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Project Duration:	**60 months (01/04/2019 – 31/03/2024)**

DELIVERABLE 6.1 (final version):
Integrated SmartShip framework

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1. Executive Summary

The SmartShip framework is a comprehensive system designed to enhance maritime operations through the integration of various components. It is built around the following main elements: IoT (Internet of Things), data storage, weather-routing tool, predictive maintenance tool, and user visualization. These components work together to collect and process data from vessels, optimize voyage routing, and improve fleet maintenance.

The development of SmartShip followed agile principles, particularly the SCRUM framework, emphasizing collaboration, transparency, and flexibility. The release plan involved two iterations, integrating data analytics and decision support modules, followed by validation, and testing by end-users. DevOps methodology was applied to software-related operations, promoting continuous integration and delivery.

SmartShip was implemented in four use cases, including voyage planning and weather routing, real-time routing adjustments, predictive maintenance, and improving user interfaces for navigation and fleet-performance monitoring. Each use case aimed to enhance existing tools and processes. Through the implementation in these use cases, principles of Circular Economy are considered to address sustainability and green economy challenges in the maritime industry. The SmartShip integrated system was effectively put to the test through its application to the use cases, each with its unique specifications and stakeholder requirements. The key participants actively participated and fulfilled their roles in alignment with the project's plan and the specific use-case criteria. To validate the performance of the initial version of the SmartShip framework, comprehensive assessments of Key Performance Indicators (KPIs) and evaluation parameters were conducted across all use cases.

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List of Acronyms and Abbreviations

Term	Description
AI	Artificial Intelligence
AIS	Automatic Identification System
CBM	Condition Based Maintenance
COTS	Commercial off-the-shelf
DevOps	Development and Operations
DSS	Decision Support System
GUI	Graphical User Interface
ICT	Information and Communication Technologies
IoT	Internet of Things
KPI	Key Performance Indicator
PBM	Performance Based Maintenance
RTD	Research and Technological Development
UI	User Interface
UX	User Experience
WP	Work Package

2. Introduction

2.1 Scope and objectives of the deliverable

This document presents the implementation of the integrated SmartShip framework as it emerges from the aggregation of the baseline framework with IoT, and advanced data analytics described in WP4, and the Decision Support and multi-layer optimization module described in WP5.

2.2 Structure of the deliverable

This deliverable demonstrates the implementation of SmartShip framework. Its structure includes the following sections:

- **Section 1** contains the executive summary.
- **Section 2** (the current) presents the structure of the deliverable, along with its main objectives and position in the project, in terms of its relation to other tasks and deliverables.
- **Section 3** presents the main components of SmartShip described in D4.1 and D5.1.
- **Section 4** presents the methods that were followed for integrating SmartShip components and the implementation process.
- **Section 5** summarizes the conclusions that are drawn from the integration and implementation of SmartShip.

2.3 Relation to Other Tasks and Deliverables

In T6.1 the integrated framework is implemented in the four use cases of maritime-performance assessment described in WP2.

In T6.2 implementation of the integrated framework will be validated.

Two versions of the integrated framework are delivered corresponding to two pilot tests that have been designed in T6.3 and conducted in T6.4 respectively:

- The **D6.1 presents the final version of the integrated SmartShip system delivered in M54[1] subject to validation (M56) and testing via the second piloting phase that will be concluded in M60**. The final version of SmartShip system is the iterated version of the initial framework that was validated and tested by the users during the first piloting phase ended in M45.
- The design and execution of the 2-phased validation and piloting of the SmartShip system will be thoroughly presented along with the evaluation results (based on KPIs' depicted in WP2 and D2.1) in D6.2 at M60.

[1] MXX is the month reference from the beginning of the project.

3. Components of SmartShip

SmartShip framework consists of the following main components: (1) IoT, (2) Data storing, (3) Weather-routing tool, (4) Predictive-maintenance tool, and (5) User visualization. The detailed description of the components may be found in D4.1 and D5.1.

IoT, focuses on tools, communication protocols, and network topology for collecting data from various sources on vessels. Data sources are either onboard or onshore, while communication between these sources is established using two methods, based either on (a) a centralized cloud repository, or (b) a synchronization application.

Data storing exposes data collected from IoT systems located on the vessels.

The **weather-routing** and the **predictive-maintenance** tool involve the application of data insight, data analytics (see D4.1), DSS and optimization (see D5.1) techniques to assess optimal decisions in the field of voyage routing and fleet maintenance correspondingly.

User visualization complements the SmartShip framework as an efficient and interactive means of demonstrating data, solutions, and recommendations, that supports decision making, best-practices adoption and strategy implementation.

Figure 1 shows the schematic representation of SmartShip framework with all the interactions among its components.

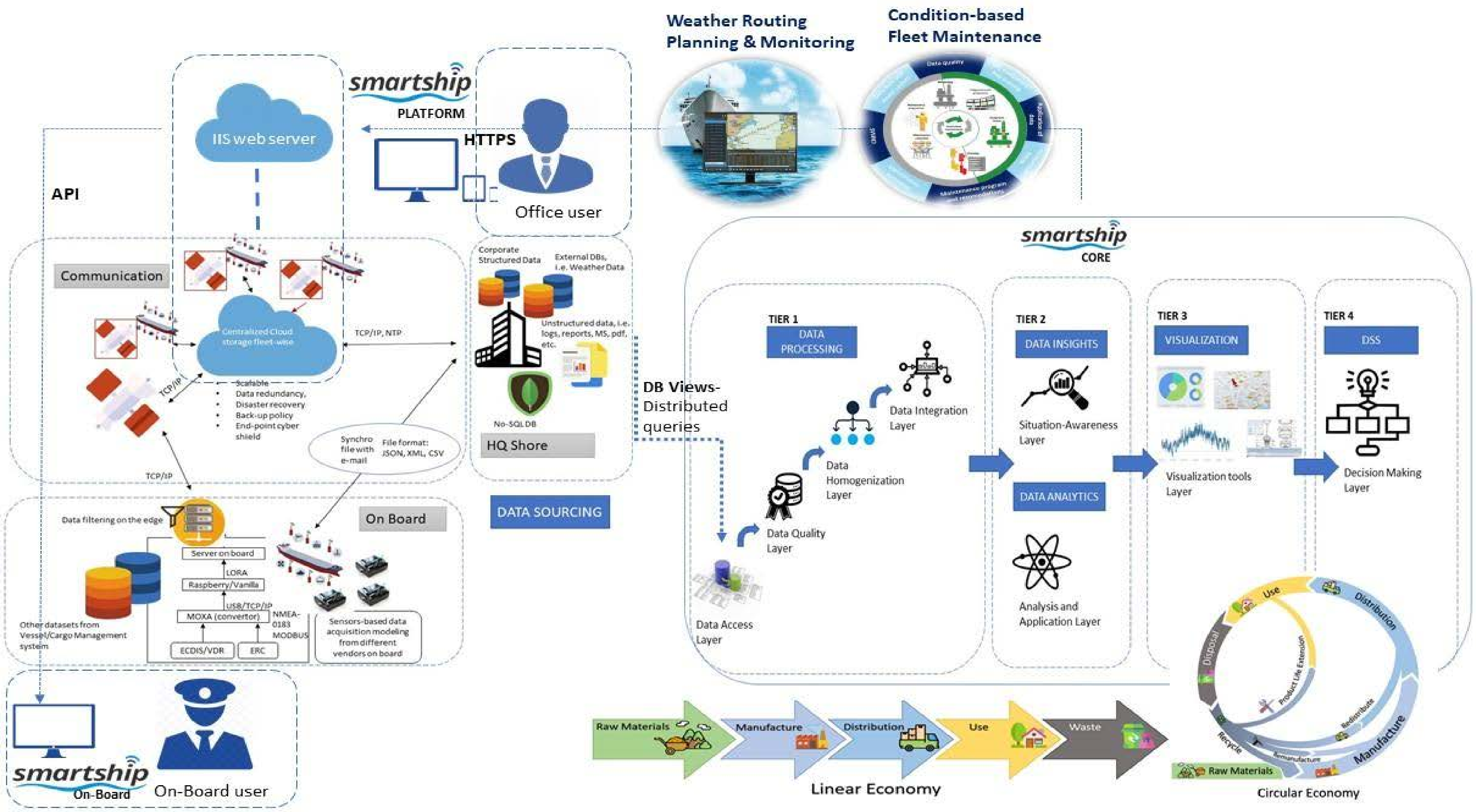

Figure 1. SmartShip integrated framework

4. Integration and implementation

4.1 Project development

Development of SmartShip followed the principles and practices of an agile framework. Specifically, the SCRUM framework was adopted, which provides a structured and iterative approach to project management that emphasizes collaboration, transparency, and flexibility. In terms of Scrum **roles**, rather than assigning them to specific individuals, they were assigned to the seconded staff of the project partners who were responsible for their respective roles but open to collaboration. Scrum **events** like sprint planning, sprint retrospective, and sprint review were conducted during consortium meetings, with progress documented in deliverable stages. Priorities were based on the proposal, and work progress was collectively accepted, with the tech leader having veto power. A more detailed description of the applied SCRUM framework may be found in Section 5 of D5.1.

The release plan of the integrated framework consists of two rounds of iteration. The first iteration integrates the initial versions of Data analytics Module (see D4.1 section 5) and the Decision support and optimization module (see D5.1) into a first integrated system following a backlog of user stories based on the user requirements as listed in D2.1. The system was validated against the set of KPIs (see D2.1 section 7) and tested by DANAOS users during the first pilot round. The feedback collected by the users was incorporated in a new refined backlog which triggered the implementation of the updated version of both Data Analytics and Decision support modules (see D4.1 section 5 and D5.1 section 6 respectively). The updated versions integrated into a new release of the integrated SmartShip system (final version) which will be validated and tested by the end-users. The final validation and evaluation results will be collected and presented in D6.2 at the end of the project (M60). The schematic flowchart of the aforementioned release plan is following the milestones as set in the project's Description of Actions (GA, Annex 1_Part B) and displayed in Figure 2.

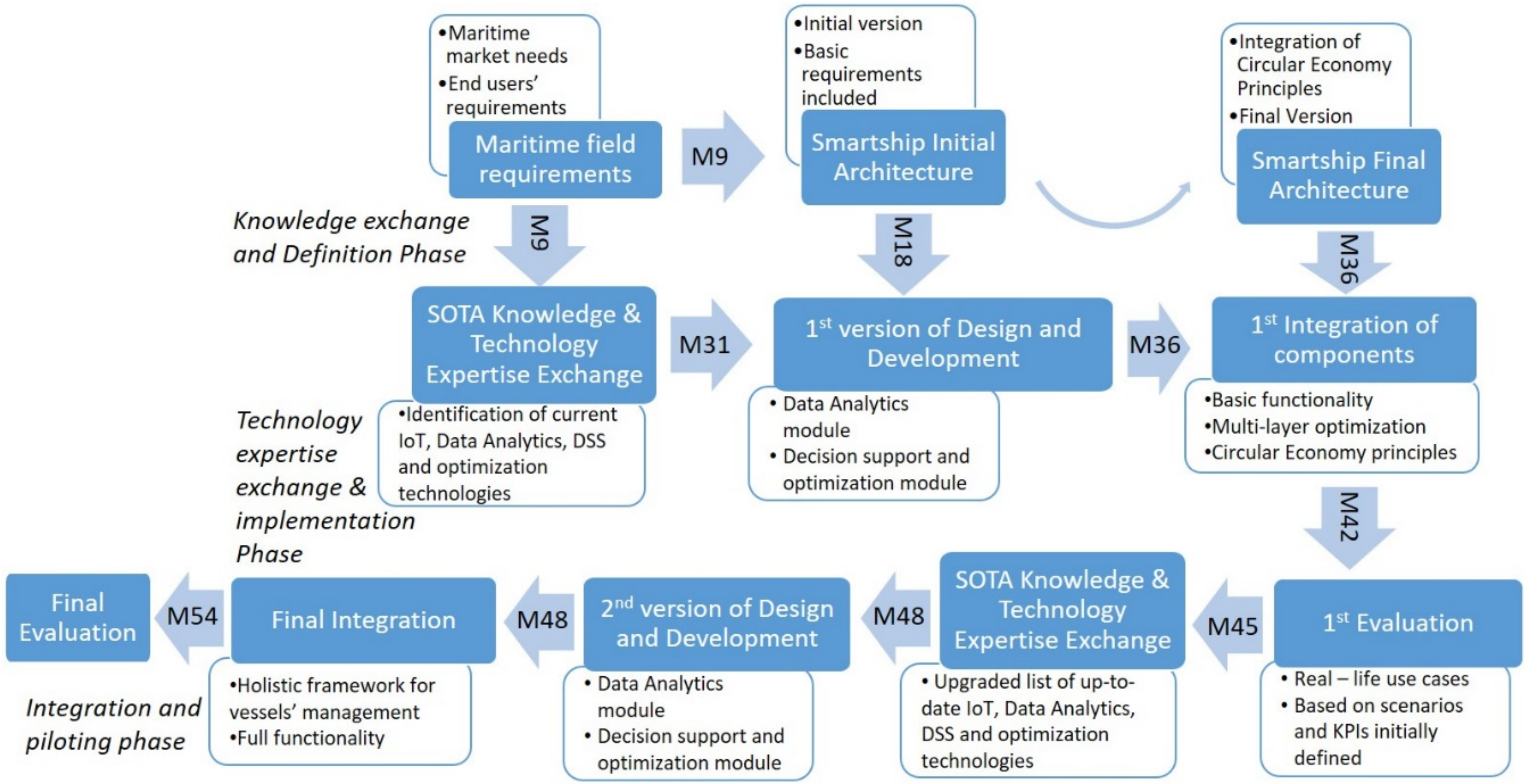

Figure 2. SmartShip release plan

4.2 Software integration

DevOps methodology was applied in the project's software-related operations, which promotes an integrated and automated approach to software development, deployment, and maintenance. At its core, the DevOps methodology is anchored in several fundamental principles. These include continuous integration, continuous delivery, and the practice of infrastructure as code. Continuous integration involves the utilization of tools like Jenkins, CircleCI, or Travis CI (see D5.1) to frequently and automatically build, test, and validate code changes. This proactive approach helps identify and rectify bugs in the early stages of development, ultimately reducing the time and expenses associated with bug fixes. A more detailed description of the applied DevOps methodology may be found in D5.1.

The APIs for data retrieval and data representation along with the common application environment of both core components of the integrated system (Advanced Data Analytics module and Decision-support optimization module) were also formalized in D5.1 section 6. These technology specifications were implemented to bridge both components in one intergraded framework. The integrated SmartShip system is hosted both on premises and on cloud whereas server specifications are scalable based on the users' number. Database and application server specification may be found in paragraph 7.2 of D5.1 and copied below for easy reference.

Database Server

Table 1. Database server specification

Users	1-5	6-10	11-25	26-50
CPU (cores)	4	6	6	8
RAM (GB)	12	16	32	64
HDD (GB)	250	300	400	500
O/S	LINUX Centos 7 or latest			

Application Server

Table 2. Component server specification

Users	1-5	6-10	11-25	26-50
CPU (cores)	6	6	8	8
RAM (GB)	12	16	16	32
HDD (GB)	200	300	300	350
O/S	Windows server 2012 or latest			
OTHER	IIS.net 4.5			

4.3 Implementation to Use Cases

SmartShip is implemented in four Use Cases, as described in D2.1. Basically, these use cases are regular maritime operations like route planning and vessel's condition monitoring. In each Use Case SmartShip acts on top of existing tools created by DANAOS Shipping, improving their efficiency, and enriching their capabilities. These tools include (a) a weather routing system, and (b) a fleet performance monitoring platform. SmartShip implementation will be assessed based on the KPIs described in D2.1. Circular-Economy concepts were also incorporated. Table 3 summarizes the implementation aspects of each Use Case.

Table 3. Implementation aspects of Use Cases

Use Case #	Description	Existing infrastructure	SmartShip implementation	KPIs	Circular Economy
1	Weather routing optimization	DANAOS weather-routing system	Embedment of external references in route planning through statistical analysis of AIS data	1. Reduction of fuel consumption 2. Reduction of emissions 3. Improvement of accuracy of the routing advise tool	Improvement of voyage environmental and economic performance
2	Route monitoring	DANAOS weather-routing system	1. Development of a warning system for real-time performance deviations based on AIS data 2. Development of a tool for actual voyage-performance evaluation and comparison against systems' route proposals.	1. Reduction of fuel consumption 2. Reduction of emissions 3. Improvement of accuracy of the routing advise tool 4. Monitoring the performance of energy-efficient operations	Improvement of voyage environmental and economic performance
3	Condition-based (predictive) maintenance	DANAOS fleet-performance-monitoring platform	1. Development of algorithms for predictive maintenance 2. Training of neural networks 3. Expansion of sources for data retrieving	1. Improvement in anomaly detection and failure prediction of the vessel-performance monitoring tool 2. Development of reuse-and-remanufacturing database of materials for engine components	Prolongment of assets lifetime
4	Visualization	DANAOS weather-routing system and DANAOS fleet-performance-monitoring platform	1. Modernization of UI 2. Improvement of UX	Acceptance evaluation from DANAOS end-users in terms of interactivity, friendliness, clarity, usability, design and overall experience	Engagement of staff community

4.3.1 Use case #1

- **Aim**: ShmartShip aims to enhance voyage planning and weather routing for ships. The integrated framework focuses on efficient providing shipmasters with weather routing advice that considers various factors, including weather conditions, vessel characteristics, and cargo specifications.

- **Existing tool**: The existing weather-routing tool implements multi-layer optimization algorithms to achieve multiple objectives like on-schedule arrival, compliance with charter party clauses, fuel savings, and cost efficiency.

- **Departure**: SmartShip leverages statistical analysis of AIS data, historical data, and digital navigational systems to create the best-fit route scenario and improve the performance of the existing tool.

- **Implementation**: SmartShip platform was implemented on real voyage scenarios for DANAOS ships. Performance testing in terms of efficient data input to the weather-routing tool was done by the Operation Department onshore. The Department received the recommended route plan, **enhanced with the trajectory analysis based on AIS data**, from the system and passed it to the navigation officers onboard. Evaluation of efficiency of the system implies the comparison of the recommended route plan to the actual one selected by the ship's master, with respect to the KPIs and the values of the relevant evaluation parameters i.e., emissions, fuel-oil consumption time of voyage etc. Results and outcomes of the SmartShip implementation will be presented in the validation report in D6.2 on M60.

- **Interface**: Representative snapshots of the system's environment where the use case applies, are presented below. Caption of the figure is displaying the interface of the user with the service

Figure 3. AIS-based traffic information for vessel trajectories clustering

Figure 4. Acquired AIS-based trajectories. Global routes in the Mediterranean Sea

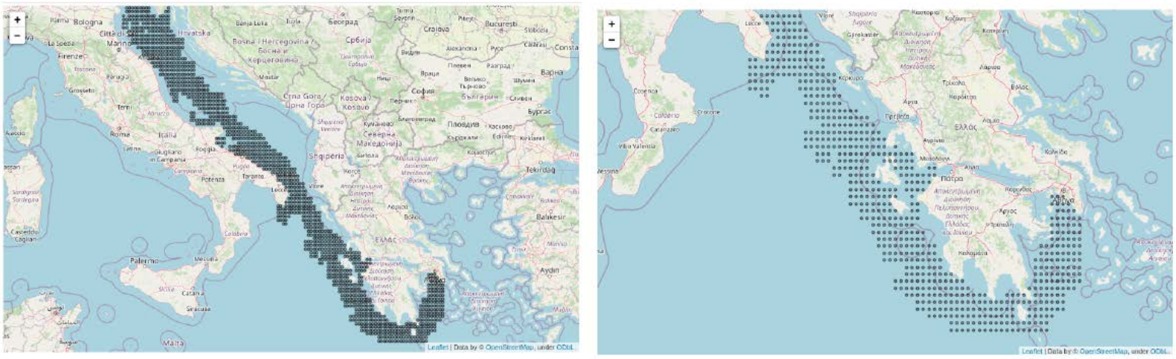

Figure 5. Generated reference sea grid based on trajectory mining

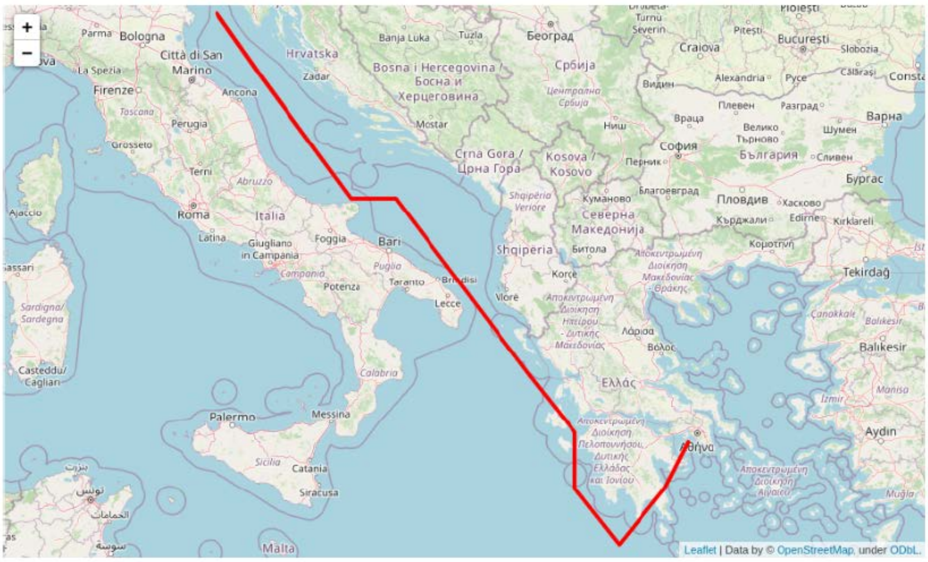

Figure 6. Route advice to the master. AIS-based service is showing greater accuracy and efficiency in narrow seas

4.3.2 *Use case #2*

- **Aim**: SmartShip aims at more efficient real-time and on-the-spot adjustments of routing advice during a voyage, through the active engagement of the ship's routing-responsible crew.

- **Existing tool**: During a voyage DANAOS weather-routing weather tool dynamically adjusts route advice to the ship's master based on real-time conditions and updated weather forecasts.

- **Departure**: SmartShip extends the capabilities of the existing tool by generating alerts for the captain in case of performance deviations from predefined indicators due to the master's navigation decisions (see D2.1 section 3). During the voyage it generates dynamic voyage performance comparisons between the actual route chosen by the master and the system's recommended route, both based on real weather data and assessed against actual voyage conditions. At the end of the voyage the system generates a comprehensive "Voyage Performance Evaluation Report" that takes into account various factors, including charter party terms, actual vessel speed and consumption, loading conditions, and encountered weather conditions. The system also generates a performance report comparing the master's route and the system's route advice, potentially leading to improvements in the routing algorithm or an evaluation of the master's navigation skills (see D2.1).

- **Implementation**: As in Use Case #1, navigation officers and the Operation Department collaborated towards obtaining optimal weather-routing during the voyages. **Real-time monitoring of weather conditions and vessel performance, together with historical data were fed into the platform with the aim of providing dynamic routing advice.** Recorded deviations between the two routing plans (see Use case #1) by the alerting system were analyzed by officers onboard and onshore. Outcomes of this dynamic comparison will be presented in the validation report in D6.2.

- **Interface**: Representative snapshots of the system's environment where the use case applies, are presented Figures 7 and 8. Caption of the figure is displaying the interface of the user with the service.

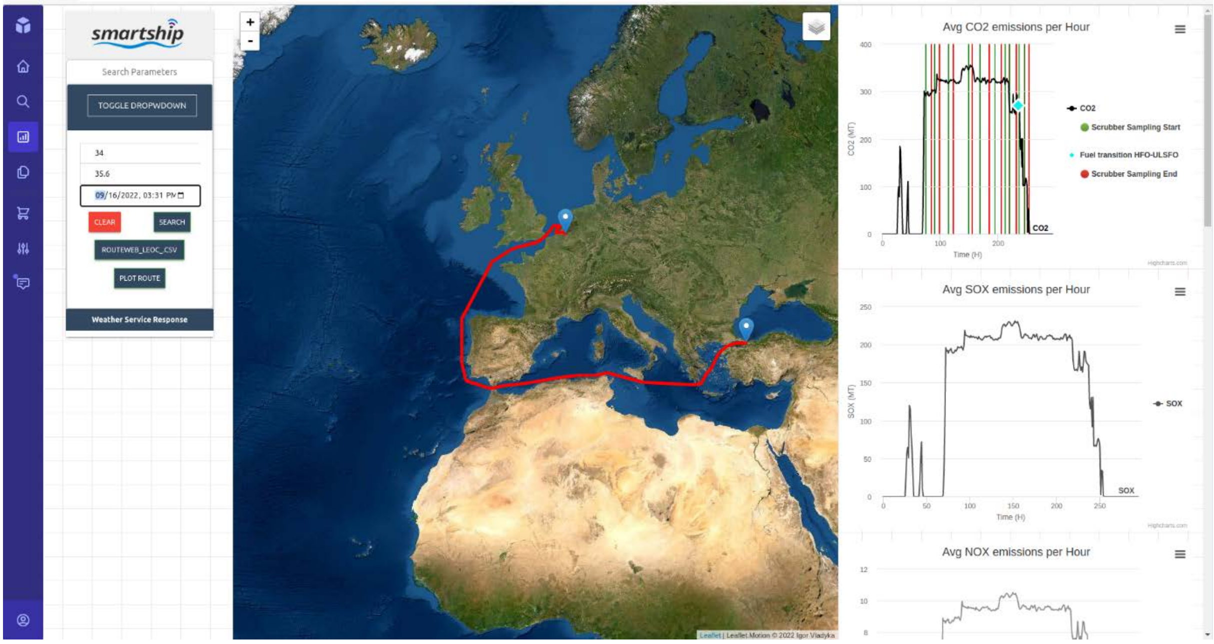

Figure 7. Dynamic route planning based on real time monitoring of voyage/vessel conditions (e.g., emissions)

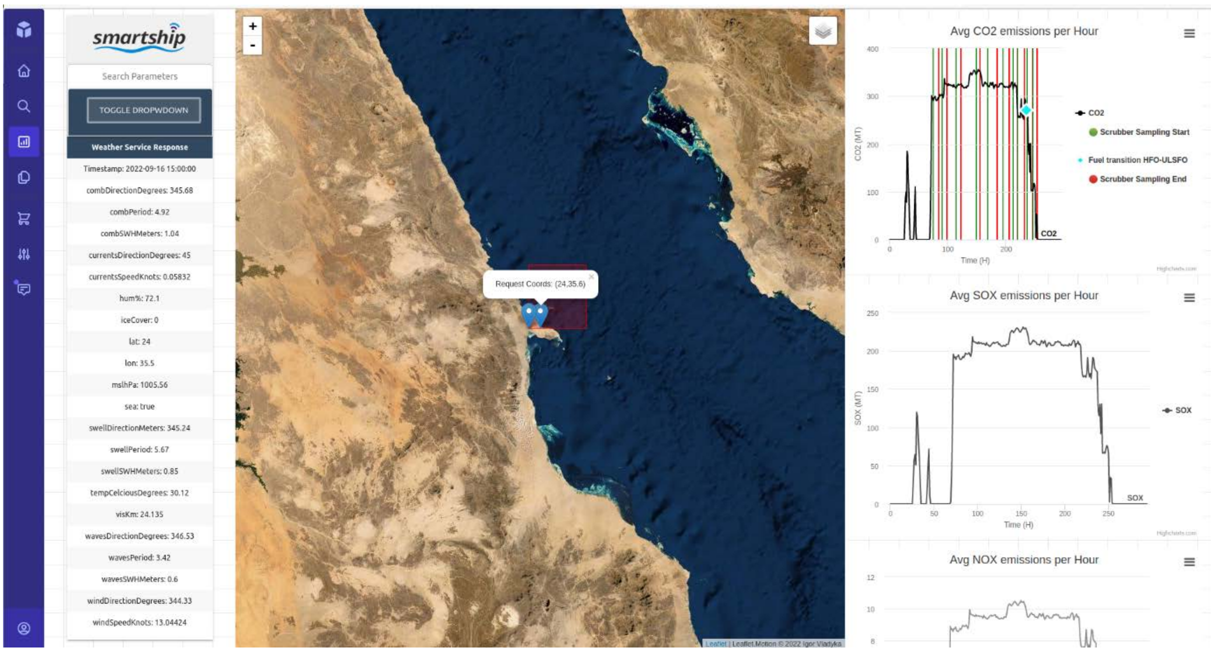

Figure 8. Real time weather conditions along the route

4.3.3 Use case #3

- **Aim**: One of the main SmartShip objectives is to facilitate and promote the shift from traditional maintenance practices based on predefined schedules to modern approaches like CBM and PBM.

- **Existing tool**: DANAOS fleet-performance-monitoring platform collects data from various sources using IoT and applies AI and machine learning techniques, in order to identify patterns for predicting future events and prevent undesirable outcomes (see D2.1).

- **Departure**: SmartShip assumes a pivotal role in analyzing historical data and formulating operational guidelines for predictive analysis through the algorithm configuration and neural-network training. SmartShip will also enhance asset performance monitoring by aggregating data from a wide range of sources.

- **Implementation**: Data collected from the vessel were processed by the onshore technical department. The fleet manager, who holds responsibility for the vessel, gained an initial **understanding of its condition by analyzing data from sensors** and offered **corrective measures when anomalies were detected**. The technical manager was responsible for error handling and the overall technical oversight of the entire fleet. The financial officer had complete visibility into asset depreciation, while the vessel's owner was constantly kept informed about its current condition and value. Finally, the supply department and procurement manager provided essential support in procuring and delivering spare parts to replace machinery components in the case of failure detection. The relevant validation report will be presented in D6.2.

- **Interface**: Representative snapshots of the system's environment where the use case applies, are presented in Figures 9 - 11. Caption of the figure is displaying the interface of the user with the service.

Figure 9. Report of fuel consumption deviations for a single voyage

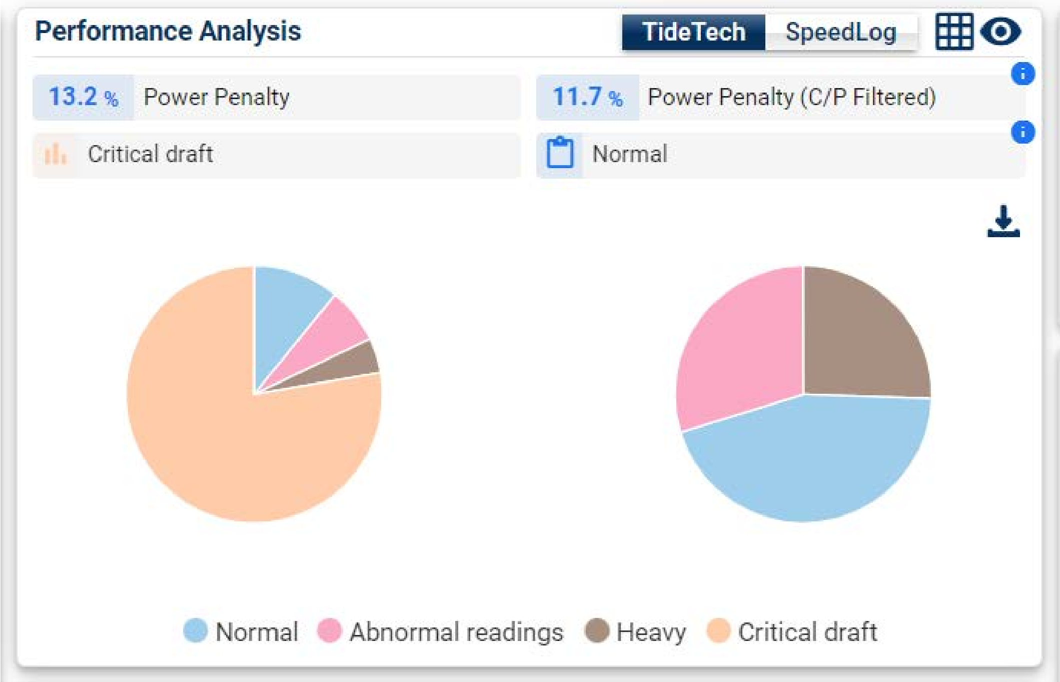

Figure 10. Performance analysis based on data recordings on vessel energy consumption. Anomaly detections of power readings trigger decision-making for corrective actions.

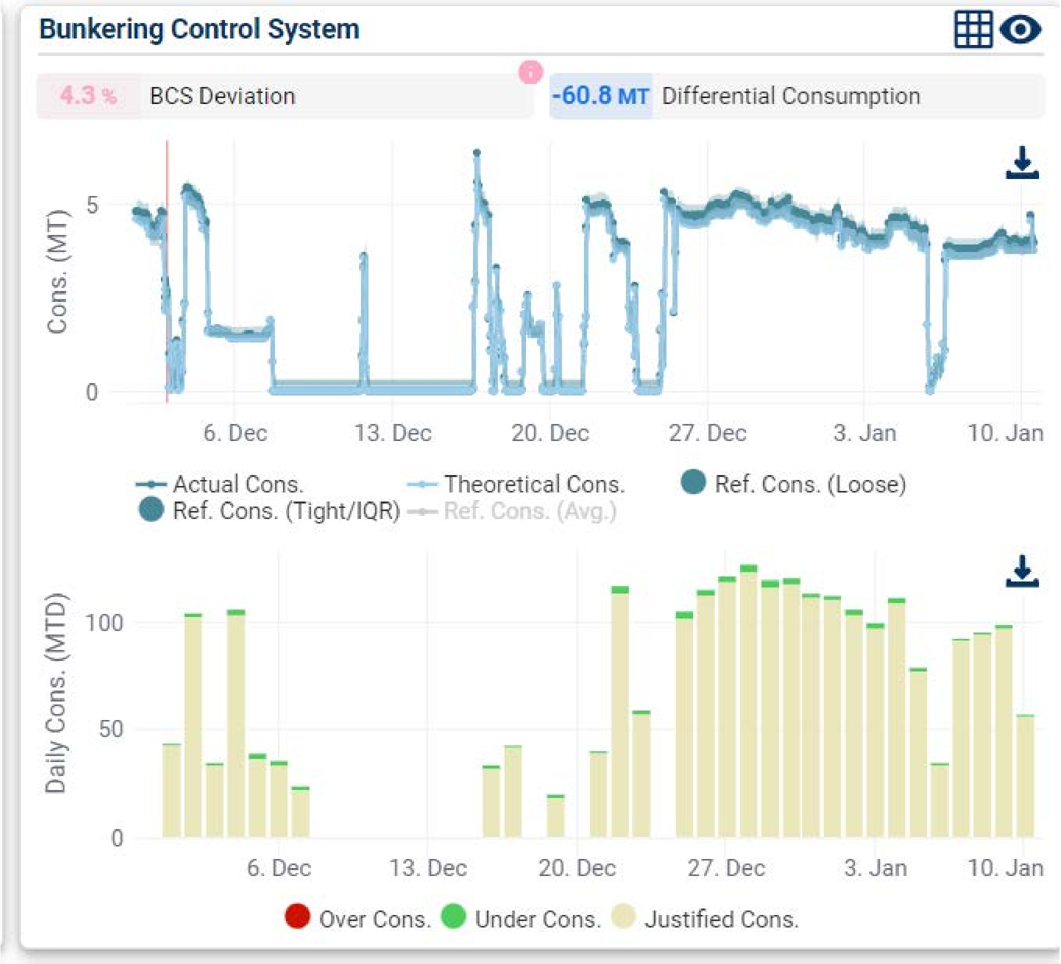

Figure 11. Monitor of daily fuel consumption of a vessel and presentation of recorded deviations from the expected baseline

4.3.4 Use case #4

- **Aim**: SmartShip aims to improve UI and UX of the existing visualization tools in the fields of displaying navigation (alternative routes, route deviations, and associated weather conditions) and fleet-performance monitoring.

- **Existing tool**: UI configuration applied to existing DANAOS Shipping tools for weather-routing and fleet-performance monitoring.

- **Departure**: SmartShip is expected to **enhance viewing of predictive maintenance reports**, recommended and calculated routes, fuel consumption, and other voyage related information in a manner that supports decision making (see D5.1).

- **Implementation**: SmartShip **enhanced the environment of end-user applications** as described in D5.1 by providing user-friendly interactive GUI. Acceptance tests were developed and delivered to DANAOS end-users to assess the visualization capabilities against specific criteria. These criteria included factors such as interactivity, user-friendliness, clarity, usability, design, and the overall experience to ensure that the platform meets user expectations and needs (see D2.1). The outcomes of these tests will be presented in D6.2.

- **Interface**: Representative snapshots of the system's environment where the use case applies, are presented in Figure 12. Caption of the figure is displaying the interface of the user with the service.

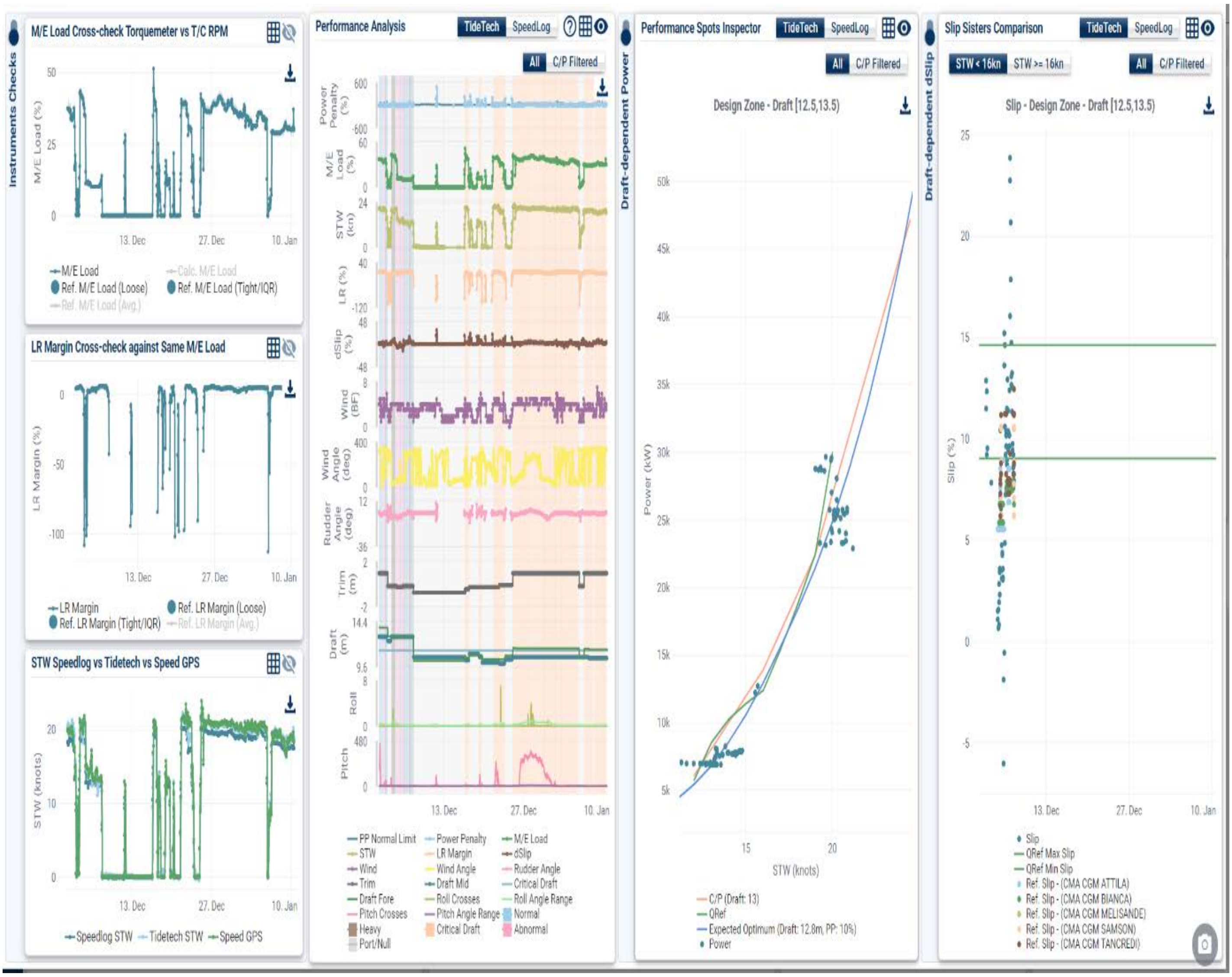

Figure 12: Comprehensive full technical report of vessel performance presented in a consolidated dashboard developed by SmartShip seconded staff and offered to the users

5. Conclusions

The SmartShip platform was developed through the aggregation of data sources, advanced data analytics, optimization algorithms, decision support systems, enhanced interactive information-display and a cloud-based communication environment.

A full integration of the data analytics and decision support components (described in D4.1 and D5.1) was realized based on the principles of the SCRUM project-management framework and the DevOps methodology on software development.

Principles and practices of Circular Economy were taken into consideration to meet the challenges of modern maritime with respect to sustainability and green economy. Thus, in the frame of incorporating the main principles of Circular Economy in the maritime field, the consortium focuses on exploiting energy efficiency, fuel consumption, and emission control optimization procedures in terms of applying such principles regarding the engines' components' operation and reusage.

The SmartShip integrated system was applied to four maritime use-cases with different specifications and stakeholders' requirements.

The main actors in the use cases were engaged and performed their roles according to the project's plan and the use-case specifications. The SmartShip research team (formalized by the seconded staff of the consortium) contributed to the deployment and configuration of the services that were implemented to satisfy the use-case requirements (see section 4.3)

The main KPIs and evaluation parameters were assessed for all use cases to validate the performance of the 1st version of SmartShip framework. The report of the outcomes will be presented in D6.2.