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AutoMated Vessels and Supply Chain Optimisation for Sustainable Short SEa Shipping

D.4.4: Specifications and development of the Autonomous Tugboats Control Station

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Contributors	NTUA, ESI, CORE, DNVGL, PCT, MHM, SEAB, TRELL	**Lead Author**	Mercedes de Juan, VPF Vicente Perales, VPF
		Reviewers	Hans van den Broek, TNO Mirjam Huis in 't Veld, TNO
			Janne Suominen, MCGRSWE

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Document Information

List of Contributors		
First Name	**Last Name**	**Partner**
Mercedes	De Juan	VPF
Jorge	Marcos	VPF
Miguel	Llop	VPF
Vicente	Perales	VPF
Nikos	Monios	CORE
Konstantinos	Louzis	NTUA
Giannis	Kanellopoulos	NTUA
Elias	Kotsidis	ESI
Chara	Georgopoulou	DNVGL
Stavros	Tsagalas	PCT
Nikolaos	Vardalachos	MHM
Elena	Krikigianni	SEAB
Jason	Whitehouse	TRELL

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List of Acronyms

Abbreviation / acronym	Description
AI	Artificial Intelligence
AIS	Automatic Identification System
APERAK	Application Error and Acknowledgement Message
API	Application Programming Interfaces
ATA	Actual Time of Arrival
ATC	Actual Time of Completion
ATD	Actual Time of Departure
ATS	Actual Time of Start
BAM	Bridge Alert Management
BERMAN	Berth Management Message
CCP	Controllable Pitch Propeller
CCTV	Closed Circuit Television
CDT	Conductivity, Temperature and Depth
CORS	Cross-Origin Resource Sharing
DOD	Deep of Discharge
ECC	Emergency Control Centre
ECDIS	Electronic Chart Display Information System
EDI	Electronic Data Interchange
EGDH	Expert Group Data Harmonization
EMSA	European Maritime Safety Agency
ENC	Electronic Navigational Charts
ETA	Estimated Time of Arrival
ETC	Estimated Time of Completion
ETD	Estimated Time of Departure
ETS	Estimated Time of Start
EU	European/ Europe
FAL	Facilitation of International Maritime Traffic
FWA	Fresh Water Allowance

Abbreviation / acronym	Description
GHG	Greenhouse Gas
GIA	IMO Global Industry Alliance
GIS	Geographic Information System
GLN	Global Location Number
GMDSS	Global Maritime Distress and Safety System
HTTPS	Hypertext Transfer Protocol Secure
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IEC	International Electrotechnical Commission
ISPS	International Ship and Port Security
JIT	Just-In-Time
IHO	International Hydrographic Organization
IMO	International Maritime Organization
ISO	International Organization for Standardization
JSON	JavaScript Object Notation
JWT	JSON Web Token
MEPC	Marine Environmental Protection Committee
MQTT	Message Queuing Telemetry Transport
PBP	Pilot Boarding Place
PCPI	Port Call Process Instance
PCS	Port Community System
PTA	Planned Time Arrival
PTC	Planned Time of Completion
PTD	Planned Time of Departure
PTS	Planned Time of Start
RDF	Radio Direction Finding
REST	Representational State Transfer
RMB	Right Mouse Button
RTA	Requested Time Arrival
RTC	Requested Time of Completion

Abbreviation / acronym	Description
RTD	Requested Time of Departure
RTS	Requested Time of Start
SD	Sailing Direction
SOC	State of Charge
SOH	State of Health
SOLAS	International Convention for the Safety of Life at Sea
SQL	Structured Query Language
SSL	Secure Sockets Layer
SSS	Short Sea Shipping
SOAP	Simple Object Access Protocol
STCS	Shore Tugboat Control Station
STCW	Standards of Training, Certification, and Watchkeeping
SWL	Safe Working Load
TCP/IP	Transmission Control Protocol/Internet Protocol
TRP	Tug Reaching Place
UKC	Under Keel Clearance
UN	United Nations
UN/EDIFACT	United Nation/Electronic Data Interchange for Administration, Commerce and Transport
UTC	Coordinated Universal Time
VHF	Very High Frequency
VTS	Vessel Traffic Services
WGS 84	World Geodetic System 1984

Executive Summary

MOSES aims to significantly enhance the SSS component of the European container supply chain by addressing the vulnerabilities and strains that relate to the operation of large containerships. The productivity of European ports is very high compared to non-EU ports. However, these ports compete with European ports with low labor costs. Maintaining competitiveness therefore means increasing efficiency, without compromising safety, in all processes and operations that take place in a port.

According to EMSA Annual Overview of Marine Casualties and Incidents (2021), half of the casualties occurred in internal waters, more precisely in port areas (41%). Most incidents happen in the approaches, anchorages or harbour basins of ports, as this is by far the busiest time for the mariner and vessel due to the concentration of activities that involve a certain risk. During the period 2014-2020, the distribution of the accidents shows that 51.7% are human action related and 37.5% are system /equipment failure related.

The ambition of the MOSES project is to increase the port operations efficiency while maintaining the safety during ship maneuvering process. Current operations for berthing and unberthing containerships are conducted by manned tugboats with low-level automation. MOSES intends to develop an appropriate framework for executing this process in an autonomous manner. In particular, MOSES has developed an autonomous swarm tug and an automated mooring system (Auto Dock system) able to reduce 70% in manoeuvring time and 20% in docking time for large container vessels.

This deliverable describes the main characteristics and functionalities of the Shore Tugboat Control Station (STCS) that monitors the autonomous manoeuvring, as well as the real-time communications protocols with the Port Authority management systems, Port Community System (PCS), the Vessel Traffic Services (VTS) with the STCS. In addition, this deliverable provides a better understanding of the data exchange in the ship-port interface and of the existing international standards that connect ships/tugs and ports.

As such, this deliverable contributes to current efforts of industry and IMO to accelerate digitalization (resolution MEPC 323(74)) and achieve the GHG emission reduction target for the shipping industry.

This deliverable also supports the efforts of the IMO Global Industry Alliance to Support Low Carbon Shipping (GIA), which is systematically assessing options to reduce emissions related to the **ship-port interface**, with a view to subsequently ranking options in accordance with their potential to cost-effectively reduce emissions:

- Contribute to the International Hydrographic Office activities regarding product specifications for Marine Harbor Infrastructure
- Contribute to the work of the IMO Expert Group Data Harmonization (EGDH) and to the IMO Compendium on Facilitation and Electronic Business by further extending it to operational data in the port-ship interface

- Contribute to the IMO E-Navigation initiative
- Contribute to the development of a World Bank Transport paper on the critical actions to improve the resilience of the maritime logistic chain at the time of COVID-19 with a focus on digitalization
- Lead to a step-by-step guide for ports how to digitize their port data

The concept of autonomous manoeuvre is a challenging one, which has been partly addressed in MOSES WP4, in particular in Tasks 4.1 - 4.3. Task 4.1 described the functional and operational architecture for enabling autonomous tugboat operation, either for a single tugboat or a swarm of tugboats inform. Task 4.2 designed the training environment, which is used for the development of the swarm intelligence algorithms carried out in Task 4.3.

This deliverable is also focused on determining the main characteristics of the Shore Tugboat Control Station (STCS), a central control platform that will act as interface between the tugboat's operator, the AutoMoor units and the port, supporting decision-making of the Port Control Authority.

The definition of the functionalities of the STCS has been approached following the chronological order of the entry of the ship into port, i.e.:

- Analysis of the communications of the STCS and Port Community System (PCS) of the port prior to the arrival of the ship.
- Communications between the STCS, the autonomous tugboat swarm and the traffic control devices during the manoeuvring.
- Communications between the STCS and the Autodock system when the vessel is in the final approaching to the berth.

The result of this analysis has not only been the definition of the communications protocol between the STCS with the rest of the actors involved, but also:

a) the creation of a standard communications protocol, which is expected to contribute to the improvement of safety in port navigation

b) the delimitation of the responsibilities of each of the stakeholders involved in the manoeuvre.

1. Introduction

1.1 Purpose of the document

This deliverable, which covers the activities carried out in Task 4.4, describes the information on the port infrastructure and services between the Pilot Boarding Place and the Berth, which will be managed by the Shore Tugboat Control Station (STCS) to conduct the vessel manoeuvring in a safe manner. This information includes general procedures (e.g., reporting formalities) or specific port information of specific port sections (e.g., depth of berthing pocket).

The most risky phase for a vessel is the departure from or arrival to a port. Most incidents happen in the approaches, anchorages or harbour basins of ports, as this is by far the busiest time for the seafarer and vessel. Therefore, the quality and the availability of port information is an important risk mitigation strategy as it will help to execute safe navigation from pilot boarding place to berth and vice versa.

Quality nautical port information is the foundation of safe, efficient and sustainable port use. Quality information means that all information is consistent, accurate, up to date, complete and most importantly, is based on a standard.

The main objective of this deliverable is **to define a standard communication protocol** between harbour pilots, autonomous tugboat swarm, Vessel Traffic Services (VTS) and the AutoMoor system, and **to determine the specifications for the Shore Tugboat Control Station (STCS).**

The MOSES Task 4.4 outcomes represent a significant step forward in the definition of communication standards at port level. Amongst others, MOSES provides a reliable solution for standardizing the berth identifiers and significantly reduces the information currently shared by emails, telephone calls or printed documents.

MOSES' contribution to communications standardization focuses on ship navigation involving port entry and departure. It covers the time range from when the ship is one hour away from the port until it is berthed at the terminal.

The complete maneuvering process has been divided in three phases:

1. PHASE 1: Communication between the ship agent and the Port Authority prior to the arrival of the vessel. Information is transferred from the Port Authority's PCS to the STCS.
2. PHASE 2: Communication between the STCS, the harbour pilot, the Vessel Traffic Services and the autonomous tugboat swarm, from the point when the pilot embarks (Pilot Boarding Place) the vessel until the ship is in the vicinity of the terminal.
3. PHASE 3: Communication between the STCS, the harbour pilot, the autonomous tugboat swarm and the AutoMoor system in the final phase of the manoeuvring.

1.2 Intended readership

The intended readership of this public document is any decision maker involved in the development of information technologies in ports. These mainly include Port Authorities, shipping companies, nautical services and any interested party wishing to know more about the advantages of the standardization of communications between the ship, the Port Authority, and the nautical services.

1.3 Document Structure

This deliverable is structured in eight chapters:

Chapter 1 introduces the MOSES project and main objectives of this deliverable. Chapter 2 presents a description of the current port call process protocol followed in large European ports, and the requirements posed by D2.4. Chapter 3 provides an operational description of the ship manoeuvring, with special focus on the communication flows between the STCS, the harbour pilot, the autonomous tugboat swarm and the AutoMoor units. Chapter 4 summarises the main functionalities of the Shore Tugboat Control Station. The Shore Tugboat Control Station interface is presented in Chapter 5, while Chapter 6 defines the software interface. Chapter 7 addresses the definition of the Mock-up that will be implemented in WP7. Finally, Chapter 8 provides lessons learned and concluding remarks.

2. Description of port call process

This section aims to describe the actual port call process followed in main CORE ports. As far as possible, attempts will be made to maintain existing communication protocols, while trying to ensure that the introduction of MOSES innovations produces the least possible interference.

When looking at ports, the current situation is highly determined by the governance model, since this model directly affects the way that a port addresses the port call process. A number of factors influences the way ports are organized, structured, and managed, including:

- The socio-economic structure of a country (market economy, open borders).
- Historical developments.
- Location of the port (e.g., in an urban area or in isolated regions).
- Types of cargoes handled (liquid and dry bulk, general cargo, containers).

Main European CORE ports operate in a landlord model. A landlord port is characterized by its mixed public-private orientation. This implies that the port authority acts as regulatory body and as landlord, while port operations (including nautical services) are carried out by private companies. Today, the landlord port is the dominant port model in larger and medium sized ports.

In the landlord port model, nautical services (towage, pilotage, and mooring) are leased to private operating companies. The lease to be paid to the port authority is usually a fixed sum, typically indexed to some measure of inflation. The private port operators provide and maintain their own equipment including vessels and buildings.

2.1 Port call protocols in large ports

The port call process is the port-ship interface where several agents, both from the ship and the port perspectives, cooperate and exchange relevant information under different means and formats. The port call process can be divided into two sub-processes:

1) Port Call Request, depicted in Figure 1
2) Port Call Execution, depicted in Figure 2

Sub-process 1 takes place prior to the ship arrival and comprises important formalities and exchange of information among national authorities and the shipping company / ship agent aiming at calling at a certain port. Sub-process 2 comprises the operational execution of the port call once all the corresponding authorisations have been approved prior to the ship arrival. Depending on the port's governance model, different barriers may manifest or influence both processes. The port call request involves the following agents:

- Ship Agent

- Port Authority
- Maritime National Authority
- Port National Authority

Figure 1 shows the information flows established by the aforementioned agents when managing a port call request according to the guidelines established by the Convention on Facilitation of International Maritime Traffic. This diagram shows a generalised version of this sub-process, which may vary depending on the world region and national / local regulations.

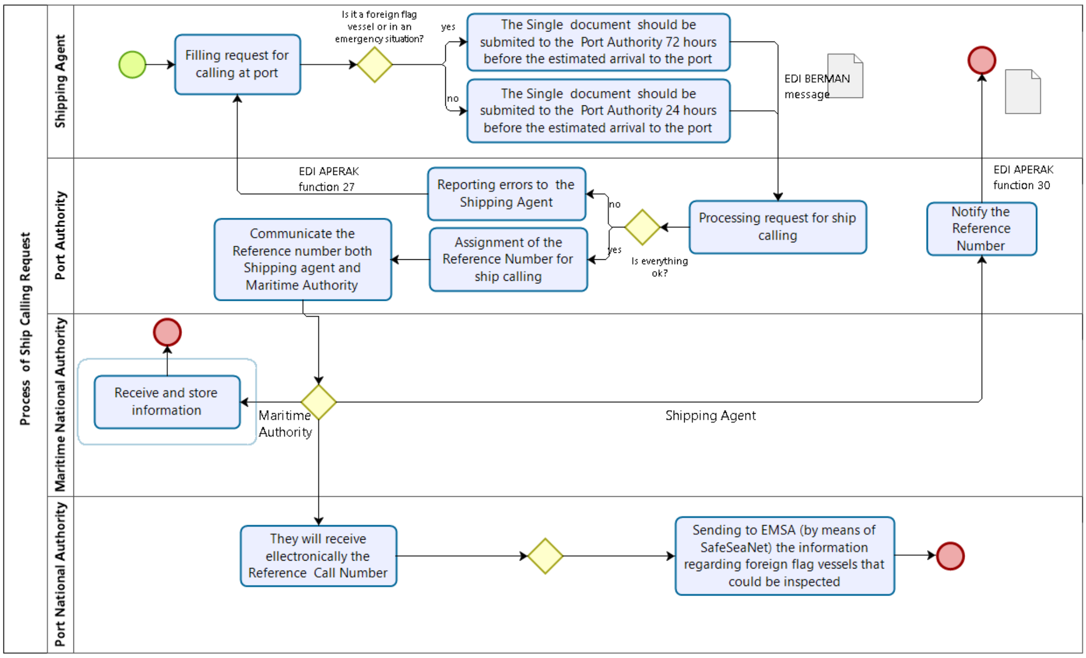

Figure 1 Port Call Request Flow Process

Source: Fundación Valencia port

This sub-process starts with the request by the shipping agent of a port call to the corresponding port authority. This request can be made electronically through a Port Community System or similar port information-exchange system or by other means (e-mail, fax, paper format).

If the request is made by electronic means, the information exchange between the shipping agent and the port authority takes place by means of the standardised EDI (Electronic Data Interchange) messages, BERMAN (Berth Management Message) and APERAK (Application Error and Acknowledgement Message).

The Berth Management Message, which follows the UN/EDIFACT[1] standard, is a message from a carrier, who is the agent on means of transport, to the authority responsible for port and waterway management, requesting a berth, giving details of the call, ship, berth requirements and expected operations. The BERMAN message is used in Electronic Data Interchange (EDI)

[1] United Nations/Electronic Data Interchange for Administration, Commerce and Transport UN/EDIFACT is the international EDI standard developed under the United Nations.

and may be used for both national and international applications. It is based on universal practice related to administration, commerce and transport, and is not dependent on the type of business or industry.

If the port call request is correct, the Port Authority informs both the shipping agent and the corresponding Maritime National Authority about the port-call reference number assigned to the port call request. The Port Call Execution corresponds to the operational process of facilitating the approach, berthing and departure of ships at ports. Figure 2 shows a generalised port call execution process.

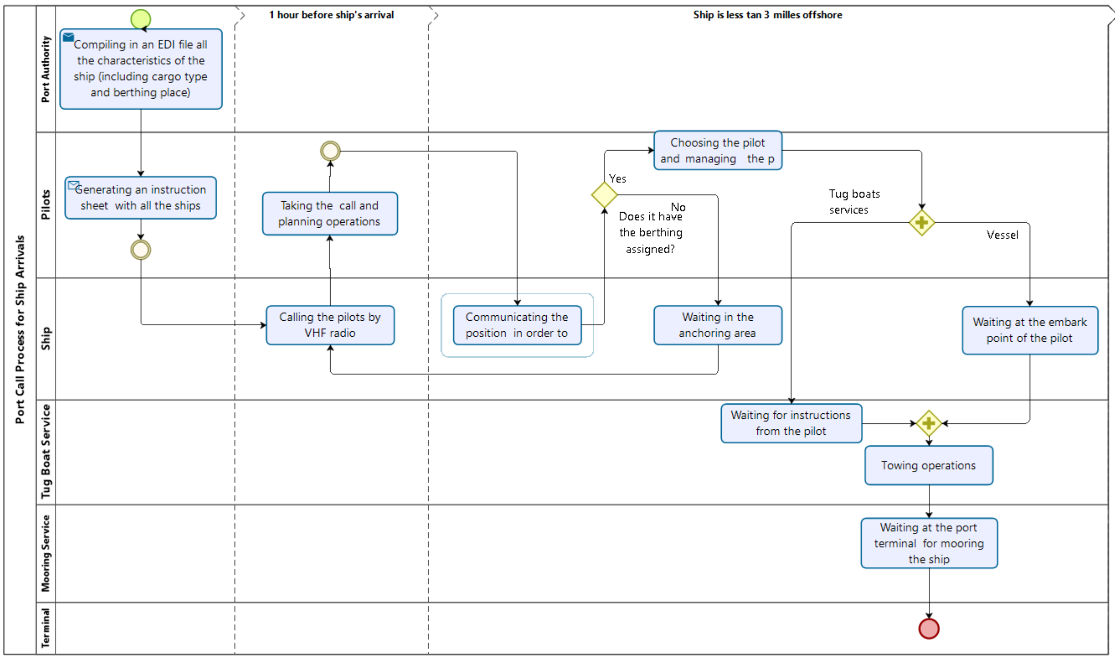

Figure 2 Port Call Execution Flow Process

Source: Fundación Valencia port

The port authority plays the role of port call coordinator in most ports regardless of the port governance model (service, tool, landlord or private).

Today, the landlord port is the dominant port model in larger and medium-sized ports, although service and tool port models are still in place in developing countries. This scheme is widely adopted in developed countries.

Assuming the landlord port governance model as the most extended model in the European sector, the port call process usually starts with a planning task of the port authority, taking as a reference the current situation of the port (number and location of ships berthed at present), and the foreseen situation within the next hours (scheduled Estimated Time of Arrivals and Departures). This task is repeated in an iterative cycle and is adapted according to the operational reality of the port.

Within this process, the port authority establishes the coordination for the next iterative cycle (e.g., next 24 hours) with the nautical service providers, who are the agents in charge of executing the berthing and departure operations of ships. In this respect, when a ship enters in the approaching area of a port and has berth authorisation (e.g., one hour before arrival), she establishes contact via radio VHF with the port, usually being the pilot's organisation the first agent contacted. Pilots usually monitor the approach of a ship and give instructions according to the current and expected traffic situation at port. Instructions examples are listed below:

- Increase speed to arrive early to the pilot boarding area, since a berth slot will be released earlier than expected.
- Reduce speed to arrive later to the pilot boarding area, since a berth slot will be released later than expected.
- Sail towards the anchorage area due to different reasons: port congestion, ship technical constraints, prioritisation of traffic (e.g., passenger ships), etc.

If the port has a slot berth available for a certain ship, the pilots start coordination with the tugboats company and the mooring companies in order to organise the port call operations, including definition of tugboats number required, manoeuvring type, berth allocation, etc. In parallel, communication with the ship takes place in order to initiate the pilot boarding at the designated boarding area. All the aforementioned communications take place via radio under the same VHF Channel (commonly known as Port Control channel).

The type and complexity of operations involved in port calls can vary significantly from one port to another, ranging from less than one hour between the port call and berthing operations (open seaports) to several hours (river ports), especially in ports which require channel navigation until reaching the cargo terminal.

Once the ship is moored at the berth, the port call process is completed from the operational perspective. Then, the cargo handling process starts with loading and unloading operations (container, bulks, ro-ro, passengers, etc.). The departure process can be described as a mirror of the port call process, since the last event of the port call process is the first action of the departure process.

2.2 Requirements

2.2.1 Technical requirements

This section describes the overall concept and the technical requirements, which ensure autonomous manoeuvring within the scope of MOSES. The technical requirements have been derived from the functional requirements and specifications defined in D2.4.

The main function of the Shore Tugboat Control Station (STCS) is to ensure the proper coordination of the mother vessel's docking process by maintaining real-time communication with the autonomous tugboat swarm, AutoMoor units and the port Vessel Traffic Services (VTS). The system will include a human operator (the remote-control operator) who will remotely supervise the manoeuvring/ docking process of the mother vessel, conducted by the tugboat swarm, from the Shore Tugboat Control Station.

The tugboat Captain(s) will have access to the data gathered on-board by the sensors, through the control unit, and to the Shore Tugboat Control Station interface. Manual control of the tugboat can be gained by the tugboat Captain(s), and remote-control can be taken by the Shore Tugboat Control Station whenever is agreed on.

The remote-control operator in the Shore Tugboat Control Station will be able to receive high-level commands from the Pilot on-board the mother vessel (at an informative level, since this information can also flow directly between the tugboats and the vessel, and will monitor the operation's progress (e.g., the position of the tugboats and the mother vessel). The Shore Tugboat Control Station will also be able to communicate with the Port Authority through the Port Community System (PCS). The Shore Tugboat Control Station operator will monitor continuously and in real-time the mooring process and the tugboats operation, aiming at assuring the situational and safety awareness of the procedure.

The autonomous tugboat swarm will operate in the following modes in terms of autonomy level:

- Manual navigation by the tugboat captain(s) with decision support by the remote operator in the STCS (**Decision support function**).
- Autonomous swarm operation with remote control capability by the remote operator in the STCS and manual override capability from the tugboat Captain(s), which can be conducted at any time (**Self-controlled function, human-on-the-loop**). However, the main role of the STCS operator is to monitor that the manoeuvring is conducted under the pre-established safety parameters.

The switching modes from autonomous to manual operational in case of failure/emergency was described in D2.4 and D4.1 and is summarised in Table 1.

Table 1 Description of operational states for the MOSES autonomous tugboat swarm

State	Description
Fail-safe / Emergency mode	The swarm operation will halt, and appropriate actions will be identified by the tugboat Captains with the support of the remote operator in the STCS (e.g., manual control or remote-control).
Hot-swap mode	Any member of the autonomous tugboat swarm can be replaced during the operation (e.g., if it is malfunctioning, or low on power) without stopping the operation. The operation will halt, and the specific tugboat will depart from the vicinity of the mother vessel manually navigated by the captain. A replacement tugboat will then also manually approach the mother vessel and assume the role of the departed tugboat. The swarm operation will then resume.
Remote-control	The remote operator in the STCS halts the swarm operation and takes over control. The STCS can control each member of the autonomous tugboat swarm remotely.
Operation completed	The mother vessel is safely docked with the MOSES automated docking system (developed in T5.1) and the tugboat swarm is ready to disengage to complete the operation.

For transitioning to the autonomous swarm operation mode, the tugboat captains check the systems and connection status and the STCS operator switches to the autonomous mode. Upon engaging the autonomous navigation mode, a message is displayed, and AI-optimised path planning and collision avoidance functionalities are engaged. If an off-nominal situation occurs, such as loss of communication to the STCS or loss of power, then the system automatically transitions to the Fail-safe / Emergency state. In case the system does not respond in time, and after evaluating the situation, the STCS operator can also manually switch the operational mode. Then, the swarm operation is halted, and the appropriate actions are identified. Once the failure has been addressed, the swarm operation is resumed. If there is a replacement autonomous tugboat available, the system can transition to the Hot-swap state, one of the swarm members is replaced by the tugboat Captain manually navigating to and from the swarm position. If there is no replacement tugboat available, then the system can either enter the states of manual navigation or remote-control and further mitigation actions can be taken.

After the autonomous tugboat swarm has achieved the pre-defined berthing position for the mother vessel, the swarm sends a mission achievement signal to the STCS. Subsequently, the STCS confirms that the mission has been achieved after receiving a confirmatory signal from the MOSES automated mooring system (developed in T5.1). The system transitions to the operation completed state where the swarm is ready to disengage and return to base. At this point, the STCS switches the autonomy level from autonomous swarm operation to manual navigation, where the tugboat Captains navigate the tugboats (independently from one another) to their base.

In this context, the requirements and specifications that were described in D2.4 for the Shore Tugboat Control Station are as described in Table 2 and Figure 3:

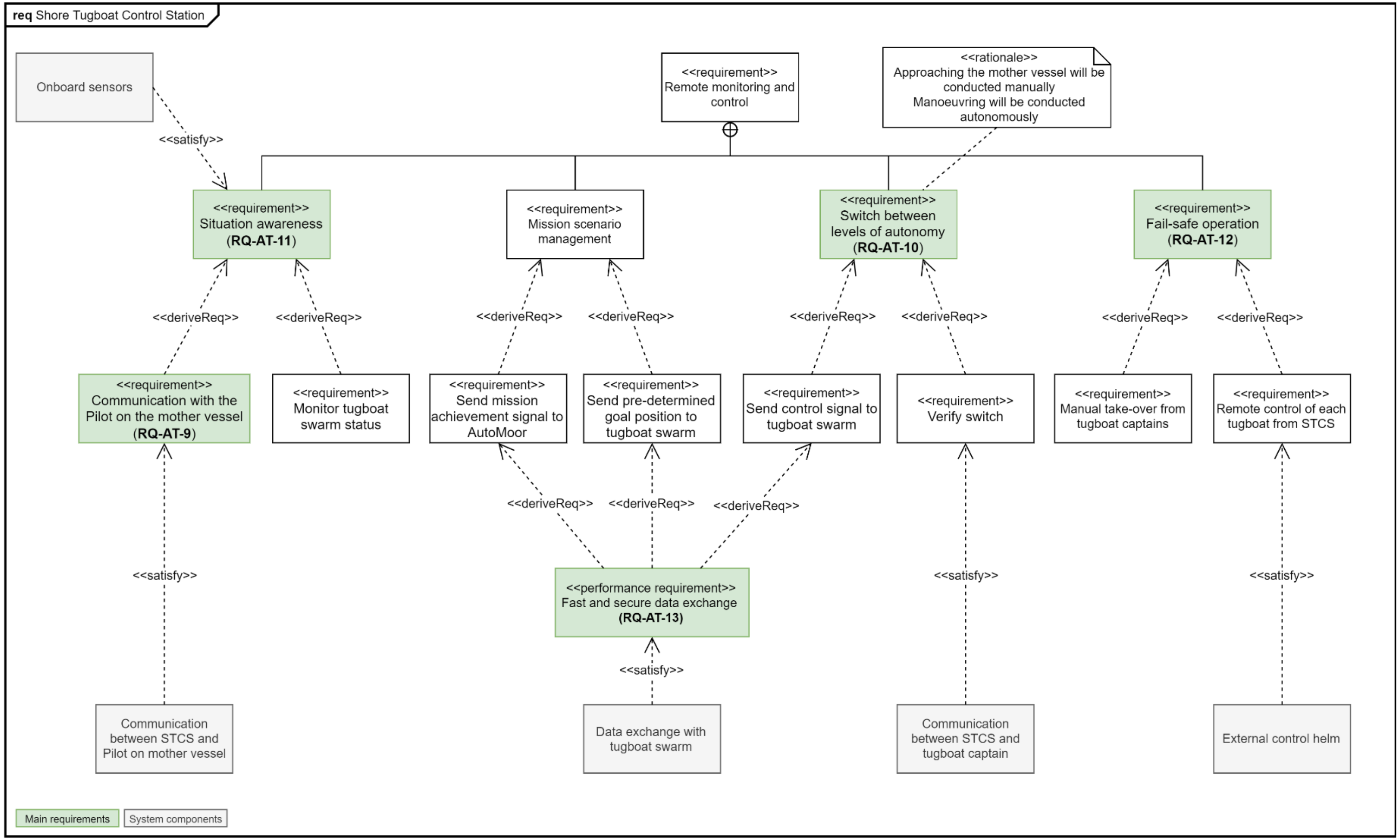

Figure 3 Requirements and specification for the STCS, as described in D2.4

Source: NTUA

Table 2 Functional requirements and specifications related to the interaction with the Shore Tugboat Control Station (STCS)

Requirement Description (Requirement ID)	Specification
Mission achievement (RQ-AT-7)	1. STCS wirelessly provides the Auto Pilot of the tugs with a predetermined target position of the mother ship at the start of the operation. 2. Wireless communication with the swarm.
Navigation memory (RQ-AT-8)	Implementation of a navigation memory module that will consist of storage (on-board the tugboats or at the STCS) where real-time operational data will be recorded from the on-board sensors.
Interaction with the Pilot on the mother vessel (RQ-AT-9)	Compatibility of STCS communication means with currently employed technologies (e.g., VHF) in order to support verbal communication between the Pilot and the STCS operator.
Switching between levels of autonomy (RQ-AT-10)	Based on the required navigation mode (autonomous/ manual), STCS to send a control signal to the tugboats Auto Pilot to engage and disengage the autonomous swarm. The operator should verify the switching operation with the tugboat Captains.
Operation monitoring (situational awareness) (RQ-AT-11)	Data exchange interfaces for getting real-time input from the sensors on-board the autonomous tugboats.
Fail-safe Operation (RQ-AT-12)	In case the autonomous operation fails: 1. Ability of the STCS to disengage the autonomous control. 2. Decision-making from the STCS between 2 options (remote-control/ manual operation) depending on (i) the type of failure and (ii) whether the tugboat-shore communication is intact. 3. Possibility for remote-control of the swarm from the STCS. Implementation through an appropriate control infrastructure that enables bypassing the Auto Pilot and sending control commands directly to the actuators on-board the tugboats. Remote control should be enabled for each tugboat and the swarm. 4. Possibility that the STCS assigns manual control to each tugboat of the swarm.
Fast and secure data exchange (RQ-AT-13)	The data exchange between the tugboats and the STCS must be done in a secure way, encrypted using the HTTPS protocol, and with minimal delay, since this delay must be less than 500 ms.
Battery monitoring (RQ-AT-14)	STCS to receive information (battery charge status and health considering power requirements for completing at least one operation) through its API from the battery monitoring software module, and to take appropriate actions to be taken in case inadequate power is identified to any of the tugboats.

The requirements and specifications create a frame for defining missing elements that will enable already deployed remote-controlled tugboats to be converted to agents that can automate specific tasks, like for example tugging a mother vessel. This frame includes the integration and cooperation of hardware, sensors, actuators, communication modules, software, and swarm AI algorithms that will define the MOSES architecture for the tugboats.

Table 3 Functional requirements and specifications related to the interaction with the Shore Tug Control Station (STCS) and the AutoMoor system

Requirement Description (Requirement ID)	Specification
Warning system (RQ-AD-6)	The automated mooring system should send a warning signal to the autonomous tugboats in case operating parameters are violated. Environmental parameters (wind speed, temperature) will be compared to pre-set values.

In addition, the definition of the Shore Tugboat Control Station will comply with the following requirements, which are related to the safe operation of the entire Autodock system.

Table 4 Key Performance Indicators for the development of the Shore Tug Control Station (STCS)

Requirement Description (Requirement ID)	Specification
Safe and efficient (un)docking operation (PI-FV-7)	The assessment of the manual or autonomous vessel's (un)docking performance (e.g., time to berth and risk-based safety assessment in case of harsh weather conditions).
Wireless communication coverage (PI-AT-9)	Ensure constant communication with the autonomous tugboats and AutoMoor within their operational area. KPI: 100% area coverage
Impact of switching between levels of autonomy on operation (PI-AT-10)	Changing between the levels of autonomy will not result in under-performance or no operation for the system. KPI: the delay caused in the operation while switching between operational modes.
Fail-safe strategy effectiveness (PI-AT-11)	Testing a range of different failure scenarios and corresponding selected strategies. KPIs: achieved level of risk, accuracy of controlling the autonomous tugboat swarm via remote control, and the time required for bypassing the Auto Pilot (related to the latency and integrity of data transmission).
Wireless communication latency (PI-AT-12)	A wireless communication module for tugboat-to-tugboat communication to ensure real-time exchange of data and commands during the operations. Indicatively required: <500 ms latency packet error rate = 0%, data rate > 125 kbps, delay jitter < 150 ms
Warning system (PI-AD-6.1)	Warning sent 100 % of time vessel too far from the jetty

Requirement Description (Requirement ID)	Specification
Warning system (PI-AD-6.2)	Warning sent 100 % of the time If environmental parameters exceeded
Warning system (PI-AD-7.1)	Warning sent to the shore control 100% of time if mooring force parameters exceeded
Warning system (PI-AD-7.2)	Warning sent 100% of the time if fender-line displacement parameters exceeded

2.2.2 Requirement posed by the Classification Societies

In addition, **Classification Societies provide guidance to the technical arrangements in remote-control centres**, aimed to facilitate remote-control and supervision of vessel functions. The objective is to ensure that remote-control and supervision, in combination with automation systems, will provide a level of safety equivalent or better compared to the functions being conventionally controlled and supervised from on-board the vessel.

Although the roles and responsibilities of a STCS operator may not follow the conventional roles and responsibilities according to the STCW code, the Classification Societies advise that there should be two operators, one for the remote duty position of **a navigational watchkeeping officer** and one for **an engineering watchkeeping officer**.

Class guidelines highlight that the remote personnel will need sufficient situational awareness to provide a firm basis for analysing the situation, planning actions and executing remote-control of the function. In particular, the remote operation of the tugboat swarm will be based on real-time situational awareness for the remote operator. Real-time information will be provided by the data collected from sensors instead of observations by personnel on board.

The analysis of the STCS performance assesses **the contribution of human senses to situational awareness**. Substitutes for these contributing human senses should be provided by sensor technology, and the information presented to the STCS operator in a logical manner, ensuring that the total situation awareness for the remote operator is equivalent to or better than conventional local situation awareness.

Substitutes for human vision will range from a reading to continuous streaming of high-definition images with zoom possibilities covering a wide sector.

In addition to sight, other human senses such as balance and acceleration, smell and temperature, are contributing to the full situational awareness in the control of the tugboat swarm. It is essential that at all times the STCS operator should be informed about hazards and developing conditions to analyse the situation, plan appropriate control actions and intervene before a situation becomes critical. Sufficient pre-warnings and caution alerts should be provided for this purpose. Examples of relevant conditions, events and hazards are as follows:

- vessel movements, including dynamic and static conditions
- ambient conditions, such as reduced visibility (fog, sunset etc.), strong wind, rough sea state, strong currents, heavy precipitation
- fire
- high and low temperatures
- vibrations

Alarms should only be used when actions are required and should clearly indicate required actions. For this reason, the same alarm shall be prevented from appearing on the dashboard of both operators (navigation/engineering), so that it only appears on the dashboard of the role responsible for executing the required action.

All navigation related alerts should be managed in accordance with the Bridge Alert Management (BAM) concept of IMO as defined in MSC.302(87). BAM is a regulatory requirement for the management, handling and harmonized presentation of alerts on the bridge.

The BAM concept prioritises alerts and changes the way they are brought to the attention of the STCS operator. Alerts are categorised, identifying who is responsible for handling them. This facilitates decision-making and allows the operator to immediately identify problems and take appropriate action to maintain safe operations.

The STCS should be arranged with sufficient overview of the condition of all the functions under the responsibility of the STCS operator. This overview should be displayed at all times and presented in such a way that the STCS operator in a simple and unambiguous way will have a full understanding of the status of all the functions.

This may be presented in three levels for each function:

- green: the function or system is operational at full capacity, including any redundancy and health condition of supporting systems
- yellow: the function or system is operational, but not at 100%. It may have lost some capacity, functionality or redundancy. It should be possible for the operator to easily obtain detailed information about the current limitations
- red: the function or system is unable to fulfil its intended purpose.

Instructions on how to sequentially restore functions or how to operate the equipment / functions during extreme conditions should, to the furthest extent, be covered by decision support functionalities or automation.

Remote monitoring and control station are widely implemented on-board vessels for relevant machinery functions, such as:

- Alarm and monitoring.
- Power Management System / auxiliary generators control.
- Auxiliary machinery control.
- Continuous monitoring of load on the towing winch.
- Heating Ventilation and Air Conditioning (HVAC).

This deliverable focuses on those functions which are conventionally operated by humans, and which, as a consequence of the implementation of the MOSES Autodock system, give rise to the need for independent human supervision to ensure that the mother vessel manoeuvring and docking is performed safely.

Data related to key vessel functions should be electronically logged and stored. The following data should as a minimum be logged:

- operational status of key vessel functions including communication links
- alerts
- manual orders
- all data input and output to/from decision support and automation systems.

If records are stored on-board, an alert should be given in due time before storage capacity is exceeded.

2.3 Architecture schematic overview

This section presents the architecture that was designed in T4.4, based on the specifications and requirements described in the previous section. A mock-up will be developed for testing the specific functionalities of the STCS in WP7. In addition, this section describes the role of each component in the architecture and how they interact with one another.

For the purposes of this deliverable, we consider that the manoeuvring of a ship is composed of three phases: before arriving to port, the manoeuvring itself and the process of mooring the ship. In each of these phases it is necessary to define a communication protocol. As mentioned in the introduction, MOSES task 4.4 also addresses the lack of standard communication protocols. These concepts will be addressed in depth in Chapter 3.

The port call process is usually initiated before the arrival of the vessel. The Port Community System (PCS) is a technological platform for the management of applications and the provision of different port services in an intelligent, centralized, secure and paperless manner. Before the arrival of the vessel, the ship agent will communicate details about the ship particulars, manoeuvring conditions, type of cargo and Estimated Time of Arrival (ETA). The PCS communicates to the shipping agent the Reference Number assigned to the port call and the berthing place and the weather forecast. The information compiled by the PCS will be transferred to the STCS for planning the maneuvering.

One hour before the arrival at the port, the mother vessel will communicate to the PCS the ETA, which will be sent to the STCS. The STCS will communicate to the vessel and the nautical services the Pilot Boarding Place (PBP) and the Tug Reaching Place (TRP). The STCS will store information related to port traffic management, which will be processed by the STCS to calculate the trajectory to be followed by the mother vessel. The trajectory will be shared with the autonomous tugboat swarm and the VTS.

Once the manoeuvring process is initiated, the data gathered from the sensors on-board the tugboat swarm will be stored in the local database, as well as the output of the AI algorithm. All the stored data will be transmitted to the STCS via a wireless module. In addition, the information gathered will be used to generate alerts and alarms for the tugboat captains or the STCS. The Auto Pilot can also receive commands, via the wireless module, for example to abandon the operation, from the STCS if necessary.

For the effective operation of the proposed system the following communication channels need to be available: communication between the tugboats, communication of the swarm with the STCS, communication of the swarm with the MOSES AutoMoor system (through the STCS), communication of the STCS with the Pilot of the mother vessel, VTS and the PCS. The communication channel between the swarm members can be used to exchange data and warning/alarm messages between the active tugboats in case some of the equipment/sensors are absent in any of the tugboats.

Figure 4 shows how the architecture for the STCS satisfies the requirements described in the previous section by allocating them to specific system components and architecture modules.

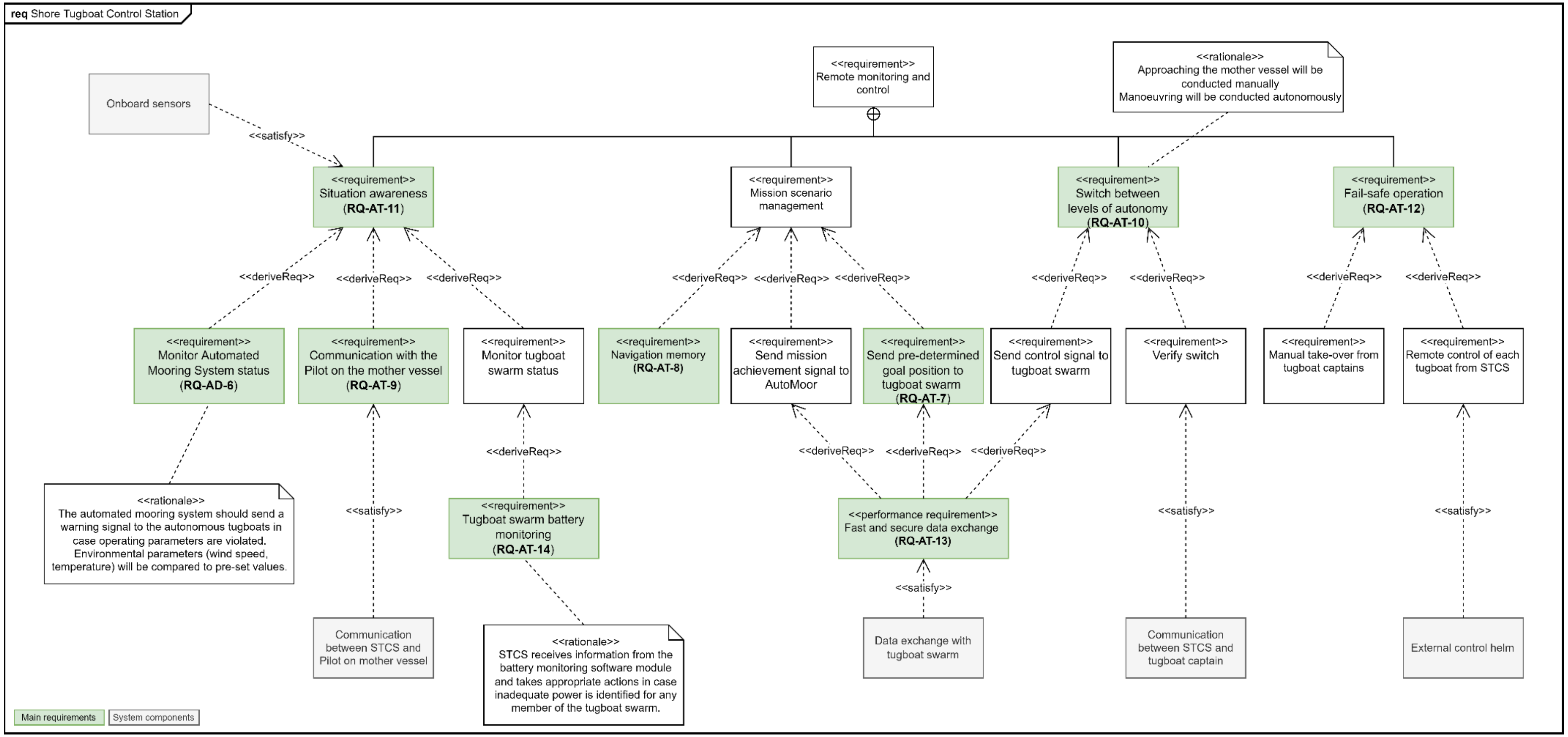

Figure 4 Allocation of functional requirements to system components and architecture modules (STCS)

According to deliverable D2.4, Table 5 shows the STCS capabilities will be tested.

Table 5 Test cases related to the communication between the Tug swarm, AutoMoor and the STCS

Test Case (Test ID)	Requirement ID	Specification
TC-AT-5 Autonomous tugboat swarm operation	RQ-AT-7, RQ-AT-10, RQ-AT-11, RQ-AT-13	The ability of the autonomous swarm to communicate with the Shore Tugboat Control Station to achieve the operation and the ability of the control interface to switch between manual and autonomous navigation will be tested.
		Successful manoeuvring and positioning of the mother vessel for mooring. Switching between different operational modes without causing delays in the operation.
TC-AT-7 Autonomous tugboat swarm fail-safe operation – multiple tugboats failure	RQ-AT-6, RQ-AT-11, RQ-AT-12, RQ-AT-13	The test will consist of two phases. In the first one, the tugboat will lose communication with the Shore Tug Control Station; its' ability to safely return to a pre-defined place after exceeding a pre-defined time threshold will be tested. In the next phase, the autonomous operation will fail and the ability of the tugboat to be 1) remotely controlled by the Shore Tugboat Control Station 2) manually controlled by the tugboat Captain will be tested. The ability of the control interface to switch between different modes will be tested.
		Selected fail-safe strategies do not endanger operational safety.
TC-AD-6.1 Communication between tugs, AutoMoor Unit and STCS	RQ-AD-6	Test communication protocols between tugs/Shore Tugboat Control Station and AutoMoor unit
		Test communication protocols between tugs/Shore Tugboat Control Station and AutoMoor unit
TC-AD-6.2 Communication between tugs, AutoMoor Unit and STCS	RQ-AD-6	Test communication protocols between tugs/Shore Tugboat Control Station AutoMoor unit and external source for weather information (e.g., Local Weather Station)
		Successful communication between tugs/Shore Tugboat Control Station, AutoMoor unit, and external source for weather information (e.g., Local Weather Station)

3. Main functionalities of the Shore Tugboat Control Station

3.1 Introduction

The main objective of this chapter is to develop a collaborative platform for data exchange related to port manoeuvring processes. The agents involved in these processes will be adequately informed and prepared to provide their services, by having access to high precision predictions and real-time information.

This chapter addresses the main characteristics of a central control platform, the Shore Tugboat Control Station, which will allow the monitoring of the entire manoeuvring procedure and will act as an interface between the STCS operator with the port, and the autonomous tugboat swarm, supporting real-time decision-making of all the manoeuvring agents.

The central control platform will be used to monitor the autonomous operation for docking of large ships (including towing and pushing) through a single user-friendly interface. The services operation procedures and the main STCS functionalities will be described in this section, while the interface components are addressed in section 5.

According to the Class requirements assessed in Section 2.2.2, two separated workstations will be installed in the STCS, one for the remote duty position of a navigation watchkeeping officer and another for an engineer watchkeeping officer. It is assumed that the engine monitoring workstation is the actual marine automation workstation, currently widely implemented on-board vessels for relevant machinery functions, such as alarm and monitoring, power management, auxiliary machinery control, etc. Consequently, this section will focus on the development of the navigation dashboard.

The content of this section is based on the specifications provided in D2.4. and the requirements posed by Class for remote-control centres. The issues addressed in previous deliverables, such as D4.1 and D4.2, will be omitted to avoid duplicities. Figure 5 below summarises the communication flow between the STCS, Autodock and other elements involved in the autonomous manoeuvring of the vessel.

3.2 High Level control

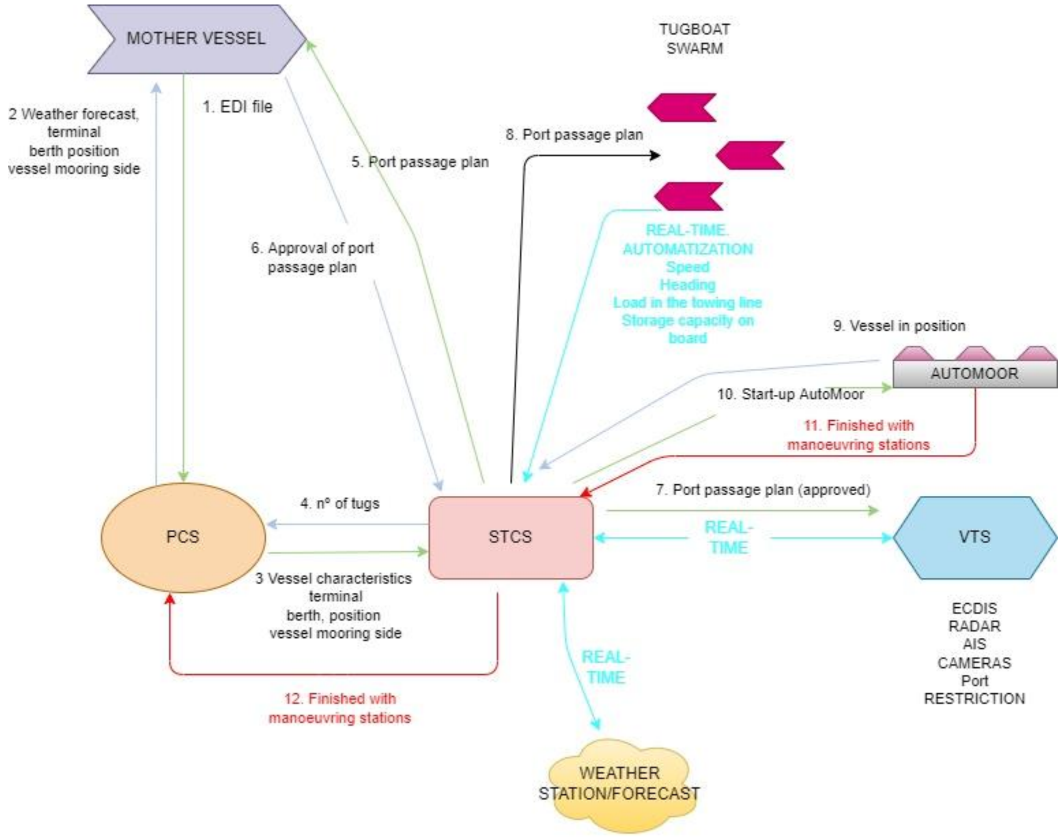

Figure 5 Communications flow between the STCS and other platforms/Autodock

The proper functioning of the STCS requires that communications between the control station, the autonomous tugboat swarm, each individual tug and the AutoMoor system are bilateral and in real-time. In this framework, it is crucial to ensure the inviolability of the transmitted information, whether due to a cyber-attack or a communication break.

The STCS operator needs to have the manoeuvring process under control. If the mother vessel is out of control, there is the danger that she collides with another vessel or against the quay. Since the communication will be wireless, an indicator of the quality of the wireless connection will provide information to the STCS operator about the real-time status of the communications. Depending on the traffic congestion or other constraints, each port will define the achieved level of risk, accuracy of controlling the autonomous tugboat swarm via remote-control or the time required for by-passing the Auto Pilot. These parameters will be configurable by the user.

In case the quality of the wireless network is below the pre-defined parameters, the STCS operator will switch the manoeuvring operation from autonomous to manual. The Captains on-board the tugboats must send a confirmation that they take manual control of the process.

In case of communication loss or any emergency, communications between the STCS operator, tug masters, Port Control and the Port Emergency Centre will be maintained via VHF.

The switching between manual and autonomous operation from the STCS will be conducted by pushing a button in the dashboard to switch from manual to autonomous mode of the whole tugboat swarm. The change of operating mode of a single tugboat will be performed by clicking the Right Mouse Button (RMB) and selecting the operating mode from a drop-down menu on the dashboard. The color of the tugboat will indicate whether it is in autonomous or manual mode.

Each port will define safety protocols in case of communication failure or emergency, which will be part of the self-protection plan of the port. **In any case, the STCS operator will be responsible for taking the appropriate decisions so that the risks during manoeuvres are under control.**

3.2.1 Dashboard

This section describes the functional navigational dashboard, while the engineering dashboard is a duplication of the engine automatization as per requirement of the Classification Societies. Before starting the manoeuvring operation, the STCS algorithms will calculate the port passage plan considering the characteristics of the mother vessel, the traffic congestion, port navigation constraints, the berth, and which side the ship will be berthed.

The port passage plan will be shared with the mother vessel Captain and the Pilot. As it is necessary to get the approval of both the Pilot and the mother vessel Captain, the port passage plan will be shared via the VTS (Vessel Traffic Service) and the manoeuvring will start.

The STCS operator will send the order to the tugboat swarm to start the mission. The tugs will meet the mother vessel at the waypoint Tug Reaching Place (TRP), starting the docking process. All this information is included in the port passage plan.

The STCS dashboard shows real-time information about the status of the manoeuvring. The STCS operator will plot the estimated route to be followed by the mother vessel, as well as the safe corridor. The operator will monitor whether the mother vessel is sailing inside the safe corridor, and whether there are any risks of collision with another vessel or the berth. The operator will also visualize in the dashboard the speed and heading of each tugboat and the mother vessel.

At any time, information related to the wind speed and direction, port agitation, tidal levels, visibility, etc., will be available.

In case any safe limit is exceeded during the manoeuvring, the action to be taken will be at the STCS operator discretion.

The information related to the engine parameters or the battery capacity status of the tugboats can be displayed on one screen, while the information related to each tugboat can be displayed on separated screens or by using dropdowns.

The operator must visualize in real-time the images from the cameras installed on-board the tugboats and from the fixed cameras installed in the berthing area. All the images received from the cameras can be displayed in one screen, as a mosaic, or a selection of images can be provided based on what the operator wants to see. The dashboard can zoom into the manoeuvring area.

Particular attention will be paid to the approaching at the berth, at the point when the mother vessel is within the AutoMoor units' detection range. The dashboard will show real-time information of the mother vessel distance to the berth, the angle of approaching and vessel speed for avoiding any potential collision with the berth. Once the mother vessel is in the right position, the STCS will activate the AutoMoor units.

As described in section 5.3.6 in D5.1, the AutoMoor system will share real-time information related to the fault mode of the units. During the berthing, the dashboard will show real-time information about:

- Weather information: tide variation, wind speed and direction, port agitation
- AutoMoor units power failure
- Maintenance mode selected.
- Holding Force at Hull strength threshold
- Vessel Holding force too high
- Vacuum level too low

Logbook

The dashboard will show the following alarms, while the alarm level will be customised by each STCS operator:

- Quality of the wireless network
- Data storage capacity on board
- Weather parameters
    - Wind speed
    - Wind direction
    - Low visibility (due to fog or rainfall)
    - Temperature
    - Humidity
    - Tide
    - Port agitation
- Load at the towing line

- Deviation from the estimate port passage plan
    - Corridor beam
- Mother vessel and tug progress
    - Speed
    - Heading
    - Mother vessel speed approaching to the berth
    - Distance to the berth
- AutoMoor units' operation
    - AutoMoor units power failure
    - Maintenance mode selected
    - Holding Force at Hull strength threshold
    - Vessel Holding force too high
    - Vacuum level too low
- Engine / battery bank parameters
    - Permanent batteries monitoring
        - Temperature (ºC)
        - Deep of Discharge (DOD) (%)
        - C-Rate charge (hours)
        - C-Rate discharge (hours)

4. Ship berthing use case description

4.1 Introduction

This chapter describes how the existing communication protocols need to be updated in order to implement the MOSES innovations. As a consequence, the tools actually supporting the port call process, the vessels traffic management, etc., will adapt their functionalities for substituting the actual manual vessel manoeuvring by a fully autonomous one.

In addition, the functionality of the STCS is to monitor that the autonomous manoeuvring is conducted in a safe manner. This chapter defines the parameters that the AI will manage, providing a physical description of each parameter and a standard format. The information received from each of the above defined tools is processed by the AI algorithm, being the STCS operator responsible for intervening only if an anomaly occurs (breakdown of a tug, safety conditions suddenly altered, etc.)

One objective of MOSES is to increase the efficiency of operations in ports. The benefit is the maximized utilization of port facilities, constrained by safety considerations. Essential for reaching tangible effects within these areas is the ability for optimal performance of ports. Such optimized performance can be reached by having an ability to predict requested resources to be provided by different actors.

MOSES innovations are expected to significantly improve the efficiency of the port operations by reducing the time requested for manoeuvring the vessel, while increasing the safety of the operation. The MOSES innovations are not unaware of the current port operations and, therefore, must be compatible with the current port management models, trying to improve it while keeping the core of the port operation.

On the other hand, the MOSES project is being developed in a context of continuous change, in which other technologies and management models are gradually being consolidated as an option for the future.

This is the case of the Just-In-Time (JIT) port call processes. Widely recognized as a means of increasing port efficiency and port call optimization, the successful implementation of the JIT Arrivals can have a significant environmental impact through reduced GHG emissions from optimizing the ships speed to arrive just in time. The concept is based on the ship maintaining an optimal operating speed, to arrive at the Pilot Boarding Place when the availability is assured of: 1) berth; 2) fairway; and 3) nautical services (pilots, tugs, linesmen). The JIT Arrivals also contribute to reduced time at anchorage and therefore reduced congestion in the port area. It is estimated that ships spend up to 9% of their time waiting at anchorage, which could be reduced through the implementation of the JIT Arrivals.

Therefore, all communication processes and protocols developed under this deliverable will be aligned with the development and implementation of these processes and will comply with the guidelines issued in this regard by the International Maritime Organization (IMO).

4.2 Port call tools

As mentioned before, the Shore Tugboat Control Station is part of a wider process, the port call process, in which it must be seamlessly integrated. This means that the STCS must be integrated with the other tools that are part of the port call process.

This deliverable identifies these tools in a brief way, to later analyze what information exchange should be performed between them and with the nautical services. This is essential when defining a standard communications protocol, which is one of the main objectives of this deliverable.

4.2.1 Port community System (PCS)

In order to enable port calls with fast turn-arounds, continuous interactions between port actors as well as shipping companies/shipping operators are essential. As each port is a multi-organisational actor, this concerns interactions between different actors within the port, between the port as a whole and its surroundings, and between different ports. Figure 6 provides a description of the Valencia Port PCS as an example.

The MOSES Shore Tugboat Control Station will be integrated with the actual Port Authority Management System (PCS), and will be connected to this platform in real-time with any other ports actors, sharing information in real-time.

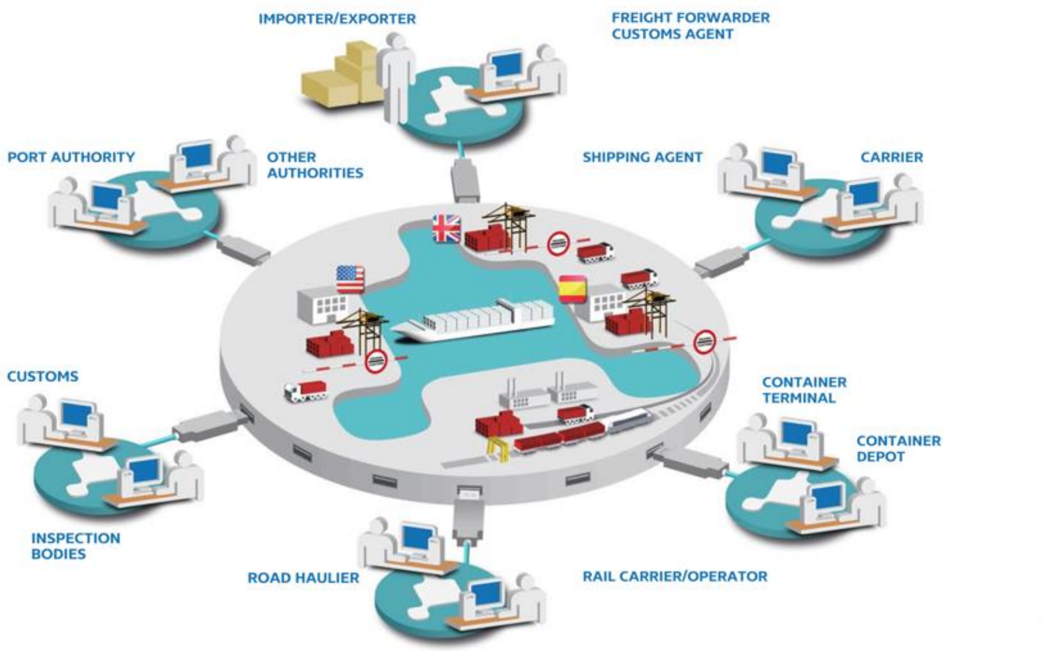

Figure 6 Valencia port PCS

Source: Valencia port

The port call management allows port call and mooring authorisation requests to be processed directly with the Port Authority and the Harbourmaster's office as well as for the corresponding authorisations for these requests to be received directly.

The PCS makes it possible to complete rapidly a request, transmitting it automatically in one go to the Port Authority and the Harbourmaster’s office prior to the entrance in port.

The Port Call Management service makes possible the transmission of the following information:

- Vessel notifications including technical details of vessels
- Berthing requests
- Passenger notifications
- Waste notifications

The Shipping Agent sends data to the Port Authority, including the port of arrival, name of vessel, the carrier, previous and following ports of call. Once accepted, the call information of passengers and crew, waste, and other relevant data is sent.

By sending the call request, the Customs ID automatically opens for the customs clearance of goods that must be loaded or unloaded from the vessel.

In turn, the PCS notifies all port actors, including the nautical services, about the arrival of the vessel, and transmits the vessel's information relevant to their activity.

4.2.2 Vessel Traffic Service (VTS)

The Vessel traffic services - VTS - are shore-side systems which range from the provision of simple information messages to ships, such as position of other traffic or meteorological hazard warnings, to extensive management of traffic within a port or waterway.

To understand the vessel traffic systems, it is important to look at VTS (Vessel Traffic Service). This is the service provided by the officer in charge of the vessel traffic within a given zone. Typical services are based on helping marines enter and pass through a zone of traffic such as a port or canal. These areas are defined as high risk and have a high probability of accidents occurrence. The service provided is therefore to identify the various risk points, as for example the distance between two vessels, speed, angle of entry, and then to assign levels of danger and a protocol of how a vessel officer must react in each circumstance. Identifying dangers in a timely manner is what vessel traffic systems are developed for.

Vessel traffic has always needed effective systems to ensure the safety of vessels and infrastructure, and today software is available to provide vessel traffic management with the tools they need. Whether it`s managing marine traffic or guarding your infrastructure, ship tracking through vessel traffic systems uses AIS, radar and video monitoring to all seamlessly integrate into one software to be controlled remotely.

IALA, The International Association of Marine Aids to Navigation and Lighthouse Authorities, is an international association established and governed by the French law of 1st July 1901 and the decree of 16th August 1901. The term `Marine Aid to Navigation` is a device, system or service, external to a vessel, designed and operated to enhance safe and efficient navigation of individual vessels and vessel traffic. The aim of IALA is to foster the safe, economic and efficient movement of vessels, through improvement and harmonization of Marine Aids to Navigation worldwide and other appropriate means, for the benefit of the maritime community and the protection of the environment.

Information systems now play a major part in allowing information to arrive on time, making it possible to see if there is an issue and then send the necessary information back to the recipient. In this way, all the information can be evaluated in real-time and put in place preventative actions that will rapidly diminish the risk of events from happening. Information in this case, such as position, heading and speed allow for a better understanding of potential risks. This information can be combined with the specificities of how the traffic passes through each unique zone to develop an advanced understanding of what constitutes a possible risk and with this in mind, a unique traffic organization system can be put in place. In reality, with a powerful information system, creating a traffic organization system instantly becomes more precise and better placed to prevent events from occurring.

Vessel traffic systems have evolved from being just radar and voice radio systems to becoming systems that can control multiple surveillance instruments from remote locations with multiple communication channels. Contacting vessels can be done through a variety of communication modes such as AIS and VHF. VTS systems integrate data sources and display this data on a marine chart. Radar, AIS/ARPA, camera, thermal sensors, meteorological data and VHF can all be displayed within the same system.

VTS surveillance systems make it possible to carry out AIS and ARPA tracking as well as images together with a communication system. Centralizing real-time data into a sole monitoring system is critical, processing the information collected by software to make the whole system efficient. Figure 7 illustrates an example of a typical VTS harbor installation.

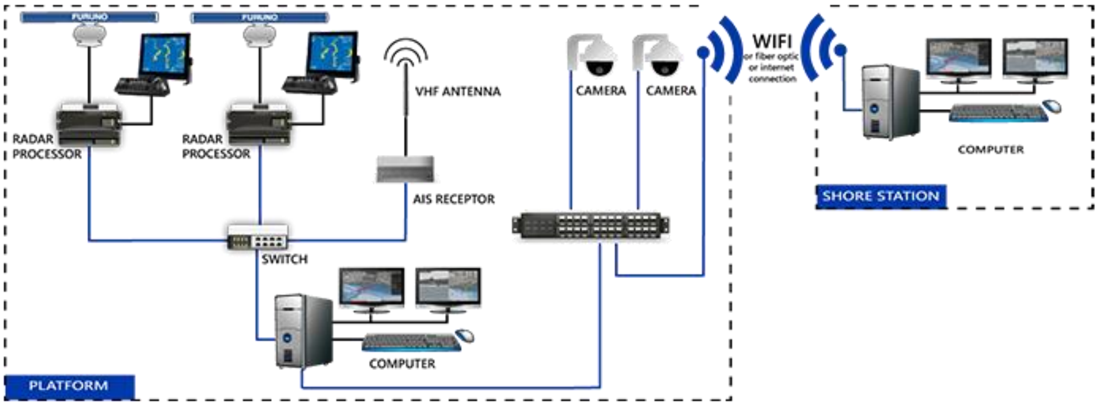

Figure 7 VTS port installation

The VTS installation provides an integrated operational traffic scenario in real-time that enables the improvement of navigation safety, the efficiency in traffic planning, the water environmental protection and the security of port infrastructures. The configuration can include data collected from a wide variety of sensors such as:

- Radars.
- CCTV (day/night).
- AIS.
- RDF.
- Radio Communications & voice integrator.
- GMDSS.
- Meteo/hydro stations.
- Other sensors per customer request

Ensuring the safety of life at sea, the safe passing of ships, the efficiency of traffic, the protection of the marine ecosystem as well as the surround marine infrastructure, requires an efficient processing of the collected data. Maritime surveillance software makes it possible to centralize and monitor real-time data including movement tracking for quick decision-making (see Figure 8). Coastal surveillance software offers the following main features:

- Provides relevant information for safe navigation, hydro /meteo information, or upcoming vessel routes in the VTS area.
- Supports the efficient flow of traffic in the VTS area. The information that is transmitted includes berth clearances, arrangements regarding lock times, speed limits, or other information valuable information to organise traffic.
- Supports the decision-making process about traffic management in the port waters, as it not only transmits information, but also closely monitors effects of decisions made. Assistance is provided through notices, traffic location, course and speed of a vessel, or warnings to a specific vessel.

Figure 8 VTS display

4.2.3 Meteo/oceanographic information tools

Weather stations

Each Port Authority has strategically distributed in the port land a network of weather stations. The information generated by these stations offers assistance for decision-making in different port operations, such as, for example, operations with containers, where these operations are stopped when the wind reaches a certain intensity. The information can be exported in csv format. Typically, the information available is:

- Wind speed and direction
- Precipitation
- Humidity
- Temperature
- Barometric pressure

Real-time and weather forecast tools

A limited number of ports have developed in-house forecast meteorological and oceanographic tools. However, it is expected that in the future these tools will be more extended.

A typical meteorological and oceanographic forecast provides each Port Authority with customized ocean-meteorological information adapted to their needs. The service consists of various modules (improved instrumentation and new forecasting systems), which are accompanied by value-added systems that allow better exploitation of the same. This system of modules is composed of:

- **Real-Time Alerts**. This module will allow the generation of real-time warnings based on the data provided by the measurement networks that transmit information in real-time.
- **High-resolution weather forecasting**. A prediction service of atmospheric parameters will be developed using very high-resolution models. This makes it possible to provide information with a level of resolution of less than 50 meters within the ports that will take into consideration the local effect of the topography and surrounding buildings of the port and port infrastructure. This module is accompanied by a pollutant dispersion modelling system, capable of mapping particles and gases.
- **Overflows**. Overtopping forecasting systems is developed for the most exposed breakwaters, introducing modern tracking cameras and new numerical models. These modules will also have an associated warning/alert system.
- **Operational forecasting by zones**. This module consists of an online operational risk prediction tool for the Port's terminals, in case of adverse weather conditions.
- **Long wave forecast**. This module incorporates two products: free surface maps and long wave current maps that will be used to spatially identify those areas in the inner harbours, channels and mouths, in case of resonant events. Information is provided at special points and is integrated into the warning system.
- **Measurement campaigns**. A series of measurement campaigns are carried out inside the ports, which will include measurement of currents, waves and local agitation, meteorology and measurement with CTD (Conductivity, Temperature and Depth) probes. This module allows validation of the operational wind, wave (agitation) and current systems.

4.3 Interchange of information between the STCS and other port call tools

The current port call process protocol was widely described in Section 2.1. The introduction of the STCS alters this process, which must be adapted to the introduction of the MOSES innovations. This section addresses the data exchange between the different platforms, defining the responsibilities for providing and processing this data. As mentioned already, both the data exchange protocol and formats, will be compatible with the guidelines issued for Just-In- Time Arrivals by IMO, IALA protocols, etc.

The scope of interface data for the deep-sea vessel is restricted to operations between the pilot boarding place and the fender line of the berth including anchorage areas. Prior to the pilot boarding place this data is normally the domain of the national hydrographic office, and beyond the fender line of the berth this data is normally the domain of the terminal.

The definition of the STCS has been performed following the chronological order of the entry of the ship into port, i.e.:

- Analysis of the communications between the STCS and Port Community System (PCS) of the port prior to the arrival of the ship.
- Communications between the STCS, the tugboat swarm and the traffic control service (VTS) during the manoeuvre.
- Communications between the STCS and the Autodock system (AutoMoor and autonomous tugboat swarm) when the vessel is in the final approaching phase to the berth.

In addition, the data interface will be aligned with the JIT Arrival fundamentals, which are described in Figure 9 and are based on:

- **ETA optimization**: focus on supervising the shipping company's planning, based on accurate monitoring of the positions of the ship in real-time, adjusting the planned ETA and comparing it with the real one.
- **Optimization of berth management**: providing the consignee and the shipping company with complete and updated information about the availability of berthing. Offering the terminal more visibility in real-time, regarding both ship-related information and the availability of port resources (pilotage, mooring, towing), as well as the status and evolution of the services provided to the ship.
- **Optimization of the port process and visit management**: providing greater visibility and coordination of operations during the stay of the vessel by sharing information via collaborative platforms with all the agents involved.

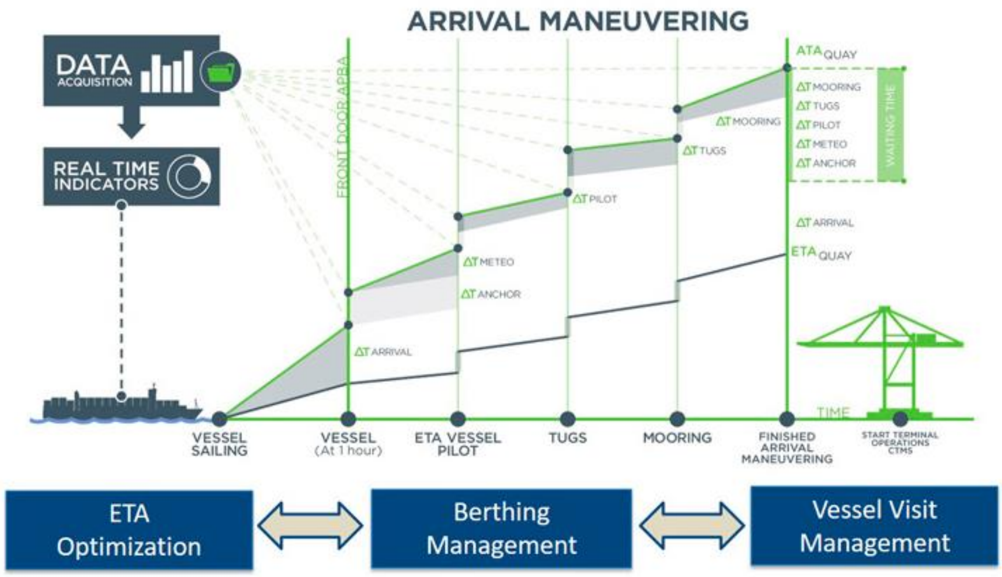

Figure 9 Port call process stages

Source: Port Authority of Algeciras Bay

Sharing data by the data owner is an important aspect of data quality. If the data owner does not share data, data updates can be delayed and might contain errors. However, this is not easy to organize. The ability of port authorities to organize data ownership and data sharing varies per port – this may be the most challenging part of improving data quality and availability. Figure 10 provides an example of the Port Call Process and the main agents involved on this.

The MOSES outcomes are oriented to increase the efficiency of coordination of the agents involved in the port call process by providing a real-time information exchange environment. In this manner, all the operational information associated to the port call process is shared in real-time and validated by the agents in charge of performing berthing operations. With this approach, predictability of berthing port operations increases as well as transparency among the agents involved. The next step of the process is the establishment of real-time information exchange between the port and the ship when arriving at port.

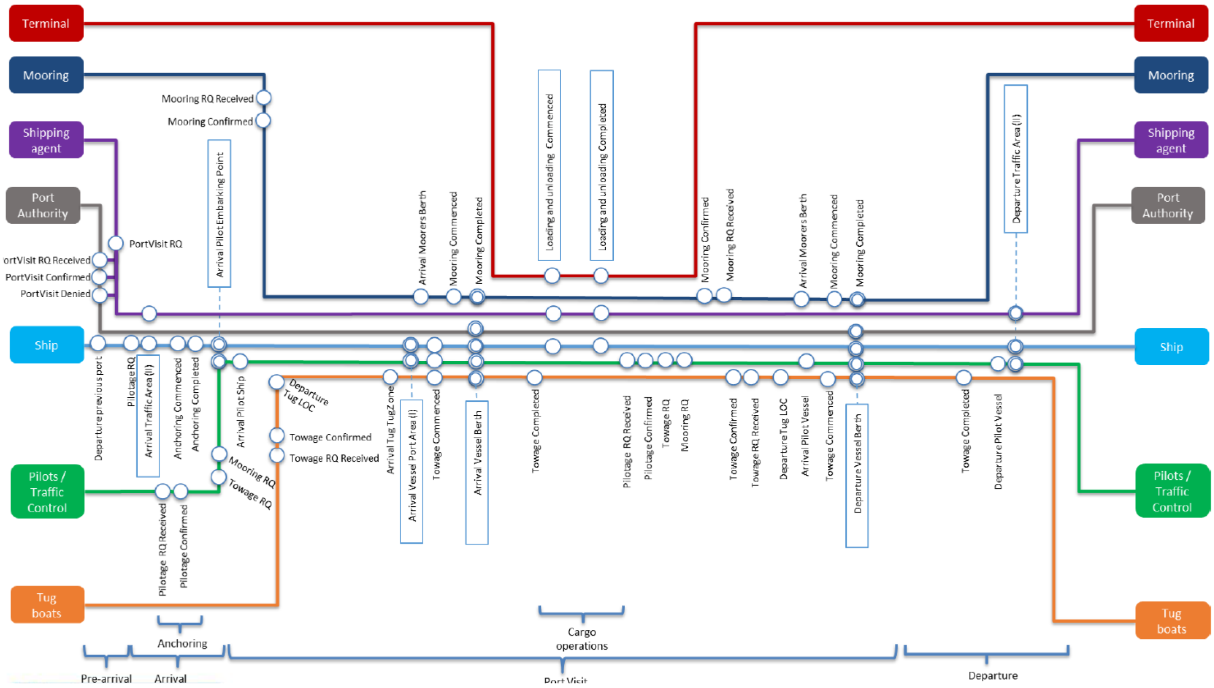

Figure 10 Example of Port Call Process and Relationships among Involved Agents

Particular benefits derived from the implementation of MOSES in ports are:

- Automatic Estimated Time of Arrival from ship to port throughout sea voyage.
- Real-time update from port to ship on Planned Time of Arrival.
- Better resource planning in ports.
- High-quality Estimated Time of Departure predictions by ports.

4.3.1 Communications between the STCS and Port Community System (PCS) of the port prior to the arrival of the ship

Port GIS

One of the most high-risk events for a vessel is departing from or arriving at a port. Furthermore, interaction with third parties such as harbor pilots, tugboats and Vessel Traffic Services (VTS) involves an additional challenge.

There are a number of sources of information related to local conditions and navigational hazards. The STCS will integrate a Geographic Information System (GIS) to centralize information on all the infrastructures that make up the port area.

- Infrastructures
- Facilities
- Bathymetries
- Beaconing
- Public Domain
- Position of AutoMoor units/fenders
- Etc.

The STCS must connect to different data sources allowing the centralization and crossing of data, thus obtaining results that previously required a great economic and temporal cost. As a basis for the development of the STCS, the port's GIS is used as a starting point. Figure 11, Figure 12 and Figure 13 describe the information available in the Valencia Port GIS

Figure 11 General overview of the port of Valencia

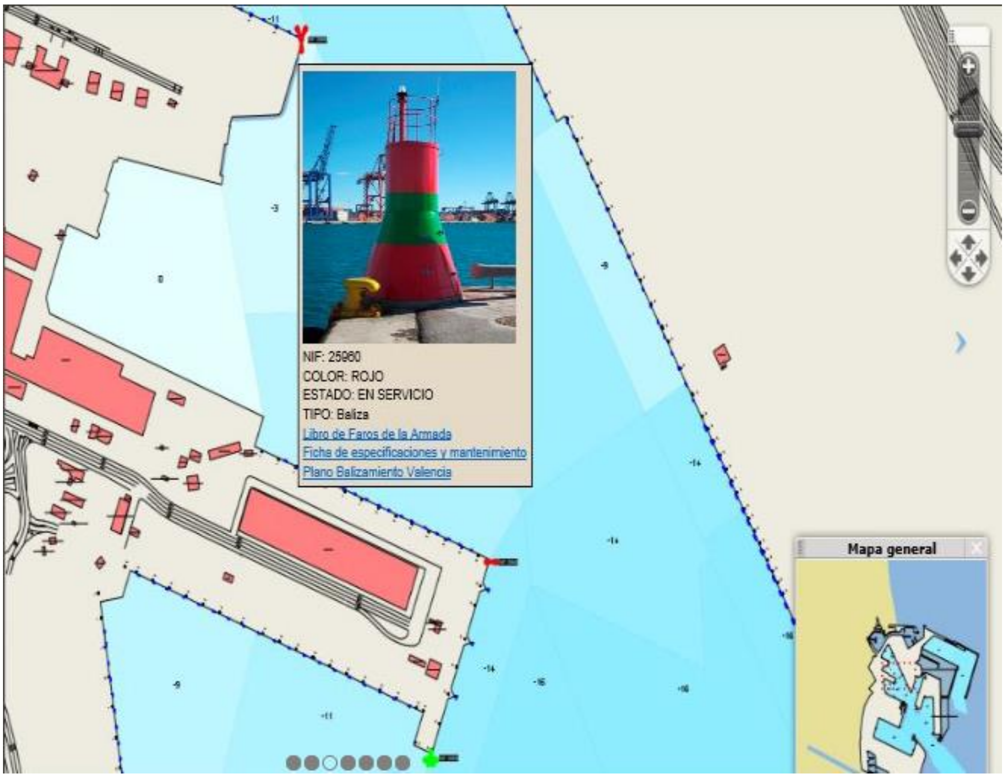

Figure 12 Beacon detail at the Port of Valencia GIS

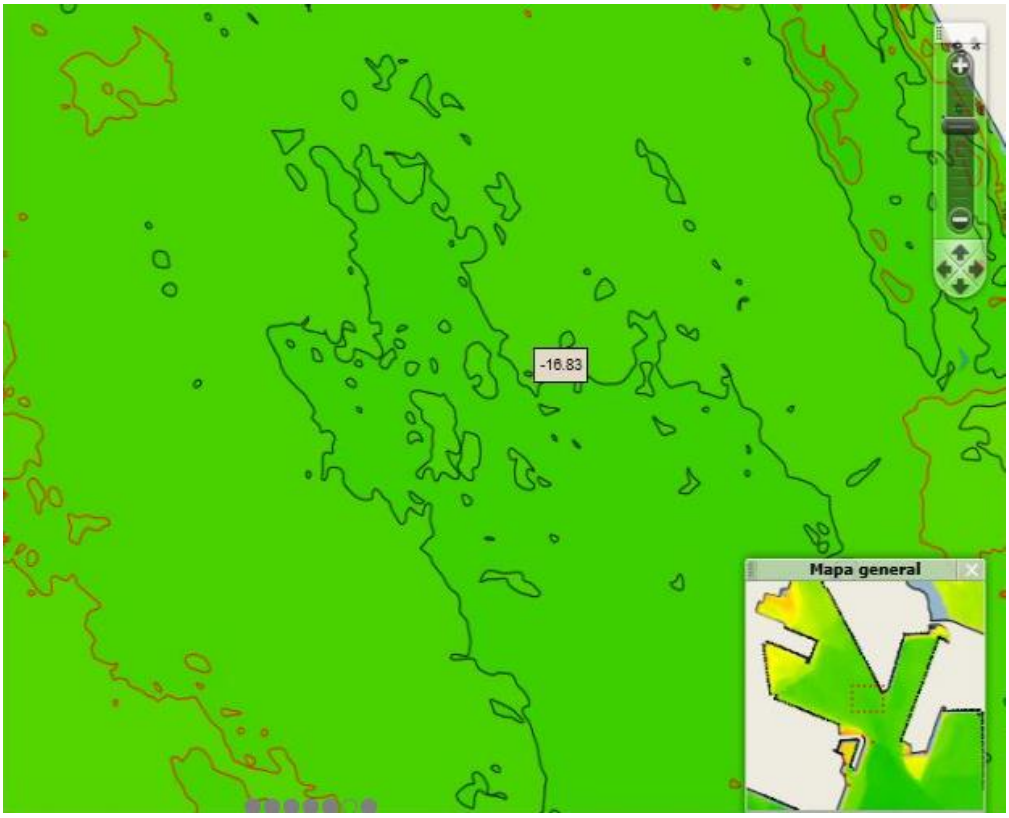

Figure 13 Bathymetry detail at the Port of Valencia GIS

Port Call Process Instance

Prior to the arrival of the ship, the STCS needs to have information from the ship/shipping agent in order to plan the berthing operation and conduct it safely. So far, the EDI file referred to in Section 2.1 contains information regarding the ship's characteristics. The MOSES autonomous manoeuvring process obliges the ship to share with the Port Authority, through the PCS, relevant information in order to define the whole berthing process.

The Port Call Process Instance (PCPI) is used as the backbone in the collaboration, capturing the main activities or events applicable for a specific port call. The Port Call Process Instance also reveals the actual dependencies amongst the activities or events identified. A configured Port Call Process Instance is created when the port call is initiated and is valid through the entire port call lifecycle. The Port Call Process Instance is also used to identify involved actors in a specific port call.

During the PCPI, the Port Authority will collect relevant information related to the specific equipment fitted to the vessel and its maneuvering characteristics. A safe manoeuvring can be only achieved through a comprehensive exchange of relevant information between the vessel and the STCS, so that both have a full and shared understanding of the intended operation, as well as the functions and duties of each actor involved.

The information exchange should include the following details:

- The vessel´s current deepest draught
- Trim
- Displacement
- Air draught (distance from waterline to highest point of the vessel)
- Overall length, including appendices
- Beam
- Freeboard

This information will dictate the route chosen to or from the berth and will ensure that planning and execution of all maneuvers makes suitable allowance for the dimensions of the vessel.

This information is critical in avoiding groundings and contact with harbour structures. For example, there has been a number of significant incidents where vessels not making way have been turned in basins using tugs without making allowance for the bulbous bow, resulting in contact being made with jetty.

It is important to know that the anchors are available and ready for use in the event of an emergency. Details of the vessel anchor equipment will be collected by the PCPI, particularly the length of the anchor cable available.

Characteristics of the vessel's manoeuvring, covering the whole manoeuvring process, at the current draught and trim, are critical to ensure the safe execution of the intended operation. This should include at least details on the following parameters:

- The number of propellers
- Whether or not they are CPP
- Their direction of rotation
- The type, characteristics and maximum allowable angle of the rudder(s)
- The turning circle and stopping distance in the current condition, shown on a readily accessible poster
- The number and capacity of fore and aft thrusters including details of the effective thruster speed
- The minimum steerage speed
- Main engine characteristics

This information will have a significant impact on how the vessel can be manoeuvred, and the number and size of tugboats required. Failure to fully advise the STCS of this information and incorporate it into a manoeuvring plan can have as a result that the vessel is unable to make an intended turn and subsequently runs aground, or makes contact with a berth or another vessel.

Information related to the type of engine(s) fitted, the maximum number of starts which can be made and the time taken to go from full ahead to full astern will allow the Pilot on-board, when the control from the STCS switches to manual, to plan the vessels manoeuvres effectively, whilst allowing suitable time for engine commands to take effect.

The ship's agent is usually in charge of requesting the port call process. Based on the experience of the Port Authority of Valencia, it is common for the ship's data to contain errors. To increase the reliability of the process, it is necessary that the vessel sends a file to the PCS, through the ship's agent, with her characteristics (propulsion and steering equipment etc.), the first time she calls a port or if the equipment has undergone any modification.

In addition, the STCS operator must be advised of any equipment defects related to the manoeuvrability and the navigation of the vessel. Depending on the nature of the defects and the individual port regulation, the vessel may not be permitted to proceed with the port call without repairs being completed or without having additional tugboats in attendance. In case that the STCS operator or the Pilot on-board detects any defect, both are required by law to report these defects to the local Port State Control officer through the PCS.

Berth and Tug Details

The PCS will provide the STCS and the vessel with details of the intended berth in order to confirm that the berth is suitable for the vessel and to confirm which side alongside the vessel will moor. The vessel will confirm that the vessel’s mooring plan is appropriate for the expected weather, taking into account the number and position of AutoMoor units, the position of other vessels in the vicinity of the intended berth and shore structures which pose a hazard to the safe movement of the vessel.

The STCS, instead of the tugboat Captains, will notify the vessel whether tugboat lines or ship lines will be used, the number, size (bollard pull) of the tugboats that will intervene in the manoeuvring, the estimated trajectory to be followed by the vessel, the position of the tugboats with respect to the vessel, and the exact location and time that they will meet the vessel. The trajectory will be also shared with the VTS for keeping the track of the mother vessel with respect to other port traffic interferences.

The pivot point, or the point around which the vessel will rotate, will move depending on whether or not the vessel is making way, moving ahead or moving astern, i.e. midships, approximately ¼ of the vessel's length from the forward perpendicular or approximately ¼ of the vessel's length from the aft perpendicular respectively.

The position of the pivot point should be considered for each stage of an intended manoeuvre when deciding on how the tugboats are to be utilized, as the tugboat's positioning relative to the pivot point will have a significant influence on the ability of the tugboat to turn the vessel. This is particularly noticeable when the required bollard pull is close to the maximum bollard pull that the tug can achieve.

The STCS API is notified of the Safe Working Load (SWL) of the ship bollards, bitts and leads, and the AI algorithm will ensure that these are not overloaded by the tugboat (s). As the tests to determine the bollard pull of a tug are static, it is important to remember that the towing force can significantly exceed the bollard pull figure in dynamic towing conditions.

Prior to the employment of the tugboats, the AI STCS algorithm will estimate the static bollard pull required given the current displacement of the vessel. The required bollard pull can be roughly calculated by the following formula[2]:

$$Bollard\ pull\ (t) = \frac{displacement\ (t) x\ 60}{100.000} + 40$$

On container ships, where there is a significant windage area, then the required bollard pull can be calculated by the following formula which is suitable for winds on the beam up to 30^{o} either side:

Total required bollard pull (Kgf) = 0.08 x A x V^2

Where:

A = the ship's longitudinal windage area in m^2,

V= wind speed in m/s

[2] The North of England P&I Association (NEPIA). 2015. Pilotage series- Master Pilot Information Exchange. NEPIA. Newcastle.

Expected weather and sea conditions

Manoeuvrability at low forward speed in strong wind and, perhaps, current, is critical for ships with large windage area, such as container ships, during approaching to and entering ports. Therefore low-speed manoeuvrability criteria require specification of the wind speed and, perhaps, current (Papanikolaou et al., 2015).

The STCS will receive real-time weather information from the weather station located at the port. With the STCS being fully informed of the expected conditions, the STCS operator will be in a position to properly monitor the progress of the vessel along the planned route and will be less likely to be caught out by unexpected changes in wind and/or current.

By assessing and understanding the conditions expected at each stage of the voyage, this information can be factored into the port passage plan (trajectory).

For tug operations, relevant for low-speed maneuverability criteria, IMO recommendations could be adopted as environmental limits for towing operations: **significant wave height up to 5 m, wind speed up to 39 knots and current up to 2 knots.**

Port passage plan

SOLAS Chapter V Regulation 34 requires the voyage to be planned in accordance with IMO guidelines: *the master shall ensure that the intended voyage has been planned using the appropriate nautical charts and nautical publications for the area concerned, taking into account the guidelines and recommendations developed by the Organization*: referring to A.893(21). Such planning results in a so- called “voyage plan”, a document describing the passage from berth to berth.

A **port passage plan (trajectory)** describes a part of the voyage plan: it is a detailed description of the passage from the berth position (or anchor berth) to the pilot boarding place at the departure port or from the pilot boarding place to the berth position (or anchor berth) at the arrival port. It consists of a route plan, manoeuvring plan, and berthing plan. Figure 14 provides a visual description of the key elements taking part in the port passage plan.

Once the STCS operator, the Pilot and the mother vessel have a thorough understanding of the proposed plan, then the vessel progress can be effectively monitored, and any error made by either party can be quickly identified and remedied.

The AI of the STCS will estimate the port passage route (trajectory) taking into account the information collected by the PCS about vessel particulars and manoeuvring characteristics, the traffic situation from the VTS devices (ECDIS, radar, ais, cameras, etc), port restriction informed by Emergency Control Center (ECC) and the weather parameters provided by the weather stations.

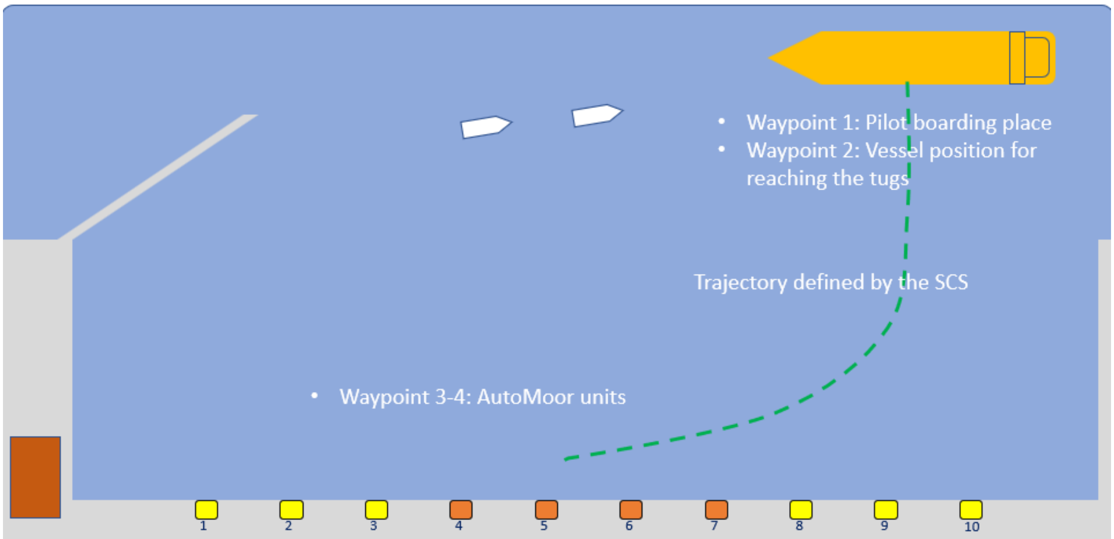

Figure 14 Port passage plan defined by the STCS

Contingency planning should be part of the port passage plan. This includes information such as the identification of abort points, emergency anchorages or no-go areas.

The mother vessel will not be allowed to enter the port until a shared port passage plan has been agreed and understood by the Pilot and the mother vessel. Notwithstanding the ultimate responsibility of the Master for berth-to-berth voyage plan, sharing and agreeing on a detailed port passage plan is a shared responsibility of the STCS operator, the mother vessel and the Pilot. The port passage plan will be also shared with the VTS for effectively monitoring the whole port traffic.

4.3.2 Communications between the STCS, the tug swarm and the traffic control devices during the manoeuvre

Once the autonomous tugboat swarm is in the Tug Reaching Place (TRP), the STCS Operator initiates the transition to the autonomous operation, and the towing of the mother vessel begins. The STCS operator monitors the autonomous tugboats swarm while manoeuvring. The monitoring process is supported by tools and protocols as described below and displayed in the STCS dashboard.

Nautical charts (Electronic Navigational Charts, ENC's) and publications (Sailing Directions, SD's) are both used to navigate the vessel. ENC's are used in the Electronic Chart Display Information System (ECDIS), which is one of the primary navigational tools to navigate a vessel. SD's provide additional information related to chart information (printed and digital) in a particular area. Both are building an information entity and must be carried by every SOLAS vessel. The chart information of the STCS has the same source and the same time stamp as of the mother vessel. This information is the foundation of a passage plan for safe berth-to-berth navigation, this information is important for safety. As accidents can also result in a breach of hull integrity, safe berth-to-berth navigation is also important for protection of the environment.

The exchange of information on the port passage plan between the STCS, the Pilot and the mother vessel happens before the mother vessel reach the PBP. It is essential that the mother vessel, the Pilot and the STCS align their port passage plans on ECDIS, as well as on the Portable Pilot Units where available.

Consequently, a detailed passage plan, that allows timely and unambiguous interventions when deviations occur, should be shared between the STCS, the mother vessel and the Pilot when the port entrance starts.

The STCS operator will monitor the trajectory followed by the mother vessel on the ECDIS system installed in the STCS. To check that the trajectory followed by the ship is within the safety parameters, the trajectory followed by the ship shall be calculated by means of triangulation to fixed points (waypoints). In addition, the information provided by VTS is essential for monitoring the progress of the vessel, as well as the relative position of the vessel length (heading) and the mother vessel speed. Figure 15 provides the global picture of this concept.

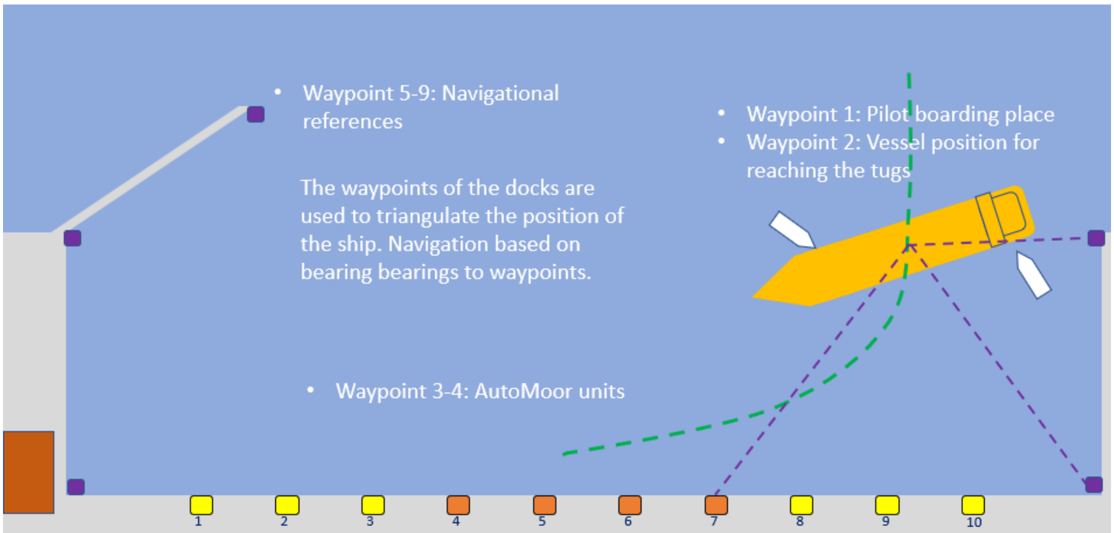

Figure 15 Real-time calculation of the route followed by the mother vessel

Data definitions

Data definitions for port passage plans, currently existing in IMO, IHO or ECDIS systems have been brought together but need to be formalized. A data model to exchange port passage plans is in development at IEC (IEC 63173-1 ED1, maritime navigation and radiocommunication equipment and systems - data Interface - Part 1: S-221 route plan exchange based on S-100).

The port passage plan is section of the Voyage Plan from the Berth Position (or Anchor Berth) to the Pilot Boarding Place at the departure port or from the Pilot Boarding Place to the Berth Position (or Anchor Berth) at the arrival port. It consists out of a route plan, manoeuvring plan, and berthing plan.

The route plan consists of a track, waypoints, legs, corridors, no go areas, safety contour, safe speed, speed limit, safety margin and commit point.

The manoeuvring plan is the plan for the dynamic positioning phase of the voyage, i.e. for the final approach to the berth or anchor berth.

The berthing plan is the intended static positioning of the vessel once at berth position or anchor berth. Figure 16 clarifies the above-mentioned concepts.

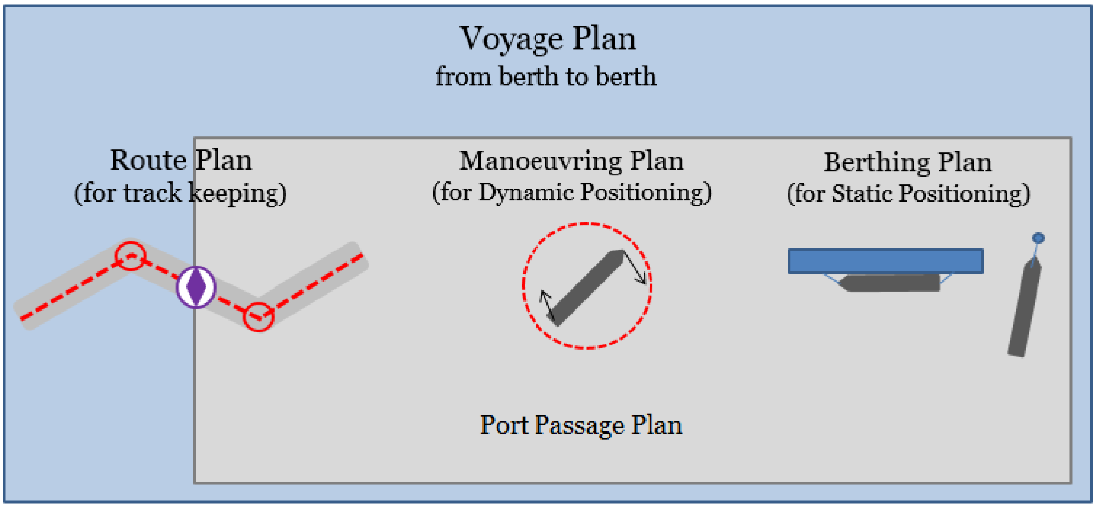

Figure 16 Voyage, port passage, route, manoeuvring and berth plan

Track is the path followed, or to be followed, between one position and another. This path may be the ground track, over the ground, or the water track, through the water. Used in the sense of ground track in the term recommended track

Waypoint is a geographical position which, together with berth points and pilot points, define the legs that comprise a passage. There may be a turn radius associated with the way point, especially in confined waters. Format: In decimal degrees to a defined precision, (minus to indicate South and West). Datum WGS 84. Example: 51.887190, 4.284030.

Leg is the basic component of a passage. Each leg is terminated by two points which may be waypoints, berth points or pilot points.

Corridor is the area on each side of the track that represents the planned navigable area for a specific vessel. A corridor is associated to a leg and it is defined by its starboard width and port width (in meters) from the track. Figure 17 clarifies these concepts.

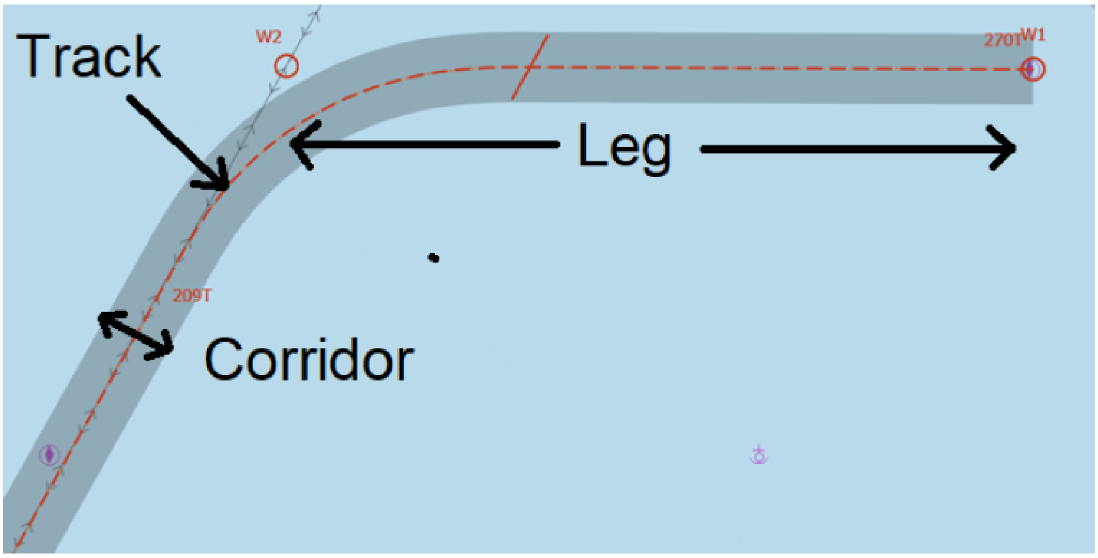

Figure 17 Track, leg and corridor

No go area is a Non-navigable geographical area (polygons) defined by a safety contour or by fixed man-made structures (breakwaters, berths).

Safety contour is the bathymetric line (in meters with 1 decimal) referred to the chart datum and defined by e.g. the vessel maximum draught plus the expected reduction of Under Keel Clearance (UKC) due to the motion in the water.

Safe speed is an interval of expected speeds over ground per individual leg (minimum and maximum decimal knots).

Speed limit is any speed restriction (in decimal knots) associated to any leg, either due to regulations or safety of navigation.

Safety margin is the additional area between the edges of the corridors and the no go areas available as reserve in case of unplanned circumstances. The safety margin can also be the reserve speed over ground between the speed limit and the maximum planned speed. Figure 18 is an example of these concepts.

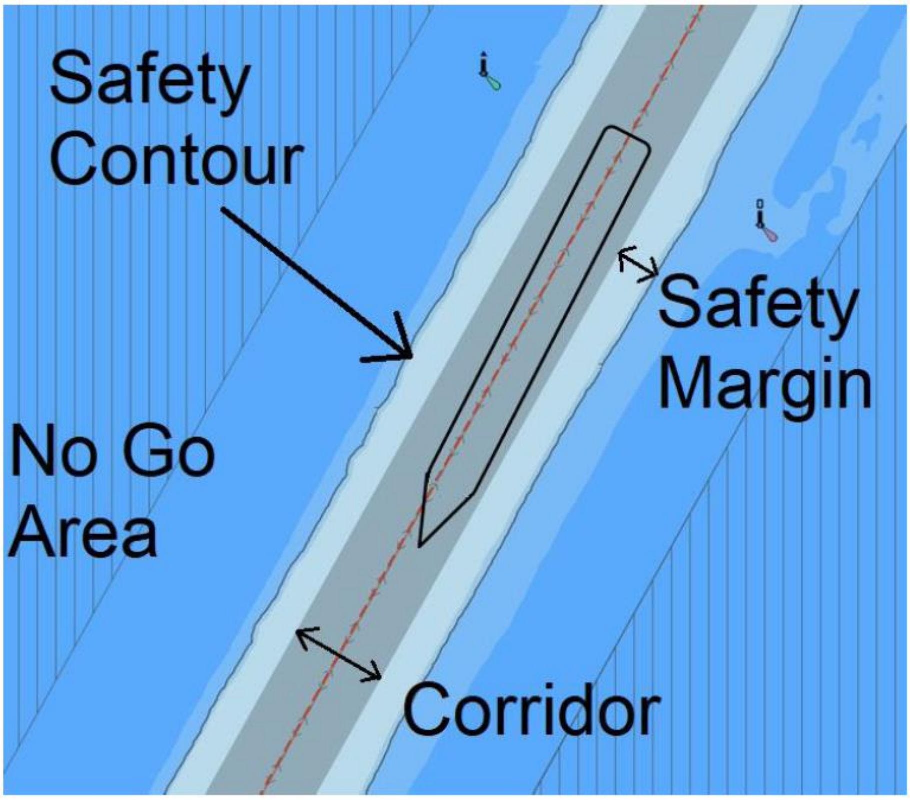

Figure 18 Safety contour and margin, corridor, no-go area

Commitment point is the geographic point of no return located on the track, beyond which the vessel is committed to enter a fairway (either inbound or outbound) or committed to a course of action.

4.3.3 Communications between the STCS and the Autodock system when the vessel is in the final approaching to the berth

Berth planning for an arriving ship is normally organized by the terminal operating the specific berth: it tells which ship will be moored at which berthing position, which side alongside and at what time. This information has been provided to the STCS through the PCS and sent to the tug swarm.

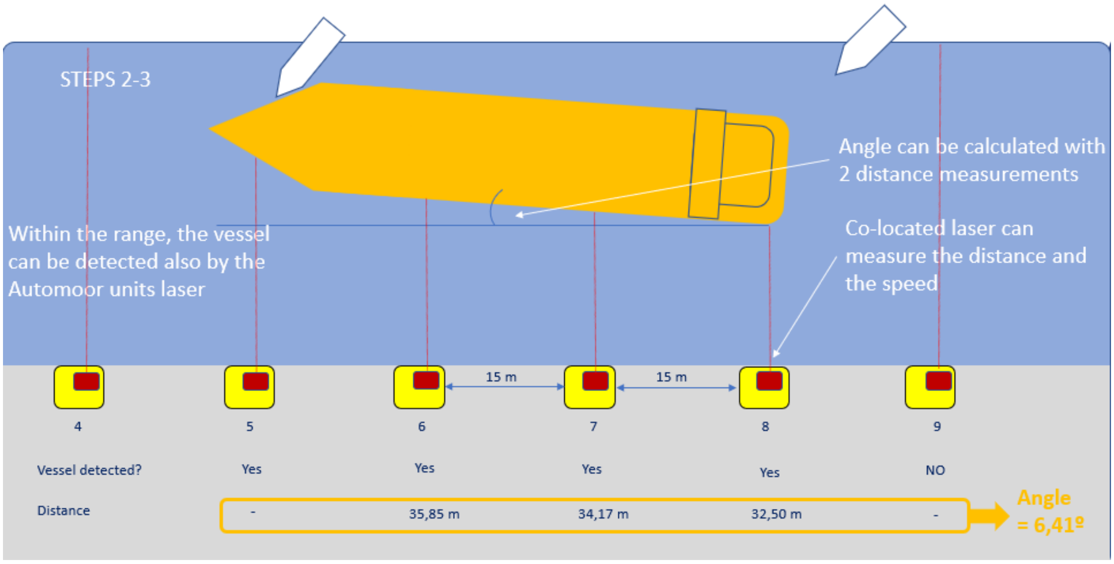

Figure 19 Approaching the mother vessel to the berth

As described in Figure 19, the mother vessel will approach the predefined berthing position. For checking the relative position of the mother vessel related to the quay, the laser sensors installed in the AutoMoor units will send information to the STCS about the vessel distance to the jetty. With this information the STCS will calculate the vessel heading with respect to the quay and the approaching speed. This information is crucial for avoiding a collision of the mother vessel with the quay.

When the autonomous tugboat swarm perfectly aligns the mother vessel with the AutoMoor units, the STCS operator, who is remotely monitoring the whole process, activates the AutoMoor. When the AutoMoor arms are successfully attached to the mother vessel and the STCS Operator ensures that the vessel is safely docked, the STCS Operator communicates with the tugboats Captains, the Pilot of the mother vessel and the port authority PCS that the mooring process has been finalized.

4.4 Data exchange format

The term "Port information" in context of this deliverable is the generic term to describe information on the port infrastructure and services between the Pilot Boarding Place and the Berth.

Most incidents happen in the approaches, anchorages or harbour basins of ports, as this is by far the busiest time for the mariner and vessel. Therefore, the quality and the availability of port information is an important risk mitigation strategy as it will help to execute safe navigation from pilot boarding place to berth and vice versa.

Data definitions for port infrastructure have been proposed to IHO Nautical Information Provision Working Group via Port Information Manual 1.4.5. The harmonized definitions for allowances for Under Keel Clearance, air draught and quay heights are in progress. A data model for the exchange of port data does not yet exist. Ports need to provide port information preferably in a worldwide-harmonised format. This deliverable provides the ports with a template to satisfy this request.

4.4.1 Data definition for objects

For the proposal of this deliverable, port is any port, terminal, offshore terminal, ship and repair yard or roadstead which is normally used for the loading, unloading, repair and anchoring of ships, or any other place at which a ship can call. The word "port" also embraces geographically, a city or borough which serves shipping interests. Other national standards and frameworks may describe such administrative entities already (IHO S-32).

Terminal refers to a number of berths grouped together and provided with facilities for handling cargo (IHO S-32).

Berth is the space assigned to or taken up by a ship when anchored or when lying alongside a quay, wharf, jetty, or other structure (IMO reference data model), while berth position refers to the position along the line of a berth, specified by one point (e.g. bollard, manifold or ramp number), allowing the ship to berth in the correct position along the berth (IHO S-32, IMO reference data model). Figure 20 and Figure 21 clarify these concepts.

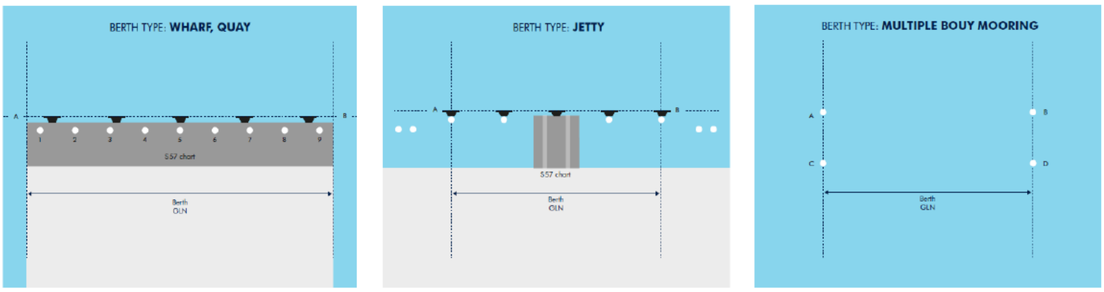

Figure 20 Berth location

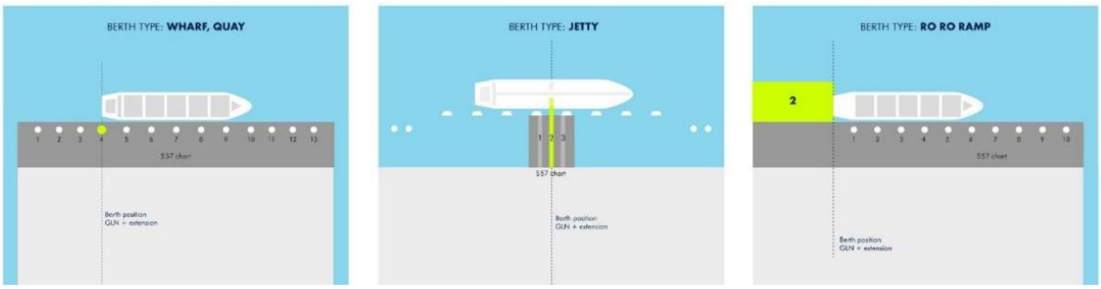

Figure 21 Berth position

The Pilot Boarding Place (PBP) is a point on the vessel's route where a Pilot is intended to be embarked / disembarked. At sea, PBP represents the meeting place to which the pilot comes out (IMO reference data model). It is also known as Pilot point. (IHO S-57, IHO S-4).

The Tug Reaching Place (TRP) is the meeting place where the tugboat swarm reaches the mother vessel. Table 6 summarizes the port data exchange formats.

Table 6 Port objects data exchange formats

Object	Parameter	Description	Indirect reference	Direct reference	Other
Port	Location	A single position which represents the port. Generally, a center of gravity position is chosen to represent the port's location. This is aligned with the airline industry.	UN/LOCODE ESVLC	Decimal degrees to a defined precision, (minus to indicate South and West) Datum: WGS 84 39.44231° / -0.316466°	Name of the port Port of Valencia
Terminal	Location	A single position which represents the terminal. Generally, a center of gravity position is chosen to represent the terminal's location	Global Location Number (GLN) (ISO/IEC 6523)	Decimal degrees to a defined precision, (minus to indicate South and West) Datum: WGS 84	Name of the terminal ISPS number SMDG code (for container only)
Berth	Location	Quay walls, berth or jetty: The berth's extent is between its two extremities as shown in the diagram below, measured in a straight line, indicated by A and B. Every point should be named and/or numbered. Orientation is not important. Letters are normally used over numbers.	Global Location Number (GLN) (ISO/IEC 6523)	Decimal degrees to a defined precision, (minus to indicate South and West). Datum WGS 84	Name of the berth Local reference Muelle del Este
Berth position	Location	A single point	Global Location Number of Berth (ISO/IEC 6523) with extension (for AutoMoor unit, manifold or ramp number).	Decimal degrees to a defined precision, (minus to indicate South and West). Datum WGS 84	Name of berth and AutoMoor unit number.

Object	Parameter	Description	Indirect reference	Direct reference	Other
Port Passage Plant	Route	Route to be followed by the mother vessel	Route exchange format according to IEC 61174 o IEC 63173-1	RTZ or S-221	Specific name

Water section

Ports can have multiple different types of water sections. The most common ones are the following:

- **Anchorage**: An area in which vessels anchor or may anchor (NP100)
- **Fairway**: The main navigable channel in the approaches to, or within, a river or harbour. Sometimes called the Ship Channel (NP100)
- **Turning basin**: An area of water or enlargement of a channel in a port, where vessels are enabled to turn, and which is kept clear of obstructions such as buoys for that purpose (NP100)
- **Basin**: A sheltered body of water available for port operations connecting either with the sea, with an outer port or with another basin. Generally, an almost land locked area leading off an inlet, firth or sound. Also, an area of water limited in extent and nearly enclosed by structures alongside which vessels can lie (IHO S-32)
- **Berth Pocket**: Body of water at the berth or anchor berth with sufficient footprint to allow the vessel to make fast to the shore or mooring buoys or to anchor (NP100)

Figure 22, clarifies the concepts related to the port water section, while Table 7 provides the data exchange formats.

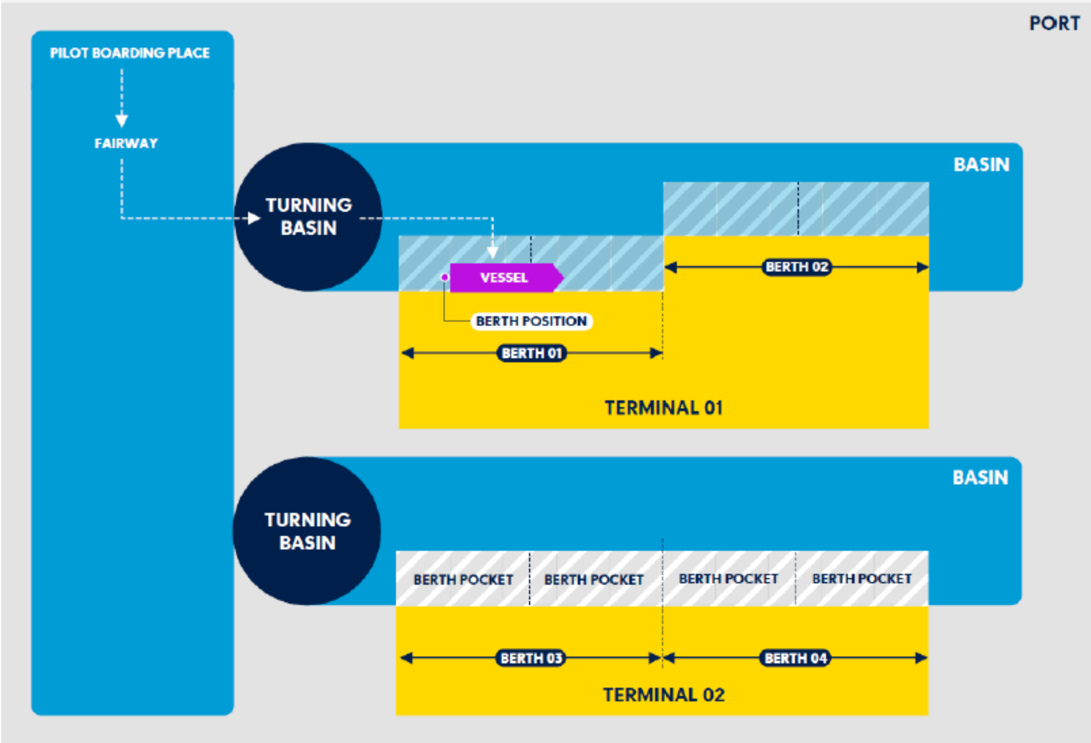

Figure 22 Water bodies and delimited port sections

Table 7 Port water section data exchange format

Object	Parameter	Description	Indirect reference	Direct reference	Other
Water section	Location	Named bodies of water or delimited port section	Global Location Number (GLN) (ISO/IEC 6523)	Sequence of positions, ordered in clockwise rotation. Decimal degrees to a defined precision, (minus to indicate South and West). Datum WGS84	Name of the port section

4.4.2 Data definitions for attributes – connected to object "port"

This section defines general information about the port area. Only the information related to the autonomous manoeuvring of the mother vessel in CORE port is included, and summarized in Table 8. As part of the port call process, the data exchange is more extensive.

Table 8 Port area objects data exchange formats

Name	Description	Format
General information	General, introductory information about the port. This should be confined to information not contained in any other definitions.	Free text
Developments	Details of any active development affecting traffic in the port.	Free text Expected completion date (DDMMYYYY)
Limits description	Description of the area covered by the information specified	Free text
ISPS security level	Current security level of the port or area within the port. Defined by The International Ship and Port Facility Security Code	ISPS Security Level: Fixed Text: One of "ISPS Level 1", "ISPS Level 2"," ISPS Level 3" Qualifying remarks: free text
Time zone	Time zones applicable to the port. All times should be expressed in Coordinated Universal Time (UTC) unless otherwise stated using ISO8601 formatting. Daylight Saving and Local Time are expressed as offsets, added to UTC to obtain the local time	• Standard Time Offset from UTC +/- hh:mm • Daylight Saving Time Offset from UTC +/- hh:mm • Daylight Saving Time Start: date and local time: ISO8601 • Daylight Saving Time End: date and local time: ISO8601
Shipping announcements	Local shipping announcements relevant to port users	Free text

Contact Information

This section defines the content of contact details referred to the Autonomous manoeuvring and only covers contact details related to:

- The emergency coordination center
- The STCS operator

Table 9 provides details of the related data exchange formats.

Table 9 Port contact details data exchange formats

Name	Description	Format
General contact information	General, introductory information about the port. This should be confined to information not contained in any other definitions.	Free text
Developments	Introductory text or high level, nonspecific information for contacting people in the port. This does not contain specific name, address or other contact details for any individual or service (these are defined as individual "point of contact").	Free text
Contact details	Detailed contact information for an official point of contact within the port	Contact o Individual Name [text] • Department / Administrative division [text] • Role [text] • Contact Instructions [text] Contact Details – Preferred Service Type Radio, Voice, Fax, Email, Online: • Enumeration • Number [text] • Address (online or email) [text] • Radio Frequency [text] • Call Name / Call Sign [text] • Service Working Hours (described in in Service Hours)
Internship communications	Specification of a communication channel for vessels in the port or a port section.	• VHF usage: fee text • VHF channel(s): free text • Information: free text

Weather and tidal Information

This section defines weather and tidal information for the port area, which is summarized in Table 10.

Table 10 Weather and tidal information data exchange formats

Name	Description	Format
Real-time weather information	Links to any official real-time weather or tidal information provided by the port weather stations.	Free text.

Name	Description	Format
Local weather and tidal phenomena	Details of any important local weather of tidal conditions within the port.	• Phenomena: free text • Details: free text • Location: free text • Expected period start: MM • Expected period end: MM

Vessel information

This section defines the information that a visiting vessel will be expected to send to the port either before arrival, during its stay in port or before and after departure. Table 11 only addresses the information that is not actually gathered by the PCS and will be collected as a consequence of the implementation of the MOSES innovations.

Table 11 Vessel information data exchange formats

Name	Description	Format
Ship particulars	Information related to the actual status of the mother vessel	• The vessel´s current deepest draught: free text • Trim: free text • Displacement free text • Air draught (distance from waterline to highest point of the vessel): free text • Overall length, including appendices; free text • Beam: free text • Freeboard: free text
Maneuvering conditions	Details of the manoeuvring equipment of the mother vessel	• The number of propellers: free text • Whether or not they are CPP: free text • Their direction of rotation • The type and maximum allowable angle of the rudder(s): free text • The turning circle and stopping distance in the current condition: free text • The number and capacity of fore and aft thrusters including details of the effective thruster speed: free text • The minimum steerage speed: free text • SWL: free text

Safety

This section defines identification of equipment, procedures and points of contact that should be used in case of an emergency within the port.

Table 12 Safety information data exchange formats

Name	Description	Format
Emergency coordination center	The Emergency Coordination Centre information for the port. Individuals should be entered as a "Point of Contact" and referenced within this information.	Text free
Emergency response equipment	Types, locations and availability of emergency response equipment.	• Equipment type: free text • Equipment availability: free text
Emergency procedures	Relevant emergency response procedures.	• Category of emergency: free text • Emergency procedure: free text

4.4.3 Data definitions for attributes – connected to object "water section"

This section refers to the restrictions per water section, such as anchorage, fairway, turning basin, basin, berthing pocket. The visualization of the data listed below is described in Figure 23:

1) Chart Datum
2) Height of tide
3) Maintained depth
4) Overdredge
5) Sounding
6) Observed depth
7) Draught
8) Under Keel Clearance (UKC)
9) Seabed

Table 13 and Table 14 present the main data exchange formats.

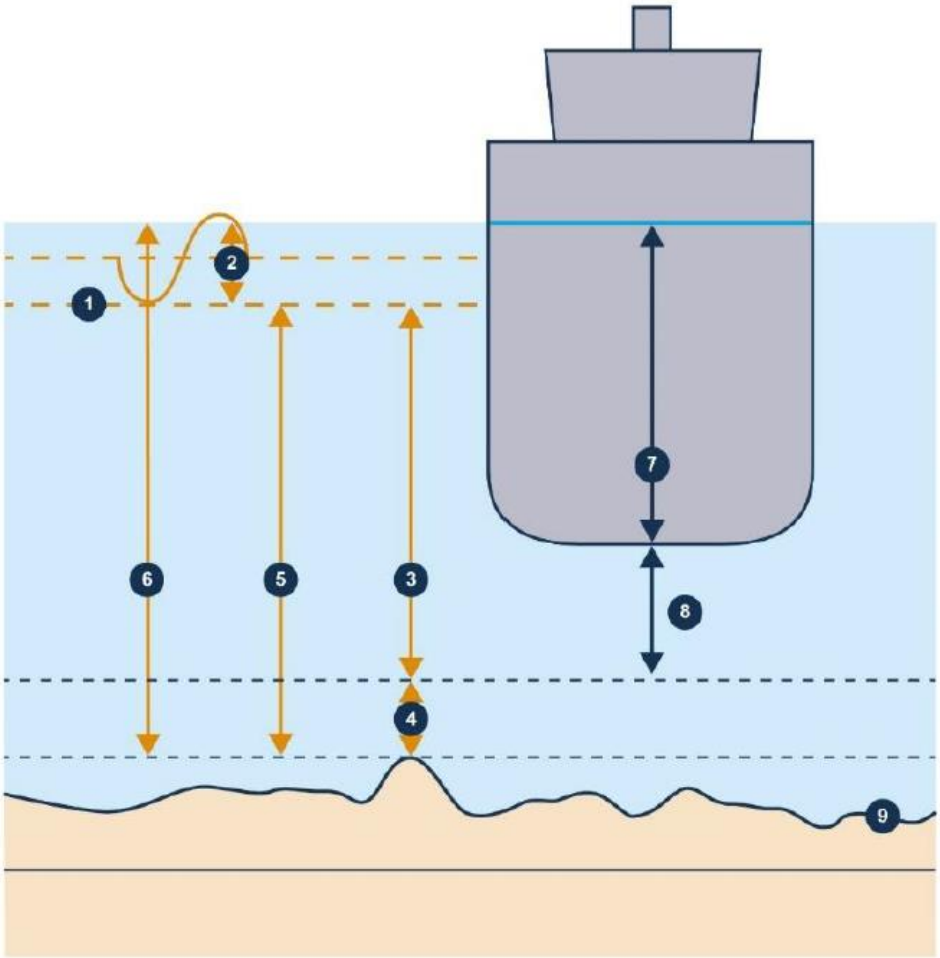

Figure 23 Restrictions due to the water section

Vertical restrictions

Table 13 Vertical restrictions due to the water section data exchange formats

Name	Description	Format
Maximum draught	Maximum vertical distance from the bottom of the keel to the waterline (NP100). Units: decimal meters to a defined water density measured in kg/m3	Text free
Maximum air draught	Maximum distance from the surface of the water to the highest point on a vessel. Units: decimal meters	Text free
Maintained depth	The Depth at which a channel is kept by human influence, usually by dredging (NP100). Units: decimal meters with reference to a specific Sounding Datum	Text free

Name	Description	Format
Sounding	Measured or charted depth of water or the measurement of such a depth (IHO S-32). Units: decimal meters with reference to a specific Sounding Datum	Text free
Overdredge	An additional depth margin provided by a dredging operation to ensure that the depth at a specific location is never less than the pre-determined maintained depth over the interval between programmed dredging operations (NP100). Units: decimal meters	Text free
Height of tide	The vertical distance from the chart datum to the level of the water at a particular time (IHO S-32). Units: decimal meters with reference to a specific Sounding Datum	Text free
Observed depth	The vertical distance from the sea surface to the sea floor, at any state of the tide.	Text free
Minimum Water Density	The minimum water density value within a particular area. (NP100). Units: kg/m3	Text free
Fresh Water Allowance (FWA)	The change in draught of a vessel due to the difference between salt and fresh water (NP100). Units: decimal meters	Text free
Under Keel Clearance (UKC)	The difference between the draught of a vessel and the available depth of water. This is usually the distance between the lowest point of the ship's hull, normally some point on the keel, and the sea bed but consideration must also be given to possible obstructions on the sea bed (IHO S-32). Units: a defined value in decimal meters or a percentage of draught and/or beam	Text free
Under Keel Clearance (UKC) policy	A restriction imposed by an authority on a vessel to ensure the depth below the keel meets an acceptable (usually minimum) single or range of values. May apply to a specific area, type of vessel on arrival, alongside or departure. Units: decimal meters or a percentage of draught and/or beam	Text free
Nature of bottom	The feature of the bottom including the material of which it is composed and its physical characteristics (IHO S-57). Format: Fixed format text according to IHO S-4 and IHO S-57 values. E.g. Sand, Mud, Clay, Silt, Stones, Gravel, Pebbles, Cobbles, Rock, Boulder, Coral	Text free

Horizontal

Table 14 Horizontal restriction due to the water section data exchange formats

Name	Description	Format
Maximum length	Maximum permitted length overall (LOA). Units: decimal meters	Text free
Minimum Parallel Mid-Body alongside (for berth pocket only)	The minimum Parallel Mid-Body length (the measurement (length) at the water line of the flat side of the vessel) requirement for the berth during time alongside, including both arriving and departing the berth. Units: decimal meters	Text free
Maximum beam	Maximum permitted beam. Units: decimal meters	Text free
Maximum Arrival Displacement (for berth pocket only)	The maximum displacement of the vessel on arrival at the berth. Units: Tonnes (1000 kg)	Text free
Maximum Displacement Alongside (for berth pocket only)	The maximum displacement of the vessel whilst alongside the berth. Units: Tonnes (1000 kg)	Text free

4.4.4 Port planning arrival

Port planning for an arriving ship is organized normally by the port authority, based on the berth planning of the terminal in their port area. It tells which ship is welcome at which pilot boarding place, based on maximum sizes and conditions, availability of the berth, fairway, nautical services and clearance by authorities. As explained in section 2.1 the arrival in port normally requires a notification to port authorities.

Port authorities normally share the port planning through Vessel Traffic Services (VTS), which use Very High Frequency (VHF) radios to inform ships.

Even though the actual port calls follow IMO FAL (FAL 43/7/1) guidelines for exchanging information, there is no data standard model available that addresses all operational needs.

The MOSES scenario, which is described in Figure 24, is to relay the Requested Time of Arrival (RTA) pilot boarding place directly to the Electronic Chart Display Information System (ECDIS). Technically this is possible: the RTA may be expressed in the schedule of the port passage plan through the route **exchange (RTZ) format (part of IEC 61174)** and the succeeding **S-221 format (IEC 63173-1).** MOSES also proposes to send the port passage plan, with an RTA at the pilot boarding place, tug reaching place and berth. In practice today most ECDIS systems cannot yet absorb this data. Table 15 gathers the proposed exchange formats.

Table 15 Port planning arrival data exchange formats

Name	Description	Format
Estimated Time of Arrival (ETA) Pilot Boarding Place	The date and time the ship estimates to arrive at a specified location (e.g. specified pilot boarding place)	yyyy-mm-ddThh:mm:ssZ
Requested Time of Arrival (RTA) Pilot Boarding Place	The date and time the ship is requested to arrive at a specified location (e.g. specified pilot boarding place)	yyyy-mm-ddThh:mm:ssZ
Planned Time of Arrival (PTA) Pilot Boarding Place	The date and time the ship plans to arrive at a specified location (e.g. specified pilot boarding place)	yyyy-mm-ddThh:mm:ssZ
Actual Time of Arrival (ATA) Pilot Boarding Place	The date and time the ship arrives at a specified location (e.g. specified pilot boarding place)	yyyy-mm-ddThh:mm:ssZ

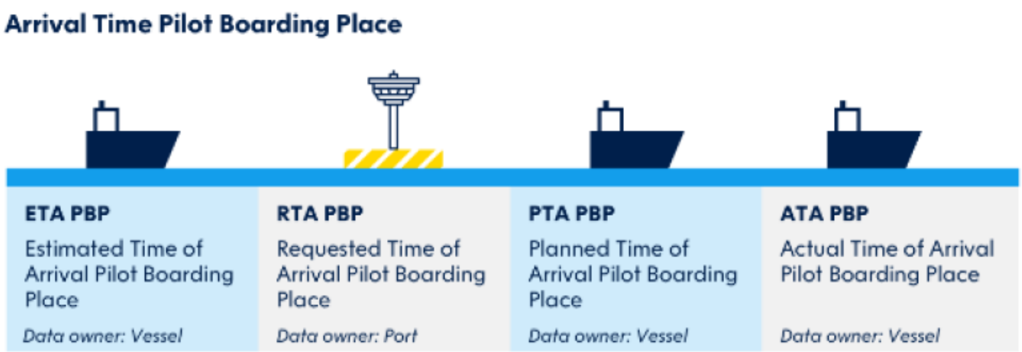

Figure 24 Arrival time to Pilot Boarding Place

4.4.5 Nautical services planning

In the framework of the MOSES project, the nautical services are the VTS, the Pilots, the autonomous tugboat swarms and the AutoMoor system.

The MOSES concept of autonomous ship manoeuvring has an impact on safe navigation. Firstly, in case that one of the nautical services is not available, it is necessary to delay the entry or departure of the ship, which affects the crew's rest. It has been proven that one of the main causes of accidents is fatigue.

MOSES also addresses specific communication gaps that actually affect the port manoeuvring to be conducted in the optimal safe conditions.

Currently, the availability of nautical services is normally not digitally communicated, nor is it available on a timely basis and is often communicated by phone or e-mail, consequently, there is no standard data communication model.

In addition, apart from ordering and cancelling tugboats, in most ports the mother vessel Master has limited understanding on tugboats movements and activities. Moreover, Pilots have no guidance how to inform the Master as tugboat orders are not provided in the IMO Standard Marine Communication Phrases.

The typical entries for nautical service times, described in Figure 25, are normally recorded in logbooks. In order to facilitate future implementation, the manoeuvre protocols proposed in this deliverable are intended to be as close as possible to the current and the exchange formats proposed in Table 16 are aligned with this approach.

Starting times:

- Pilot on board – ATS pilot service
- Tug(s) standby & ready to assist – ATS tug service
- AutoMoor units activated – ATS mooring service

Completion times:

- Pilot disembarked – ATC pilot service
- Tug(s) dismissed – ATC tug service
- AutoMoor unit secured – ATC mooring service

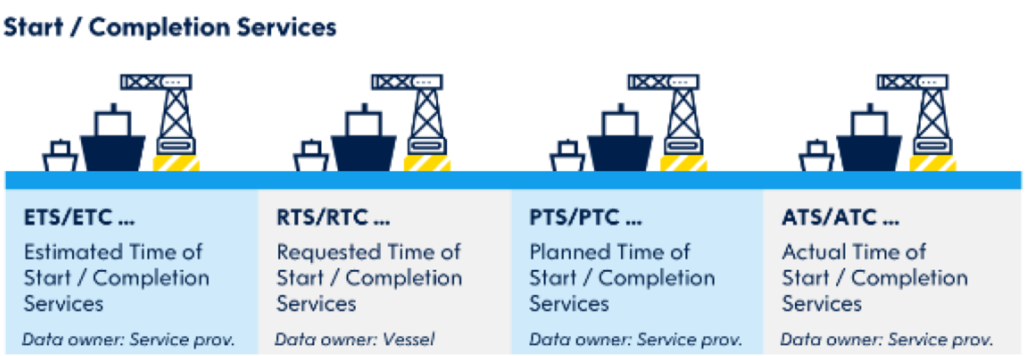

Figure 25 Start / completion times for nautical services

Table 16 Nautical services planning data exchange formats

Name	Description	Format
Estimated Time of Start (ETS)	The date and time a service provider estimates a specified service will start	yyyy-mm-ddThh:mm:ssZ
Requested Time of Start (RTS)	The date and time a service provider is requested to start a specified service	yyyy-mm-ddThh:mm:ssZ
Planned Time of Start (PTS)	The date and time a service provider plans to start a specified service	yyyy-mm-ddThh:mm:ssZ
Actual Time of Start (ATS)	The date and time a service provider starts a specified service)	yyyy-mm-ddThh:mm:ssZ
Estimated Time of Completion (ETC)	The date and time a service provider estimates a specified service will be completed	yyyy-mm-ddThh:mm:ssZ
Requested Time of Completion (RTC)	The date and time a service provider is requested to complete a specified service	yyyy-mm-ddThh:mm:ssZ
Planned Time of Completion (PTC)	The date and time a service provider plans to complete a specified service	yyyy-mm-ddThh:mm:ssZ
Actual Time of Completion (ATC)	The date and time a service provider completes a specified service	yyyy-mm-ddThh:mm:ssZ

4.4.6 Port planning departure

Port planning for a vessel departing the berth, described in Figure 26, is normally organized by the port authority, based on the completion time of vessel and cargo services, availability of the fairway, nautical services and weather and tide conditions. This is different from port planning on arrival, in which the port planning is dependent on the berth availability and therefore berth planning. This can be different to when a vessel is shifting to another berth; then the port planning is again dependent on the berth planning. Departure from port normally requires a notification to port authorities.

The planning of crew rest hours is affected by a delay to the departure. This also impacts the ship safety, due to rushed decisions to depart, not allowing the STCS operator to properly prepare a safe port passage. In addition, the impact of port planning for a departing vessel is directly related to the incoming vessel bound for the same berth. Consequently, the Requested Time of Departure Berth must be sufficiently notified to the vessel to allow proper rest hour planning and safe port passage. The exchange formats proposed in Table 17 address these issues.

Table 17 Port planning departure data exchange formats

Name	Description	Format
Estimated Time of Departure (ETD) Berth	The date and time the ship estimates it departs from a specified location (e.g. specified berth)	yyyy-mm-ddThh:mm:ssZ
Requested Time of Departure (RTD) Berth	The date and time the ship is requested to depart from a specified location (e.g. specified berth)	yyyy-mm-ddThh:mm:ssZ
Planned Time of Departure (PTD) Berth	The date and time the ship plans to depart from a specified location (e.g. specified berth)	yyyy-mm-ddThh:mm:ssZ
Actual Time of Departure (ATD) Berth	The date and time the ship departs from a specified location (e.g. specified berth) (last line released in ship's logbook)	yyyy-mm-ddThh:mm:ssZ

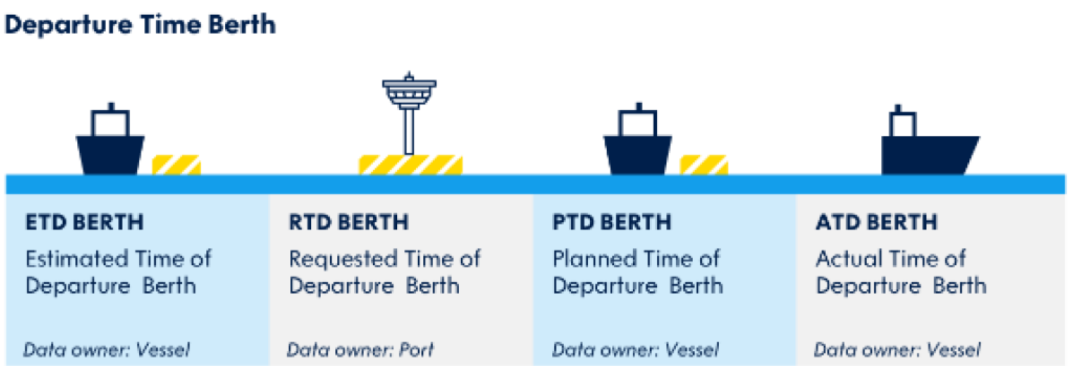

Figure 26 Departure time berth

4.4.7 Progress of the mother vessel and the autonomous tugboat swarm

The STCS operator must continuously monitor the heading and speed of both the mother vessel and each of the tugboats in the swarm, as depicted in Figure 27.

Figure 27 Course and speed of the mother vessel (source: Marine Traffic)

He/she must be also able to know the availability and technical status of each of the tugboats. For this reason, the STCS operator must receive information in real-time about the battery's performance:

- Permanent batteries monitoring.
    - Temperature (ºC)
    - Deep Of Discharge (DOD) (%)
    - C-Rate charge (hours)
    - C-Rate discharge (hours)

The STCS will monitor in real-time key functions of the tugboat swarm operation such as:

- Load in the towing line provided by the load cell
- On-board data storage capacity

Table 18 summarizes the data exchange formats.

Table 18 Vessel control data exchange formats

Name	Description	Format
Heading	Direction in which the bow vessel is pointed Units: decimal degrees	Text free
Speed	Current vessel speed. Units: Knots	Text free
Temperature	Temperature in batteries compartment or the battery Units: Celsius degrees	Text free
Load	Load in the towing line Units: Tn	Text free
Storage capacity	Data storage capacity on board Units: Megabits	Text free
SOC	Units. (%, Ah, kWh)	Free text
SOH	Units. (%)	Test free
DOD	Units. (%)	Text free
C-Rate	Unit. (hours)	Text free

5. Shore Tugboat Control Station interface

The objective of this chapter is to determine the main characteristics of a central control platform that will act as an interface between the tugboat's operator with the port that will support decision-making of the Port Control Authority. Port Control is responsible for coordinating ship movements within the port with the right balance between efficiency and safety. This process will be facilitated by providing real-time access to information about port operations and availability of assets, such as the available tugboats. The central control platform will be used to manage autonomous operation for docking of large ships (including towing and pushing) through a single user-friendly interface that will include: a web-app dashboard component for high-level command control being able to override agents (tugboats) and for visualization of task progress and localization of tugboats and mother ship; a reporting component that contains all necessary logs during operation (e.g. alarms etc).

Specifically, this section first defines the functional and non-functional requirements of the STCS (Section 5.1) including main use cases that can be inferred from a system communications sequence diagram. Then, we focus on describing the desired Dashboard, both in the towing (Section 5.2.1) and in the mooring (Section 5.2.2) autonomous view. To get to the point of having that desired Dashboard, we must start by describing a simple mock-up (Section 5.2.3), where some graphs with data from the tugboats are shown. Finally, the reporting component (Section 5.3) is described, where a history of the events and alerts that have occurred in the system is shown.

5.1 Network architecture and STCS derived requirements

It is possible to infer requirements list and use cases expected in the STCS from the sequence diagram of messages exchanged between the STCS and the rest of the system components.

The requirements will be:

- Functional: Those destined to satisfy the needs of system users, that will determine if the final solution is accepted or not. In turn, we have subdivided them into requirements for external interfaces, graphical interfaces with the user, and calculation or internal processing.
- Non-functional: Those quality criteria or restrictions that apply to the operation of the system. We have focused above all on describing those related to communications.

The sequence diagram or general communications scheme of the system has been presented in Figure 5 of section 3.2.

STCS FUNCTIONAL REQUIREMENTS:

a) Sequence diagrams of use cases:

- User story: "AS a PCS operations user I CAN launch the process of generating, approving, and distributing the port passage plan" (Figure 28)

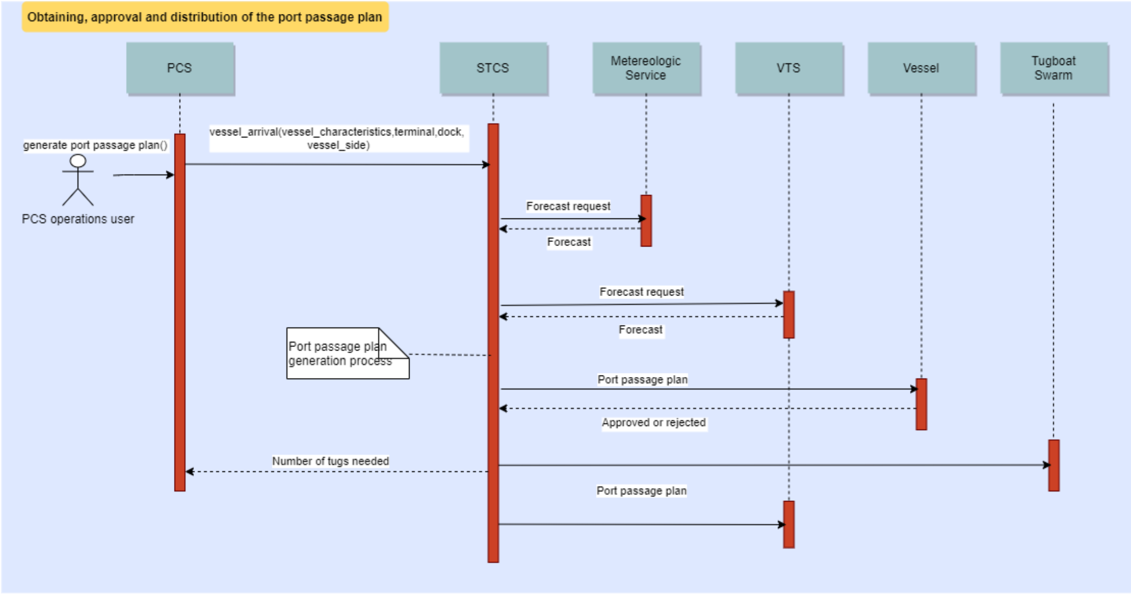

Figure 28 Use case of obtaining, approving and distributing the port passage plan

A PCS operations user, faced with the imminent arrival of a ship at the port, can launch the process of generating, approving, and distributing the port passage plan. This process consists of the following steps:

1. Provide the STCS with the characteristics of the ship, which terminal and dock will arrive at, and which side of the ship will be moored.
2. The STCS consults the weather service dependent on the PCS the forecast for the next few hours.
3. The STCS consults maritime traffic prediction for the next hours from the VTS.
4. The STCS, with the information from the previous points, performs internal processing, and generates, on the one hand, the port passage plan, and on the other, the number of tugboats that will be necessary to carry out the operation.
5. The STCS provides the necessary number of tugboats to the PCS.
6. The STCS sends the port passage plan to the ship, and confirms that it is approved.
7. STCS sends the approved port passage plan to the tugboat swarm.
8. The STCS sends the approved port passage plan to the VTS.

- User story: "AS a monitoring user of the STCS I CAN supervise autonomous towing operations in real-time, and if necessary, give up control of one or more tugboats to their respective captains" (Figure 29)

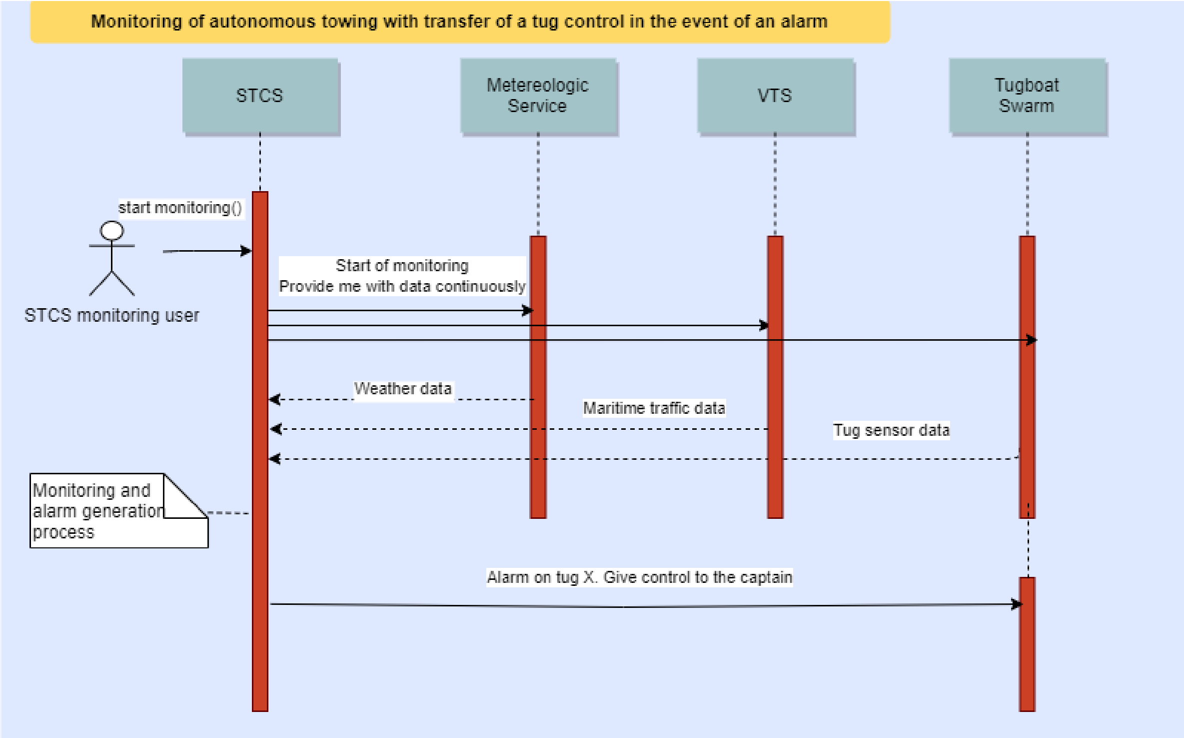

Figure 29 Use case of monitoring of autonomous towing with transfer of a tug control in the event of an alarm

Consult section 5.2.1 to see the requirements details that can be derived from this user story.

This monitoring process consists in that once started by the STCS operator, it immediately begins to receive real-time information on meteorological data, the status of maritime traffic in the port, and sensors that are on-board tugboats.

In the event that any of the alarm conditions indicated in section 5.2.1 are met, an order will be sent to the tugboat in question to relinquish control to the captain.

- User story: "As a monitoring user of the STCS I CAN supervise autonomous mooring operations in real-time, and if necessary, change the control of a mooring point to manual" (Figure 30)

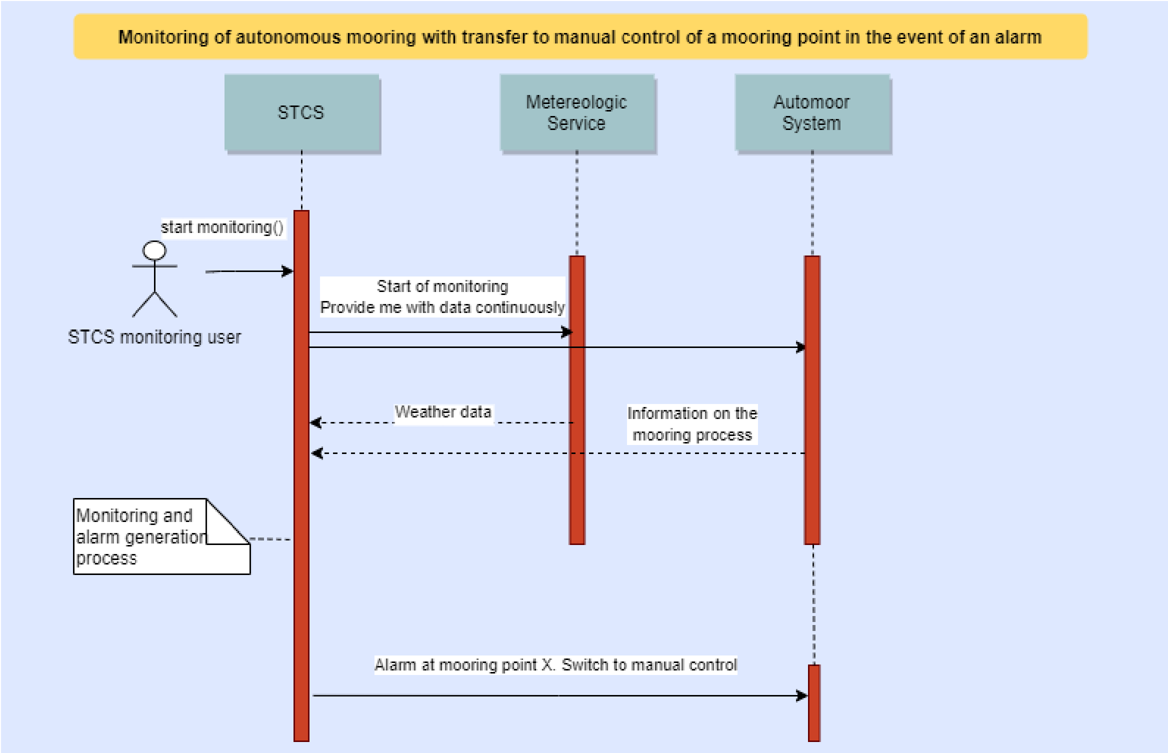

Figure 30 Use case of monitoring of autonomous mooring with transfer to manual control of a mooring point in the event of an alarm

Consult section 5.2.2 to see the details of the requirements that can be derived from this user story.

This monitoring process consists in that once started by the STCS operator, it immediately begins to receive real-time information on meteorological data, and from the autonomous mooring system.

In the event that any mooring point enters an alarm state, the order to switch to manual control will be sent.

b) List of requirements for external interfaces

- INPUTS: Have an API through which information update requests can be received, which will then be saved in the database:

- Receive the arrival report of a vessel from the PCS, indicating the vessel characteristics, which terminal and dock it will moor at, and which side of the vessel will be moored.
- Receive port passage approval from a vessel.
- Receive real-time information from the tugboats (speed, heading, distance to the dock, deviation from the approved passage plan, etc.)
- Receive real-time information from the VTS.

- Receive real-time information from the automated mooring system.
- Receive notification from the automated mooring system, both when the vessel is in position to start the process, and when the process has finished.

- OUTPUTS: Make requests to other APIs:

- Consultation: Know in detail the weather forecast for the next few hours from a weather web service dependent on the PCS.
- Consultation: Find out the current and forecast situation in the coming hours of vessel movements within the port from a web service of the VTS system.
- Update: Indicate the tugboats number that will be necessary for a given vessel to the PCS web service.
- Update: Send the port passage plan to the vessel web service.
- Update: Send the approved port passage plan to the tug swarm web service.
- Update: Send the approved port passage plan to the VTS web service.
- Update: Send to the web service of the tug swarm the order of changing to manual control a certain tug.
- Update: Send the order to start the process to the web service of the automatic mooring system.
- Update: Send the order to switch to manual control of a certain mooring point to the web service of the automatic mooring system.

c) Calculations

These are internal processes that communicate with the external interface, from which they receive their input parameters, then perform a function, and finally return the processing results to that same external interface. In summary, the STCS will perform the following calculation:

- Will return how many tugboats will be necessary taking as input the ship characteristics, the weather forecast, and the maritime traffic forecast.
- Will return the port passage plan, which includes the trajectory to the dock and the maximum deviation limits with respect to that path, taking as input the ship characteristics, the tugboats number, the weather forecast, the maritime traffic forecast, the terminal and berthing dock, and the berthing side.

d) Information requirements

For elaborating the above-mentioned calculations, the STCS needs to get data from the following sources:

- Show graphically for each tugboat, and at periodic intervals, parameters such as speed, heading, distance to the dock, deviation from the passage plan, etc., reading this information from the database (see details in section 5.3.3).
- Map view of the port to monitor and control the autonomous towing process (see details in section 5.3.1).
- View that graphically represents the mooring dock with the ship, to monitor and control the autonomous mooring process (see details in section 5.3.2).

STCS NON-FUNCTIONAL REQUIREMENTS:

The data storage will be done in a PostgreSQL relational database. The justification of why this database has been selected is explained in section 5.2.3.1.

a) STCS Inbound communications

- Communication with the STCS will be encrypted using the HTTPS protocol.
- The STCS will have a REST API secured by means of a JSON web token.
- Access to this REST API will be restricted so that only the following system components can access: PCS, vessel, weather service, tug swarm, VTS, and autonomous mooring system.
- The available endpoints in the REST API will be documented and will be possible to consult it.

a.1) Incoming real-time communications via MQTT

MQTT is an open communication protocol distinguished by its lightness and simplicity, thanks to which it can be successfully used in small microcontrollers, with limited hardware resources and also with low link bandwidth, so it fits perfectly with the IoT concept

In MQTT, a client is a device that can publish messages, subscribe to receive messages, or both. The broker is the server that accepts messages posted by clients and broadcasts them to subscribed clients. Posting is when a client sends a message to the broker.

The input communication with the tug swarm, the meteorological service, the VTS, and the automated mooring system will be carried out through the MQTT protocol as described in Figure 32, so that STCS will play the SUBSCRIBER role, and the swarm/VTS/meteorological service/mooring system the PUBLISHER role, thus allowing the intermediate broker service between publisher and subscriber to continuously push messages to the subscriber.

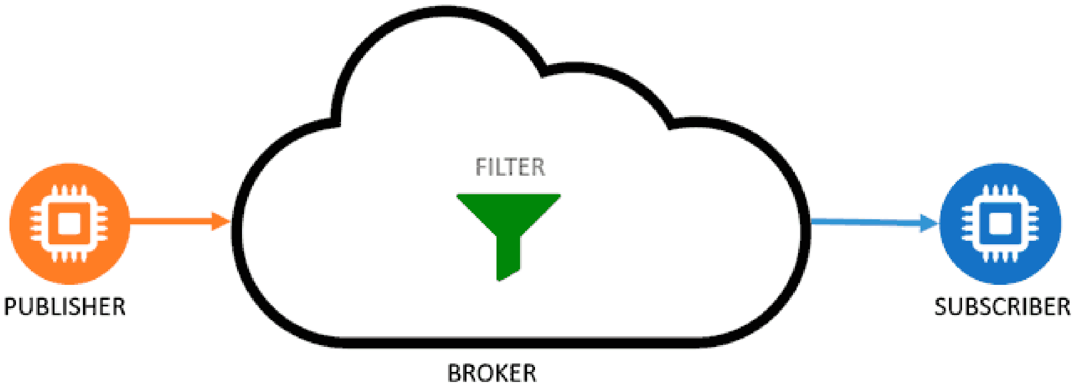

Figure 31 Basic components of the MQTT protocol

Regarding the tugs swarm/docking system, the PUBLISHER will be a Gateway with a 4G module to which all the tugs/docking points will be connected.

In this way, it will be possible to have in real-time both the information coming from the tug sensors, as well as from the VTS, meteorological service, or mooring system, in case the operator has to take any corrective action.

It is important to highlight that two types of gateways will have to be used:

1) To convert the Modbus over TCP/IP information used by the different components of the mooring system to MQTT

2) To send the MQTT messages over TCP/IP from these systems to the HTTP REST API of the STCS.

b) Outbound to the PCS:

- The communication will be carried out through requests in XML format to a SOAP web service.
- This communication will require a first request where authentication takes place using a username and password in order to obtain a token. This token then will be the one used in successive requests.

5.2Dashboard

The Dashboard of the Shore Tugboat Control Station is described in Figure 32, and will reflect the information coming from different data sources, during approach and tour inside the port from the Port Community System (PCS), the Vessel Traffic Management System (VTMS), the weather service, and the tugboats swarm, and finally during its mooring from the Automated Mooring System and also the weather service.

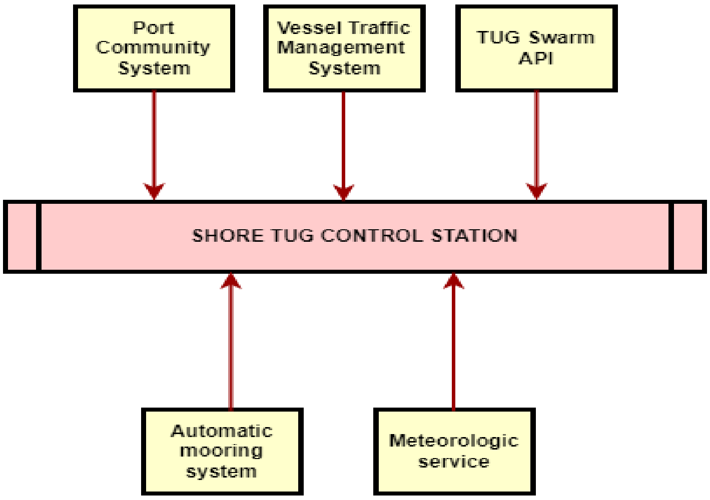

Figure 32 STCS System Context Diagram

It will consist of two main screens used by the control station operator, as described below.

5.2.1 Screen to monitor autonomous towing

The operator will be able to monitor the correct evolution of the towing operation. In the event that an alarm occurs in any of the tugboats, the operator will be able to see the details, and if necessary, change the control mode of the autonomous tugboat to manual (Figure 33).

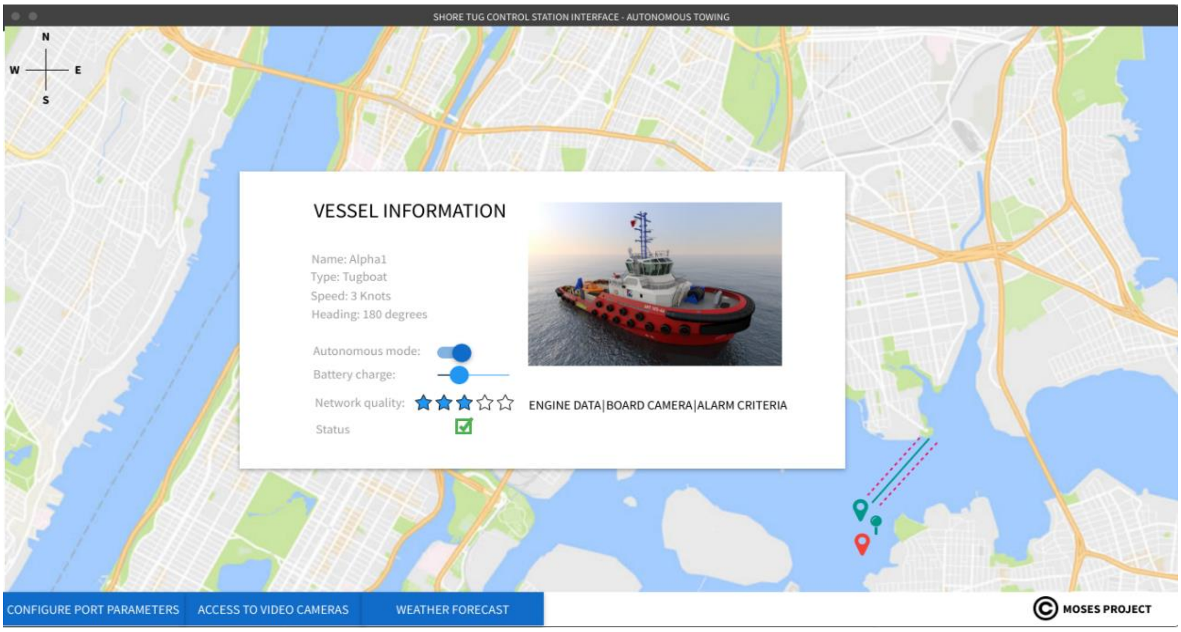

Figure 33 Screen to monitor autonomous towing

a) For which, in the first place, the operator will have to carry out a previous configuration process (which is done only once) consisting of:

- Set the specific security parameters of the port related to the ship's transit ("Configure Port Parameters" option).

- For each of the tugboats, go to the “Alarm criteria” option, and set the speed or positioning ranges, so that if the tugboat, during its planned route, moves away by a value greater than indicated in ranges, then an alarm will go off.

b) Once this prior configuration process has been carried out, the operator is ready to monitor the towing process. This monitoring allows:

- Access the video surveillance system of the port.
- Check the detailed weather forecast.
- See on the map the movement of the different tugboats, and the ships they serve.
- See the planned trajectory for the tugboats to the mooring point (continuous green line), and the maximum margins allowed for deviation from that trajectory (dashed red lines).
- View the position of the towed vessel -> Green pin marker 
- View tug status as follows:
    - When they are working autonomously correctly -> Green marker 
    - When a tug is in alarm state -> Red marker 

      A tugboat can enter a state of alarm for different reasons:

        - Engine failure
        - Discharged electric batteries
        - Worsening network connection quality
        - The trajectory/speed marked has been left by a value greater than the established range.
        - Risk of collision risk

      The operator will simply have to open the tugboat file by clicking on it, and there will be a detailed description of the alarm in the "Status" field.

      If, after analyzing the alarm, the operator considers that the tugboat is no longer able to operate autonomously, the operator may disable the “Autonomous mode”, and give control to the tugboat captain.

  - If after giving up control, the tugboat captain continues with the towing maneuver manually -> Orange marker 

- See detailed information on each tugboat by opening its file, in which the operator will have available:

  - Speed
  - Heading
  - Vessel type
  - Vessel image
  - State of charge of the batteries
  - Network connection quality
  - Status. It will be a green check for OK, or a detailed description in case of alarm.
  - Access to on-board cameras
  - Access to engine performance data

5.2.2 Screen to monitor autonomous mooring

When the towed boat is very close to the dock, the control system will automatically switch to the automated mooring view. In this view, the operator will be able to monitor the entire process, and if necessary, deactivate the autonomous mooring for one of the mooring points and switch it to manual (Figure 34).

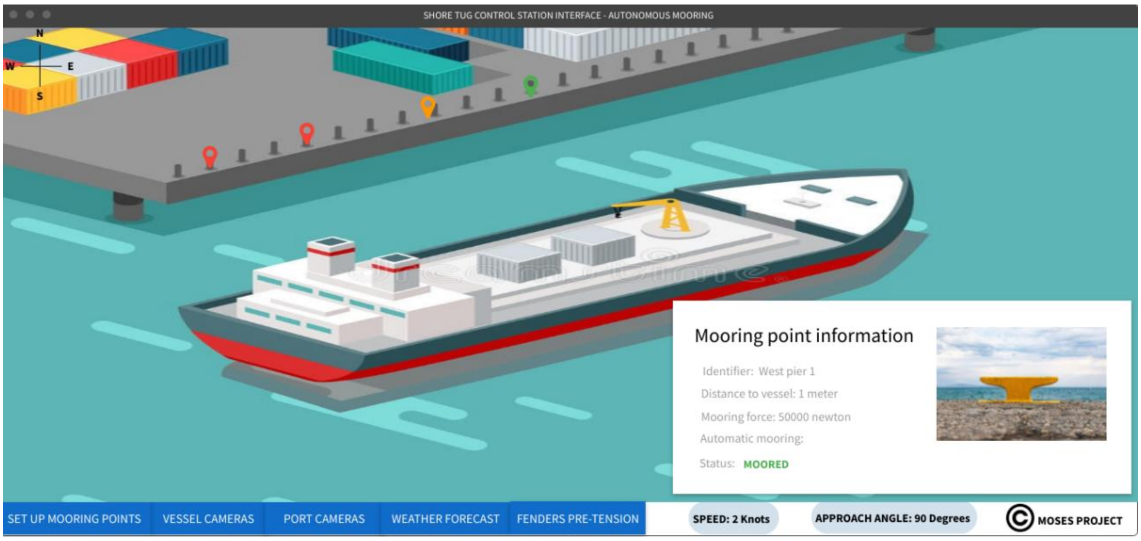

Figure 34 Screen to monitor autonomous mooring

Therefore, he must first configure (once only) the dock characteristics with its mooring points.

Once configured, he is ready to perform monitoring, so that each of the mooring points is marked with a different colored marker:

- White  when the vessel is 5 meters away or more

- Orange when the vessel is between 1 and 5 meters
- Red when the vessel is 1 meter away or less, and not yet moored
- Green when the ship is moored

By clicking on each of the mooring points, the operator will be able to:

- See the mooring point identifier and a photo

- Activate/deactivate the automatic mooring

- See the force in newton that is being applied.

- See the status (“Moored" in green when the process successfully completes autonomously, or another message in the event that there has been any problem).

In addition, the operator has access to:

- The ship's cameras

- The port cameras

- The weather forecast

- The stress values that are being applied to each of the fenders

- The ship's speed

- The approach angle

5.2.3 Dashboard Mockup

As a first simplified approximation and proof of concept, we propose to show some simple graphs with information coming from the tugboat sensors.

We will also describe in this section:

1. Technologies used in development.
2. Data model on which we expect to receive the information through the API to save it in the database, and then visualize it graphically.
3. How an external user can invoke API methods.
4. How this solution is deployed.

The result displayed for the case of the automatic towing process and a specific tug, is what is shown in Figure 35:

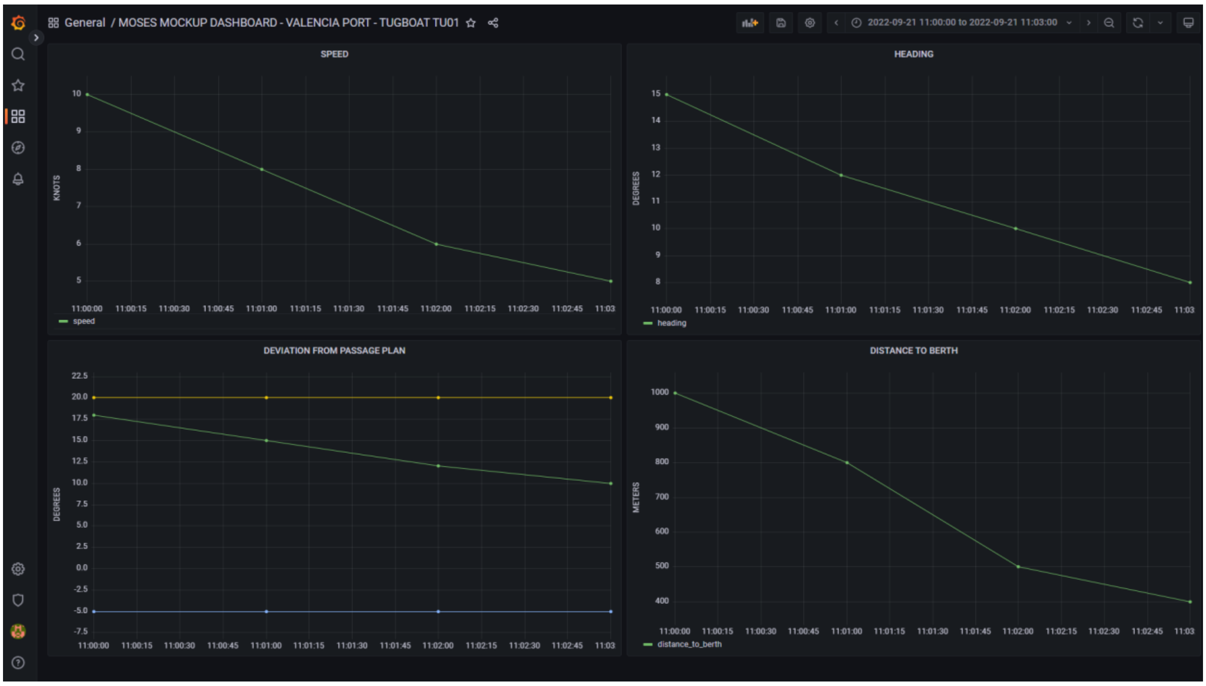

Figure 35 Four simple graphs in Grafana showing the time evolution for a specific tugboat of the autonomous towing process

As can be seen, we graphically show only the temporal evolution of four parameters: speed in knots, course in degrees, deviation from the passage plan in degrees, and distance to the dock in meters. In the graph of deviation from the passage plan, the maximum ranges of upper and lower deviation allowed are also shown as two lines. The mockup architecture is shown in Figure 36:

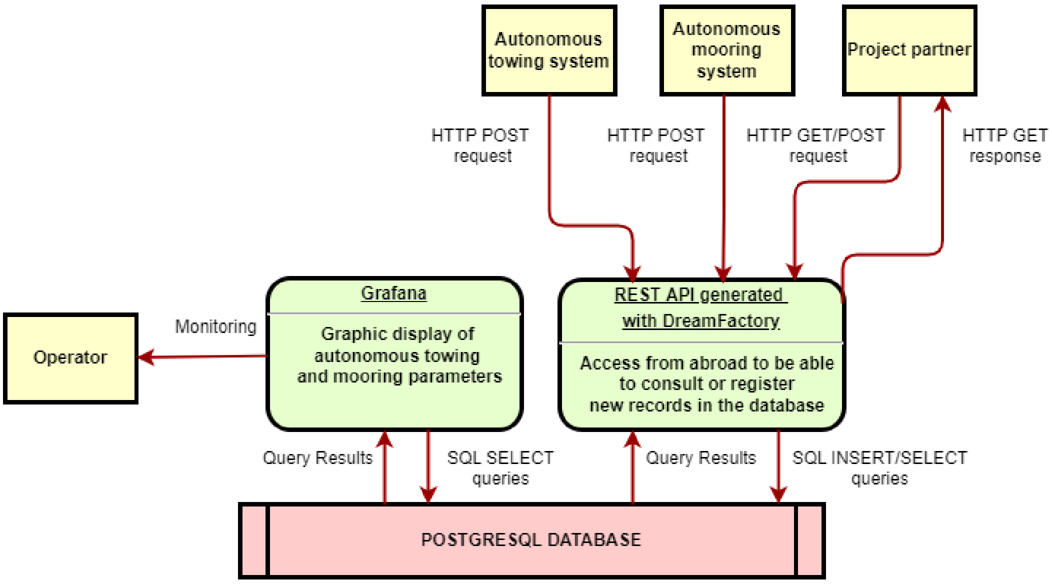

Figure 36 Mockup architecture: Components that integrate it

The process begins with the STCS REST API receiving data from the autonomous towing or mooring system through HTTP POST requests. Next, the REST API would dump the information using SQL INSERT statements in the PostgreSQL DB. Finally, Grafana reads the database content, and represents it graphically.

5.2.3.1 Technologies

Regarding technologies, free open-source tools have been chosen:

Grafana: It is a tool to visualize temporary or statistical data in a fast and public way. It allows you to run data analytics, extract metrics that make sense of huge amounts of data, and monitor with the help of customizable dashboards.

Its philosophy is to unify the data, not the databases, and that these data can be viewed in many ways, offering flexibility and versatility.

Examples of current Grafana users are Wikidata, CERN, DigitalOcean, etc.

Dreamfactory: Open-source middleware platform that automatically generates a complete, customizable, and secure REST API from backend resources and data sources, including SQL and NoSQL databases, stored files, and emails.

PostgreSQL: An open source, object-oriented, relational database management system that can also execute non-relational queries.

Relational queries are based on SQL, while non-relational queries use JSON.

This system is one of the most solid and widespread databases available.

It has advanced data types, and also allows to run advanced performance optimizations, which are features typically only seen in commercial database systems, such as SQL Server or Oracle.

This database has been selected based on the following approach:

- It is supported in the free open-source versions of both Dreamfactory and Grafana.
- It is stable, and widely spread.
- Although it is used in relational mode at the moment, in the future, when will receive huge amounts of real-time data from both the tug swarm, VTS, and the mooring system, it will be able to be used in non-relational mode.

5.2.3.2 Data model

The relational data model that we have in the PostgreSQL database is described in Figure 37:

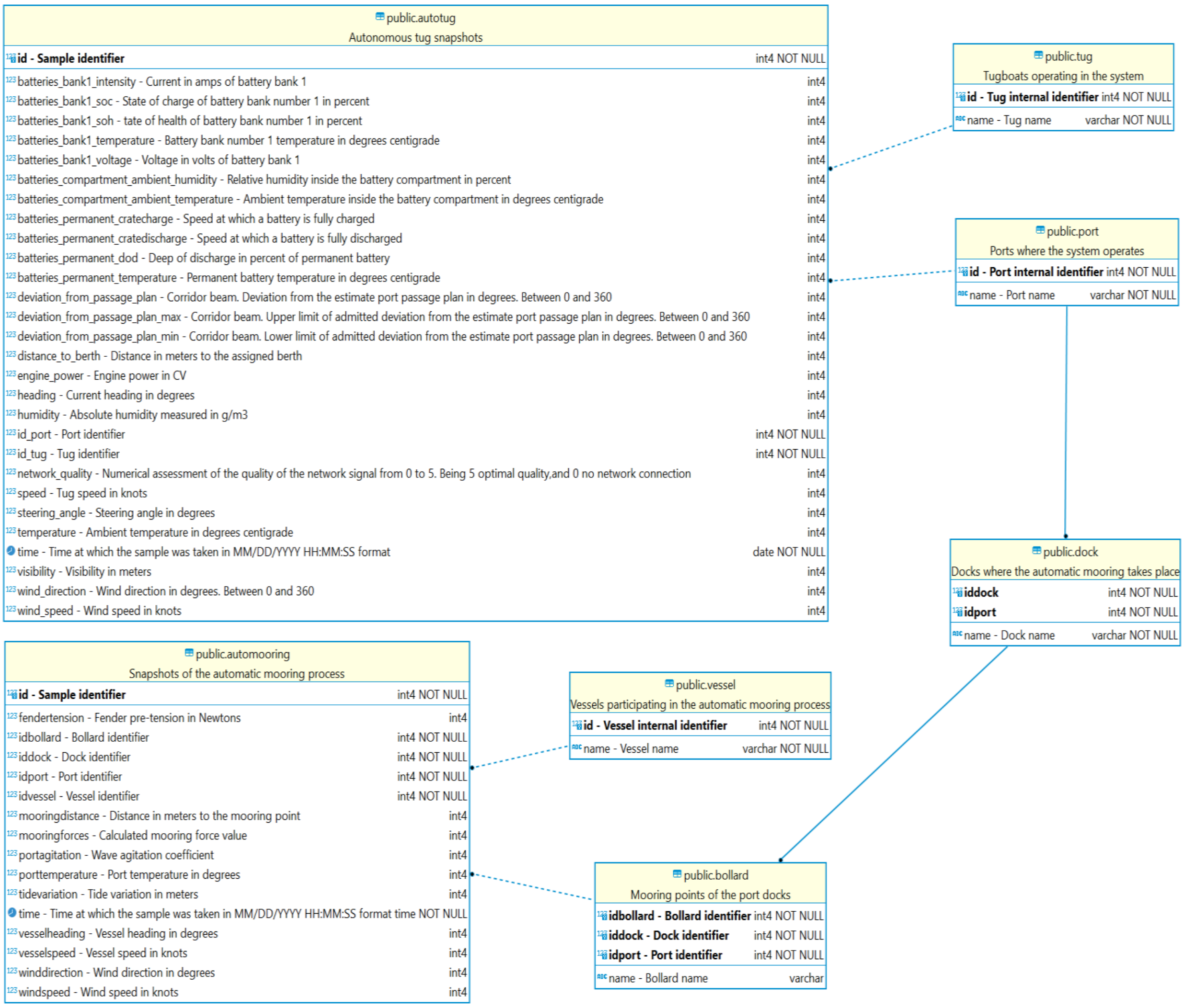

Figure 37 PostgreSQL Database Design for Mockup: Entity-Relationship Schema

5.2.3.3 How to interact with the API

Actors that will interact with this mockup API are as depicted in Figure 38:

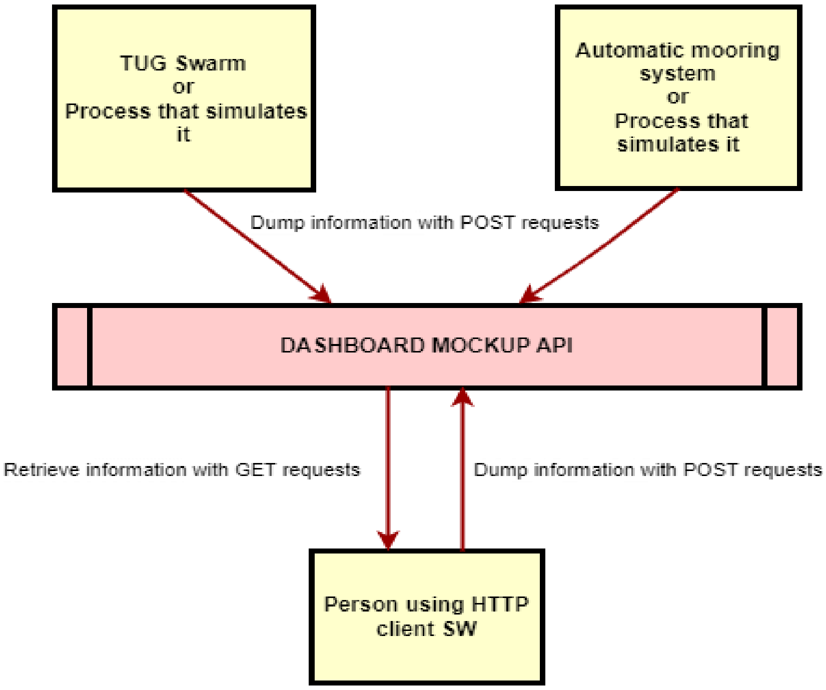

Figure 38 Actors that interact with the Dashboard Mockup API

We have three possible actors that can make use of this mockup API:

1) A process that simulates the continuous sending of information by each of the tug in the swarm, or it could even become the tugs swarm.

2) A process that simulates the continuous sending of information by each one of the mooring points, or it could even become the automated mooring system.

3) A person using a SW client that can launch custom HTTP requests, such as POSTMAN.

The API generates a JSON Web Token (JWT), which is provided to the three actors. A JWT is an open standard based on JSON to create a token used to send data between applications or services and ensure that it is valid and secure.

To interact with the API it is necessary to know that token value. This token is associated with a role in the API.

In the mockup, there is currently only one role (editor) that is not restricted, and therefore, allows any HTTP REST request to be launched on any available resource. This could be restricted, and also new roles can be created. Even access could be limited to only certain origin domains.

As an example of the role concept, instead of the editor role that we currently have, these five roles could be defined, each with its own token. The data model is that of section 5.2.3.2:

1) Tug: Can only dump information through POST requests in the autotug object of the data model. That is, write information in real-time about the evolution of the autonomous towing process.

2) Tug manager: Can manage information through any request type only in the tug object of the data model. It is the role in charge of managing the different tugboats that are part of the swarm.

3) Docking point: Can only dump information through POST requests in the automooring object of the data model. That is, write information in real-time about the evolution of the autonomous mooring process.

4) Docking point manager: Can manage information through any request type only in the dock and bollard objects of the data model. It is the role in charge of managing the different mooring points that exist in a certain port.

5) System administrator: It would be like the editor role, that is, it can launch any request type against any data model object. It is the role that would be used by human actors using an HTTP client.

To complete the example, if we take advantage of the CORS functionality that allows us to restrict the domains that can make requests, we could differentiate by port and consequently have even more roles, that is, we could have a "Valencia Tug" role that would allow write access to the autotug object only to those subdomains of valenciaport.es, and another "Pireo Tug" role that would allow write access to the autotug object only to those subdomains of pireoport.gr.

In order to launch HTTP requests, the value of the token must be set in an "X-DreamFactory-API-Key" header that will be included in all requests.

Usage examples:

- Consult the API documentation -> GET request to:

https://dreamfactory.moses.dataports.com.es/api/v2/api_docs/moses

- Query the content of the autotug table -> GET request to:

https:///dreamfactory.moses.dataports.com.es/api/v2/moses/_table/autotug

- Register a new sample in autotug -> POST request to:

https://dreamfactory.moses.dataports.com.es/api/v2/moses/_table/autotug

And a body like the following:

{

″resource″: [

{

″id″: 4,

″id_port″: 1,

″id_tug″: 1,

″time″: ″2022-09-21T09:03:00+00:00″,

″speed″: 5,

″heading″: 8,

″deviation_from_passage_plan″: 10,

″distance_to_berth″: 400,

″deviation_from_passage_plan_max″: 20,

″deviation_from_passage_plan_min″: -5

}

]

}

5.2.3.4 Deployment of the mockup components

The deployment has been done on a Linux Ubuntu machine, and the following components have been installed using docker-compose: PostgreSQL, Grafana, and DreamFactory.

In addition, for greater security, the access to the Grafana and Dreamfactory components from the outside were done through an NGINX reverse proxy (Figure 39), which includes automatically renewing SSL certificates from letsencrypt (cronginx).

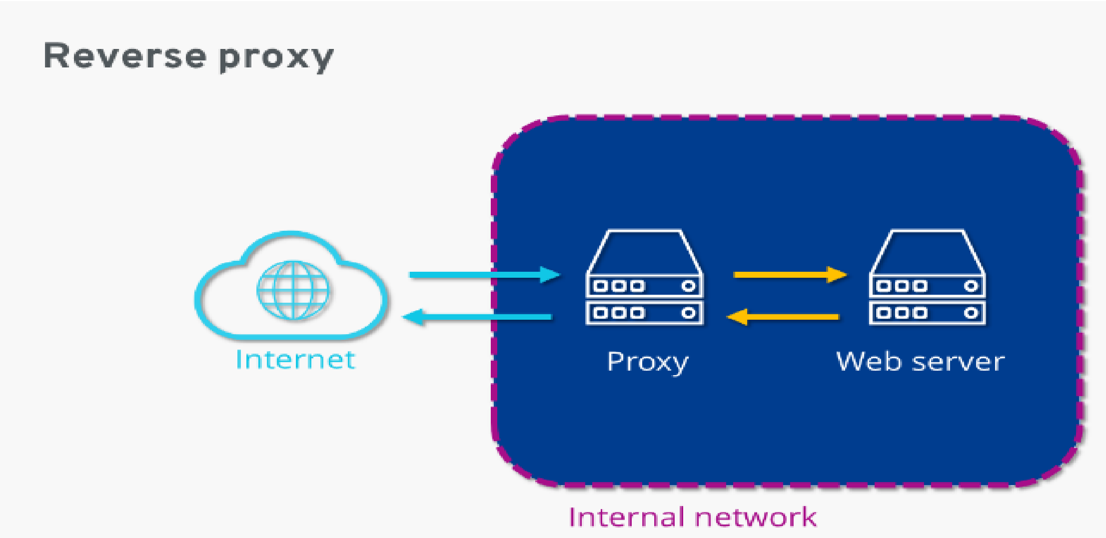

Figure 39 Graphical representation of the location of the reverse proxy

All components, including the reverse proxy, are deployed as docker containers, connected to the same docker network as is described in Figure 40.

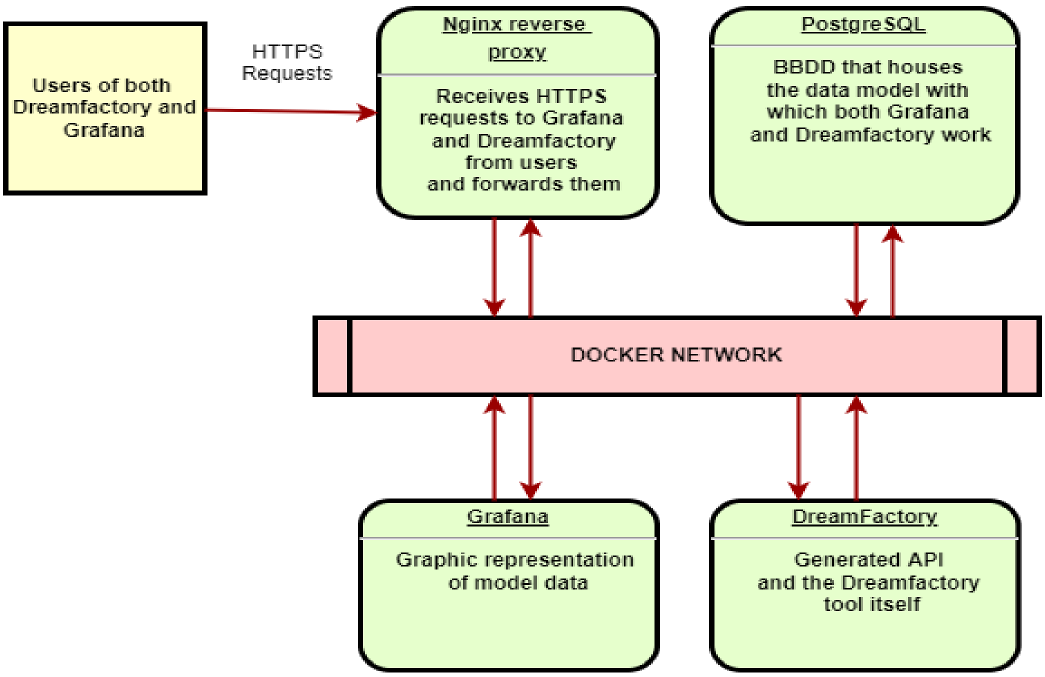

Figure 40 Mockup deployment architecture in Docker containers.

5.3 Reporting component

As a complement to the Dashboard, it would be advisable to have an additional component, which allows having a centralized view to look into the events history, whether they are warnings or not, that have occurred to a certain tugboat or mooring point.

We will be able to filter by a date range as shown in Figure 41.

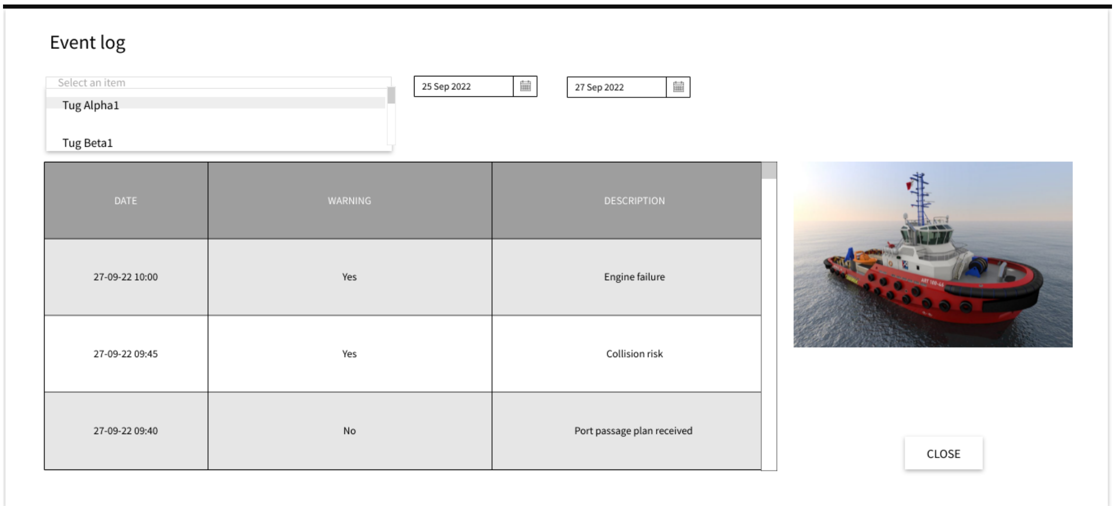

Figure 41 View of the historical event visualization component.

6. Conclusions

This deliverable describes the functional and operational architecture and interfaces required for enabling and monitoring autonomous manoeuvring operations of the MOSES Autodock system in large European Ports.

The Shore Tugboat Control Station will monitor the progress of the manoeuvring process and ensure its safety. For reaching this objective, it is fundamental to assure fluent communication of the STCS with other existing platforms in the port, such as PCS, VTS, etc. In order to facilitate future implementation, the manoeuvre protocols proposed in this deliverable are intended to be as close as possible to the current protocols.

Task 4.4 also analyses the current problems associated with the port call, addresses them and proposes credible solutions. The information available to all actors involved in a ship's manoeuvre is unique, avoiding duplication or misinterpretation, which contributes significantly to improving safety and reducing inefficiencies. In addition, this deliverable provides valuable information for updating the PCS (Port Community System) to the integration of autonomous vessels in the regular port activity.

Moreover, this deliverable deals with the lack of standard data exchange protocols. The work presented in this task is a step forward in developing standardized communication protocols. Improvement of ship-port interface data normally results in an improvement of safety, environment and security, which is a justification for any investments related to such data improvement. Efficiency is interconnected with these matters, but can be different for every port.

Most incidents happen in the approaches, anchorages or harbour basins of ports, as this is by far the busiest time for the mariner and vessel. After a nautical incident has happened, the Marine Accident Investigation Authorities often conclude that there was a lack of port passage information being exchanged before the ship’s arrival.

Prior exchange of port nautical information, routes, passage plans and weather information is an important risk mitigation strategy. The improvement and rationalisation of port information allows an efficient and effective assessment of whether the manoeuvre can be carried out safely. Advance exchange of port nautical information, passage plans and meteorological information is an important risk mitigation measure.

Therefore, the MOSES autonomous manoeuvring and the data exchange protocol of port information are an important risk mitigation strategy as it will help to execute safe navigation from pilot boarding place to berth and vice versa.

As ports try to become more efficient, the easiest route to expansion is to utilise current assets better, either in the form of allowing bigger vessels, or allowing vessels to arrive with a deeper draught, or to allow a more efficient exchange of ships at the berth. Utilising automation of e.g. vessel manoeuvring or better data management is another way of making the port more efficient.

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