Ship Operation Analysis and Optimization via Mobile Application

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Abstract

This paper is devoted to studying the structure and prospects of ship operations analysis and optimization via mobile applications, focusing on integrating multiple existing onboard monitoring and control systems. The main parts of the paper describe the current state of the most essential components of future overall shipping and ship design optimization using onboard and cloud-based monitoring systems from a dual transition point of view. Special attention is paid to the ship's and its equipment's efficiency improvements, fuel consumption and emissions reduction, cost-effectiveness enhancement, metrological accuracy, and compliance with current regulations. Timely development and deployment of the proposed onboard monitoring systems, in combination with up-to-date mobile applications and cloud computing, should play a crucial role in promoting sustainable and environmentally friendly shipping practices, improving operational performance, and reducing risks to human life at sea and the environmental impact of shipping. Another objective of this research is to review the current state of infrastructure used

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for fuel control, focusing on measurement systems and related analytics using appropriate mobile applications. The recommendations for integrating new and adopting existing monitoring systems and equipment for promising alternative fuels must be given to meet current regulations and provide required safety levels and measurement quality.

Keywords: Operation efficiency analysis, data analytics, mobile applications, ship safety, onboard measurement, green fuels, hybrid structure, cloud calculations, edge computations.

1 Introduction

In the maritime industry, efficient ship operation is essential for reducing costs, ensuring safety, and minimizing environmental impact. Ship operation analysis and optimization via a mobile application is a technological solution designed to streamline and enhance the management of vessels. Recently, ship operation and efficiency analysis have attracted a lot of concern in connection with the still-growing impact of shipping activity on air pollution with exhaust gases and other harmful and toxic emissions [1].

Some progress in solving the tasks set by the objectives of dual transfer of tasks before shipbuilding and operation of ships, in turn, has shown the need to process vast amounts of onboard measurement information utilizing mobile applications. The energy mentioned above efficiency and carbon reduction goals pushed the Information Communication Technologies (ICT) sector forward to incorporate designs focused on low carbon and sustainable growth [1, 2]. The ICT sector is solving this task in specific ways [3–5], reducing energy demands (green networks, green IT). ICT should be used for carbon displacements, and ICT collaborates with other sectors of the economy to provide energy efficiency – smart grids, ships and shipyards, intelligent transportation systems, etc.

On the other hand, AI technologies based on mobile applications (MAP) have a good perspective on the marine industry, which is very important for human life safety and overall efficient shipping. These tasks are not new and have been a primary concern and focus of research and development in the shipbuilding and shipping industries for centuries. With the coming era of AI, mobile applications, and digitalization, developing appropriate design, engineering, monitoring, and control systems has exponential progress. For example:

- The AI multi-software complexes are successfully used in design and engineering processes in shipbuilding, ship-repairing, and modernization [6].
- Intelligent polymetric sensor systems are highly efficient as information components of the integrated ships' control systems [7–10].
- Intelligent automation and robotics systems are exclusive to smart shipyards' production quality and cost efficiency [11–20].

2 State of Art and Problem Statement

As mentioned above, particular attention should be paid to reducing the impact of shipping activity on air pollution with exhaust gases and other harmful and toxic emissions in future research and development of the maritime economy [1]. It's well known that shipping is one of the most energy-efficient means of transportation for various goods. Ships carry over 80% of global trade by volume; therefore, shipping plays a central role in global supply chains and the economy. At the same time, shipping is also regarded as one of the most complicated industries to decarbonize because most existing ships use diesel (or heavy oil) as a marine bunker fuel. This causes a strong trend in developing and using various alternative fuels, requiring corresponding adaptation and development of measurement techniques/equipment.

The study and comparison of physical properties, the economic feasibility of various alternative fuels, the corresponding readiness level of regulations, and technological equipment must be performed. Early and current research on ship safety monitoring systems focuses on using sensors and other hardware devices to detect hazards such as collisions, fires, capsizes, and leaks. Such systems effectively recognize potential dangers and warn crew members and other stakeholders early. However, these systems' existing hardware/software limitations could influence their effectiveness. For example, these systems were often limited by the processing power of the hardware devices, which can result in delays in data analysis and decision-making. In any case, they still are DSS - Decision Support Systems [7, 8, 17–19], proposing to the ship Master visualized forecasted options and limitations on speed and routing choice.

The latest achievements in developing AI instruments, such as Digital Twins (DT), Autonomous Ships, Smart Shipyards and Transshipment Terminals, Cyber-Physical systems (CPS), Smart Engineering, etc., showed the high potential of ship operations data analysis using these instruments and novel mobile applications [24–31].

Smart Shipyards use Automation and Robotics, Industrial Internet of Things (IIoT) and 3D Printing, Supply Chain Integration, Augmented (AR) and Virtual Realities (VR), Cloud Computing and Connectivity Instruments, etc. Smart engineering leverages advanced technologies and digitalization to enhance efficiency, safety, and productivity in the ship navigation and maintenance processes. Primarily, smart engineering uses digital twin technology to create virtual replicas of physical assets, such as ships, allowing for real-time monitoring, including mobile monitoring of the efficiency of ships in their everyday operations and maintenance based on testing of different scenarios.

Digital Twins became widely used in ship design, manufacturing, operation, maintenance, modernization, and, finally, their utilization. The output of DT and operations data analytics returns to ship as recommendations for quick actions and, in some circumstances, for timely automated control. Also, these outputs are returned to the designer as ideas for further optimizing the next generation of ships. The above outcomes increase safety and reduce operational costs; design new green and digitalized ships, equipment, etc.; train operators and predictive maintenance; oversee compliance monitoring, emergency response, etc. As highlighted in [32], integrating sophisticated sensors and AI is pivotal in improving situational awareness, a critical factor in ships' autonomous and flexible connectivity, driving the industry's transition to more digitally advanced operations.

According to research [33, 34], smart ships and mobile applications, combined with cloud computing and big data analytics, significantly contribute to increased safety and optimized cost operations in marine traffic. This integration allows for more dynamic, real-time decision-making and situational awareness, vital in navigating the complex and often hazardous marine environment.

Mobile applications can play a crucial role in maritime education and training [35], especially in combination with state-of-the-art modeling capabilities, creating and utilizing DT with various solutions, and utilizing high-performance computing for different scenarios analysis and optimizing capabilities. Moreover, DC and mobile multimedia capabilities make distance training possible for both ship personnel and future ship or fleet designers. Unfortunately, despite the importance and significant investments in the maritime industry, it has a much lower digitalization level than traditional ICT sectors [36].

While there still are challenges to implementing this approach based on mobile applications for solving all described tasks, the potential benefits make it a worthwhile investment for the shipping industry. Further research and development are needed to fully realize the potential of AI-based ship safety monitoring systems [7, 12, 20]. It is necessary to highlight four main directions to solve the problems described above to accelerate the implementation of promising instruments for the maritime economy's dual, green, and digital transition.

Direction 1. Establish, as a first approximation, a set of the primary criteria for the dual transition of the maritime industry to be used in the current study.

Direction 2. Comparison of functional, technical, commercial, and other pros and contra of existing onboard ship operations monitoring systems and efficiency of AI-based cloud and edge computing platforms from reliability and cost point of view. Set up the rational distribution, decomposition or integration of their functions to develop a hybrid structure of both systems' utilization with further optimization of cloud and edge calculations.

Direction 3. Comparison of specialized equipment and measuring instruments for safe and efficient use, storage and replenishment of ships and other floating structures using environmentally friendly and green energy sources.

Direction 4. Increasing the efficiency of ships manufacturing technological processes, supply logistic monitoring systems, and autonomous unmanned (crewless) marine vehicles for fulfilling their mission by correcting the planned path, speed, and course in the current sea environment based on embedded robotics and mobile applications integration.

2.1 Set of the Primary Criteria for the Dual Transition of the Maritime Economy

Several EU regulations focus on energy efficiency and carbon reduction in shipping [36–43]. Some of the requirements are critical for solving tasks of this research, namely the following: Energy Efficiency Design Index (EEDI), Ship Energy Efficiency Management Plan (SEEMP); Energy Efficiency Existing Ship Index (EEXI), Carbon Intensity Indicator (CII), Data collection system (DSC) for fuel consumption of ships. The EEDI is a mandatory regulation that sets specific energy efficiency standards for new ships. It requires new vessels to meet certain energy efficiency levels based on size and type. The law promotes developing and using more energy-efficient, clean ships and fleets.

The SEEMP urges the ship owners and operators to improve the energy efficiency of a ship cost-effectively, considering new technologies and practices when seeking to optimize the operational performance of a ship. It also provides an approach for shipping companies to manage ship and fleet efficiency performance over time using recognized monitoring tools.

Before 1 January 2023, all ships of 400GT and above had to calculate their attained EEXI, which reflects the "technical" or "design" efficiency. Ships must meet IMO EEXI's requirement by choosing the most appropriate means for the shipowner or charterer for engine/shaft power limitation, waste heat recovery, wind-assisted propulsion, etc. Based on CII, the ship's Administration determines the operational carbon intensity rating of the ship given on a scale {A, B, C, D, or E} indicating inferior performance level. A ship rated D for 3 consecutive years or rated E shall develop a "Plan of correction actions."

It is also important to emphasize that these indices encompass the entire ship lifecycle, from commissioning to recycling, allowing for a comprehensive assessment and management of the vessel's carbon footprint. This lifecycle approach ensures that every stage of ship operation is optimized for sustainability, aligning with broader environmental responsibility goals and green economic practices.

The maritime industry's high carbon footprint and energy consumption are often a result of complex interplays between various known and unknown factors. These factors' correlation and causality analysis are essential for understanding and mitigating their impact. While numbers such as the EEDI, EEXI, CII, etc., and DCS data for fuel consumption are only the first steps towards accountability and improvement, they also bring to light the multifaceted nature of maritime environmental impact.

Ship design, operational patterns, fuel type, and maintenance practices contribute significantly. However, there are also less understood or unexpected factors like varying oceanic and weather conditions, local and global changes in trade routes, and even market dynamics affecting cargo loads and speeds that can alter a ship's environmental impact.

Advanced data analytics, supported by cloud computing, are vital to unraveling these complex relationships. By harnessing big data and machine learning, stakeholders can identify patterns and correlations between operational behaviors and environmental impact. These insights can lead to more informed decisions, such as identifying the most efficient routes, optimal speeds, the best times for maintenance and refueling, crew operations and training, etc. They can also help to estimate/predict the outcomes of various operational decisions, allowing for better planning and reduced environmental impact.

Understanding and mitigating the maritime industry's carbon footprint requires a deep dive into the causality and correlations of several interdependent and complex factors. Leveraging cloud computing for data collection, analysis, and predictive modeling, enabling a more sustainable and environmentally responsible maritime sector is vital in this endeavor.

2.2 Ship Safety Monitoring and Control Systems Revisited for Further Optimization

Nowadays, thousands of software packages, solutions, and platforms that are applicable for ship design, manufacturing, safety and efficiency provision, monitoring, and control are developed by small or very big companies. Depending on various reasons, these systems are already used by different stakeholders of the global or local added value or supply chains.

This paper proposes installing advanced intelligent sensors and AI algorithms onboard the ship server and/or servers for cloud computations and appropriate AI instruments. This approach would require the development of new intelligent hardware devices and software applications that can support real-time data analysis and predictive capabilities.

Cloud-based monitoring systems are used for storing and processing big data aggregates to enable comprehensive analytics and global accessibility and enhance decision-making and operational efficiency of the ship/fleet/company/industry. Current approaches for maritime shipping are numerous predictive analytics to optimize routes, reduce fuel consumption, and foresee maintenance needs. Cloud computing's primary advantage lies in its ability to integrate and foster collaboration among diverse maritime supply chain stakeholders, thereby boosting transparency and efficiency. This digital evolution is steering maritime operations toward a future that is more resilient, adaptive, and committed to environmental sustainability.

The generalized structure of the hybrid system is shown in Figure 1. It includes the cloud data processing and integration layer – the main part of the entire system. Cloud applications can be easily configured to store and process data from various sources. One on-site systems node is shown with corresponding processing and communications layers. This node can also include a sensing layer depending on the desired functionality. Localized system parts can be installed on any facility and work in autonomous and isolated mode (ship, port warehouse, fuelling station, etc).

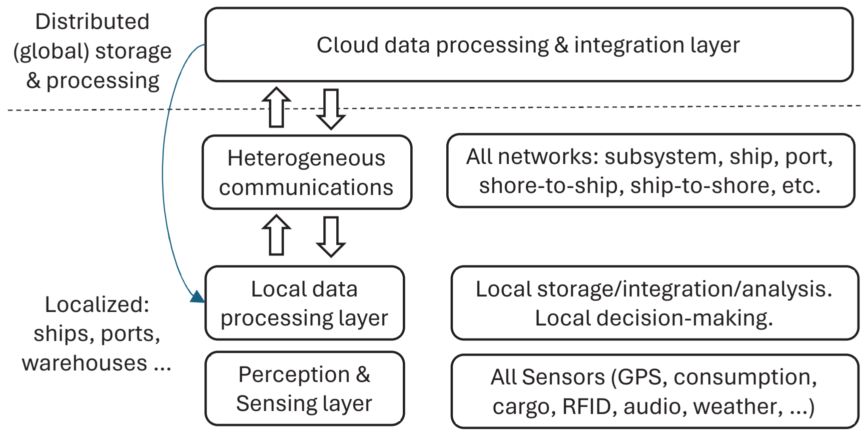

Figure 1 Generalized structure of a hybrid cloud system.

The node's computational capabilities and structure elements are selected according to its main functionality (ship, mobile robot, onshore measurement system). The generalized node structure is shown in the bottom part of Figure 1. It can act as an independent computational or measurement part of a global system. The communication layer makes various equipment connected utilizing standard interfaces. It's important to note that the communication layer is crucial for building an adaptive and flexible system. For large-scale cloud-based systems, it's necessary to provide stable connections for ships and ports, autonomous or controlled robots, enabling communication between ship-to-ship or ship-to-robot, ship-to-shore, etc. In this case, the node can interact with other nodes (equipment) and receive/send information from/to the cloud system. As an example of connected equipment, an autonomous robot can be presented that performs operations on inspecting/cleaning a ship's hull during the anchorage at port. The flexibility of the cloud-based application is based on the decentralized structure of the data sources and significant computational power.

On the contrary, embedded ship safety monitoring systems are still critical for ensuring the safety of crew members and the cargo onboard the ship. These systems are designed to detect potential hazards and provide early warning so appropriate action can be taken to prevent accidents timely [7–11, 24]. For example, in Figure 2 the generalized structure of sensor-information components (SIC) of the cyber-physical system (CPS) "Supply vessel" is presented. SIC of this system is designated to monitor its operation in stormy seas, its operability, resilience, and safety [9]. The central

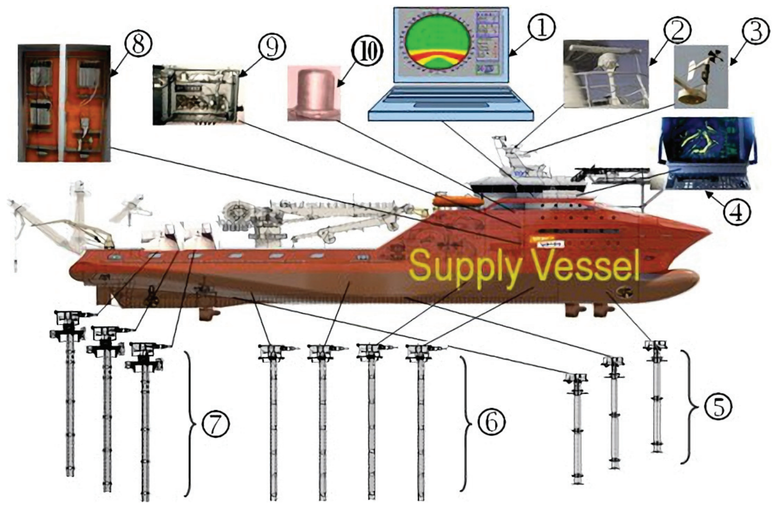

Figure 2 The component structure of the cyber-physical system "supply vessel."

server or operator workplace (1) is the primary sub-agency of the sensory CPS of any type of ship. The set of sensors and devices comprises a radar antenna (2), an onboard anemometer (3), the radar display and a keyboard (4), a sub-agency of sensors for ship draft monitoring (5), a set of polymetric sensors for fuel-oil, ballast water, and other liquid cargo quantity and quality monitoring and control (6), a set of polymetric sensors for liquefied petroleum (LPG) or natural (LNG) gas cargo quantity and quality monitoring and control (7). Next come switchboards of the subsystems or actuating devices and operating mechanisms control (8), a basic electronic block of the subsystem for liquid, liquefied, and loose cargo monitoring and control (9), and a specialized electronic block with sensors for real-time monitoring of parameters of ship dynamics (10).

This structure has met the most necessary and sufficient requirements for the ships' safety and efficiency control systems and similar embedded systems for hazardous onshore maritime infrastructure entities [11]. Nevertheless, the proposed approach for the hardware/software structure of AI-based ship safety monitoring systems involves using advanced sensors and AI algorithms to detect and analyze potential hazards. This approach would involve the integration of multiple sensors, including cameras, and other devices, providing real-time data on conditions onboard the ship and operational parameters of all electrical equipment, main and auxiliary engines, pumps and valves, and embedded monitoring and control system, etc. Another

Figure 3 The ALERD and conventional dredger combined multifunctional fleet concept for joint operations scheme.

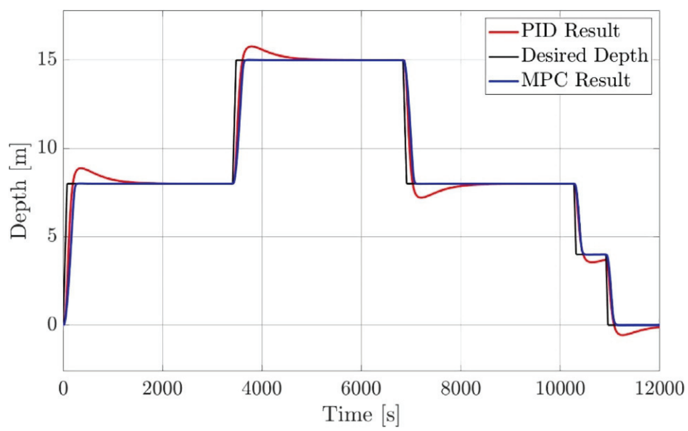

Figure 4 PID and MPC depth control comparison [46].

example of an innovative ship, ready to operate and integrated into a ship's fleet, is the Autonomous Submerged Dredging ALERD (Figure 3) designated to perform dredging activities sustainably and energy-reduced [45–47].

Figure 4 presents the results of tracking and controlling the desired dredging depth. A comparison between the performance of the Proportional Integral Derivative (PID) controller and Model Predictive Control (MPC) reveals that MPC exhibits superior tracking of the reference depth, with significantly reduced overshoot compared to PID. This performance improvement is also reflected in Table 1. The evident reduction in energy consumption for controlling depth can be observed, based on comparative Key Performance Indicators (KPIs) data (i.e., Maximum Power, Energy, Overshoot, Settling Time, Rise Time) [46].

Table 1 MPC and PID controllers' depth control performance comparison

KPI	PID	MPC	Difference
Maximum power [kW]	46	47	+2%
Energy [kWh]	1.98	1.47	−26%
Overshoot [m]	0.879	0.0154	−98%
Settling time [s]	2129	620	−70%
Rise time [s]	200	286	+43%

A comparison between the energy requirements of the ALERD and a conventional dredger for the same operational profile and hopper volume indicates that autonomous submerged dredging can potentially decrease total energy requirements by 66% [32]. Furthermore, one should consider the substantial positive influence of autonomous underwater dredging on the ecological safety of the maritime environment, human beings, sea fauna, and flora.

2.3 Mobile Applications, as Part of the Developed Concept

Mobile applications are an important part of leveraging cloud computing. Some prominent applications for the maritime industry are listed next:

- *Energy Consumption and Emission Analytics, Ship Benchmarking.* Such mobile apps can offer recommendations for reducing fuel consumption, provide alerts for the crew about important thresholds for a specific region, regulatory compliance issues, etc. The next logical progression is to compare vessel performance against industry benchmarks to catalyze innovation and drive forward the ship's efficiency and sustainability [44].
- *Remote Fleet Operations and Diagnostics.* Mobile applications can be used for remote monitoring and diagnostic of onboard equipment. Crew members and onshore teams can receive alerts, perform remote troubleshooting, and even control predictive maintenance of the ship's systems directly from their mobile devices.
- *Adaptive Weather and Environmental Routing:* Captains and navigational officers can use mobile applications that provide instant access to dynamic routing information and environmental data. This ensures timely navigational decisions and can leverage the latest data for route optimization.
- *Mobile-Enabled Integrated Logistics and Freight Management, Port Operations Management Tools.* Enhance the cloud-based logistics

system with mobile applications that provide real-time tracking, documentation, and communication capabilities for freight and cargo management. Supply chains can also be analyzed and optimized by facilitating end-to-end visibility and coordination in the chain.

By developing and utilizing various mobile applications and cloud-based solutions, the maritime industry can benefit in all aspects, ensuring operations are more connected, efficient, and responsive to changes. It's crucial to emphasize the importance of robust cybersecurity measures. As operations become increasingly digital and interconnected, protecting data integrity and system operations from cyber threats is paramount to maintaining maritime operations' safety, efficiency, and reliability.

2.4 Onboard and On-shore Measurement & Monitoring Systems

An essential part of the implementation and widespread application of alternative fuels is a system for online monitoring and analysis of demands in various fuels for the planning of supply chains and distribution. The sources of information for the system should consider historical data about demand in various fuel types, the current state of inventory for a region/port of scope, and data about planned/current ships in port, etc.

As ports have information about the current and planned ships' arrivals, their demands in fuels and bunkering, and the current state of inventory, simple predictions can be made. Scaling the problem from one port to some country or geographical region, it's possible to project the demands for various fuel types and predict overall demands with some uncertainty levels. Accurate data about inventories and consumption is necessary to build a monitoring system that works with real-time data. Like the onshore systems for traditional fuel inventories, monitoring onboard ship systems for alternative fuels must be developed and implemented (or existing systems upgraded). The data about current fuel balances in onshore storages and generation plants must be accurately measured, collected, and processed for energy safety and production optimization. Therefore, accurate measurement of alternative fuel quantities and automation of storage and transportation processes are essential for alternative fuel applications.

The ships' fuel consumption data is also collected and reported by the "Monitoring, Reporting, and Verification (MRV) System," integrated with a "Data Collection System (DC)." MRV and DCS systems are related to monitoring and reporting greenhouse gas (GHG) emissions in the context of international regulations, particularly within the shipping industry. It can also

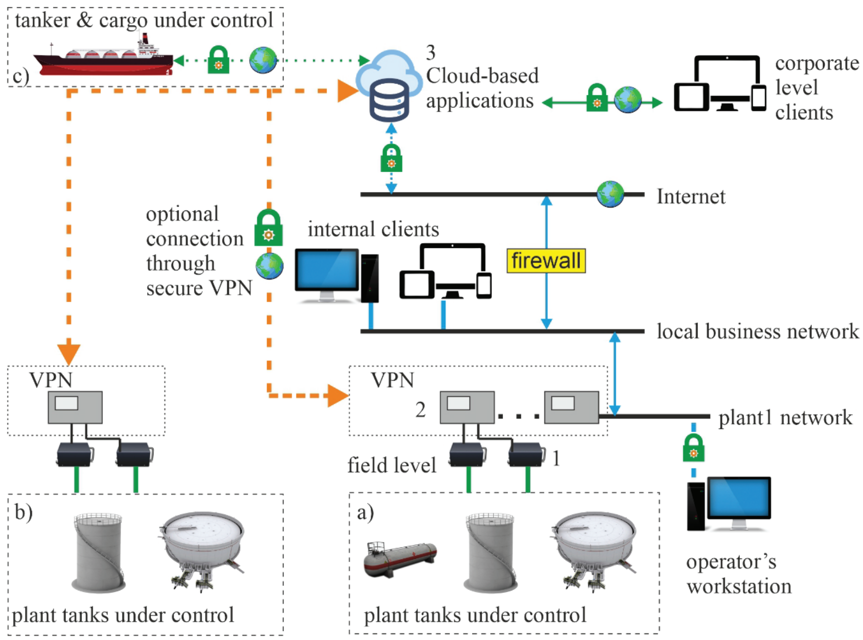

Figure 5 The structure of a system for data collection and processing system for fuel inventory and consumption.

be used for analysis and predictions. By processing the data about onshore and onboard inventories together and enriching it with the data about cargo, it seems possible to make predictions about demands more accurately and optimize production or supply chains – see Figure 5 for more details.

The proposed system can be essential to a global data collection system that gathers data from onshore production/distribution facilities and onboard cargo and fuel control systems [48]. Data can be collected periodically through secured channels to the cloud storage and used by various applications for further analysis and processing. Collected data must be used by the end-users and governments together with market players for analysis of fuel flows and supply chain optimization. As the collected data is commercially sensitive, it can be anonymized so that only generalized statistics will be given to end-users or vice versa. It can be the open access system with the data available for all market players online or with some delay/aggregation.

Any data analysis system requires properly measured values as input data, so advanced measurement and monitoring instruments are required for fuel consumption and inventory measurements. As for fuel consumption estimation, EU regulation [49] says that companies should select and use one of the following four monitoring methods: Bunker Fuel Delivery Notes (BFDN), bunker fuel tank monitoring on-board, flow meters for applicable combustion processes or direct emission measurements. A monitoring plan is specific to each ship and should document the choice made and provide further details on the application of the selected method: procedures for the measurement of fuel uplifts and fuel in tanks, description of the measurement equipment used, and the corresponding procedures for recording retrieving, transmitting, and storing information regarding measurements, as applicable.

The mentioned procedures and equipment must comply with the requirements of the regulations, national laws, and customer contracts to ensure that the total uncertainty of fuel measurements is consistent and sufficient.

2.5 Dual Transition Criteria for the MSFs Monitoring and Efficiency Assessment Model

The current fuel consumption, in most cases, can be estimated by flow meters, which measure the flow through the pipes and give the data about the fuel consumed or mass consumed for a given time interval – see Figure 6 for an explanation. Fuel consumption measurement is essential not only because of legal and environmental requirements.

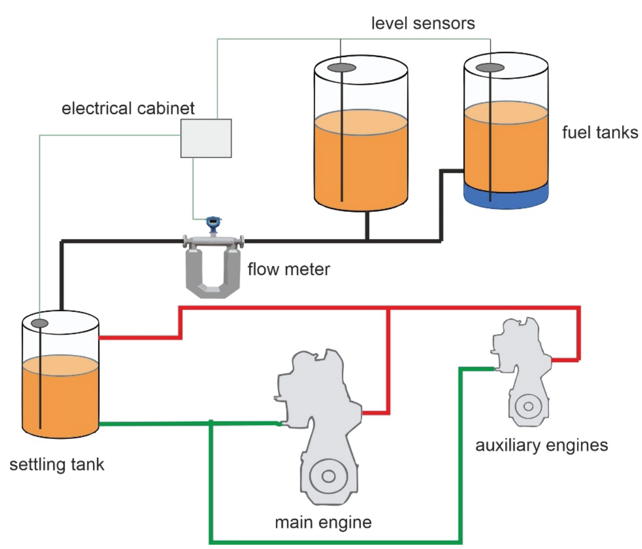

Figure 6 Onboard measurement of fuel quantities and consumption.

The fuel consumption data is one of the leading indicators for the ship's operational efficiency because part of fuel costs in operational expenses are up to 70% of the total OPEX of all types of ships and fleets. Increasing the efficiency of the nearest future fleet requires permanent and fast innovational development commercialization, scaling up smart shipyard manufacturing processes, and ships' navigation efficiency. On the other hand, the maritime economy should drastically reduce the impact of shipping activity on air pollution with exhaust gases and other harmful and toxic emissions.

One of the subtasks of this process is the development of specialized monitoring systems and measuring transformers for the green fuels supply, transshipment and efficiency of use control, appropriate data collecting, preliminary signal processing, clustering, analysis, final optimization of ships, and seafaring.

Nevertheless, ships' propulsion innovations and the use of green fuels imply the presence of appropriate infrastructure. Increasing the use of low-carbon and renewable fuels must be provided by creating a comprehensive infrastructure. To enable the widespread adoption of low- and zero-emission vehicle bunkering, many investments should be made to build a reliable supply chain, creating new infrastructure networks for electricity, natural gas, hydrogen, and other alternative energy sources.

The energy efficiency of each ship of the above-described Multifunctional Ships' Fleets should be monitored quantitatively, targeting the goal indicator set out in [1–5, 37–43].

"Carbon Intensity Indicators" (CIIs) should be calculated following the guidelines developed by the IMO [3–5] and adjusted, as necessary, to a specific ship and trade. CIIs are the metrics indicating the average CO_2 emissions per transport work of a ship, etc.

"Energy Efficiency Operational Indicator" (EEOI) is a measure used in the shipping industry to assess the energy efficiency of a vessel. Specifically, EEOI is calculated by dividing the total fuel consumption of a ship by a measure of its transport work (such as ton-mile or container-mile). EEOI provides a standardized way to compare the energy efficiency of different vessels and track performance over time.

"Annual Energy Requirement" (AER) describes the total energy needed to support a specific vessel activity and functional process over a year. It is also widely used in buildings, industrial processes, transportation, and other energy-consuming activities.

In its most simple form, the attained annual operational CII of an individual ship is calculated as the ratio of the total mass of CO_2(M) emitted to the total transport work (W) undertaken in a given calendar year, as follows:

$$attained\ CII_{ship} = M \times W^{-1} = FC_j \times CF_j \tag{1}$$

where: j is the fuel oil type; FCj is the total mass (in grams) of consumed fuel oil of type j in calendar year, as is reported under IMO DCS; CFj represents the fuel oil mass to CO_2 mass conversion factor for fuel oil j in line with those of specified by Energy Efficiency Design Index EEDI [37].

Another example of a transparent and recognized approach to assessing a ship's greenhouse gas efficiency concerning CO_2 emissions is the implementation of EEOI.

An appropriate environmental management system should be performed in line with the implementation of any other chosen indicator and follow the main elements of the recognized standards (planning, operations checking, corrective action, management reviews, etc.).

The basic expression for EEOI for a voyage is defined and calculated as:

$$EEOI = \left(\sum_j FCj \times CFj \right) \Big/ Mc \times D \tag{2}$$

where: Mc is the cargo mass, and D is the ship's dead weight.

The average of the indicator for a period or for *i* voyages is calculated as:

$$EEOI(A) = \left(\sum_i \sum_j FCij \times CFij \right) \Big/ (Mci \times Di) \tag{3}$$

A generalization of the model of calculation of operational indicators of energy efficiency of ships in case of qualitative assessment of the efficiency of the above examples of smart sensory multifunctional fleets or flotillas of *k* ships is the following formal model:

$$EEOI(FA) = \left(\sum_k \sum_i \sum_j FCijk \times CFijk \right) \Big/ (Mcik \times Dik) \tag{4}$$

This criterion modification is only one example of the primary criteria for the dual transition of the MSFs used in the current study. In general, the overall objective of optimizing the dual green and digital transition of the maritime economy could be formulated as follows: minimization of direct negative impact on the environment of all parts of the respective supply chain by implementing innovative solutions in the field of monitoring the proposed performance criteria based on the capabilities of cloud computing systems (platforms), AI, Analytics, ML, IIoT, etc. [50].

3 Conclusions

The proposed hybrid intelligent system, enhanced with cutting-edge connectivity, cloud computing, and mobile applications, is poised to revolutionize the maritime industry by enabling thorough all-around analysis and fostering the development of numerous value-adding applications.

The next steps for increasing the efficiency and ecology friendliness of ships and ship fleets' technological processes for fulfilling their missions are:

- Further development of embedded energy and logistic monitoring systems of all ships of MSFs and autonomous unmanned marine vehicles to correct the current sea environment's planned path, speed, and course on time based on embedded robotics and mobile applications integration.
- Modification and wide implementation of intelligent polymetric and other innovational highly efficient sensor systems such as MRV and DCS systems information components for integrated smart ships and ship fleet control based on hybrid calculations and mobile applications.
- Development of intelligent automation and autonomous underwater robotic systems for smart navigation and production quality and cost efficiency.

Mobile applications, robotics, and AI methods are extremely important for further research and development of innovational projects in the maritime industry, like the optimization of the Multifunctional Ship Fleet in the OPUSS project or solving the highly complex task of integrating underwater unmanned dredger into the special vessels fleet in ALERD project.

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