	-	-	-	X	-	-	X	-	-	-
ROC.NF.07	-	-	-	X	X	-	X	-	X	-
ROC.NF.07.1	-	-	-	X	X	-	X	-	X	-
ROC.NF.07.2	-	-	-	X	X	-	X	-	X	-
ROC.NF.07.3	-	-	-	X	X	-	X	-	X	-

4.7 CONNECTIVITY SYSTEM

The identified non-functional requirements for the Connectivity System (CS) are listed in Table 23. The NFR ID for the connectivity system is CS.NF.sequence. The CS NFR applies to all phases; hence, no phase mapping table is included.

Table 23: Connectivity System identified non-functional requirements

ID	Name	Description
CS.NF.01	**Connectivity**	All building blocks and their subsystems depends on sufficient connectivity. The connectivity system bandwidth and latency requirements can be derived from the subsystem connectivity requirements.

4.8 MODALNET

The identified non-functional requirements for the ModalNET are listed in Table 24. The NFR ID for the ModalNET is MNET.NF.sequence. The mapping of the ModalNET NFRs to the planning and operational phases are given in Table 25.

Table 24: ModalNET identified non-functional requirements

ID	Name	Description
MNET.NF.01	**Cybersecurity**	Cybersecurity shall be ensured
MNET.NF.01.1	TLS	Secure TLS protocols used in all layers
MNET.NF.01.2	JWT	Use of JWT (JSON Web tokens)
MNET.NF.01.3	HTTP	Use only HTTP protocol
MNET.NF.01.4	Firewall	Use of firewalls to allow data in secure ports
MNET.NF.01.5	Access control	Access control verification in each HTTP request

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MNET.NF.01.6	Redundancy	Use of Kubernetes cluster infrastructure over set of hosts to provide redundancy
MNET.NF.01.7	Redundancy	Use of MongoDB cluster database over a set of hosts to provide redundancy
MNET.NF.01.8	Backup	Periodic backups of data is automatically performed every x hour
MNET.NF.01.9	CI/CD	Implement Continuous integration/ Continuous deployment
MNET.NF.01.10	Interoperability	Maintain the docker images and hosts with latest stable versions
MNET.NF.01.11	Host security	Use VPN or ssh secure channels with public-private keys to ensure the secure administration of the hosts
MNET.NF.01.12	Password	Store a hash of any user password to access the system
MNET.NF.01.13	Encryption	Encrypt any file and data that should not be registered in plain format on the database (e.g. passwords, security tokens, files)
MNET.NF.02	**User friendliness**	The ModalNET UI shall be user-friendly to facilitate correct and efficient use of the platform
MNET.NF.02.1	Browser support	Provide compatibility with latest web browsers and different user devices
MNET.NF.02.2	User experience	Provide a uniform user experience
MNET.NF.02.3	UI components	Introduce user interface components that simplify data access and data filling to the users.
MNET.NF.03	**Interfacing other building blocks**	ModalNET shall interface other building blocks to monitor the transport status and cargo operations.
MNET.NF.03.1	API	Provide APIs for third party systems to be able to provide or obtain data to/from ModalNet.
MNET.NF.03.2	Authentication	Facilitate the use of secure JWT for third party systems be able to authenticate to ModalNet with the proper data access rights
MNET.NF.03.3	Third party link	Provide push/pull mechanisms and configuration options to provide or receive data from third party systems.
MNET.NF.03.4	Message formats	Provide capabilities to easily transform the data in different message formats (e.g. XML, EDIFACT, JSON) and data structures.
MNET.NF.04	**Matchmaking**	The ModalNET platform shall propose transport options for multimodal transport, and book transport upon user (customer) request. This requires a consistent decision basis.
MNET.NF.04.1	Vessel Schedule	The vessel schedule is transferred to the ModalNET within x minutes of a change to the schedule
MNET.NF.04.2	Vessel route	The vessel route is fixed in the sense that the sequence of ports does not change. There can, however, be changes in scheduled time of arrival and departure between each voyage
MNET.NF.04.3	Vessel capacity	Vessel capacity is known with an accuracy within x units, and y tonne.
MNET.NF.04.4	Booking consistency	Any booking of cargo to a vessel shall either be done via ModalNET or communicated to ModalNET within x minutes of making the booking. This ensures that ModalNET has an overview of the vessel remaining capacity per voyage and

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		voyage section. This is needed for the computational engine. Two possible scenarios: • The consignor registers a multimodal booking (truck-barge/ship-truck) in ModalNET, the computational engine gives the suitable options, the consignor selects the best option and the road transport orders (i.e road consignment notes) and ship/barge bookings are generated automatically in ModalNET. • The consignor requests the booking in the barge/ship operator system and the barge/ship operator system registers the booking in ModalNET using the API defined in ModalNET (or alternatively using the ModalNET user interface for registering the bookings). In this case, the computational engine will not be applicable (as the transport selection will not be made with ModalNET with the support of the computational engine) and the consignor could register the additional road transport orders (i.e. road consignment note) to complete the multimodal transport.
MNET.NF.04.5	Transport option route	Transport option (e.g., truck) route is known
MNET.NF.04.6	Transport option cost	Transport option cost is known with an uncertainty of maximum x Euro
MNET.NF.04.7	Transport option duration	Transport option duration is known with an uncertainty of x minutes
MNET.NF.05	**Logistics monitoring**	ModalNET shall facilitate monitoring of transporting the customer cargo. This requires timeline status updates.
MNET.NF.05.1	Loading status	Loading status report is transmitted from VCOP within x minutes of completion of cargo unloading
MNET.NF.05.2	Discharge status	Discharge status report is transmitted from VCOP within x minutes of completion of cargo unloading
MNET.NF.05.3	TOS API	TOS shall have an API for gate in/out orders and reporting to external systems
MNET.NF.05.4	TOS API	ModalNET implements the TOS API for gate in/out orders and reporting
MNET.NF.05.5	Vessel schedule updates	Vessel ETA, ATA, ETD and ATD for each location on its route is refreshed and transmitted to ModalNET with a refresh rate of minimum x minutes
MNET.NF.05.6	Building block data refresh rate	Other building block data refresh rate needs to be above threshold
MNET.NF.05.7	Reporting	ModalNET shall provide facilities for electronic reporting to authorities. This requires consistent data from the other building blocks.
MNET.NF.05.8	Electronic reporting	Accuracy of data for creating electronic report, received from the ROC, within threshold
MNET.NF.06	**Training**	Users (e.g., transport customer) are trained in ModalNET usage.

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MNET.NF.07	**Connectivity**	The connectivity needs to be sufficient to allow communication with other building blocks.
MNET.NF.07.1	Bandwidth	Link bandwidth shall be above threshold
MNET.NF.07.2	latency	Link latency shall be below threshold

Table 25: ModalNET NFR mapping to planning and operational phase

ID	PA	PB	P1	P2	P3	P4	P5	P6	P7	P8
MNET.NF.01	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.1	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.2	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.3	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.4	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.5	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.6	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.7	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.8	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.9	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.10	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.11	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.12	X	-	X	X	X	X	X	X	X	X
MNET.NF.01.13	X	-	X	X	X	X	X	X	X	X
MNET.NF.02	X	-	X	X	X	X	X	X	X	X
MNET.NF.02.1	X	-	X	X	X	X	X	X	X	X
MNET.NF.02.2	X	-	X	X	X	X	X	X	X	X
MNET.NF.02.3	X	-	X	X	X	X	X	X	X	X
MNET.NF.03	X	-	X	X	X	X	X	X	X	X
MNET.NF.03.1	X	-	X	X	X	X	X	X	X	X
MNET.NF.03.2	X	-	X	X	X	X	X	X	X	X
MNET.NF.03.3	X	-	X	X	X	X	X	X	X	X
MNET.NF.03.4	X	-	X	X	X	X	X	X	X	X
MNET.NF.04	X	-	-	-	-	-	-	-	-	-
MNET.NF.04.1	X	-	-	-	-	-	-	-	-	-
MNET.NF.04.2	X	-	-	-	-	-	-	-	-	-
MNET.NF.04.3	X	-	-	-	-	-	-	-	-	-
MNET.NF.04.4	X	-	-	-	-	-	-	-	-	-
MNET.NF.04.5	X	-	-	-	-	-	-	-	-	-
MNET.NF.04.6	X	-	-	-	-	-	-	-	-	-
MNET.NF.04.7	X	-	-	-	-	-	-	-	-	-
MNET.NF.05	-	-	-	-	X	-	-	-	-	-
MNET.NF.05.1	-	-	-	-	X	-	-	-	-	-
MNET.NF.05.2	-	-	-	-	X	-	-	-	-	-
MNET.NF.05.3	-	-	-	-	X	-	-	-	-	-
MNET.NF.05.4	-	-	-	-	X	-	-	-	-	-
MNET.NF.05.5	X	-	X	X	X	X	X	X	X	X
MNET.NF.05.6	X	-	X	X	X	X	X	X	X	X
MNET.NF.05.7	-	-	X	-	X	X	-	-	-	-
MNET.NF.05.8	-	-	X	-	X	X	-	-	-	-
MNET.NF.06	X	-	X	X	X	X	X	X	X	X

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MNET.NF.07	X	-	X	X	X	X	X	X	X	X
MNET.NF.07.1	X	-	X	X	X	X	X	X	X	X
MNET.NF.07.2	X	-	X	X	X	X	X	X	X	X

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5 UC1: THE NORTHERN EUROPEAN CASE - CONOPS

The baseline for Use Case 1 (UC1) is described in detail in SEAMLESS deliverable D2.1 [1]. Relevant information from [1] will be included where this is necessary for the discussions in this chapter. The interested reader is encouraged to consult [1]. This section will focus on the SEAMLESS concept applied to UC1, the implications for the architecture in Figure 12, and it will define the elements of the proposed CONOPS format of [7].

5.1 CONTEXT

5.1.1 Case introduction (big picture)

The UC1 is based on the plans to move the container terminal from the Bergen city centre to the rural port in Ågotnes, which is west of Bergen, closer to the main fairway. The motivation for moving the terminal is to free up valuable area in the city centre for city development, and to reduce local truck traffic in the city centre. In addition, it will reduce the port call time and sailing distance for container vessels. However, the re-relocation of the terminal comes at a cost of increased regional truck traffic. UC1 will therefore investigate a shuttle service between Ågotnes and Bergen, which is in line with the Bergenhus municipality plans to keep a small terminal within the city. This small terminal will have reduced storage capacity and is intended for containers originating or destined to location in the Bergen city, or its immediate vicinity. This will reduce the volume going through the city centre. In addition, investigations are ongoing for expanding the shuttle service to regional ports, or quays, close to the origin and destination of cargo, to further reduce regional truck traffic. An autonomous fleet of container shuttles could make such a transport network competitive to trucks. The network and the business case will be studied in WP6 of SEAMLESS. This section will deal with the application of the technical concept to UC1.

While the feeder loop service will include several locations in the region, UC1 focuses on the direct link (24/7 feeder loop service) between Bergen and Ågotnes. The route is 11nm, estimated to approximately 1.5 hours, in each direction. The feeder loop service will be operated by autonomous vessels without onboard crew, supervised by a ROC. The project ambition is to achieve an autonomy level that enables fleet operations (three vessels) by a relatively small ROC team. This implies that the vessels must be able to operate independently of the ROC operators for most of the time. This in turn puts requirements on the vessels systems that they need to handle most interaction scenarios with other vessels without support from the ROC (as elaborated in section 2).

Kystverket, the Norwegian Coastal Authority (NCA), provides reference routes[4] for navigation for the UC1 area. While these routes are not strictly speaking obligatory, they provide quality assured routes for inbound and outbound traffic. Furthermore, if the voyage plan is based on these routes, the navigational safety is improved, according to NCA. Local regulations and alignments with port and quay definitions in SafeSeaNet[5] is also available through the service. Voyage planning should be

[4] https://www.kystverket.no/navigasjonstjenester/artikkel-digital-rutetjeneste---routeinfo.no/
[5] Norwegian portal for ship reporting: https://www.kystverket.no/sjotransport-og-havn/safeseanet-norway/

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based on the reference routes to ensure safe navigation and minimize difficult interactions with other vessels, and to simplify the to be required EMSWe reporting, which will be done via SafeSeaNet.

The UC1 route is given in Figure 25, while a heatmap of the traffic, based on AIS data, is given in Figure 26. As can be seen, the feeder loop route is in a relatively heavily trafficked area. Most of the voyage follows the main fairway, however, the route passes through some areas where complex encounter situations are likely to arise occasionally. These are the three areas where shipping lanes connect, which implies that the SEAMLESS vessel will have to cross the reference routes. The reference routes, with the three areas marked, are given in Figure 27. Notice area B, which has the highest probability of complex situations according to [1]. This is also shown in more detail in Figure 28. Also notice that area A is in one of the most trafficked sections of the route, see Figure 26 and Figure 27. This is due to the small high-speed passenger ferry operating between Bergen and Kleppestø, see Figure 28. The R&A vessel will not cross paths with this traffic, in the normal case, but relatively close navigation should be expected.

Figure 25: Route for the feeder loop service between Ågotnes and Bergen[6]

Figure 26: Heatmap of traffic density[7]

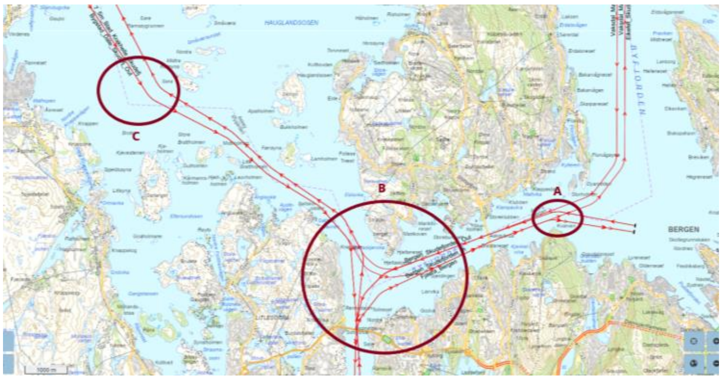

Figure 27: Reference routes for navigation[8] - the areas where the vessel will cross the reference routes

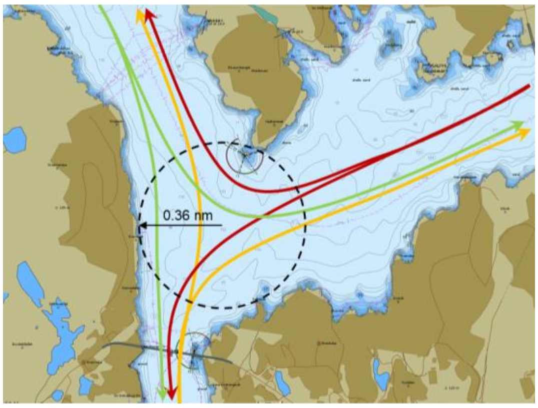

Figure 28: Area with high potential for complex traffic situations[9]

[6] Source: The figure is taken from [1]
[7] Source: https://a3.kystverket.no/kystinfo
[8] Source: Kystinfo (kystverket.no)
[9] Source: The figure is taken from [1]

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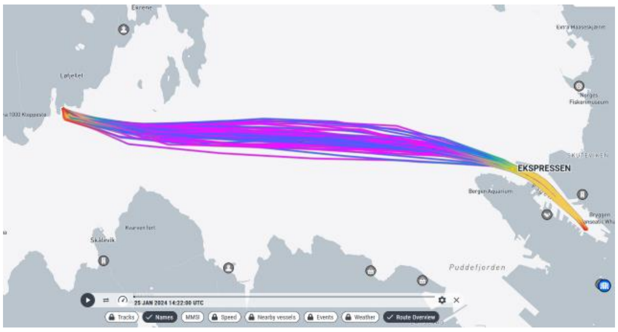

Figure 29: Track for the Bergen-Kleppestø high-speed passenger ferry[10]

The port navigation in Bergen is within a speed restricted zone, where leisure crafts can sail at a maximum of 5 knots, and commercial vessels at 8 knots, see Figure 30. The terminal Dokken, which the autonomous vessel will be operating from in Bergen, is marked in the left image of the figure.

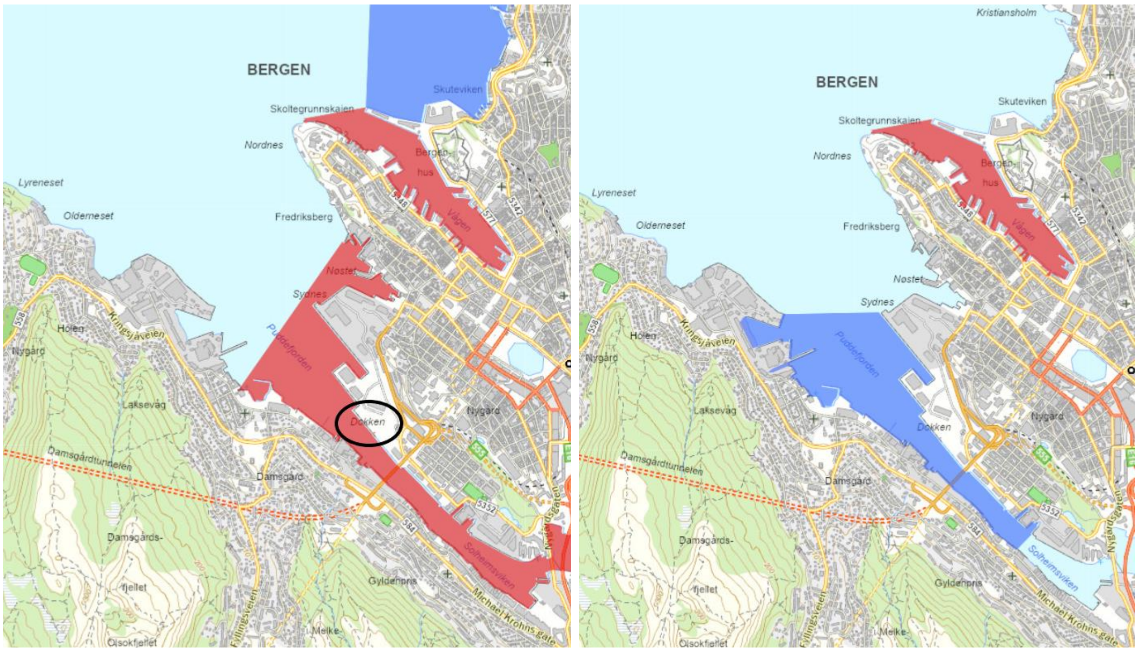

Figure 30: Speed limit zones - leisure crafts to the left [5knots], commercial vessels to the right [8knots] [11]

As for the case in [7] there is "also local unpredictable traffic, for instance leisure boats often sailing closer to one of the shore sides." The route is mostly part of the Fedje VTS area, see Figure 31. This means that reporting to VTS will be required.

[10] https://www.marinetraffic.com/en/ais/home/centerx:5.274/centery:60.401/zoom:14

[11] Source: Kystinfo (kystverket.no)

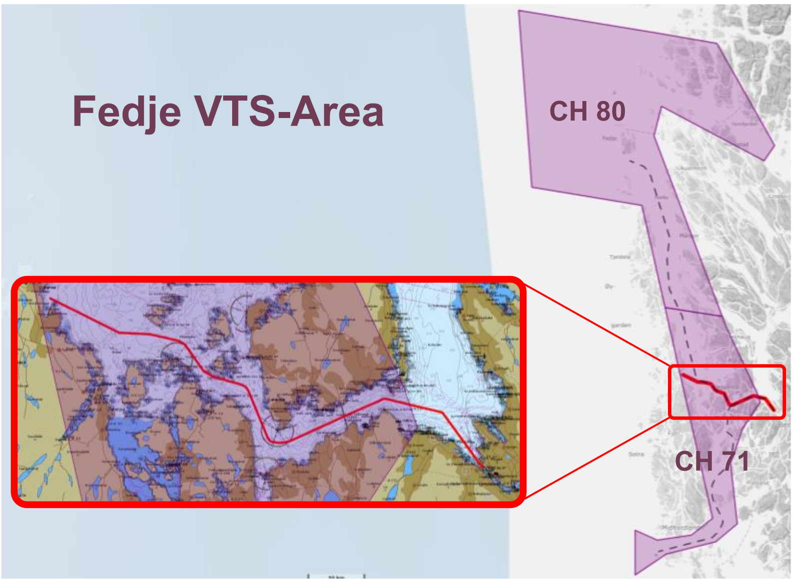

Figure 31: Boundaries of Fedje VTS-Area with radio channels[12]

[12] Source: the figure is taken from [1]

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5.1.2 System architecture: systems and actors

The SEAMLESS concept architecture for UC1 is given in Figure 32 where building blocks 1 to 3 are included.

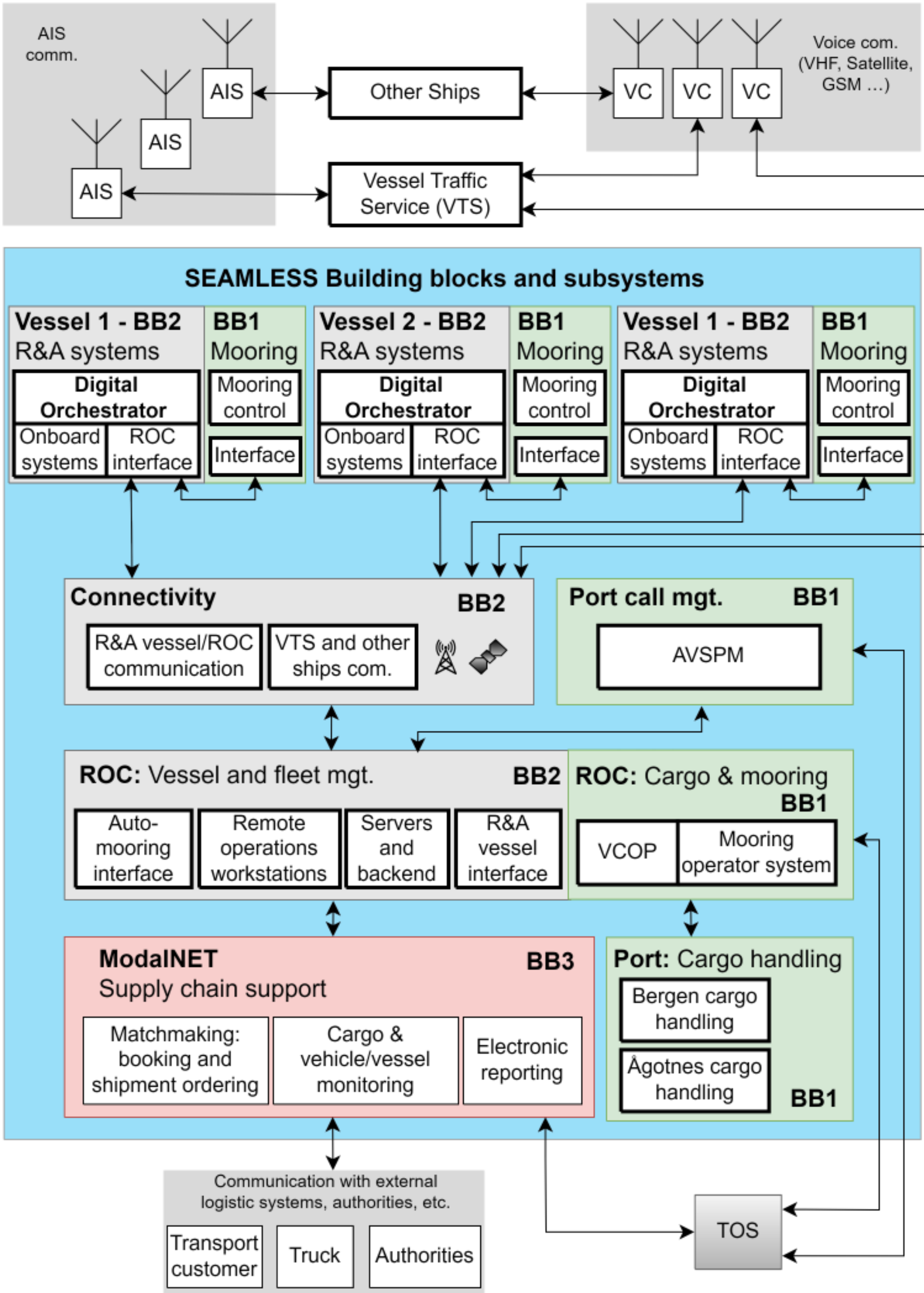

Figure 32: The SEAMLESS concept architecture adapted for UC1

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The actors in the autonomous ship system as defined in [7] are the *onboard systems*, the *autonomous onboard controller*, the *ROC operators*, and the *external systems, persons, and other ships*. In the SEAMLESS concept the included actors extend beyond the ship, or vessel, operation scope to include actors related to logistics, cargo handling, mooring, and port call planning and execution. The actors are given in the UC1 architecture of Figure 32 and a brief description is provided in Table 26. More details for the actors defined as Type "building block subsystem" are given in section 2.

Table 26: UC1 involved actors

Actor	Short Description	Type
Autonomous Mooring System	Executes automatic mooring line fastening to bollards, automatic line tensioning, and adjustment of vessel position. Consists of one or more robotic arms, and (typically) four winches each with one mooring line. Has own sensors for situational awareness.	Building block 1 subsystem
Autonomous cargo crane	Executes automatic container handling. Consists of a triple joint crane, a winch, and a spreader. Has own sensors for situational awareness.	Building block 1 subsystem
VCOP	Automatically plans the stowage, based on placed shipment orders from the ModalNET and a vessel model for stability calculations. Automatically plans loading and unloading sequences based on the stowage plan. Gives high level commands to the autonomous crane during cargo operations, and coordinates cargo operations with the TOS.	Building block 1 subsystem
AVSPM	Plans and monitors port calls. Reserves terminal and berth bookings. Provides local environmental and traffic condition data to the ROC. Analyses port calls for future decision support to the port operators.	Building block 1 subsystem
R&A vessel systems	Onboard Systems such as automation and power management systems, navigation and manoeuvring systems, situational awareness systems, safety functions, and communication interface to ROC. In addition, the Digital Orchestrator, which is the system tying everything together, communicates with the ROC, and which automates the execution of the vessel mission.	Building block 2 subsystem
ROC	The Remote Operations Centre holds the remote operators who holds the role of the master and which monitors and manages the execution of the vessel mission.	Building block 2 subsystem
Connectivity systems	Provides an appropriate communication link between the ROC, vessel, logistics and port systems. It is also does data transfer	Building block 2 subsystem

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	prioritisation based on communication link quality.	
ModalNET	Logistics platform for proposing transportation option for shipments, booking of transport, monitoring and management of transport.	Building block 3 subsystem
TOS*	Communicates with the ROC, via the VCOP, organises and executes all cargo handling at the terminal (from the locations where the autonomous crane picks up or places containers).	External actor
VTS*	Monitors traffic within the VTS area. Gives clearance for entering the area.	External actor

5.2 SCENARIO

5.2.1 Voyage and voyage phases

The voyage will be a roundtrip from Ågotnes to Bergen, and back. While the generalised operational phases are proposed in chapter 3, this section will split the voyage into the phases based on the geographical location of the vessel and make connections between these and the operational phases defined in chapter 3.

For a trip from Ågotnes to Bergen, the sequence of phases is given in Figure 33. The planning phases A and B occurs independently of the vessel operations and are as such not placed in sequential order along the route. The trip starts by phase 3 Activities at location, where the vessel loads cargo destined to Bergen. During this phase, the phase 4 Plan departure is initiated. Once phases 3 and 4 are completed and the ROC receives the "Terminal ready for vessel departure message", it enters phase 5 Depart location. The ROC initiates the unberthing, and once the last mooring line is released, the vessel manoeuvres from quay and navigates out of the Port, entering phase 6 Navigate. At this time, the phase 1 Plan port call is executed for planning the Bergen port call. The vessel continues in phase 6 Navigate until it arrives at the Bergen port area.

During the Navigation phase, it is possible that the vessel is operated in low attention mode from the ROC for the full duration of the phase. However, it is also possible that a situation requiring high operator attention arises, in which case the ROC operator will change mode to high attention (see section 2.2 for more details on high and low attention operator modes).

Once the Bergen port area is reached, phase 2 Approach location is initiated. In the first part of this phase the vessel will slowly approach the quay and move into the Berth, where it initiates mooring. Once the last mooring line is fastened, it moves to phase 3 Activities at location. This phase starts by discharging all containers before loading containers.

A trip from Bergen to Ågotnes implies moving through the same phases as for a trip from Ågotnes to Bergen, in the same sequence. See Figure 34

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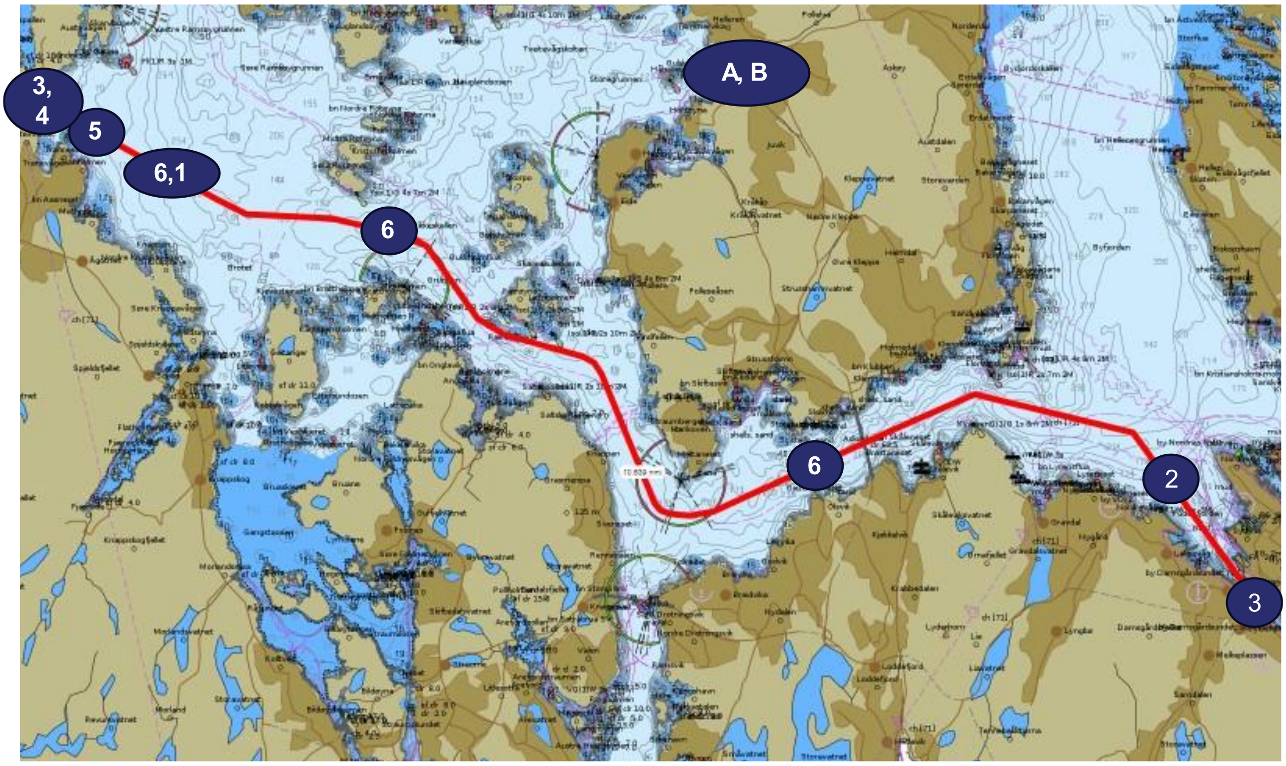

Figure 33: UC1 voyage Ågotnes – Bergen

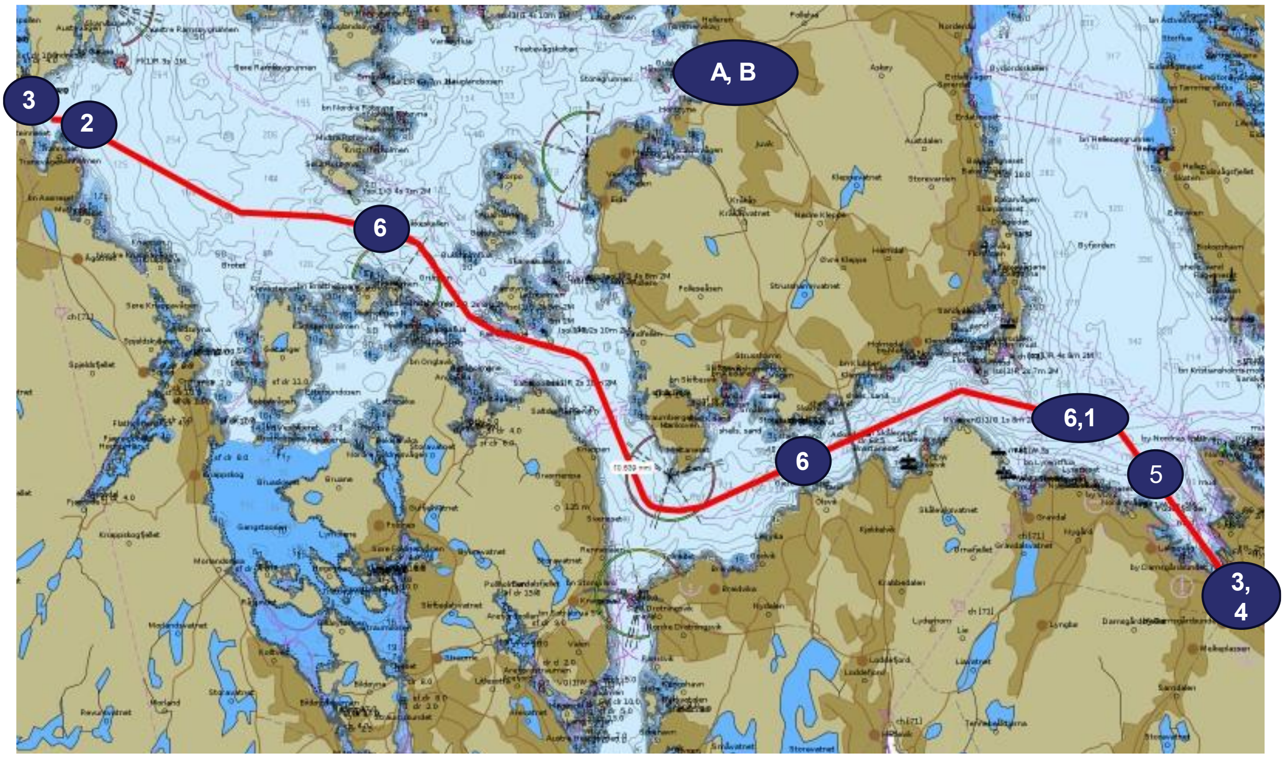

Figure 34: UC1 voyage from Bergen to Ågotnes

In summary, the relevant voyage phases for UC1 are:

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- Plan shipment
- Early port call planning
- Activities at location - Ågotnes
- Plan departure - Ågotnes
- Depart location – Ågotnes
- Plan port call – to Bergen
- Navigate – low attention
- Navigate – high attention
- Approach location – Bergen
- Activities at location – Bergen
- Plan departure - Bergen
- Depart location – Bergen
- Plan port call – to Ågotnes
- Approach location – Ågotnes

5.2.2 Voyage phase patterns

The identified voyage phases in section 5.2.1 can be represented by the generalised voyage phase patterns that were presented in chapter 3 as the SEAMLESS concept operational phases. For UC1 the relevant voyage phase patterns are:

- Phase A: Plan shipment
- Phase B: Early port call planning
- Phase 1: Plan port call
- Phase 2: Approach location
- Phase 3: Activities at location
- Phase 4: Plan departure
- Phase 5: Depart location
- Phase 6: Navigate

Table 27 shows which actors and voyage phase patterns that are associated, where "X" marks an association.

Table 27: UC1 System and use-case associations.

Actor / Phase pattern	Plan shipment	Early port call planning	Plan port call	Approach location	Activities at location	Plan departure	Depart location	Navigate
Autonomous mooring system	-	-	-	X	X	-	X	-
Autonomous cargo crane	-	-	-	-	X	-	-	-
VCOP	X	-	-	-	X	-	-	-

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AVSPM	-	X	X	X		X	X	X
R&A vessel systems	-	-	X	X	-	X	X	X
ROC	X	X	X	X	X	X	X	X
Connectivity systems	X	X	X	X	X	X	X	X
ModalNET	X	-	X	X	X	X	X	X
TOS*	X	-	X	-	X	X	-	-
VTS*	-	-	-	-	-	-	-	X

* External actors

5.2.3 System processes

As the SEAMLESS concept extends beyond the systems of the autonomous ship in [7], the "ship processes" is renamed as the System processes. These are the most important system functions of the SEAMLESS concept that are either automatically executed by automation systems, or manually handled by operators. For UC1, these are given in Table 28, some of which are based on [7].

Table 28: Main system processes of the SEAMLESS concept

System process	Description
Navigation	This process includes building situational awareness based on all available sensory data. This includes determining the position, speed and heading of own vessel and other vessels, detect and classify objects, observe and determine weather, sea state and visibility, assess own vessel state by monitoring the status of navigational equipment, sensors, technical systems and machinery, and assess traffic situation. It also includes manoeuvring the vessel, which is to keep track, course and speed, short term planning of safe operations, avoid obstacles and grounding, and performing berthing and unberthing.
Voyage management	Planning and re-planning the voyage based on schedule, weather, predicted traffic, events disrupting or potentially disrupting operations, etc. Monitor the voyage and do tactical adjustments if needed.
Nautical communication	VHF communication, or digital communication, with other vessels, ROCs, ports (AVSPM) and VTS.
Technical systems and machinery control	Operate automation systems such as setting the power plant mode, ballasting setpoints, initiating a berthing and mooring sequence, initiating cargo operations, etc.
Cargo handling on/off vessel	Loading and unloading containers to the vessel according to pre-planned loading and unloading sequence, and stowage plan.
Mooring	Fastening mooring lines to bollards and maintaining safe mooring by adjusting individual mooring line tension.
Cargo handling management	For each received shipment booking, plan cargo placement while ensuring stability, and plan cargo handling sequences. Manage cargo handling execution and coordinate actors.
Logistical management	Planning and booking transportation of shipments, monitoring progress, re-planning transport if necessary. Report formalities.

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5.3 USE CASES

5.3.1 State space

As defined in [7] “The state space for each ship control task is described by a set of variables used to describe the conditions under which the ship system will operate in this use case.”. In our case, this translates to: *The state space for each system control task is described by a set of variables used to describe the conditions under which the SEAMLESS concept will operate in this use case.*

In [7] some typical variables are defined. In our case, we take the variable definitions from the non-functional requirements (NFRs) defined in section 4, voyage phase patterns, degree of autonomy, and ROC operator mode to define the state space.

Some of the NFRs defined in section 4 are pre-conditions. These are either satisfied per design or not and will not change during operation. Examples are ROC.NF.01.1, ROC.NF.01.2, and ROC.NF.01.3 which deals with API implementation requirements. Such NFRs are relevant for ensuring the proper functioning of the SEAMLESS concept, and thus the CONOPS, however, they are not relevant for defining the state space. Example NFRs that are relevant for defining the state space are AMS.NF.01 and AMS.NF.02 which deals with visibility and sensor status conditions respectively. These are conditions that may change during operations, and if they are no longer met, should lead to either an operation mode change (from low to high attention), an operator action, or a fallback.

The state space for UC1 is given in Table 29. It is a listing of NFRs giving the conditions for operating at a given level of autonomy and operator mode, for a given voyage phase pattern. Appendix 1 (see section 9.1) provides the corresponding table with all NFRs relevant to a Voyage phase pattern, including pre-conditions.

Table 29: State space for UC1

Voyage phase patterns	Level of autonomy	ROC Operator mode	Non-functional requirements
Phase A: Plan shipment	Automatic Operations	High attention	VCOP.NF.01.1, VCOP.NF.02, VCOP.NF.07, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.03, ROC.NF.05, CS.NF.01, MNET.NF.01, MNET.NF.04.1, MNET.NF.04.4, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.07
Phase B: Early port call planning	Automatic Operations	High attention	AVSPM.NF.03, AVSPM.NF.05, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.05.3, CS.NF.01
Phase 1: Plan port call	Automatic Operations	High attention	AVSPM.NF.03, AVSPM.NF.04.3, AVSPM.NF.04.4, AVSPM.NF.04.5, AVSPM.NF.05, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.05.3, CS.NF.01, MNET.NF.01, MNET.NF.05.5. MNET.NF.05.6, MNET.NF.05.7, MNET.NF.05.8, MNET.NF.07

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Phase 2: Approach location	Constrained Autonomous, if NFRs are not satisfied switch to Automatic Operations	Low attention, if NFRs are not satisfied, switch high attention	AMS.NF.01, AMS.NF.02, AMS.NF.03, AMS.NF.04, AMS.NF.05, AMS.NF.06, AMS.NF.07.5, AMS.NF.08, AMS.NF.09, AMS.NF.10.5, AVSPM.NF.03.2, AVSPM.NF.03.3, AVSPM.NF.03.4, AVSPM.NF.04, AVSPM.NF.05, R&A.NF.all (except R&A.NF.11.1 and 11.3), ROC.NF.01.4, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.03, ROC.NF.05, ROC.NF.06, ROC.NF.07.2, ROC.NF.07.3, CS.NF.01, MNET.NF.01, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.07
Phase 3: Activities at location	Constrained Autonomous	Low attention, if NFRs are not satisfied, switch high attention	AMS.NF.03, AMS.NF.05.3, AMS.NF.06, AMS.NF.08, AMS.NF.09, AMS.NF.10.5 ACC.NF.all (except ACC.NF.07.1 and 07.4), VCOP.NF.03.4, VCOP.NF.03.5, VCOP.NF.03.6, VCOP.NF.03.7, VCOP.NF.04, VCOP.NF.05, VCOP.NF.07, R&A.NF.11.3, R&A.NF.11.4, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.05, ROC.NF.06.1, ROC.NF.07.2, ROC.NF.07.3, CS.NF.01, MNET.NF.01, MNET.NF.05 (except 05.3 and 05.4), MNET.NF.07
Phase 4: Plan departure	Automatic Operations	High attention	AVSPM.NF.03, AVSPM.NF.04.3, AVSPM.NF.04.4, AVSPM.NF.04.5, AVSPM.NF.05, ROC.NF.01.4, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.05, ROC.NF.06.1, CS.NF.01, MNET.NF.01, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.05.7, MNET.NF.05.8, MNET.NF.07
Phase 5: Depart location	Constrained Autonomous	Low attention, if NFRs are not satisfied, switch high attention	AMS.NF.01, AMS.NF.02, AMS.NF.03, AMS.NF.04, AMS.NF.05.1, AMS.NF.05.2, AMS.NF.05.3, AMS.NF.05.5, AMS.NF.06, AMS.NF.07.3, AMS.NF.07.4, AMS.NF.07.5, AMS.NF.08, AMS.NF.10.5 AVSPM.NF.03.2, AVSPM.NF.03.3, AVSPM.NF.03.6, AVSPM.NF.04, AVSPM.NF.05, R&A.NF.01, R&A.NF.02, R&A.NF.03, R&A.NF.04, R&A.NF.05, R&A.NF.06, R&A.NF.07, R&A.NF.08, R&A.NF.09, R&A.NF.10, R&A.NF.11.2, R&A.NF.11.4, ROC.NF.01.4, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.05, ROC.NF.06, ROC.NF.07.2, ROC.NF.07.3, CS.NF.01, MNET.NF.01, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.07
Phase 6: Navigate	Constrained Autonomous	Low attention, if NFRs are not satisfied, switch high attention	AVSPM.NF.05, R&A.NF.all (except R&A.NF.11), ROC.NF.01.4, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.03, ROC.NF.05

5.3.2 System control tasks

The System Control Tasks (SCTs) are the high-level system functions which can be automated under certain conditions, given by the State space. The SCT are defined by the System processes (section 5.2.3) and the Voyage phase patterns (section 5.2.2). The SCTs for UC1 are given in Table 30. The level of autonomy is indicated by colours where green means Constrained Autonomous, orange means Automatic Operations, grey means Direct Control, and black means that the "system process – voyage phase pattern" combination is irrelevant.

The connection between the State space, Table 29, and a given SCT, Table 30, is by the Voyage phase patterns that the SCT is defined for. The indicated autonomy level for a given SCT in Table 30 hence depends on the corresponding conditions in the State space being satisfied. If conditions are not satisfied, the execution of the SCT cannot continue at the specified autonomy level. Depending on the situation at hand the operator involvement might have to be increased, or a fallback may have to be initiated. A definition of the action to be taken if a condition is no longer satisfied should be clearly defined, e.g., by UML Activity diagrams as proposed by [7].

A total of 10 SCTs are defined. The following will provide a brief description of each.

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Table 30: System Control Task UC1

System processes/ Voyage phase patterns	2 - Approach location	5 - Depart location	3 - Activities at location	6 - Navigate	1 - Plan port call	4 - plan departure	A - Plan shipment	B - Early port call planning
Navigation	SCT1: Navigation port, berthing and unberthing			SCT2: Navigate transit				
Voyage management	SCT3: Manage voyage, coordinate actors, make tactical decisions.							
Nautical communication	SCT4: Communication with other vessels, ROCs, VTS, terminal, etc.							
Technical systems and machinery	SCT5: Monitor and control machinery and technical systems							
Cargo handling on/off vessels			SCT6: Cargo handling					
Mooring	SCT7: Fasten mooring lines, maintain safe mooring line tension, and release mooring							
Cargo handling management			SCT8: Manage cargo handling		SCT9: Plan stowage and manage stability			
Logistical management	SCT10: Manage logistics							
Colour coding								
Constrained Autonomous		**Automatic operations**		**Direct control**		**Not applicable**		

SCT1: Navigation port, berthing and unberthing

This system control task deals with the navigation during the approach and depart phases. I.e., navigation within ports, including to and from the berth position. This will typically be low speed manoeuvres handled by Autodocking and Auto-tracking controllers. Typically, traffic will be heavy within the port area compared to when the vessel is in transit, and the available space for manoeuvring is limited. As such, there is a relatively significant potential for difficult situations that could require high operator attention. It is also likely that some applications will have port areas where Automatic Operations level of autonomy would be the most common mode of operation. The berthing phase should not be troubled by heavy traffic, however, higher positioning and tracking accuracy will be required, and distances to obstacles could be very short.

For UC1, the default autonomy level for SCT1 is set to Constrained Autonomous, and operator mode to low attention. This is because the involved port areas are relatively small, with relatively low traffic

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compared to larger cargo terminals. The AVSPM supports the ROC with traffic information, which in addition to the vessels own sensors, should make it possible to predict traffic conditions requiring a transfer to high attention operator mode in time to make a safe mode transition.

If the state space variables cross their thresholds, the primary action is to switch operator mode for SCT1 to high attention and autonomy level to Automatic Operations. However, some conditions, if not met, may require the initiation of a fallback directly. Some potentially relevant fallbacks are:

- Reduce speed and continue mission
- Abort/stop and keep position
- Move to safe position and keep position
- Drop anchor

SCT2: Navigate transit

This system control task deals with navigation between port areas. I.e., compared to port navigation, the available space for manoeuvring is bigger, distances to other vessels are greater, speed is higher, traffic is typically lighter, and vessels generally follow traffic separation schemes. Encounter situations with other vessels may still occur, e.g., when shipping lanes cross. However, traffic prediction at a greater prediction horizon than for SCT1 should be possible, enabling speed and course adjustment early, making situations requiring high operator attention rare compared to SCT1.

For UC1, the default autonomy level for SCT1 is set to Constrained Autonomous, and operator mode to low attention. This is because it is expected that complicated encounters with other vessels will be rare. If the state space variables cross their thresholds, the primary action is to switch operator mode for SCT2 to high attention and autonomy level to Automatic Operations. However, some conditions, if not met, may require the initiation of a fallback directly. Some potentially relevant fallbacks are:

- Reduce speed and continue mission
- Stop and keep position
- Move to safe position and keep position
- Stop and drop anchor

SCT3: Manage voyage, coordinate actors, make tactical decisions

This System Control Task is relevant during the execution of all voyage phase patterns. It deals with the voyage management, coordination of the actors who are involved in the voyage, including cargo operations, and to make tactical decisions. Tactical decisions include necessary schedule changes or mission updates, e.g. due to a new shipment having been booked, disruptions (terminal unavailability, port notices update, or some unexpected event or issue impacting traffic conditions on the route), or predicted disruptions (e.g., based on weather forecast, delays in other parts of the logistic chain, etc.). Voyage management includes planning, such as early port call planning, or re-planning when a new shipment is booked to a given voyage.

The SEAMLESS concept in UC1 involves operating a fleet of 3 autonomous vessels. Part of the voyage management is coordination of voyages by aligning schedules such that over-all planned

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operator workload is within manageable limits. This implies that a situation requiring high attention for one vessel, may cause the need for a tactical decision to be made for another vessel. Or potentially to handover one or more SCTs to another ROC operator, or ROC operator team.

In UC1 the default autonomy level for SCT3 is set to Automatic Operations, and ROC operator mode to high attention. This is because the decision making related to SCT3 will be by the ROC operators, however, they will have decision support from the subsystems of the SEAMLESS concept. It should be noted that even though SCT3 is indicated as relevant in all voyage phase patterns, and operator mode is set to high attention, it is not involving all ROC operators, and it is not a continuous task in the sense that it does not demand full attention by an operator all the time. E.g., the need for tactical decision making, or voyage management, is triggered by some event that is notified to the ROC. With no active events, the focus of the ROC operator team is monitoring the execution of the missions of the vessels in the fleet, in low operator attention mode.

If the state space variables related to SCT3 cross their thresholds, the primary action depends on the situation at hand. Some operations may have to be aborted, in some cases a fallback should be initiated, while in some cases the operations may continue, e.g., until some critical point is reached. One possibility is also to handover the R&A vessels to another ROC.

SCT4: Communication with other vessels, ROCs, VTS, terminal, etc.

This system control task deals with the nautical communication with other stakeholders. It is relevant for voyage phase patterns related to nautical operations. Included subtasks are mandatory VHF watchkeeping, communication with other vessels and VTS over VHF. Communication with other ROCs. Communication with the terminal during cargo operations.

In UC1 the autonomy level is set to Direct Control as the currently envisioned solution is direct operation of communication systems such as VHF. The operator mode will be high attention; however, it should be noted that even though SCT4 is relevant for most of the time, it is not a continuous task in the sense that the need for communication depends on the situation at hand.

If the state space variables related to SCT4 cross their thresholds, the primary action depends on the situation at hand. The operator may choose to update the vessel mission, some operations may have to be aborted, in some cases a fallback should be initiated, while in some cases the operations may continue, e.g., until some critical point is reached. It could also be a possibility to handover the R&A vessels to another ROC.

SCT5: Monitor and control machinery and technical systems

This System Control Task is relevant for all phase patterns except planning phases A and B. It deals with the operation and monitoring of vessel systems such as for ballasting, power production, thrusters and thrust allocation. In general monitoring and controlling the systems that take setpoints and commands from higher level systems, or operators in case of Direct Control autonomy level. These are systems that are highly automated also on conventional vessels. The main tasks are thus to give commands and setpoints to effectuate the execution of the voyage mission, and to monitor the systems to predict the need for maintenance, to detect faults, and deviations from setpoints and commands, and to analyse consequences in terms of degraded system performance.

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For UC1, the autonomy level is set to Constrained Autonomous, and the operator attention mode to low attention. This is because these are systems that are highly automated on conventional vessels today; unattended machinery spaces are common. And because advanced diagnostics tools and decision support is increasingly being deployed. If the state space variables cross their thresholds, the primary action is to switch autonomy level to Automatic Operation and operator attention mode to high attention. However, for some of these systems some state space variables, e.g. those related to no active faults being present, might require an automatic activation of a fallback. Some potentially relevant fallbacks are:

- Reduce speed and continue mission
- Stop and keep position
- Go to predefined area and keep position
- Issue emergency alert and drift (in case of blackout causing loss of propulsion)
- Drop anchor

SCT6: Cargo handling

This System Control Task deals with the cargo handling and is relevant for the voyage phase pattern *Activities at location*. Given a cargo handling sequence, cargo data (ID, weight, type, etc.), origin and destination placement, SCT6 is about moving cargo between the vessel and the terminal.

In UC1, the autonomy level is set to Constrained Autonomous as the full cargo handling sequence is to be handled by the Autonomous cargo crane. The operator mode is low attention, however, for activation of SCT6 the operator mode needs to be high attention to ensure that the area is clear and blocked off. If state space variables are not satisfied, the autonomy mode can be switched to either Automatic Operation, or Direct Control. In which case the operator attention mode would be changed to high attention. Some cases may require the activation of a fallback, such as:

- Stop operations keep pose
    - Crane motion is stopped
- Stop operation return to parking position

SCT7: Fasten mooring lines, maintain safe line tension, and release mooring

This System Control Task deals with the mooring of the vessel and is relevant for the phase patterns Approach location, Activities at location, and Depart location. Given that the vessel is positioned at berth, and bollards to be used is provided, SCT7 deals with placing mooring lines on bollards, maintaining safe line tension (e.g., during tidal water level changes, or cargo operations), and releasing and retrieving mooring lines.

In UC1, the autonomy level is set to Constrained Autonomous as the full mooring sequence is to be handled by the Autonomous mooring system. The operator mode is low attention, however, for activation of SCT7 the operator mode needs to be high attention to ensure that the area is clear and blocked off. If state space variables are not satisfied, the autonomy mode can be switched to either Automatic Operation, or Direct Control. In which case the operator attention mode would be changed to high attention. Some cases may require the activation of a fallback, such as:

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- Stop operations keep posture
    - Mooring arm motion is stopped
- Stop operation return to parking position
- Abort mooring and move away from berth

SCT8: Manage cargo handling

This System Control Task deals with the cargo handling management and is relevant for the phase pattern Activities at location. The SCT includes uploading cargo handling sequences and cargo data to the autonomous crane and notifying the autonomous crane about status updates such as when the next container is available for loading. Similarly, it includes uploading cargo handling sequences and cargo data to the TOS, receiving status updates from the TOS, and giving status updates to the TOS. It also includes reporting to ModalNET.

In UC1, the autonomy level is set to Constrained Autonomous as the process will be automated by the VCOP. Operator mode is low attention, as only high level supervision and commands such as acknowledge/commence/stop, will be required by the operator. If state space variables are not satisfied, SCT8 may be taken over by the ROC operator who would switch mode to high attention. Depending on the situation at hand, the autonomy level would switch to either Direct Control or Automatic Operation. It is also possible that operations may have to stop until the situation is resolved.

SCT9: Plan stowage and manage stability

This System Control Task deals with the stowage planning, i.e., the placement of containers within the cargo hold, while considering stability. It is relevant for the phase patterns plan port call, plan departure and plan shipment.

For UC1, the autonomy level is set to Constrained Autonomous as the VCOP will automatically perform the tasks of this SCT. The operator mode is low attention, as the operator will only need to give high level commands such as acknowledge/approve, and since the operator actions will typically not be time critical compared to SCT1 and SCT2. If state space variables are not satisfied, SCT9 may be taken over by the ROC operator who would switch mode to high attention. Depending on the situation at hand, the autonomy level would switch to either Direct Control or Automatic Operation. It is not likely that operations related to the voyage would be impacted, except if stowage and handling sequences are not ready by the time the phase pattern Activities at location is active. If that should occur, the cargo operations would have to wait until plans are manually completed and transferred to relevant stakeholders.

SCT10: Manage logistics

This System Control Task deals with the booking process for shipments, proposing transport options, effectuating transport orders, and monitoring transport and logistical operations. It is relevant for all voyage phase patterns; however, it is not a continuous task in the sense that it is activated based on events. When a transport option for a given shipment is chosen and booked, the SCT10 includes booking the shipment to a given vessel and voyage. This involves communication with the ROC and

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the VCOP. It also includes booking of other transport means, such as trucks, which includes communication with trucking companies.

For UC1, the autonomy level is set to Operator Assisted as several subtask is handled automatically by ModalNET, but the decision making is left to the users. Also, some communication might require manual actions by an operator or user of ModalNET. The ROC is not directly involved in the execution of SCT10, which means that ROC operator attention mode is not relevant. However, ModalNET do have its human users who provide inputs, makes decisions, and who monitors data through the ModalNET user interface. If the state space variables are not satisfied, the autonomy level might have to change to Direct Control, and manual actions may have to be taken.

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6 UC2: THE CENTRAL EUROPEAN CASE – CONOPS

The baseline for UC2 is described in detail in deliverable [1]. Relevant information from [1] will be included where this is necessary for the discussions in this section. The interested reader is encourage to consult [1].

This section will focus on the SEAMLESS concept applied to UC2, the implications for the architecture in Figure 12, and it will define the elements of the proposed CONOPS format of [7]. To avoid repeating information, this chapter will refer to chapter 0 where information is identical. Furthermore, explanations of the concepts applied in the subsections of this chapter, such as System Control Task and the State Space, are given in chapter 0 and in section 1.3.4.

6.1 CONTEXT

6.1.1 Case introduction (big picture)

The European commission has set ambitious goals for increasing the share of inland shipping for transports within Europe. However, current market developments show that the political objectives are at risk, with no observable movements toward a modal shift [14]. The challenges that inland waterway transportation (IWT) faces and opportunities are discussed in more detail in [1]. Among others, the IWT sector is challenged by shortage of personnel, tense market conditions which are expected to become more dynamic in the upcoming years as common commodities transported by IWT today are reducing in demand, and low water periods impacting cost and reliability. Another issue is that the existing fleet is dominated by fossil-fuelled vessels with significant air pollutant emissions. On the other hand, the increasing demand for transport of containerized commodities and the prospect of automating IWT, combined with new low or zero-emission energy propulsion, provides opportunities for realising the modal shift targets. UC2 will therefore investigate the use of zero-emission and autonomous self-propelled inland vessels, such as the X-Barge [1]. The X-Barge is a CEMT Class IV vessel that has a length of 85 meters and a beam of 9.6 meters. It is optimized to carry containerized cargo and thus, comes with an expected capacity of 90 TEU. Propulsion of the X-Barge is realized using an electric drive supplied by a swappable container-based energy system, consisting of three 20' battery container units which can be loaded to a special on-deck compartment at the aft of the vessel. Depending on available solutions, the battery capacity is expected to be 1.5-2 MWh.

The waterborne transport concept of UC2 addresses automated seaport hinterland transport, connecting the Port of Antwerp to inland hubs along the Rhine up to Duisburg (as Europe's largest inland port) as well as with inland ports within the French-Belgian waterway network. As such, the use case considers a heterogeneous corridor in terms of waterway dimensions and characteristics, traffic density, as well as the regulatory and market setting. An overview of the addressed corridor is shown in Figure 35.

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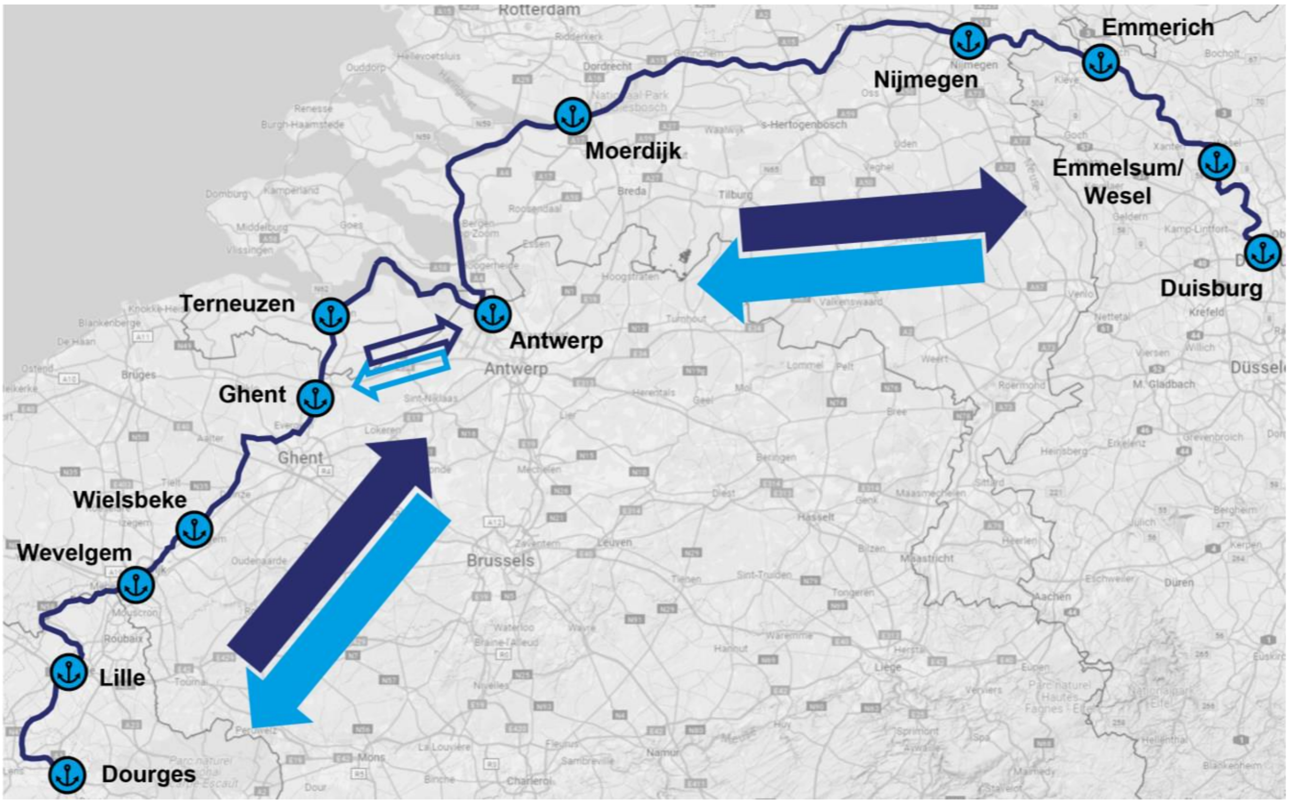

Figure 35: Envisioned UC2 corridor and possible ports
Source: [1]

French-Belgian Waterway Network

The first stretch of the corridor connects the city of Dourges (FR) as well as several inland ports along the route with the Port of Antwerp (BE). Starting from Dourges, the route is defined by the "Canal de la Deule" and the river "Lys". On French territory, vessels have to pass two locks (Grand Carré and Quesnoy) which are operated by Voies Navigables de France (VNF). After crossing the border to Belgium, regulatory responsibility is passed over to the waterway authority of Wallonia (SPW), which handles operations of the Comines lock. Further on, the corridor passes the area of Flanders, i.e., regulatory responsibility lies with the Flemish waterway authority "De Vlaamse Waterweg" (DVW). From Wielsbeke on, traffic density in this area is increasing further towards Ghent. Reaching the city of Ghent, two routes may be used to get to the Port of Antwerp. First, vessels can sail via the Lower Sea Scheldt, which is challenging from a nautical perspective due to tidal influence and current. Another possibility is to sail via Terneuzen and the Westerscheldt, which involves crossing Dutch waterway territory maintained by "Rijkswaterstaat" as well as the area of the Gemeenschappelijk Nautische Authoriteit (Flanders + the Netherlands).

Port of Antwerp

The Port of Antwerp as one of the largest seaports worldwide represents a very complex environment for inland vessel operations. With approximately 50 percent, the main hinterland mode of transport for the Port of Antwerp is inland waterways. Therefore, traffic density within the port is high and leads to congestion and complex traffic situations. Given these conditions, traffic within the port area is subject to close VTS supervision. As most of the container terminals are located in the inner docks, the port area contains a number of locks, most of them capable to accommodate several vessels during one lockage. Currently, inland vessels may book lockage slots using the digital platform APICS [13].

The deep-sea container terminals within Antwerp serve seagoing and inland vessels at the same time. As berth capacity is sparse, operational delays may lead to waiting times during port calls. This becomes even more complicated when vessels need to visit various terminals during one port call so that delays are passed over to subsequent terminal visits [15].

Antwerp – Duisburg

The route between Antwerp and Duisburg leads into Dutch territory over the Scheldt-Rhine-Canal and the Volkerak waterway. The stretch includes the Kreekrak and Volkerak locks, the latter representing Europe's largest inland waterway lock with three chambers up to 350 m length and 24 m width, which is operated by Rijkswaterstaat. The passage continues into the free-flowing Rhine estuaries "Hollands Diep", "Nieuwe Merwede" as well as the "Waal". The route leads further across the Rhine, crossing borders to Germany and finally reaching Duisburg. The Port of Duisburg is considered Europe's largest and most frequented inland port with various basins that host a multitude of terminals for different commodities.

In the last decades, the Rhine and its estuaries have become an important link for containerized hinterland traffic in the ARA region. Therefore, the port of Duisburg currently hosts ten intermodal container terminals. Given the dimensions of the Rhine, container transportation is carried out using some of the largest inland vessels and push-combinations, thus allowing to exploit economies of scale. Against this background, the SEAMLESS concept in UC2 addresses one of the most challenging market segments in IWT and therefore requires significant cost or service differentiation in order to gain competitive advantage. Specifics of the business case will be studied in WP6 of SEAMLESS. This following section will deal with the technical concept and requirements.

6.1.2 System Architecture: Systems and Actors

The SEAMLESS concept applied to UC2 is somewhat different than in UC1. Firstly, UC2 deals with one vessel in a container line loop service between several existing terminals. While the R&A vessel systems and ROC developed in SEAMLESS will not be demonstrated in DUC2, it is assumed that the operational concept and system requirements for these systems in UC2 are as for the SEAMLESS concept. This assumption should hold as the technologies should be transferrable to inland waterways. This is supported by the fact that the R&A vessel and ROC technologies being further developed in SEAMLESS are those who were demonstrated in the AUTOSHIP project, where one of the demonstrations was for autonomous navigation of an inland vessel.

Secondly, in contrast to UC1, the vessel will have to pass locks in UC2. While DUC2 will only demonstrate automated mooring at a terminal, the concept is transferable to mooring in locks. Therefore, we will assume that the autonomous mooring system is used for mooring in locks.

Third and finally, while container loading and unloading could be done by the autonomous cargo crane from a technical perspective, the fact the ports and terminals have existing equipment makes it a reasonable assumption that these will be used. Especially when the business case is considered as the required investment for autonomous cargo handling could not be supported without a vast amount of R&A vessels. Planning and management of cargo handling will still be handled by the VCOP.

The involved actors from the technical system perspective are thus the same as given in Table 26, except for the autonomous cargo crane, and the updated roles for the actors listed in Table 31.

Table 31: Actors with updated roles for UC2

Actor	Short Description	Type
VCOP	Automatically plans the stowage, based on placed shipment orders from the ModalNET and a vessel model for stability calculations. Automatically plans loading and unloading sequences based on the stowage plan. Coordinates cargo operations with the TOS.	Building block 1 subsystem
ROC	The Remote Operations Centre includes the remote operators who holds the role of the master, and which monitors and manages the execution of the vessel mission. The ROC operators also communicate with the terminal and monitors cargo operations.	Building block 2 subsystem
TOS*	Communicates with the ROC, via the VCOP, organises and executes all cargo handling at the terminal including to and from the vessel.	External actor
VTS*	Monitors traffic within the VTS area. Gives clearance for entering the area. Involved in planning and execution of passing locks and moveable bridges.	External actor

* External actors to the SEAMLESS concept.

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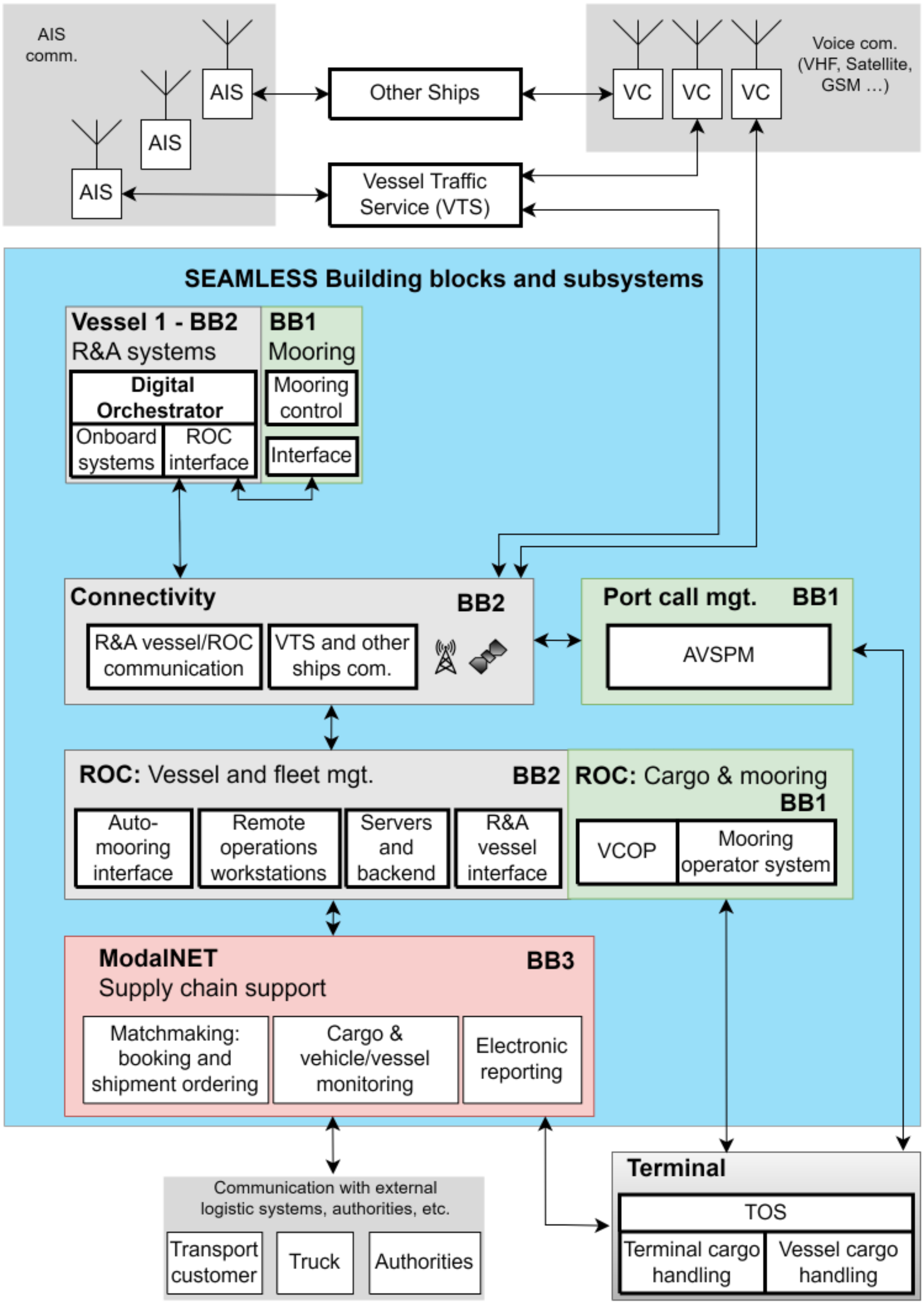

Figure 36: The SEAMLESS concept architecture adapted for UC2

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6.2 Scenario

6.2.1 Voyage and voyage phases

The voyage is a container liner loop service between the endpoints Dourges and Duisburg. It consists of a series of inland and seaport port calls, at predefined ports. However, for each specific voyage, only a subset of the ports is called to, depending on the cargo booked to the voyage. The exception is the endpoints Dourges and Duisburg. The voyage variations are thus many, and for the purpose of simplifying the discussion, we include one example with assumed port calls. Investigating the route in Figure 35, with the assumed port calls, by using the EuRIS voyage planning tool [16], we find that there are 11 locks (lock chambers) on the route and that there are no bridges that will need to be opened. There are however some bridges where the vessel will need to lower masts (where e.g. the radar is located). It should be noted that the exact terminal berths configured for investigating the UC1 route are preliminary best guesses. The further case study within SEAMLESS WP6 will determine the exact terminals and berths.

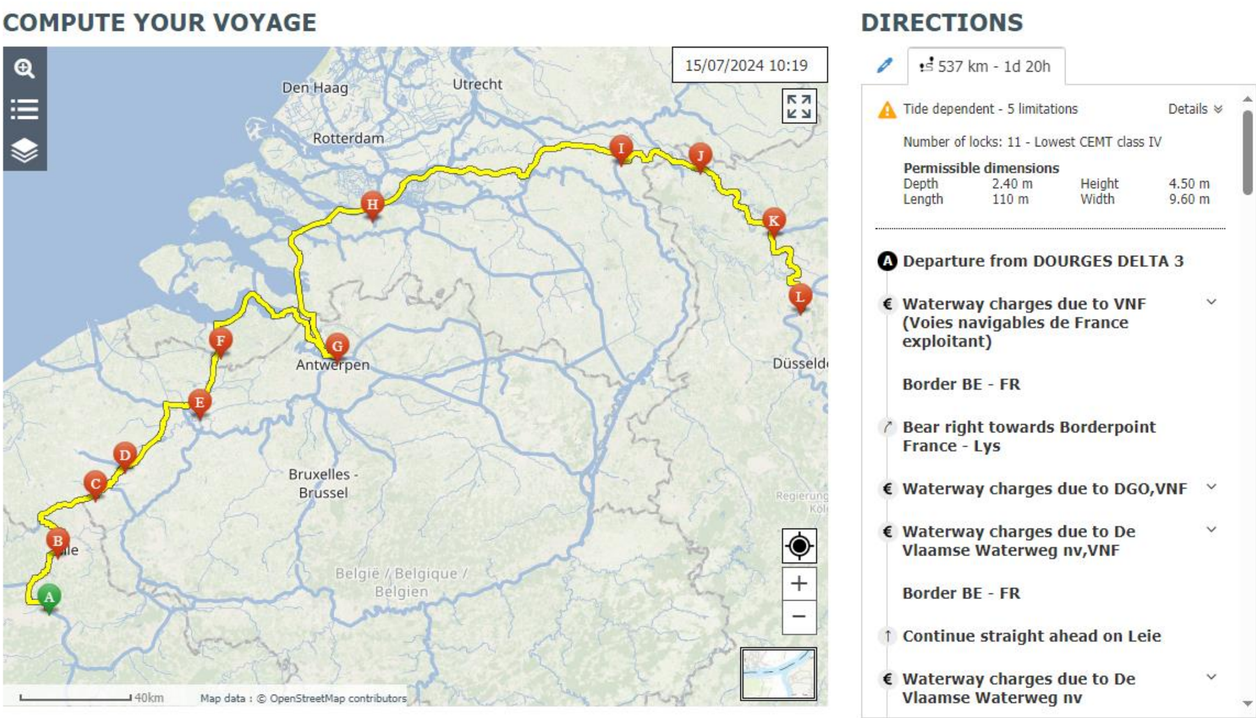

Figure 37: UC2 voyage

Source: EuRIS - Voyageplanner (eurisportal.eu)

To define the Voyage for UC2, we will discuss the sequence of voyage phases on a North – South voyage from Duisburg to Antwerp, and further on from Antwerp to Dourges, based on the port calls given in Figure 37. As for UC1, the phases A: Plan shipment and B: Early port call planning occurs independently of the vessel operations and are as such not placed in sequential order along the route.

Starting in Duisburg (see Figure 38), the first activity is to load cargo, i.e., phase 3: activities at location is executed. Meanwhile, the departure is planned in phase 4. Once cargo operations are

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completed phase 2 is initiated, the vessel releases mooring and navigates out of the berth and port area and moves into phase 6 Navigation towards Emmelsum. Phase 1 Plan port call is executed ahead of the Emmelsum visit.

Arriving Emmelsum, the system enters phase 2; Approach location, navigates to berth and moors. Next, cargo operations are completed in phase 3: Activities at location, while phase 4: Plan departure is done. Once cargo operations are finalized, the system enters phase 5: Depart location, releases mooring and navigates out from the berth and port area and enters phase 6: Navigate towards Emmerich. When the vessels enter the port area the system goes into phase 2: Approach location, navigates to berth and moors. At Emmerich, phase 3: Activities at location and phase 4: Plan departure is executed before the system enters phase 5: Depart location, and then phase 6: Navigate.

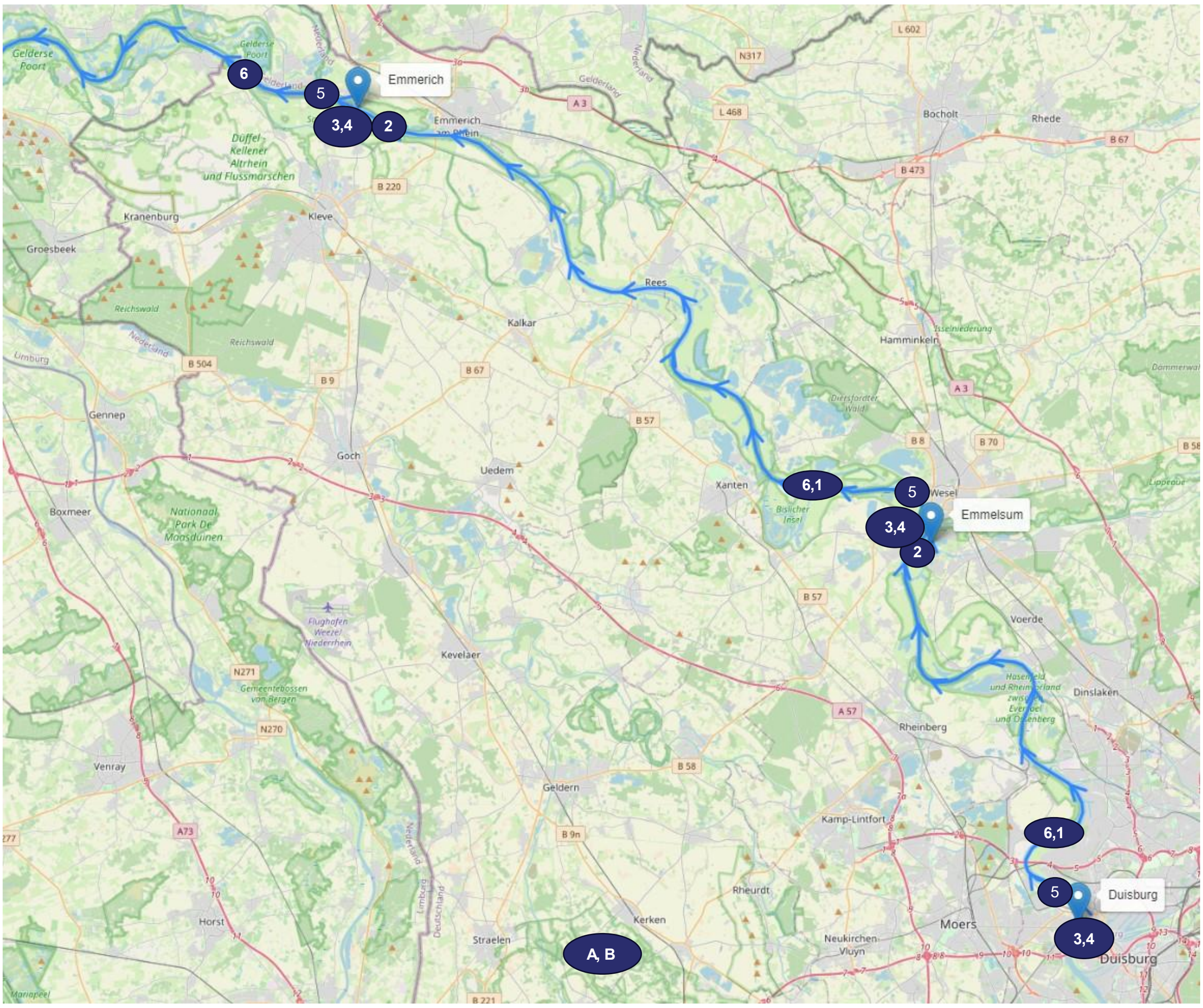

Figure 38: UC2 voyage from Duisburg to Emmerich, via Emmelsum

The next port call is to Nijmegen, see Figure 39. The phase 1: Plan port call is executed prior to calling on Nijmegen. Just before arriving, the vessel reaches the first lock of the voyage, and the

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system enters phase 7: Pass lock. Next the system enters phase 2: Approach location, Phase 3: Activities at location, Phase 4: plan departure, and Phase 5: Depart location, Phase 7: Pass Lock, and finally Phase 6: Navigation towards Moerdijk.

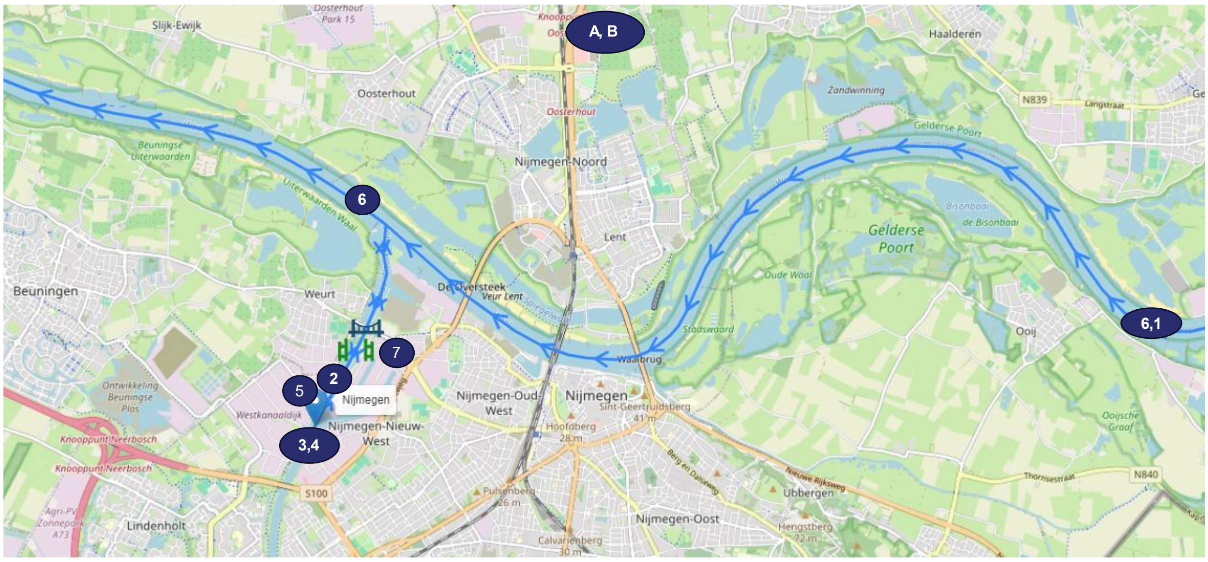

Figure 39: UC2 voyage from Emmerich to Nijmegen

Before arriving to Moerdijk, see Figure 40, phase 1: Plan port call is executed. When the vessel arrives the port area, the system enters phase 2: Approach location, then phase 3: Activities at location, phase 4: Plan departure, and phase 5: Depart location before it moves into phase 6: Navigate towards Antwerp.

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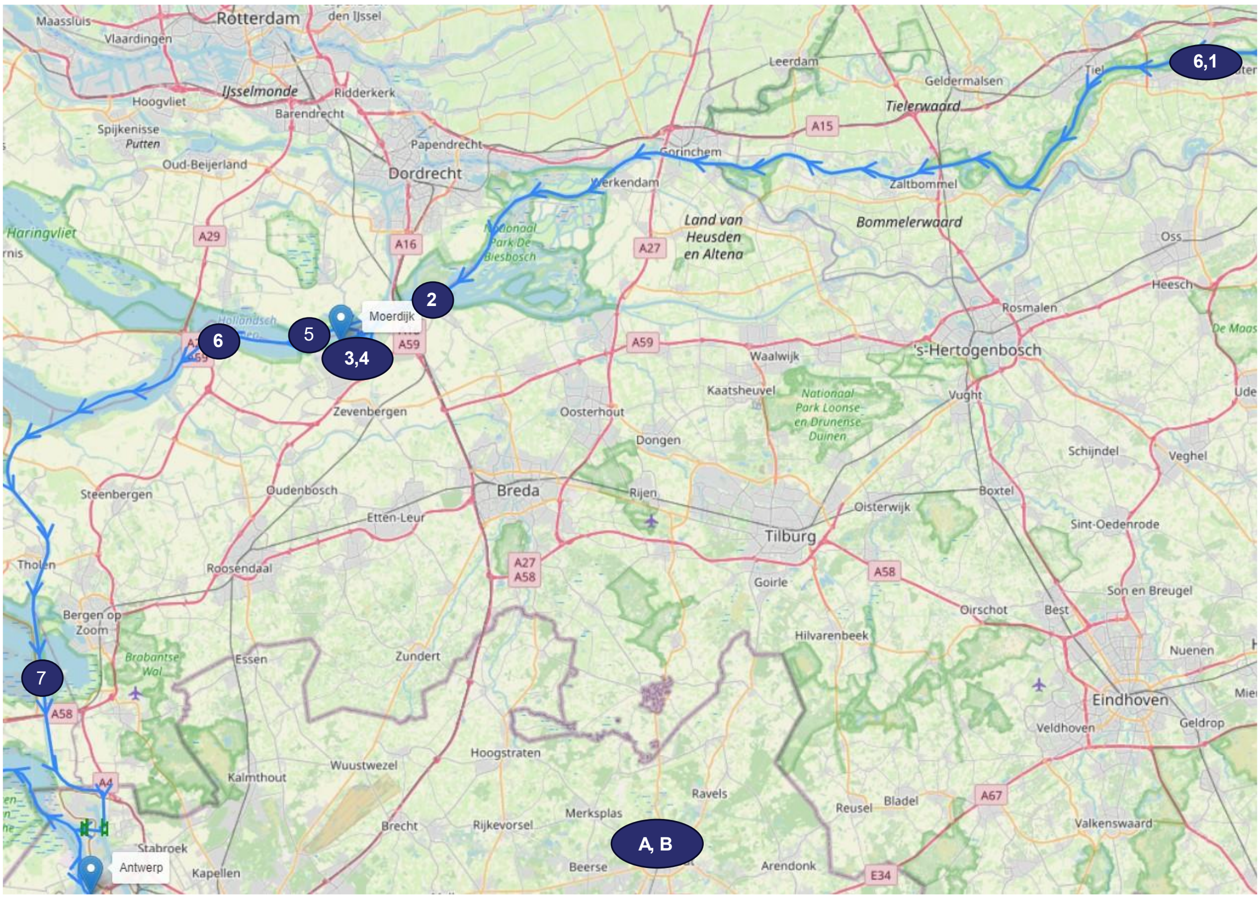

Figure 40: UC2 voyage via Moerdijk to Antwerp

Before the vessel gets to Antwerp, the phase 1: Plan port call is executed. Approaching Antwerp, the vessel arrives at a lock North of Antwerp and enters phase 7: Pass lock, see Figure 41. After passing the lock, the vessel enters the port area with heavy traffic and the system enters phase 2: Approach location. Before arriving to the Antwerp terminal, the vessel encounters another lock, and the system enters phase 7: Pass lock. After passing the lock, the system enters phase 2: Approach location where the vessel navigates towards the berth, moors, and the system enters phase 3: Activities at location, and phase 4: Plan departure. After cargo operations are completed, the system enters phase 5: Depart location, and the vessel starts on the southbound voyage towards Dourges. When the vessel exits the port area, it enters phase 6: Navigate, and the phase 1: Plan port call is executed before arriving Terneuzen. The vessel enters Terneuzen by passing a lock, and the system enters phase 7: Pass lock. After the vessel passes the lock, the system enters phase 2: Approach location, then phase 3: Activities at location and phase 4: Plan departure. Once cargo operations are done, the system enters phase 5: Departure location, and when the port area is reached, phase 6: Navigate.

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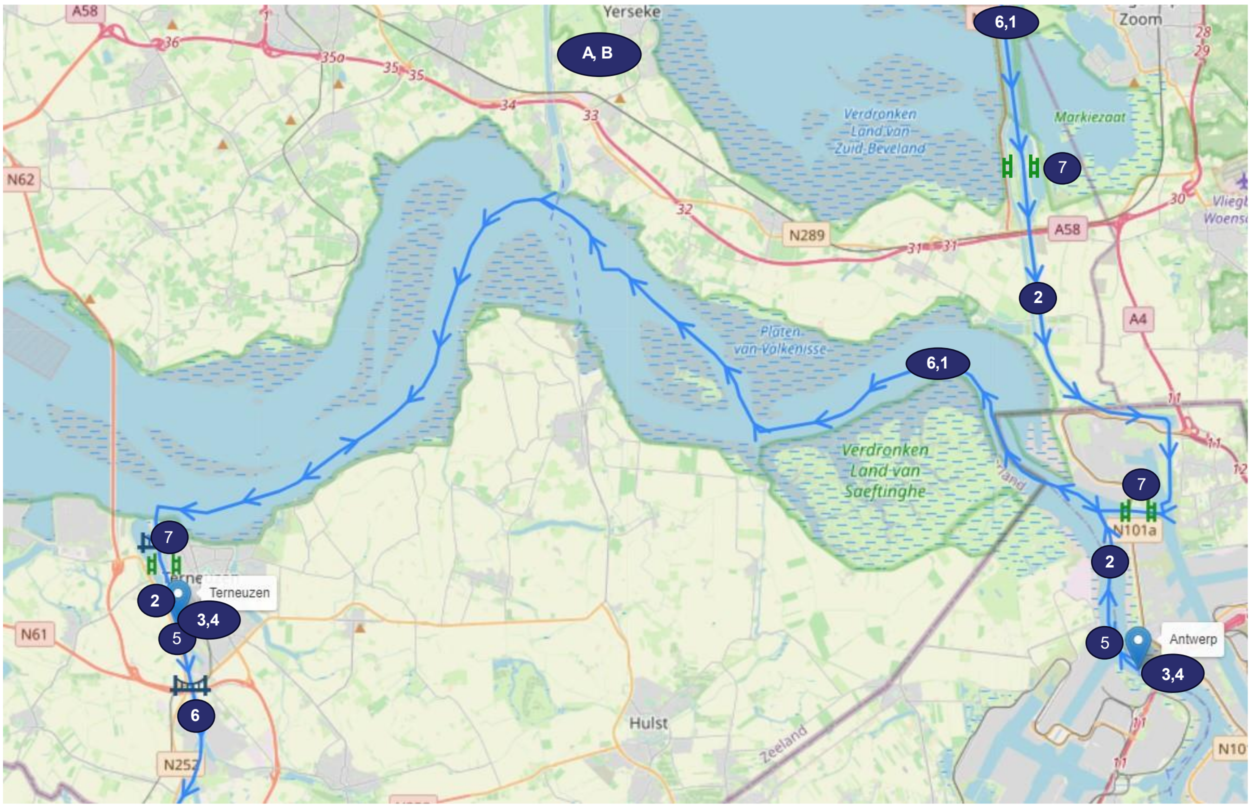

Figure 41: UC2 voyage arriving at Antwerp, departing for southbound voyage.

Before arriving at Gent, the phase 1: Plan port call is executed, see Figure 42. When the vessel reaches the Gent port area, the system enters phase 2: Approach location, then phase 3: Activities at location, and phase 4: Plan departure.

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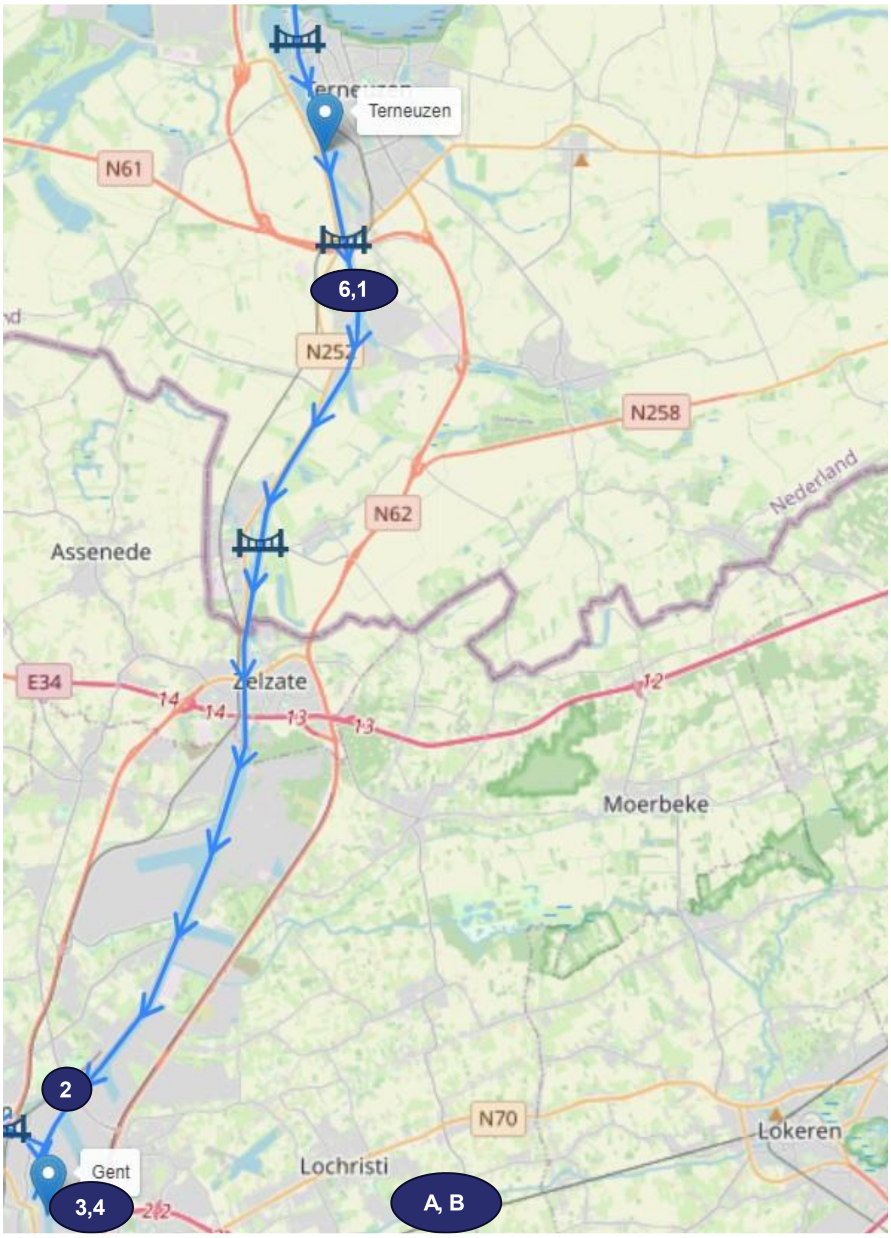

Figure 42: UC2 voyage from Terneuzen to Gent

Once cargo operations at Gent are completed, the system enters phase 5: Depart location, and then phase 6: Navigate, see Figure 43. The vessel arrives at a lock West of Gent, and the system enters phase 7: Pass lock. After passing the lock, the system enters phase 6: Navigate and phase 1: Plan port call. Before arriving to Wielsbeke, the vessel reaches a lock, and the system enters phase 7: Pass lock, before returning to phase 6: Navigate. Arriving the port area at Wielsbeke, the system enters phase 2: Approach location, and then phase 3: Activities at location, phase 4: Plan departure, phase 5: Depart location, and then phase 6: Navigate. Meanwhile, phase 1: Plan port call is executed by the system, ahead of the Wevelgem port call.

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On the way to Wevelgem, the vessel encounters another lock, and the system enters phase 7: pass lock. After passing the lock, the system returns to phase 6: Navigate. When the vessel arrives to the Wevelgem port area, the system enters phase 2: Approach location.

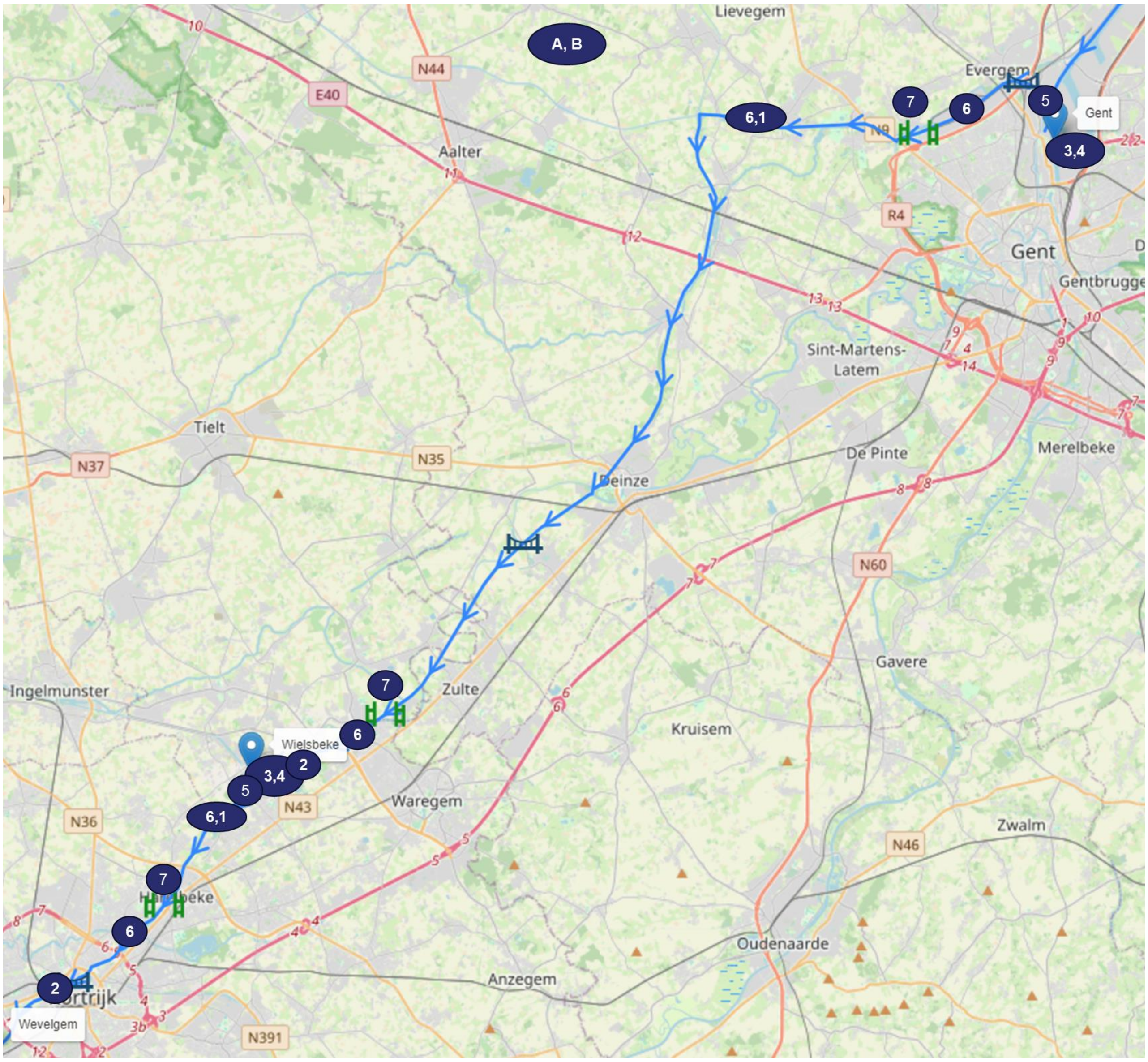

Figure 43: UC2 voyage from Gent to Wevelgem via Wielsbeke

At Wevelgem, the system enters phase 3: Activities at location and phase 4: Plan departure, see Figure 44. Once cargo operations are completed, the system enters phase 5: Depart location, and then phase 6: Navigate. On the way to Lille, the vessel passes three locks. For each lock passing, the system enters phase 7: Pass lock, and returns to phase 6: Navigate. During this period, the phase 1: Plan port call is also executed by the system.

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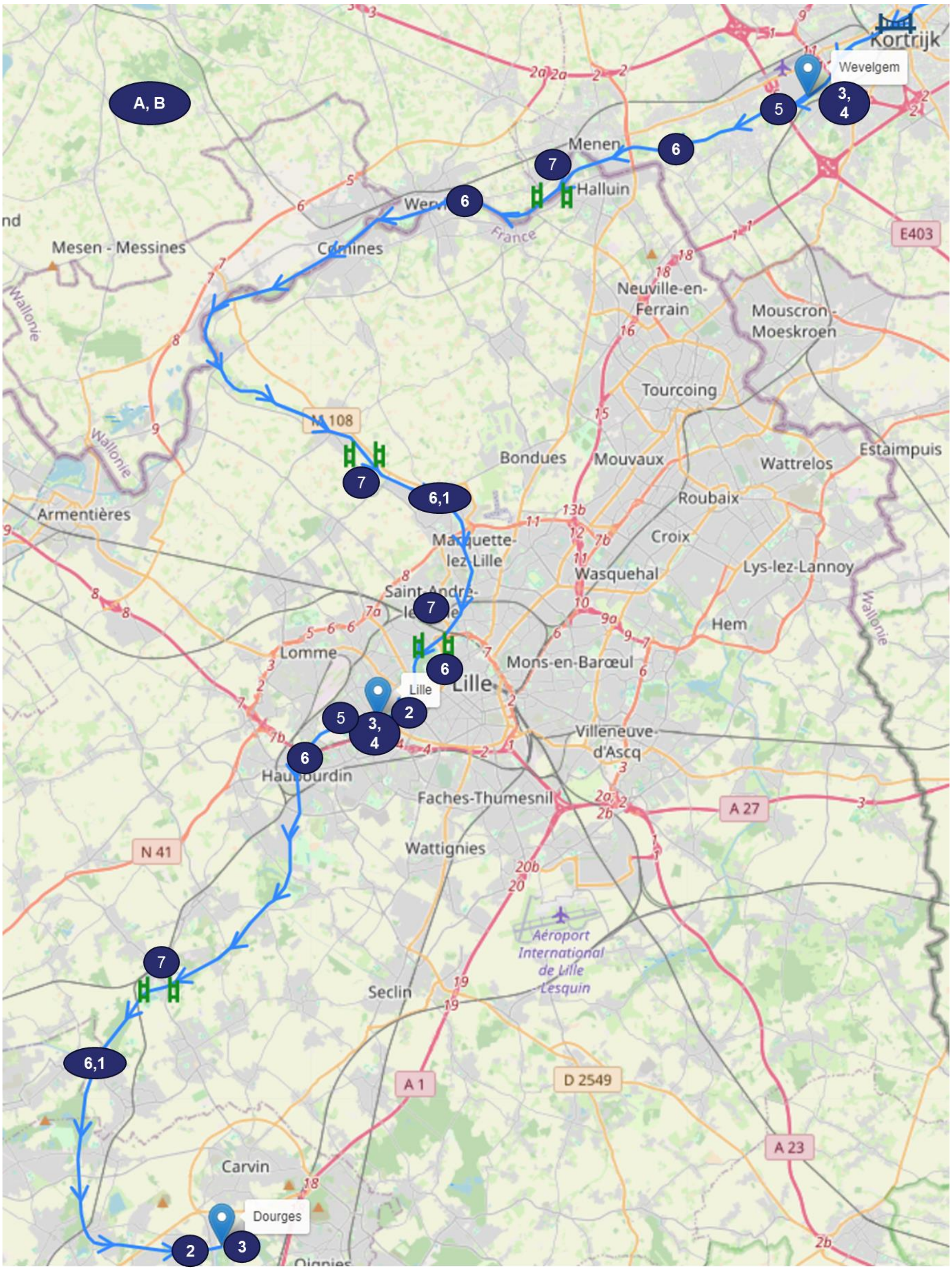

Figure 44: UC2 voyage Wevelgem to Dourges, via Lille

When the vessel arrives the port of Lille area, the system enters phase 2: Approach location, see Figure 44. At Lille, the system executes phases 3: Activities at location, and 4: Plan departure. When cargo operations are completed, the system enters phase 5: Depart location and then phase 6:

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Navigate towards the final destination, Dourges. On the way to Dourges, the vessel encounters one lock, where the system enters phase 7: pass lock, before returning to phase 6: Navigate, while executing phase 1: Plan port call. When the vessel arrives the port area at Dourges, the system enters phase 2: Approach location, and finally phase 3: Activities at location.

6.2.2 Voyage phase patterns

As shown in section 6.2.1, the UC2 voyage includes an extensive sequence of voyage phases. However, as for UC1, the identified voyage phases in section 6.2.1 can be represented by the generalised voyage phase patterns given in chapter 3. For UC2 the relevant voyage phase patterns are thus:

- Phase A: Plan shipment
- Phase B: Early port call planning
- Phase 1: Plan port call
- Phase 2: Approach location
- Phase 3: Activities at location
- Phase 4: Plan departure
- Phase 5: Depart location
- Phase 6: Navigate
- Phase 7: Pass lock
- Phase 8: Pass bridge*

* While no bridges need to be opened for the voyage in UC2, we include this phase in the further discussions to show how NFRs would be associated with this voyage phase pattern.

Table 32 shows which actors and voyage phase patterns that are associated, where "X" marks an association. This is mostly identical to UC1, however, there are some significant differences as UC2 includes the phase patterns Pass lock and Pass bridge, and the autonomous mooring crane is not included as an actor in UC2.

Table 32: UC2 System and use-case associations.

Actor / Phase pattern	Plan shipment	Early port call planning	Plan port call	Approach location	Activities at location	Plan departure	Depart location	Navigate	Pass lock	Pass bridge
Autonomous mooring system	-	-	-	X	X	-	X	-	X	-
Autonomous cargo crane	-	-	-	-	-	-	-	-	-	-
VCOP	X	-	-	-	X	-	-	-	-	-
AVSPM	-	X	X	X		X	X	X	-	-
R&A vessel systems	-	-	X	X	-	X	X	X	X	X
ROC	X	X	X	X	X	X	X	X	X	X

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Connectivity systems	X	X	X	X	X	X	X	X	X	X
ModalNET	X	-	X	X	X	X	X	X	X	X
TOS*	X	-	X	-	X	X	-	-	-	-
VTS*	-	-	-	-	-	-	-	X	X	X

* External actors

6.2.3 System processes

The relevant system processes for UC2 are the same as for UC1, see Table 28, with one minor update; the system process *navigation* includes navigation in locks.

6.3 USE CASES

6.3.1 State space

The state space for UC2 is quite similar to that of UC1 given in Table 29. The difference is that the phase patterns Phase 7: Pass lock and Phase 8: Pass bridge are added, that some of the Phase 3: Activities at location state space variables are not relevant as the container handling is by the terminal cranes, and that state space variable values will be different to capture the differences in operating in shortsea and in inland waterways. The state space of UC2 is thus taken to be Table 29 combined with Table 33 (where Phase 3: Activities at location from Table 33 is used instead of that of Table 29).

Appendix 1 provides the corresponding table with all NFRs relevant to a Voyage phase pattern, including pre-conditions

Table 33: State space amendment for UC2

Voyage phase patterns	Level of autonomy	Operator mode	Non-functional requirements
Phase 3: Activities at location	Constrained Autonomous	Low attention, if NFRs are not satisfied, switch high attention	AMS.NF.03, AMS.NF.05.3, AMS.NF.06, AMS.NF.08, AMS.NF.09, AMS.NF.10.5, VCOP.NF.03.4, VCOP.NF.03.6, VCOP.NF.04, VCOP.NF.07, R&A.NF.11.3, R&A.NF.11.4, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.05, ROC.NF.06.1, ROC.NF.07.2, ROC.NF.07.3, CS.NF.01, MNET.NF.01, MNET.NF.05 (except 05.3 and 05.4), MNET.NF.07
Phase 7: Pass lock	Constrained Autonomous, if NFRs are not satisfied switch to AO	Low attention, if NFRs are not satisfied, switch high attention	AMS.NF.01, AMS.NF.02, AMS.NF.03, AMS.NF.04, AMS.NF.05, AMS.NF.06, AMS.NF.07.5, AMS.NF.08, AMS.NF.09, AMS.NF.10.5, R&A.NF.all (except R&A.NF.11.1), ROC.NF.01.4, ROC.NF.01.6, ROC.NF.03, ROC.NF.05, ROC.NF.07.2, ROC.NF.07.3, CS.NF.01, MNET.NF.01, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.07

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Phase 8: Pass bridge	Constrained Autonomous, if NFRs are not satisfied switch to AO	Low attention, if NFRs are not satisfied, switch high attention	R&A.NF.all (except R&A.NF.11), ROC.NF.01.4, ROC.NF.01.6, ROC.NF.03, ROC.NF.05, CS.NF.01, MNET.NF.01, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.07

6.3.2 System control tasks

The system control tasks (see section 1.3.4) for UC2 are quite similar to those of UC1 in section 5.3.2. The notable difference is that SCT1 definition is updated to make it applicable to Phase pattern 7: Pass lock. As such, it is defined as Navigation port and lock, berthing and unberthing. The reason for this is that both lock and port navigation will be in heavy traffic, with potentially short distances to other vessels. Furthermore, both port and lock navigation involve berthing and mooring.

Table 34: System control tasks UC2

<table>
<tr><th>System process / Phase pattern</th><th>7 – Pass lock</th><th>2 - Approach location</th><th>5 - Depart location</th><th>3 - Activities at location</th><th>6 - Navigate</th><th>8 – Pass bridge</th><th>1 - Plan port call</th><th>4 - plan departure</th><th>A - Plan shipment</th><th>B - Early port call planning</th></tr>
<tr><td>Navigation</td><td colspan="3">SCT1: Navigation port and lock, berthing and unberthing</td><td></td><td colspan="2">SCT2: Navigate transit</td><td colspan="4"></td></tr>
<tr><td>Voyage management</td><td colspan="10">SCT3: Manage voyage, coordinate actors, make tactical decisions.</td></tr>
<tr><td>Nautical communication</td><td colspan="8">SCT4: Communication other vessels, ROCs, VTS, terminal, etc.</td><td colspan="2"></td></tr>
<tr><td>Technical systems and machinery</td><td colspan="8">SCT5: Monitor and control machinery and technical systems</td><td colspan="2"></td></tr>
<tr><td>Cargo handling on/off vessel</td><td colspan="3"></td><td>SCT6: Cargo handling</td><td colspan="6"></td></tr>
<tr><td>Mooring</td><td colspan="4">SCT7: Fasten mooring lines, maintain safe line tension, and release mooring</td><td colspan="6"></td></tr>
<tr><td>Cargo handling management</td><td colspan="3"></td><td>SCT8: Manage cargo handling</td><td colspan="2"></td><td colspan="3">SCT9: Plan stowage and manage stability</td><td></td></tr>
<tr><td>Logistical management</td><td colspan="9">SCT10: Manage logistics</td><td></td></tr>
<tr><td colspan="11">Colour coding</td></tr>
<tr><td colspan="3">Constrained Autonomous</td><td colspan="3">Automatic operations</td><td colspan="2">Direct control</td><td colspan="3">Not applicable</td></tr>
</table>

SCT1: Navigation port and lock, berthing and unberthing.

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This system control task deals with the navigation during the approach and depart phases, as well as the pass lock phase. I.e., navigation within ports and locks, including to and from the berth or mooring position. This will typically be low speed manoeuvres handled by Autodocking and Auto-tracking controllers. Typically, traffic will be heavy within the port area compared to when the vessel is in transit, and the available space limited. More so than in UC1, as UC2 includes some of the busiest ports in Europe. Furthermore, locking procedures implies navigation very close to other vessels, and any disruption to lock and port traffic would be unacceptable.

For UC2, the default autonomy level for SCT1 is therefore set to Automatic Operations, and operator mode to high attention. The AVSPM supports the ROC with traffic information, which in addition to the vessels own sensors, should make it possible to predict traffic conditions aiding the ROC operator. If the state space variables cross their thresholds, the primary action is for the operator to mitigate the situation, e.g., giving mission updates. However, some conditions, if not met, may require the initiation of a fallback directly. Some potentially relevant fallbacks are:

- Reduce speed and continue mission
- Abort/stop and keep position
- Move to safe position and keep position
- Drop anchor

SCT6: Cargo handling

This System Control Task deals with the cargo handling and is relevant for the phase pattern Activities at location. Given a cargo handling sequence, cargo data (ID, weight, type, etc.), origin and destination placement, SCT6 is about moving cargo between the vessel and the terminal.

In UC2, the autonomy level is set to Direct Control as the cargo handling is to be handled by the existing terminal cargo handling equipment. The ROC operator mode is high as the operator needs to communicate with the terminal operators, replacing the digital communication between the autonomous cargo crane and the VCOP in the voyage phase pattern, and monitor vessel stability.

SCT2-SCT5 & SCT7-SCT10

These System Control Tasks are the same for UC1 and UC2, refer to section 5.3.2 for more details.

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7 CONCLUSION

This report has presented the SEAMLESS building blocks and described their intended functionality. This includes a breakdown into the subsystems representing the technologies being developed within the SEAMLESS project, and how these are interconnected within the building blocks. Furthermore, functional requirements per building block subsystem have been defined.

The SEAMLESS concept has been defined and presented as the integration of the building blocks to one system. This includes the SEAMLESS concept architecture, which defines the main interfaces and distribution of systems. It also includes a definition of planning and operational phases for deployment of the SEAMLESS concept. For each defined phase, detailed diagrams defining functional distribution and message exchanges between building block subsystems have also been provided.

The non-functional requirements (NFRs) have been defined per building block subsystem. These define the conditions for the correct functionality of the subsystem. A mapping between the NFRs and the phases which they apply to has also been defined.

The SEAMLESS concept has been applied to the project use cases, and the non-functional requirements have been used to define the state space, i.e., a parametrisation of the conditions for the execution of system control tasks at defined autonomy levels.

The presented functional and non-functional requirements in this report summarises what has been identified in this phase of the project development through stakeholder engagement and workshops. It will serve as the basis for development of building blocks, which will continue in the next project phase. Work related to this report will also be continued under Task 4.3 Simplification of risk-based approval procedures, by developing modelling methods for improving the CONOPS definition.

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9 APPENDICES

9.1 APPENDIX 1: NFRS PER VOYAGE PHASE PATTERN

This appendix gives the full list of NFRs relevant for each voyage phase pattern, including those that are pre-conditions.

Voyage phase patterns	Level of autonomy	Operator mode	Non-functional requirements
Phase A: Plan shipment	Operator Assisted	High attention	VCOP.NF.01.1, VCOP.NF.02, VCOP.NF.06, VCOP.NF.07, ROC.NF.01.1, ROC.NF.01.2, ROC.NF.01.5, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.02, ROC.NF.03, ROC.NF.04.1, ROC.NF.04.2, ROC.NF.04.2, ROC.NF.05, CS.NF.01, MNET.NF.01, MNET.NF.02, MNET.NF.03, MNET.NF.04, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.06, MNET.NF.07
Phase B: Early port call planning	Operator Assisted		AVSPM.NF.01, AVSPM.NF.02, AVSPM.NF.03, AVSPM.NF.05, ROC.NF.01.3, ROC.NF.01.5, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.04.3, ROC.NF.04.4, ROC.NF.05.3, CS.NF.01
Phase 1: Plan port call	Operator Assisted		AVSPM.NF.01, AVSPM.NF.02, AVSPM.NF.03, AVSPM.NF.04.3, AVSPM.NF.04.4, AVSPM.NF.04.5, AVSPM.NF.05, ROC.NF.01.1, ROC.NF.01.3, ROC.NF.01.5, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.04.2, ROC.NF.04.3, ROC.NF.04.4, ROC.NF.05.3, CS.NF.01, MNET.NF.01, MNET.NF.02, MNET.NF.03, MNET.NF.05.5. MNET.NF.05.6, MNET.NF.05.7, MNET.NF.05.8, MNET.NF.06, MNET.NF.07
Phase 2: Approach location	Constrained Autonomous, if NFRs are not satisfied switch to OA	Low attention, if NFRs are not satisfied, switch high attention	AMS.NF.all, AVSPM.NF.03.2, AVSPM.NF.03.3, AVSPM.NF.03.4, AVSPM.NF.04, AVSPM.NF.05, R&A.NF.all, ROC.NF.01.1, ROC.NF.01.3, ROC.NF.01.4, ROC.NF.01.5, ROC.NF.01.6, ROC.NF.01.7, ROC.NF.01.8, ROC.NF.02, ROC.NF.03, ROC.NF.04.2, ROC.NF.04.3, ROC.NF.04.4, ROC.NF.04.5, ROC.NF.05, ROC.NF.06, ROC.NF.07, CS.NF.01, MNET.NF.01, MNET.NF.02, MNET.NF.03, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.06, MNET.NF.07
Phase 3: Activities at location	Constrained Autonomous		AMS.NF.03, AMS.NF.05.3, AMS.NF.06, AMS.NF.08, AMS.NF.09, AMS.NF.10.4, AMS.NF.10.5, ACC.NF.all, VCOP.NF.03, VCOP.NF.04, VCOP.NF.05, VCOP.NF.06, VCOP.NF.07, R&A.NF.11.1, R&A.NF.11.3, R&A.NF.11.4, ROC.NF.01.2, ROC.NF.01.5, ROC.NF.01.6, ROC.NF.01.7, ROC.NF.01.8, ROC.NF.04.1, ROC.NF.04.4, ROC.NF.05, ROC.NF.06.1, ROC.NF.07, CS.NF.01,

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			MNET.NF.01, MNET.NF.02, MNET.NF.03, MNET.NF.05, MNET.NF.06, MNET.NF.07
Phase 4: Plan departure	Operator Assisted		AVSPM.NF.01, AVSPM.NF.02, AVSPM.NF.03, AVSPM.NF.04.3, AVSPM.NF.04.4, AVSPM.NF.04.5, AVSPM.NF.05, ROC.NF.01.1, ROC.NF.01.3, ROC.NF.01.4, ROC.NF.01.5, ROC.NF.01.6, ROC.NF.01.8, ROC.NF.04.2, ROC.NF.04.3, ROC.NF.04.4, ROC.NF.05, ROC.NF.06.1, CS.NF.01, MNET.NF.01, MNET.NF.02, MNET.NF.03, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.05.7, MNET.NF.05.8, MNET.NF.06, MNET.NF.07
Phase 5: Depart location	Constrained Autonomous		AMS.NF.01, AMS.NF.02, AMS.NF.03, AMS.NF.04, AMS.NF.05.1, AMS.NF.05.2, AMS.NF.05.3, AMS.NF.05.5, AMS.NF.06, AMS.NF.07, AMS.NF.08, AMS.NF.10, AVSPM.NF.03.2, AVSPM.NF.03.3, AVSPM.NF.03.6, AVSPM.NF.04, AVSPM.NF.05, R&A.NF.01, R&A.NF.02, R&A.NF.03, R&A.NF.04, R&A.NF.05, R&A.NF.06, R&A.NF.07, R&A.NF.08, R&A.NF.09, R&A.NF.10, R&A.NF.11.1, R&A.NF.11.2, R&A.NF.11.4, ROC.NF.01.1, ROC.NF.01.3, ROC.NF.01.4, ROC.NF.01.5, ROC.NF.01.6, ROC.NF.01.7, ROC.NF.01.8, ROC.NF.04.2, ROC.NF.04.3, ROC.NF.04.4, ROC.NF.04.5, ROC.NF.05, ROC.NF.06, ROC.NF.07, CS.NF.01, MNET.NF.01, MNET.NF.02, MNET.NF.03, MNET.NF.05.5, MNET.NF.05.6, MNET.NF.06, MNET.NF.07
Phase 6: Navigate	Constrained Autonomous	Low attention	AVSPM.NF.05, R&A.NF.01, R&A.NF.02, R&A.NF.03, R&A.NF.04, R&A.NF.05, R&A.NF.06, R&A.NF.07, R&A.NF.08, R&A.NF.09, R&A.NF.10, ROC.NF.01.1, ROC.NF.01.3, ROC.NF.01.4, ROC.NF.01.5, ROC.NF.01.6, ROC.NF.01.7, ROC.NF.01.8, ROC.NF.02, ROC.NF.03, ROC.NF.04.2, ROC.NF.04.3, ROC.NF.04.4, ROC.NF.04.5, ROC.NF.05

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