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Project Acronym:	**SmartShip**
Project Full Title:	**A data analytics, decision support and circular economy – based multi-layer optimization platform towards a holistic energy efficiency, fuel consumption and emissions management of vessels**
Project Duration:	**60 months (01/04/2019 – 31/03/2024)**

SmartShip Circular-Economy based functional architecture

Work Package	**WP3 – SmartShip Circular-Economy based functional architecture design**
Due Date:	**31.03.2022**
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Executive Summary

The main objective of this deliverable is to adjust and customize the SmartShip Architecture building on top of the existing DANAOS infrastructure and according to the design, specifications, functional requirements, current standards, and circular economy core principles. The focus areas are energy efficiency, fuel consumption, and emissions control optimization procedures. Thus, D3.1 provides the Smartship architecture based on the design combining the different components and mechanisms and supporting both the Telecom Functions and the O&M Functions. This architecture considers the specification of the system entities and the self-healing, energy efficiency, and web-based functionalities and the specification of interfaces and the corresponding signaling protocols for the interactions.

D3.1 also describes the SmartShip functionalities focusing on the mechanisms to reduce the average IP acquisition latency and the network overhead; naming, addressing, and object localization in networks of internet-connected marine vessels; mechanisms to extend the coverage time of nodes in internet-connected marine vessels from a DHCP perspective and the investigation of routing protocols including tunneling through non-IP links.

In the end, D3.1 describes the adjustment and customization of the SmartShip architecture as developed based on functional requirements and existing standards to incorporate the core principles of circular economy in the maritime field. The main focus is exploiting energy efficiency, fuel consumption, and emission control optimization procedures to apply such principles to engines' components' operation and re-usage.

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List of Acronyms and Abbreviations

Term	Description
AIS	Automatic Identification System
AMS	Alarm Monitoring System
AoI	Area of Interest
API	Application Programming Interface
BHP	Brake Horsepower
CBM	Condition-based (predictive) maintenance
CE	Circular Economy
CIDR	Classless Inter-Domain Routing
CNN	Convolutional Neural Network
DB	DataBase
DDL	Data Description Language
DHCP	Dynamic Host Configuration Protocol
ECR	Engine Control Room
ECDIS	Electronic Chart Display and Information System
EIGRP	Enhanced Interior Gateway Routing Protocol
ERP	Enterprise Resource Planning
ETA	Estimated Time of Arrival
ETSI	The European Telecommunications Standards Institute
FOC	Fuel Operational Consumption
GRE	Generic Routing Encapsulation
HQ	HeadQuarters
HTTP	Hypertext Transfer Protocol

IoT	Internet of Things
IP	Internet Protocol
IMO	International Maritime Organisation
ISG	Industry Specification Group
KPI	Key Performance Indicator
LCA	Life Cycle Analysis
LTE	Long Term Evolution
MAC	Media Access Control
M/E	Main Engine
OSPF	Open Shortest Path First
PCS	People-Centric Sensing
RDBMS	Remote onboard database Server
REST	Representational State Transfer
SOG	Speed Over Ground
SQL	Structured Query Language
STW	Speed Through Water
SOAP	Simple Object Access Protocol
VDR	Voyage data recording
VPN	Virtual Private Network
XML	Extensible Markup Language

1. Introduction

1.1 Scope and objectives of the deliverable

Deliverable D3.1 builds on top of the existing DANAOS infrastructure. It aims to provide the specification of the Smartship functional architecture in terms of translation of the requirements into functions, grouping them into functional blocks, and the specification of interfaces between blocks to build the architecture. Moreover, it aims at shedding light on the incorporation of the core principles of the circular economy in the SmartShip final architecture.

1.2 Structure of the deliverable

This deliverable contains the SmartShip Circular-Economy-based functional architecture design. It includes the first part after the introduction to the deliverable, and it is structured as follows:

- **Section 2** describes the specification of the SmartShip functional architecture, including SmartShip infrastructure components, data sourcing (IoT) network, SmartShip core system, and the user description
- **Section 3** describes the supporting functionalities of SmartShip functional architecture, including the mechanisms to reduce the average IP acquisition latency and the network overhead, naming addressing, and object localization in networks of internet-connected marine vessels, mechanisms to extend the coverage time of nodes in internet-connected marine vessels from a DHCP perspective, and investigation of routing protocols, including tunneling through non-IP links
- **Section 4** describes the incorporation of the Circular Economy Principles in SmartShip functional architecture, including the increasing need for sustainability in the maritime industry, digitalization enabling the circular economy, SmartShip circular architecture requirements, and the opportunities for the circular economy in the project
- **Section 5** points out three main conclusions of the deliverable

1.3 Relation to Other Tasks and Deliverables

This deliverable expands upon SmartShip WP 3. Task 3.3 Integration of Circular Economy principles in Smartship architecture uses inputs from Task 3.1 Design and specification of the SmartShip architecture and Task 3.2 Supporting functionalities for SmartShip. Based on the requirements described in WP2, Task 2.3 Roadmaps for marine vessel management optimization provided information about the critical steps for incorporating the circular economy core principles in the SmartShip architecture.

2. Design and Specification of the SmartShip Architecture

SmartShip develops & delivers a holistic framework for energy efficiency and emissions control incorporating technological advancements, information harvesting, short/mid-term decision support tools, and human intellect, thus materializing the next-generation paradigm for the maritime industry.
SmartShip is based upon an architectural design comprising concrete components to achieve state-of-the-art deployment, which is described below. SmartShip ecosystem includes **three layers/components**. From a bottom-up perspective, these components are:

1. Data Sourcing (IoT)
2. SmartShip Core system
3. Users Applications

The high-level approach of SmartShip architecture is presented below in Figure 1:

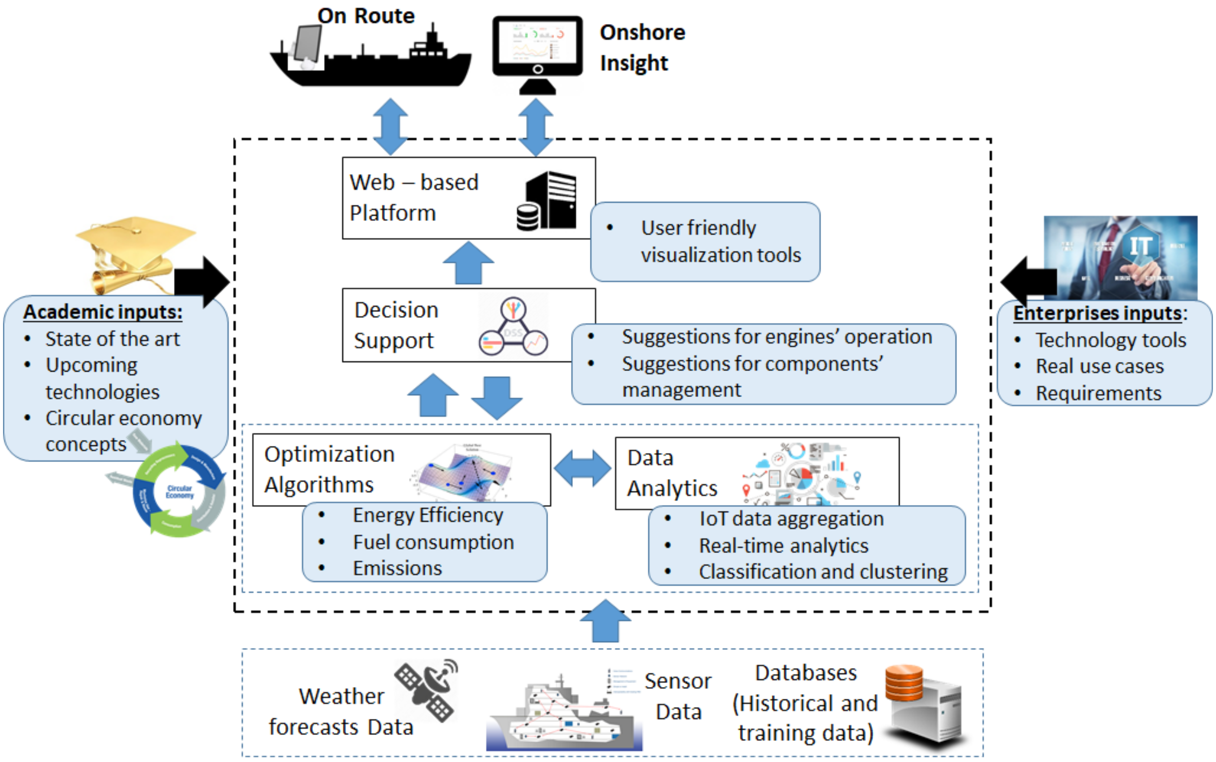

Figure 1 SmartShip architecture design (high-level)

A thorough breakdown of all system layers is presented in the following sub-sections. Features, technologies, and interfaces of all the components are configured in an integrated SmartShip architecture design (see Figure 7), which constitutes the final elaborated version in continuation of the high-level architecture definition as presented in Figure 1.

2.1 SmartShip infrastructure components

As mentioned above, in the framework of T3.1, "Design and specification of the SmartShip architecture," we identified three components of the SmartShip Infrastructure: (i) Data sourcing; (ii) Core Systems; and (iii) Users applications. Each component includes individual tools, methodologies, and processes towards an integrated SmartShip ecosystem able to offer a multi-layer optimization in the fields of fuel consumption, energy efficiency, and emissions control management, in full respect to the implementation of the requirements of maritime sector regulations and taking into account applications of circular economy concepts in the maritime as well.

2.1.1 Data Sourcing (IoT) definition

This SmartShip system component considers tools, communication protocols, and network topology for data retrieving, pre-processing at the edge, and finally, transferring information to the SmartShip core for further processing and analysis.

2.1.2 SmartShip Core system definition

The SmartShip core is the heart of the whole ecosystem. Data is processed, analyzed, and visualized to support decision-making for critical maritime operational procedures defined in the project's Use cases.

2.1.3 User Applications

This layer identifies how the meaningful information as a product of data processing and analysis is consumed by users either ashore or onboard. In this system component, the user consumes information as represented in the SmartShip core, reaches decisions for critical tasks (refer to use cases), and configures the fleet's management in an optimized manner in terms of energy efficiency and emission control. This layer also facilitates active interaction between shore and vessel, where information is returned to the source (vessel) as valuable feedback for a sustainable and green operation. This layer is where SmartShip architecture realizes circular economy principles.

2.2 Data Sourcing (IoT) Network

The data sourcing network is presented below in Figure 2:

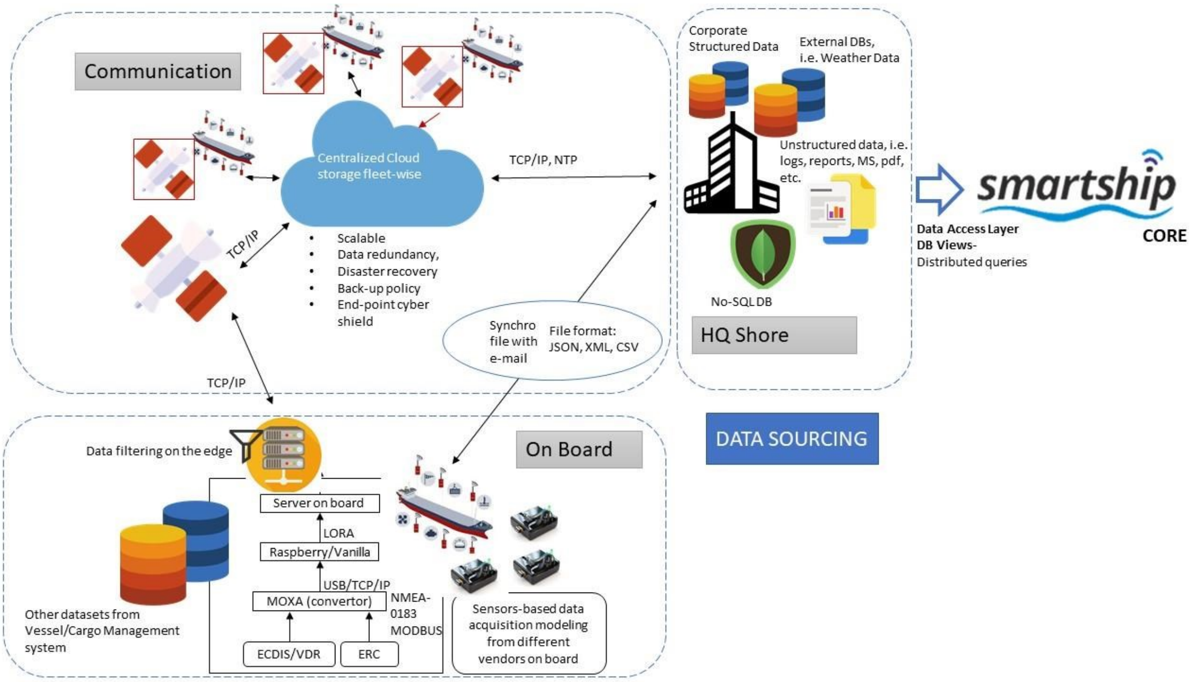

Figure 2 Data Sourcing Network

2.2.1 Network Description

Onboard

Vessel's data from acquisition systems modeled from various vendors (e.g., LAROS, MARORKA, ENIRAM) is mainly captured from the bridge and the ECR (Engine Control Room). On the bridge, there are ECDIS and voyage data recording (VDR) from which data for the ship's navigation, such as position, speed through water (STW), and speed over ground (SOG), among other information, is mainly collected. The ECR data is collected from the AMS (Alarm Monitoring System), scavengers, torque meter, cylinders, diesel generator, and flowmeter. Data from sensors is captured and stored on a dedicated server onboard. There is an option for sensor datasets to be interrelated with raw data captured from other onboard systems (vessel and cargo management systems, ERPs, etc.) to pre-process synchronous information (data insights) on the edge. Before transmitting data to the shore, initial filtering and cleansing of data streams are performed at the edge, validated, and consistent datasets are sent to the shore for further exploitation.

Communication

Vessel-to-shore (and vice versa) communication is activated in two ways. One way is through a centralized cloud repository aggregating all data streams from the fleet. Cloud is dedicated and configured at scale. Cloud service is agnostic to a third-party provider (Amazon, Azure, etc.). Service is configured based on the company's specific data traffic, security policies, scale, constraints, area of operation, etc. The other way is through a synchronization application. Synchro app activates one-to-one email service link synchronizing vessel database and a clone database replica in the office. Synchro app automatically transmits data records from vessel to office in pre-configured intervals and vice versa. Datasets comprised of raw data records of any type compiled in data files of different data representation format while transmitted to shore or vessel (depending of whom is the sender and the receiver) in a pre-configured secure manner.

HQ Shore

Sensor-based data streams from vessels are collected to shore. Data configuration, correlation, processing, and analysis are performed at the shore through SmartShip Core. Fleet sensor data is correlated with other data sourced from other systems onboard and at the shore (corporate office). These datasets could be structured and generated from operation software (ERPs), could be semi-structured, captured from forms that support internal formalities (doc., Xls, pdf,) or unstructured (logs, reports, etc.). Data is also captured from external sources (e.g., weather service) and correlated with internal information. These synchronous and asynchronous data configured in different streaming frequencies constitute the chunk of information that is processed and analyzed in SmartShip Core to leverage data into knowledge and decision making.

2.2.2 Network Hardware Components

OnBoard environment

For data acquisition modeling H/W devices from third-party providers are used. Those recommended and globally established in the industry are:

- ***Laros Quax Unit[1]:*** LAROS hardware (Quax units) provide the synchronized and reliable signals (data) collection from any type of sensor, measuring device, instrument, or control system onboard under the operation of a wireless network. Quax units are remotely configurable and operate on a "plug and play" principle allowing easy expansion of collectors network very fast and easily***,***
- ***Raspberry PI:*** Most common computer platform for data acquisition. A Raspberry Pi, 4 Model B, offers a 64-bit quad-core ARM processor, gigabit ethernet, wireless, Bluetooth, 4 USB ports, micro SD slot, and dual HDMI outputs,
- ***Data acquisition devices*****:** USB and Ethernet are mainly used. Capture data from sensors and equipment onboard (ECDIS, VDR, etc.) and connect to a computer platform (e.g., Raspberry PI) to transmit the collected/acquired data,
- ***Remote onboard Server:*** Hardware specs configured at scale. Typically supports 200 GB disk space for cache, 8 CPU cores, and 16GB RAM,
- ***MOXA converter:*** Moxa's serial media converters allow devices with different serial interfaces to communicate effortlessly. The purpose is to receive output from sensor layers (equipment onboard as ECDIS) and convert it to USB or ethernet (serial to serial, serial to ethernet, serial to fiber, etc.),
- ***Display/Monitor:*** Connected to the computer platform of the acquisition system (i.e., Raspberry) for visualization of information on the edge or programming,
- ***Multiplexer:*** Activated to forward analog or digital signals from two or more sensors/equipment on board at the same place to a single unit/line.

Communication environment

Cloud server: Data storage in a vendor-agnostic agile and scalable cloud repository (e.g., Azure). A dedicated cloud service. Specs are rendered according to fleet size, data stream frequency, and data storage needs

HQ Shore environment

Database server: Agnostic vendor. Specs are configured at scale following the company's digital configuration volume and network design. For SmartShip, a dedicated database replica of the onboard database schema is needed to mirror the structure of collected data onboard.

2.2.3 Network Software Components

OnBoard environment

Data acquisition systems and computer platforms

[1] https://www.laros.gr/

The operating system is agnostic (i.e., windows/Linux). The programming language for Raspberry configuration is mostly Python under Linux operating system.
Remote onboard database Server:
RDBMS: Any vendor (i.e., Oracle express)
Operating System: Any environment (i.e., Windows Server)
Purpose: Storing collected data
Synchro App.
A synchronization application is used to transfer data batches to shore (or receive from shore) through an automated mail service link. At this point, the vessel environment is composed of a database server, an application server, and an application client Database and application server constitute a logical distinction, as they are co-hosted on the same physical machine. The application server might also host the application client in the vessel environment.
Software hosted on the application server: Synchro app.
Purpose: A) Establish pop3/smtp connections with the mail server to send/receive emails with synchronization files attached. B) Execute DDL sql commands based on synchronization files contents. C) Generating synchronization files
Synchro data files representation/standard format. CSV. XML, JSON, etc
Data Types
Typical data collected from sensors onboard, stored on a remote onboard db server, and sent ashore for further processing, is displayed in the following table:

Table 1: Data collected from sensors onboard

Bridge Data	
Wind-speed (kn)	
GPS speed (kn)	
Speed through water (kn)	longitudinal
	transverse
Wind angle (0-359.99 degrees)	
Vessel draft (m)	at port-side (left-side looking to the fore)
	at starboard-side (right-side looking to the fore)
	at stern
	at fore
Speed through water (kn)	calculated by stw_trans and stw_lon
Vessel's position,	latitude
	longitude

Main Engine Data	
Air Cooler Cooling Water Inlet Pressure (Pa)	
Cyllinder (#12) (°C)	Scavenge Air Fire Detection Temperature
	Exhaust Gas Out Temperature
	Jacket Cooling Fresh Water Outlet Temperature
	Piston Cooling Outlet Temperature
Air Cooler Cooling Water Inlet Temperature (°C)	
Cooling Fresh Water Inlet Pressure (Pa),	
Control Air Pressure (Pa),	
Cylinder Lube Oil Temperature (°C)	
Exhaust Valve Spring Air Inlet Pressure (Pa)	
Fuel Oil	Flowrate (lt),

	Inlet Pressure (Pa)
	Inlet Temperature (°C)
Heavey Fuel Oil Viscosity High Low (mm2/s)	
HPS Bearing Temperature (°C),	
Jacket Cooling Fresh Water Inlet Temperature Low (°C)	
Turbo-Charger (#4)	Exhaust Gas Inlet Temperature (°C)
	Exhaust Gas Outlet Temperature (°C)
	Lube Oil Inlet Pressure (Pa)
	Lube Oil Outlet Pressure (Pa)
	Water Outlet Temperature (°C)
	RPMs
Order RPM (Bridge Lever)	
Rotations per minute of the main shaft	
Scavenge Air	Inlet Pressure (Pa)
	Receiver Temperature (°C)
Starting Air Pressure (Pa),	
Thrust Pad Temperature (°C),	
Main Lube	Oil Inlet Pressure (Pa)
	Oil Inlet Temperature (°C)
Fuel Oil	Temperature (°C)
	Total Volume (lt)
	Consumption (lt/min)
Consumed power (kW),	
Scavenge Air Pressure (Pa)	
Torque of the main shaft (N/m),	

Generator Engine Data #5 G/E	
Winding Temp-R	
Change	Air Pressure (bar)
	Air Temperature (°C)
Engine RPM Pick-up	
Lube Oil Purified Inlet (Lt)	
Power (kW)	
Starting Air Inlet Pressure (bar)	
Voltage (V)	
Fuel Oil Inlet Pressure (bar)	
High Temperature	Water Inlet Pressure (bar)
	Water Inlet Pressure (bar)
	Water Outlet Temperature (°C)
Lube Oil	Inlet Pressure (bar)
	Inlet Temperature (°C)
Low Temperature Water	Inlet Pressure (bar)
	Inlet Temperature (°C)
	Outlet Temperature (°C)
Cylinder Exhaust Gas Temperature (°C)	
Turbo-Charger	In A Exhaust Gas Temperature (°C)
	In B Exhaust Gas Temperature (°C)
	Lube Oil Inlet Pressure (bar)

	Out Exhaust Gas Temperature (°C)
	RPM Pickup

Communication environment

Cloud server operation system/framework

Depends on the vendor. Compatible either with Linux or Microsoft Windows or with both. For Azure, a globally used cloud service in today's maritime industry, windows environment/framework is provided for any necessary cloud computing. SmartShip will also exploit marine data analytics as a cloud solution (.net framework, SQL services, SharePoint, dynamics, interoperable environment supporting multiple internet protocols such as HTTP, REST, SOAP, XML).

HQ Shore environment

Database server

Agnostic vendor. Specs are configured at scale following the company's digital configuration volume and network design. For SmartShip, a dedicated database replica of the onboard database schema is needed to mirror the structure of collected data onboard.

2.2.4 Network Communication interface

OnBoard environment

Sensors/Equipment output

Marine equipment onboard (VDR, ECDIS, AMS, etc.) devices for outputting their data use the NMEA-0183[2] or MODBUS protocol[3], keeping in mind that for the hardware layer, they have RS 422 or RS 485 ports, respectively.

From data acquisition systems/computer platforms to remote onboard server

SmartShip enables data transferring from acquisition systems to onboard servers wirelessly using LoRa communication protocol[4]

Data Pre-processing before delivery to shore

Data is pre-processed onboard in the remote onboard server to reduce the cost of data transfer. Data is also validated and cleansed with pre-configured validation rules against range constraints (i.e., negative power values), mandatory constraints (i.e., null values), and self-membership constraints. This addresses the common threat of garbage in – garbage out in data processing and results.

Data Compressed: Less than 1 Mb of data transfer per day. Allows the use of narrowband satellite

Sample frequency: Typically 5 minutes, minimum 1 second.

Processing Method: Typical methods are first, last | (circular) mean | (circular) standard deviation | Minimum/Maximum | Trend

Batch transfer to shore intervals: On average, every 4 hours, with a minimum interval of 1 minute (for extreme real-time monitoring)

Server connection to ship network

The remote onboard server is connected to the ship's communication network (satellite, 4G/5G, or LTE), and data reports are transferred at fixed (user-defined) intervals

The communication link to the server is secured by VPN and firewall

The onboard communication network is commonly secured with two different lines of Ethernet links. One for the crew and one for all the other businesses. A relevant diagram of the ship network is presented below.

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[2] https://en.wikipedia.org/wiki/NMEA_0183

[3] https://en.wikipedia.org/wiki/Modbus

[4] https://en.wikipedia.org/wiki/LoRa

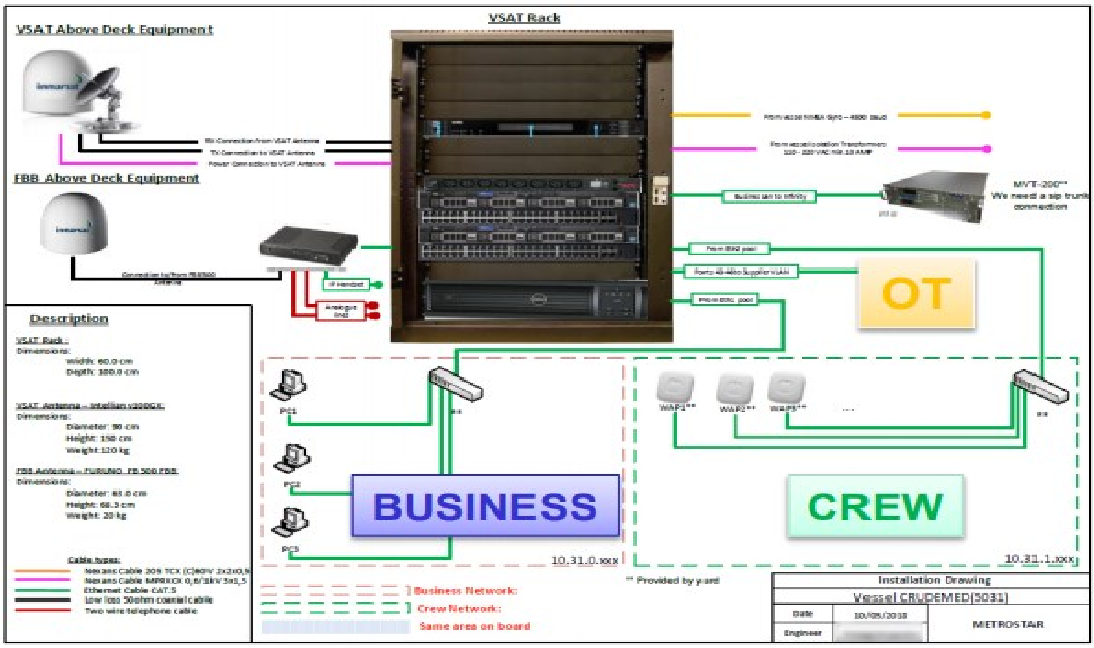

Figure 3 Ship network

Communication with HQ shore

The main communication link (to the cloud or mail synchro service) for data delivery to shore is via satellite (common marine standard INMARSAT's Fleet Xpress[5]), which features standardized plug-and-play service with 24/7/365 management, monitoring. It supports globally high data speed (4 MB download and 1MB uplink).

2.3 SmartShip Core system

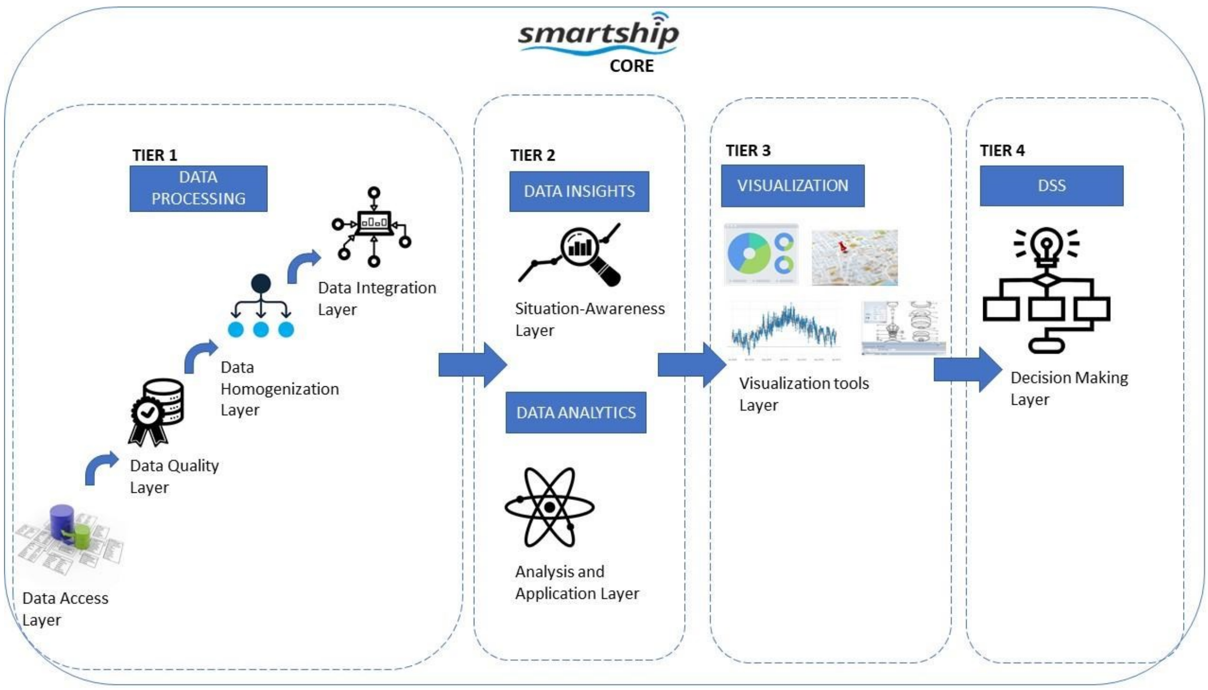

Figure 4 SmartShip Core Tiers

[5] https://www.inmarsat.com/en/solutions-services/maritime/services/fleet-xpress.html

2.3.1 SmartShip Core system Description

SmartShip core system comprises four tiers for the Data that is processed from the source and analyzed to be transformed into meaningful information for supporting users' decision making,

Tier 1. Data processing

Data processing consists of four layers interlinked sequentially. Begins with data access layer with build-in database views and connectors querying data from a distributed network of data sources (refer to 2.2). The data quality layer is followed and triggered in two instances (vessel and office sides). The vessel side includes data pre-processing and compression before delivery to shore, as described in section 2.2.4. The office side is a second step featuring validity, accuracy, and consistency checking once data batches are transferred to shore for further processing. The third layer is related to the data homogenization or conceptual representation layer. This layer deals with the transparent manipulation of data provided by heterogeneous sources and consists of two sub-layers naming the data heterogeneity manipulation and the data uniformity. The homogeneity of multi-source data using ontologies will assist in achieving the correlation of different measurements for the same value from other devices or sources across the fleet. For example, wind speed is streamed from a different acquisition system in vessel A (i.e., Laros) and another third-party provider in Vessel B (ENIRAM). SmartShip is homogenizing these data streams of the same domain acquired from independent parties hiding semantic heterogeneity and enabling common interpretation of data values. Data uniformity sub-layer triggers an auto unit conversion of data pooled from different locales to single measures (e.g., Vessel A gives M/E power in Kw and Vessel B in BHP). The final layer deals with data integration. This layer associates and integrates the same information from different sources to escalate machine-accessible low-level data to higher-level abstractions suitable for decision making. For example, Vessel A streams fuel consumption for the main engine from a high-frequency flow-meter, telegraphs in daily intervals, and lab analysis after bunkering. SmartShip, through operator-defined rules, combines and synchronizes values to translate data into meaningful information.

Tier 2. Data Insights and Data analytics

This tier of the SmartShip core system deals with the integrated SmartShip advanced data analytics module as a build-in system function. Tier 1 feeds the SmartShip analytics module, where data is presented in two manners:

1. Data insights are the situation awareness data representation field. The user quickly grasps the big picture over large data volumes, observes in real-time, uncovers hidden patterns in the underlying data, and gains knowledge. Data insights could be consumed through the user application interface in near real-time close to the edge of the source (fog layer); thus user onboard will instantly reflect insights to a fast response and decision. Data insights are mostly consumed following the data integration layer (refer to tier 1).
2. Data analytics is the operator-defined algorithmic analysis of fused data. Data analytics are performed ashore (office environment). Analytics allow "hindsight" to reflect and learn from past data by statistical processing past observations (trend analysis, etc.) and detecting hidden correlations among seemingly unrelated data. This is where deep knowledge of various aspects of vessels' lifecycle is achieved (LCA knowledge base). Analytics gives "insight" interpreting data and responding efficiently to the present by providing KPI's real-time monitoring (operational efficiency, safety performance, etc.), enabling vessel's benchmarking against theoretical curves. Specifications, tests, sea trials, and competitors or sister vessels trigger timely anomaly detection / alerting for abnormal behavior and deviation from predefined thresholds. Finally, Analytics offers "foresight" predicting and getting ready for future events by activating what-if scenarios (forecasting based on current observations) and performing risk assessment (multi-factor). Apart from user-defined (based on subject expert judgment) algorithms data analytics module enables machine learning AI models for forecasting.

Low latency and high throughput are two critical characteristics of the data analytics module that support fast decision-making. In such a module, events are processed in real-time, e.g., after the consumption of an event, the system must output a result inmediately. In a real-world scenario, approximately 200,000 vessels globally transmit more than 16,000 AIS[6] messages per second, totaling 46 GB a day. Each AIS receiver is flooded with 5 to 8 AIS messages per second. Therefore, a streaming system that balances latency and throughput needs to be developed to classify vessel activities in real-time. To this end, a deep learning streaming methodology will be proposed for the mobility patterns' identification[7] that will act as an external service to the SmartShip system, and a REST API will be developed for easy access. The external service will consist of two phases, the offline model training phase, and the real-time vessel activity classification phase:

Offline model training: This phase will create the deep learning model. For the training of the model, representative trajectories of the mobility patterns of interest will be required to be used as the ground truth. Thus, already labeled trajectories from historical AIS data, which will be annotated, will be used. These trajectories will be converted into images [1], used as training instances of the deep learning model. For the implementation, the Keras[8] library with a TensorFlow[9] backend will be used, which consists of APIs to create neural networks and pre-trained CNN models. These pre-trained models will be employed and fine-tuned to classify images of mobility patterns in the next phase.

Real-time vessel activity classification: There are several frameworks for distributed stream processing, such as Apache Spark[10], Apache Flink[11], and Kafka streams[12], out of which only Apache Spark has support for the Python programming language, which is needed for the implementation of the neural networks and the creation of the images. Apache Spark is not preferred since it performs micro-batching over streams of events, and a system is needed to handle real-time event processing. Therefore, to balance event-processing with low latency and high throughput, the Apache Kafka[13] framework will be used in this phase, a distributed publish-subscribe and message-exchange platform similar to a message queue able to process streams of events as they occur. Three concepts exist in the Apache Kafka ecosystem: topics, producers, and consumers. A Kafka topic is a category/feed name to which messages are stored and published. A producer is an application that continuously publishes or stores messages in a topic. A consumer is an application that is subscribed to a topic and continuously reads or consumes messages. A Kafka topic can be divided into *n* partitions, with each partition storing different messages. Specifically, messages with the same key will be stored in the same partition. *n* consumers can be subscribed to the partitioned topic with each consumer consuming from a different partition, thus enabling high throughput. A producer can store messages to the partitioned topic, and Apache Kafka will handle the load balancing of the messages among the partitions internally. In our use case, the vessel identifier can be considered the message key, the AIS receiver as the producer, and the prediction modules as the consumers. An even distribution of the load within the nodes of the system reduces the probability that a node would turn into a hotspot, and this property also acts as a safeguard to the system's reliability [2] [3].

The prediction modules will be the main components of our methodology. Each prediction module will be responsible for consuming AIS messages from a set of vessels and classifying parts of their trajectories based on the deep learning model created in the previous phase. The module will use a temporal sliding window W of user-defined length L and step S. Every S AIS messages to classify parts of the vessels' trajectories. The module will consider all of the AIS messages of the corresponding vessel that belong to the current window *W* and convert them to an image. Next, the deep learning model will read the image and will output for each of the predefined vessel activities probability. The vessel activity with the highest chance will be the final prediction of the module. **Error! Reference source not found.** illustrates the sliding windows of the prediction modules. A window of length *L* and a step of *S=2* events is presented, which slides from left to right (W_1 to W_3). The upper temporal limit of the window is the time *t* the incoming message is consumed, and the lower time limit of the window is *L* hours/minutes/seconds before *t*, *t-L*. Messages that fall within the window *W* were used for the prediction.

---

6 A vessel tracking system that allows vessels to report their position periodically and inform nearby vessels

7 The annotation and identification of parts of the trajectories of moving objects, e.g., vessels.

8 https://keras.io/

9 https://www.tensorflow.org/

10 https://spark.apache.org/streaming/

11 https://flink.apache.org/

12 https://kafka.apache.org/documentation/streams/

13 https://kafka.apache.org/

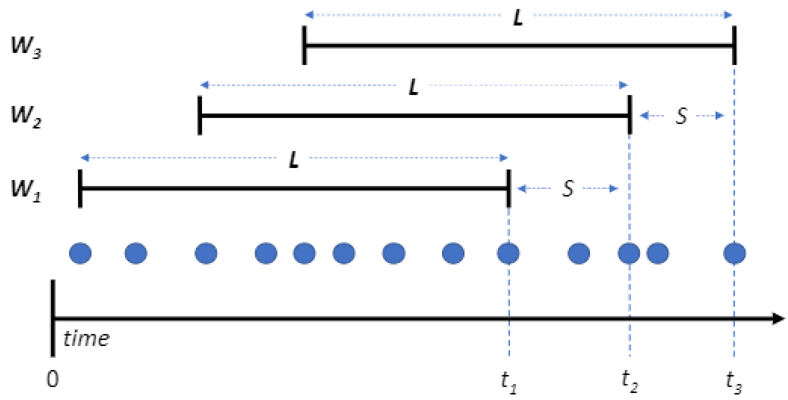

Figure 5 Example of sliding windows with a sliding step of S=2 events

Finally, Figure 5 visualizes the entire system architecture of our proposed external service. Initially, historical AIS messages that will be collected from AIS receivers will be transformed into images. These images will then be used to train a deep learning model offline. Messages received through the AIS receivers will be stored in a Kafka topic for real-time classification. The prediction modules will then consume these messages. They will be transformed into images, which will be fed to the already trained deep learning model to predict the vessel activity. During the real-time vessel activity classification, more than one prediction module can be employed to increase the system's throughput.

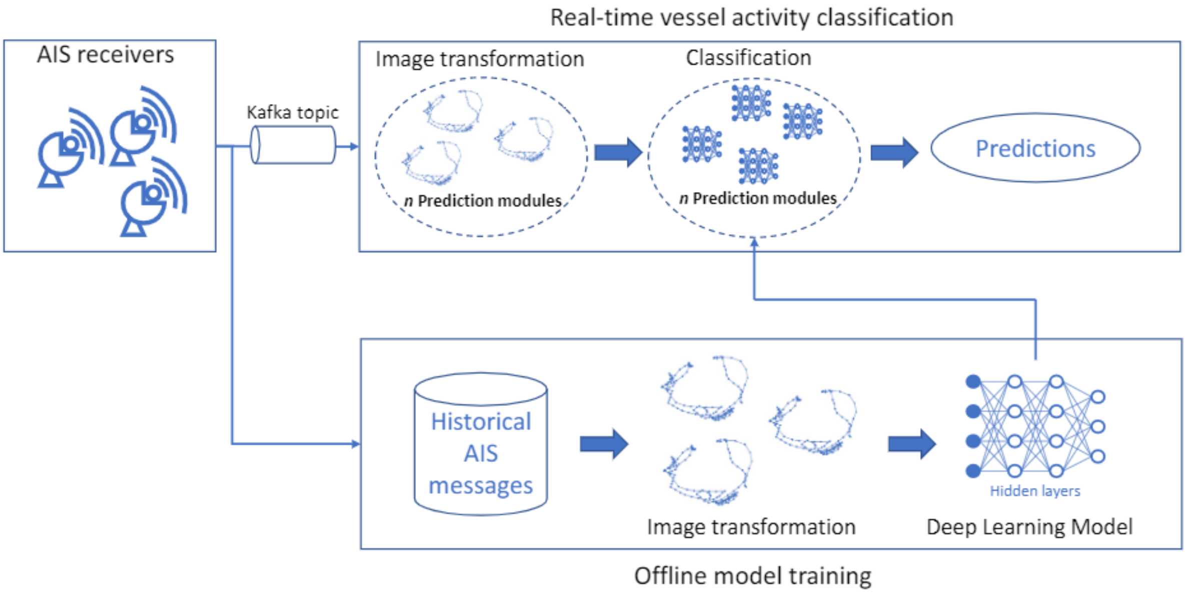

Figure 6 System architecture of the proposed external service to SmartShip System

Tier 3. Visualization

Visualization aggregates tools and mechanisms to populate data and information to the user as fused from tier 2 and SmartShip advanced analytics module

Tier 4. Decision Support System

This tier fosters automation in the decision-making by integrating the SmartShip decision support module (DSS). DSS encompasses a rule-based and operator-defined workflow management mechanism for timely and effective response to rising events while populating actions to be followed for the event response. DSS realizes communication of the most advantageous and optimum advice to the user among alternatives. DSS also enables AI thinking to optimize further decision making and automate the operation.

2.3.2 Hardware Components

Indicatively for server specs (either on-premise or cloud hosting), the following is recommended for optimal usage (estimated up to 50 concurrent users at scale)

- Server: At least 6-cores, RAM: 64GB, HD: 1x1TB SSD | 2x512GB SSD, Windows Server 2019, SQL Server 2019
- Workstation: Windows 10

2.3.3 Software Components

Programming
Web enabled SmartShip platform: HTML5, CSS front-end, View Js for web interface
Core programming language: C#.NET
Visualization tools
Dashboards wizards (owned development or open-source)
Google maps or open street (geospatial x.y.z)
DataGraph plotters
Embedded routines for the algorithmic definition of standard procedure in data correlation and analysis
Routines such as mini micro apps written in c#.NET to accommodate analytics objectives and use cases scope (performance management for emission monitoring, bunker analysis, route optimization, etc.)
TBD (to be further defined)
Artificial Intelligence (AI) component for optimum computation/analysis of data and decision support automation
Python-based
FlaskAPI micro web framework to deploy machine learning models
Flask-Stats library for stats models (fine series, etc.)

2.4 User Applications

2.4.1 Description

This is the architecture layer where both ashore and onboard users interact with SmartShip applications. The SmartShip data analytics and decision support module, co-hosted in SmartShip core, reflects data analysis and digital assistance in decision making into SmartShip Use case requirements (Note: refer to D2.1, section 4 for the presentation of requirements per use case). SmartShip architecture conveys information from the SmartShip core in two environments: The Cloud-based SmartShip platform interfaced with office users. The offline SmartShip onboard interfaced with onboard users (e.g., Captain). Therefore, information is consumed in two instances bridging shore-based officers with crew on board (Refer to D2.1, section 6 for users' definition and interaction per use case). The services that realize use case scenarios in both instances (office and vessel side) are weather routing planning and monitoring & condition-based fleet maintenance

2.4.2 User Interface

User Interacts with two instances of SmartShip applications:

- Cloud-based SmartShip platform hosted preferably in the same environment with the cloud repository of the framework located across the communication link between HQ shore and fleet. Office user access (HTTP over TLS) web platform hosted in an ISS web server.
- On-Board SmartShip reflects an offline light instance of the SmartShip platform to accommodate bandwidth capacity and communication bottlenecks when vessels travel oceans. An API for versioning updates is bridging onboard versions with the cloud environment. After being processed in SmartShip core, information is transmitted from HQ shore back to the remote onboard server through the same communication links (synchro app, cloud) and populated in the application client.

2.5 SmartShip final architecture

The final integrated version of SmartShip Architecture is depicted below in **Error! Reference source not found.**7.

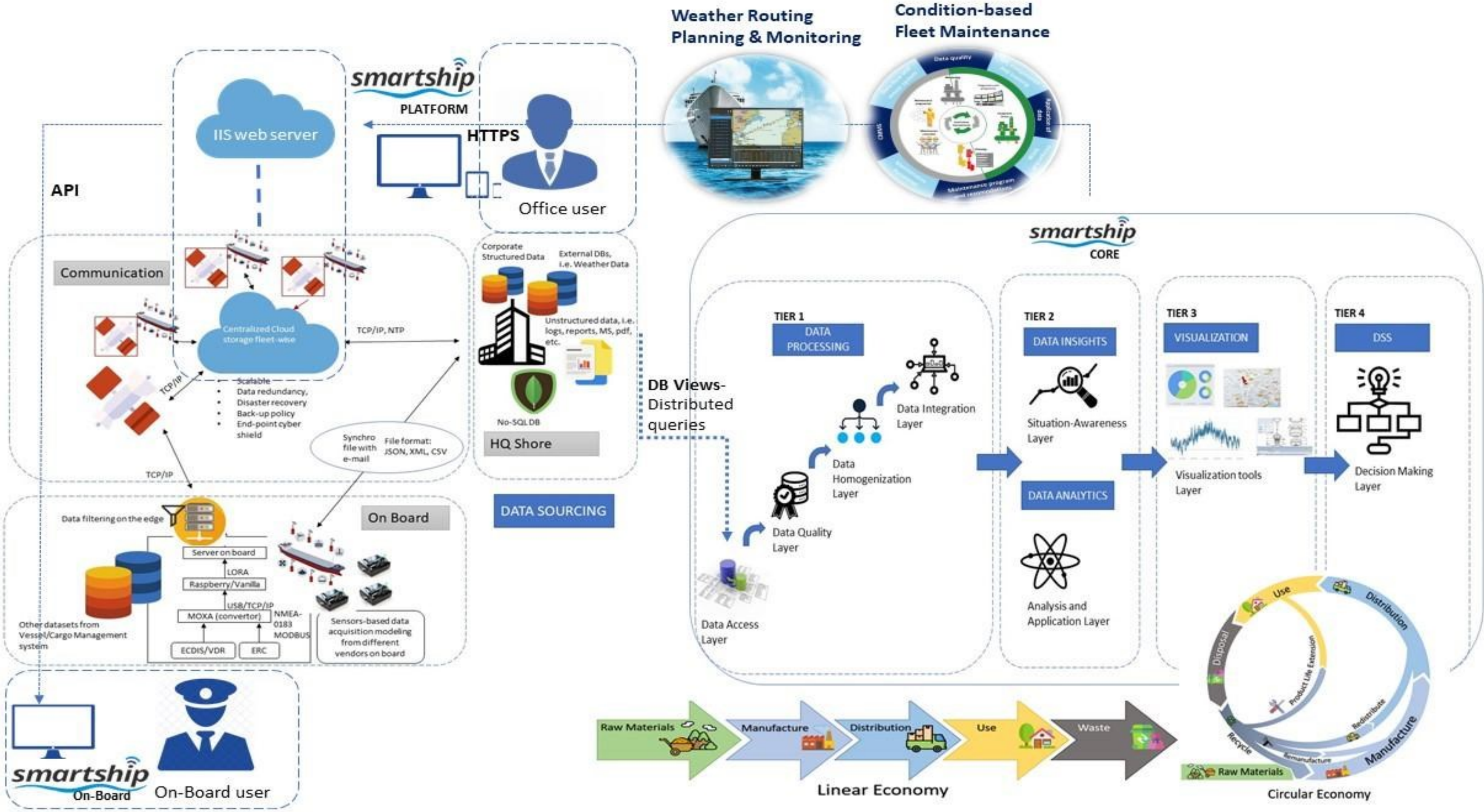

Figure 7 SmartShip architecture final design

3. Supporting Functionalities for SmartShip architecture

In this section, all supporting functionalities for the SmartShip system are presented, including mechanisms and techniques to configure network loads, object localization, communication nodes, and routing protocols in the most efficient manner.

3.1 Mechanisms to reduce the average IP acquisition latency and the network overhead

Since Big data and IoT technologies are evolving at an extraordinary speed, allowing individuals to gather, process, and analyze related data at enormous volumes, latency has become a significant factor and network functionality. A mechanism to address this problem is multiplexing several messages or data flows into a single persistent connection. This allows better measurement of network conditions and enables faster transmission. Another proposal is to exploit multiple network paths, like Wi-Fi, Ethernet,5G, LoRaWAN. This idea focuses on using low latency data transmission for latency-sensitive network traffic. State-of-the-art GPUs can also improve the average IP acquisition latency and edge computing combined with AI. Concerning the network overhead, a LoRa 2.4 GHz can be applied to achieve robust coverage and can serve as a base station that collects ship's sensors data and interact simultaneously with other ships' stations. A different approach is using an NB-IoT as it focuses on indoor coverage and a high connection density. Finally, the use of sensors is enhanced with edge AI technology as it can process and analyze the data before the flow to the base station and reduce the data volume. This mechanism is state-of-the-art and can rapidly decrease the total amount of data and enhance the data flow while reducing network latency and preventing overhead. Edge AI improves real-time analytics, which can be crucial in critical situations and cases of massive data flows. Since the cloud comes with the cost of latency and bandwidth limitations, autonomous systems and intelligent IoT devices become less suitable for developing Edge AI models trained in a cloud-based environment that can perform at the appropriate level.

3.2 Naming, addressing, and object localization in networks of internet-connected marine vessels

Concerning the naming and addressing of the marine vessels, AIS (Automatic Identification System) and ECDIS (Electronic Chart Display and Information System) can be used as support for electronic mapping services. Although, the use of a handy tool would be necessary for each active network which can provide the addresses interface with or without CIDR notation, the vendor's name of MAC address, the broadcast and network address, Cisco wildcard mask, class and host range by giving the IP address and CIDR or netmask. In this case, a tool like SHIP should be developed (a Simple, handy network addressing multitool with plenty of features). This deliverable proposes a remote sensing image ship object detection method based on a brain-like visual attention mechanism to obtain accurate ship detection results. This also refers to the robust expression mode of the human brain, designing a vector field filter with active rotation capability and explicitly encoding the direction information of the remote sensing object in the neural network. The progressive enhancement learning model guided by the visual attention mechanism is used to solve the problem dynamically, and the object can be discovered and detected through time-space information.

3.3 Mechanisms to extend the coverage time of nodes in internet-connected marine vessels from a DHCP perspective

DHCP (Dynamic Host Configuration Protocol) allows access to network configuration information when an individual connects to the network. This technique has several advantages over storing network configuration information in local files. A practical approach for energy conservation in wireless sensor networks is scheduling sleep intervals for extraneous nodes while the remaining nodes stay active to provide continuous service. A technology that can be used to achieve the sensing coverage for a given Area of Interest (AoI) in a People-Centric Sensing (PCS) manner to extend the coverage time of nodes is a concept of (α, T)-coverage of the target field where each point in the area is sensed by at least one node with a probability of at least α during the time period T. Two algorithms can be proposed which are the inter-location and inter-meeting-time. These optimization algorithms can be examined to the location of nodes in and near the AoI during period T to achieve more accurate coverage at a lower cost by removing useless nodes and adding some extra nodes that can expand the coverage. Finally, a k-degree coverage algorithm can be applied to optimize nodes' deployment. This algorithm can optimize the node coverage and solve the issues of the wireless sensor network.

3.4 Investigation of routing protocols, including tunneling through non-IP links

Non-IP Networking emphasizes that the technology is not dependent on IP packet formats or protocols; however, it supports the TCP/IP suite and other systems such as Information-Centric Networking and RINA. The European Telecommunications Standards Institute (ETSI) started a new Industry Specification Group (ISG) on "Non-IP Networking", claiming that TCP/IP is an old protocol, unsuitable for the new types of applications promised by 5G, such as tactile applications and industrial robots. Tunneling is a method for transporting data across a network using protocols not supported by that network. Tunneling works by encapsulating packets, which refers to wrapping packages inside of other packs, and this is often used in VPNs. IPSEC VPN can be used for encrypting and securing communications between networks, but it supports only IP unicast traffic.
In contrast, GRE protocol (Generic Routing Encapsulation) can encapsulate routing protocols (OSPF, EIGRP), multicast traffic, and non-IP traffic inside a point-to-point tunnel. However, it is not as secure as IPSEC. In our case, a combination of both technologies can provide security and support for a wide range of network protocols. Also, a Layer 2 Tunnelling Protocol (L2TP) can transmit data securely and is often used to transmit non-IP protocols.

4. Circular Economy Principles in SmartShip Architecture

The project consortium will adjust and customize the SmartShip Architecture as developed based on functional requirements and existing standards in section 2, to incorporate the main principles of Circular Economy in the maritime field. The focus will be on exploiting energy efficiency, fuel consumption, and emission control optimization procedures in terms of applying such principles regarding the engines' components' operation and reusage

4.1 Increasing need for sustainability in the maritime industry

Shipping emissions can influence air quality long distances from the emitting source [4] [5]. The primary pollution is the exhaust emissions from heavy fuel oil powering ship engines [6]. According to the European Environment Agency (2019), Greece is among the European cities with the highest levels of PM2.5 air pollution. Perspectives on the trade market indicate that the number of goods transported by shipping may triple by 2050, leading to a corresponding increase in fuel consumption. The increasing level of trade leads to a significant rise in carbon dioxide emissions. Container vessels contributed around 205 million tons of CO_2 in 2012, making them the highest contributor to international shipping [7].
Therefore, there is a need to reduce direct and indirect emissions from the shipping sector and shift towards sustainable ship recycling, ensuring the re-introduction of materials into the cycle to manufacture new products and propel vessels differently. The shift from a linear to a circular economy model where production and consumption involve sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible will allow implementing strategies for energy efficiency and fuel consumption management in the maritime sector. Shipping is permanently engaged in efforts to optimize fuel consumption and reduce greenhouse gas intensity [6], focusing on lowering the CO_2 emitted from the vessel while operating at the port and sailing in the sea. According to the International Maritime Organisation (IMO), shipping could obtain reductions through operational measures such as voyage optimization, lower speed, etc. These strategies included in SmartShip use cases will help comply with environmental regulations regarding emissions control.

4.2 Digitalization enabling the circular economy

Digitalization is also an enabler of a circular economy. In particular, the circular economy impacts industries, products, markets, business models, value chains, and infrastructure, of which maritime, in essence, forms the backbone. The circular economy allows for new interfaces between sectors to develop new business models and customer or partner relationships. Understanding the source, the production schedule, and producers of goods and services is vital in a circular economy for the successful mapping of actors. Two elements are essential: intelligent assets and how to track them, while the three main intelligent value drivers for circular economy are location, condition, and availability. Therefore, increased connectivity, gathering, sharing, and data analysis will maximize the value of materials to produce better products and services. Circular business models adopt new technologies and materials that create additional value by taking a systemic view across the whole life cycle of assets. Sufficient, reliable, relevant data requires cross-value collaboration, possibly encouraged by political or legislative measures. Many different technologies are available today, and while the circular economy remains material and resource focused currently, there is a correlation with future digitalization. The outreach and uptake of such technologies will enhance the transition towards a circular economy, possibly securing the role of shipping in a coming digital age [8]. Players actively participating in the circular transition will connect more closely with customers by supporting their circular growth. Such a shift will support revenue generation through more stable access to repeatable cargo flows and the creation of reverse logistics cargo flows and a home for a supply chain intelligence product.

Nevertheless, a gradual but global shift towards a circular economy and the next generation of technologies is also likely to reduce seaborne trade volumes, types and flows, change trading patterns and parcel sizes, economics, and location of production, ship designs, ship operation, ship recycling, etc. Flows of information and data drive tomorrow's global agenda and technological changes that reshape industry value chains. Initially, these changes might seem more of a threat than a business opportunity for the shipping industry. Traditional shipowners who do not seize the potential of digitization are unlikely to turn the shift towards a more circular global economy into a business opportunity. However, the players that understand the emerging opportunity could benefit hugely [8].

4.3 Circular requirements in the SmartShip architecture

Advantages of using digital technologies may include faster resolution of technical faults and reduced reliance on having a technician traveling to the site (reduced emissions or pollutants). About 47% of maritime businesses use IoT to measure fuel consumption (electronic reporting), and their implementation will increase by 100% by 2023. Increased IoT uptake will then improve the monitoring of ship components and improve longevity and performance, while real-time monitoring will enhance the scheduling of maintenance when necessary. The use of 5G could potentially optimize the routing undertaken by vessels, resulting in less distance traveled and lowered emissions.

Embedding circular economy principles in the different components of the SmartShip ecosystem (Data sourcing (IoT), SmartShip Core system, and Users Applications) can help optimize the overall operations of the SmartShip maritime fleet. Circularity characteristics to consider in the development of the platform are:

- Circular Attributes: Location, Condition, and Availability.
- Circular design: Modularity, Scalability, Functionality
- Data collectors' requirements: End-to-end security/privacy, Dependability, Operability
- Trust: Trustworthiness, Confidentiality, Security

Circular Attributes: location, condition, and availability.

Data sourcing IoT component considers tools, communication protocols, and network topology to retrieve data pre-processing at the edge and transfer information for further processing and analysis. The data sourcing IoT network consists of onboard, communication, and HQ shore.

The onboard acquisition systems capture and store data in a dedicated server. Before transmitting data to the shore, initial filtering and cleansing of data streams happen at the edge, sending only the validated and consistent datasets to the shore for further exploitation. The communication network sends the information from the vessel to the shore and vice versa. Sensor-based data streams from ships arrive at the HQ shore to perform data configuration, correlation, processing, and analysis through the SmartShip Core system component.

Applying the circular attributes (location, condition, and availability) for intelligent assets value drivers in the different stages of the data sourcing component will permit the collection of the necessary information to grasp circular economy insights in the following analytics steps regarding the monitoring of devices and maintenance actions recommendations.

Circular design: Modularity, Scalability, Functionality

The development of an open modular platform for IoT sensors-based data streams from ships assisted with Big Data analytics and Cloud services (SmartShip core system) can improve the lifecycle of ships by enabling onboard and shore networks to produce and exchange information and alerts in real-time and in a trustworthy and sustainable manner. **SmartShip core system** comprises four tiers, including the data processed from the source, analyzed, and transformed into meaningful information to support user decision-making. The platform's modularity and scalability will initially depend on the basic functional capabilities designed and expects further refinements due to the experience gained from implementing the consecutive versions of the platform. The modularity can improve the performance of the SmartShip platform in terms of efficiency, flexibility, and agility by creating a flexible system to create different requested configurations. The efficiency will help determine the number of building blocks needed. The flexibility will evaluate the capability for different configurations, and the agility will determine the number of additional components required for other applications besides the use cases. Modularity will aim to provide interoperability with existing IoT environments and support the platform's evolution for relevant future changes.

End-to-end security/privacy, dependability, operability, and trust

Data collectors need to protect the privacy and usage of the collected data and implement different anonymization, encryption, and authenticity preserving mechanisms when required to protect sensitive information available only with the user's consent. Moreover, ensuring trustworthiness, confidentiality, and general security between parties is vital to secure trustworthy information exchange by design.[14]

4.4 Opportunities for the circular economy in SmartShip

The shipping sector has a significant potential for pairing circular economy and Smart ICT. Implementing the circular requirements described above to the SmartShip platform will improve the information received in the **user application** component resulting from data processing and analysis for the users either ashore or onboard. The opportunities identified through the SmartShip use cases are:

- **weather routing optimization** and monitoring: i) optimized vessel routing and ii) improved monitoring of fuel consumption
- **condition-based (predictive) maintenance (CBM)**: i) predictive maintenance and ii) facilitate remote support

Thus, in this system component, the user consumes the information due to the analysis performed in the SmartShip core system to support the decision-making to optimize fleet management. Moreover, a continuous feedback loop between shore and vessel operations will allow a sustainable and green operation regarding energy efficiency and emission control to achieve the circular KPIs determined in WP2 (Table 2)

Table 2: Circular Economy related KPIs

Enhance environmental performance in Shipping operation	At least 5% enhancement in environmental performance due to SmartShip routing scenarios against existing algorithmic-based routing advice
The value-added proposition to existing tools	- At least 5% improvement in accuracy of routing advice and voyage performance evaluation due to SmartShip build-in functionalities

[14] GSMA (2018) Data value chain

	- At least 5% enhancement in anomaly detection and failure prediction of vessel machinery components due to SmartShip build-in functionalities
Through Circular Economy monitoring or energy-efficient operations, performance	Identify at least a 10% improvement on the Fuel Operational Consumption (FOC) model
Engine performance	- At least 5% improvement in Engine fatigue treatment and performance monitoring to prolong asset lifetime and retain value. - Development of at least one reuse and remanufacturing Database of materials for engine components
Relevance of the circular economy criteria	User acceptance validation test by DANAOS staff

5. Conclusions

- This deliverable shows the successful translation of the requirements into functions resulting in the SmartShip functional architecture and maximizing the opportunity to incorporate circular economy principles. It also shows that developing relevant partnerships is critical to providing novel IoT offerings to the maritime industry
- The primary obstacles to more outstanding IoT applications for maritime businesses include data privacy and usage, security, and interoperability
- Lastly, this deliverable considered the potential application of IoT to encourage responsible ship recycling for maritime vessels' reaching their end-of-life (generally up to ~ 30 years' lifespan).

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