Integrated Digital Platform for Marine Energy Management

Alexandra Baicoianu
Siemens Industry Software
Brasov, Romania
alexandra.baicoianu@siemens.com

Dan Pescaru
Siemens Industry Software
Brasov, Romania
dan.pescaru.ext@siemens.com

Daniela Sasu
Siemens Industry Software
Brasov, Romania
daniela.sasu@siemens.com

Calin Husar
Siemens Industry Software
Brasov, Romania
calin.husar@siemens.com

Roberta LUCA
Siemens Industry Software
Brasov, Romania
roberta.luca@siemens.com

Lars Petter LARSEN
Corvus Energy
Bergen, Norway
lplarsen@corvusenergy.com

Abstract—Marine transportation plays a crucial role in global commerce, yet its environmental impact remains a concern. This paper proposes a draft architecture for a maritime digital platform, with a focus on optimizing ship energy systems to enhance sustainability. A key component of the proposed platform architecture is the integration of digital models with real-time data and predictive analytics, providing operators with valuable insights into energy consumption, battery health, and distribution management. By facilitating informed decision-making, the proposed platform aims to enhance system performance, durability, and environmental responsibility. Sensitive maritime data is protected through the implementation of advanced security protocols and encryption techniques, ensuring adherence to recognized industry cybersecurity standards. This paper introduces the fundamental components of the proposed digital platform, emphasizing its potential to revolutionize ship energy management and contribute to a more sustainable maritime industry.

Keywords—maritime, ship hybridization, cloud computing, digital twin, digital platform

1. INTRODUCTION

The maritime industry stands at the cusp of a transformative era, driven by the imperatives of sustainability and technological advancement. In the existing literature, numerous articles and studies have focused on marine energy management, addressing key issues such as optimizing energy consumption, enhancing system efficiency, and minimizing environmental impact [1]. Various solutions have been proposed, ranging from advanced energy management strategies to innovative technological systems. Some notable works in this field include [2-12], which highlight the importance of integrating digital tools for effective energy monitoring and management.

The NEMOSHIP EU-funded project facilitates the implementation of a digital platform that aims to address these challenges by providing a comprehensive solution for marine energy management. The ambition of the NEMOSHIP [13] is to develop, test and demonstrate new innovative technologies, methodologies and guidelines to accelerate large Battery Energy Storage Systems (BESS) deployment and optimal exploitation toward 2030 on both hybrid and full-electric arrangement. To help achieve this ambition, the NEMOSHIP project will develop a modular and standardized battery energy storage solution that is able to exploit heterogeneous storage units and a cloud-based digital platform to enable data-driven, optimised, and safe exploitation.

The proposed NEMOSHIP Digital Platform, architecture analysis delves into the comprehensive design and operational framework of the platform, underscoring its role in revolutionizing the management of large battery systems on ships. The proposed platform offers a modular and scalable architecture that seamlessly integrates with diverse maritime operational environments and focuses on maximizing the potential of digital twin models, data analytics, machine learning algorithms, and real-time data processing to optimize performance and energy consumption.

Significant to the platform's architecture is its ability to provide a holistic view of a ship's energy systems, enabling operators to make informed decisions based on precise data and predictive analytics. The platform's robust architecture supports a wide array of functionalities, from monitoring battery health to managing energy distribution and consumption patterns. This ensures optimal performance and longevity of the battery systems, a critical aspect in maintaining operational efficiency and reducing environmental impact.

Furthermore, the NEMOSHIP Digital Platform is designed with a strong emphasis on security and data integrity. Recognizing the sensitivity of maritime operational data, the platform incorporates advanced security protocols and encryption techniques to safeguard against cyber threats. This security framework is not only a testament to the platform's reliability but also aligns with the industry's growing focus on cybersecurity in the digital age. In addition, the platform's architecture is crafted to facilitate seamless integration with existing maritime infrastructure and systems. This interoperability is vital for ensuring a smooth transition to more advanced, data-driven operational models within the shipping industry. By enabling easy integration, the platform paves the way for widespread adoption and sets a new standard in maritime digital solutions.

As this study unfolds, it provide an in-depth analysis of the architectural components, functional capabilities, and strategic implementations of the NEMOSHIP Digital Platform that will be developed and implemented as part of the collaborative EU project. The paper explore how each element of the platform's architecture contributes to its overall efficacy and how it stands as a cornerstone in the journey towards a more sustainable and efficient maritime future.

2. State of art of maritime digital platforms

Current maritime digital platforms harness cutting-edge technologies such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and cloud computing to optimize ship energy systems and enhance overall maritime operations. Key types of these platforms include Fleet Management Systems (FMS), which enable real-time monitoring and optimization of vessel performance, and Voyage Optimization Platforms, which use real-time data and advanced algorithms to recommend efficient routes, reducing both fuel consumption and emissions. Energy Management Systems (EMS) focus specifically on optimizing a ship's energy usage by monitoring and controlling various onboard energy-consuming components.

Notable real-world examples include Kongsberg's K-Fleet [14] and Wärtsilä's Fleet Operations Solution (FOS) [15] in fleet management, as well as ABB's Marine Advisory System – OCTOPUS [16] and StormGeo's BonVoyage System (BVS) [17] for voyage optimization. Siemens' SISHIP EcoMAIN [18] and Schneider Electric's EcoStruxure for Marine [19] are prominent energy management solutions. Additionally, digital twin technology, which creates virtual replicas of ships to simulate and analyze performance in real time, is gaining momentum with solutions like GE's SeaStream Insight and Wärtsilä's Digital Twin. These platforms rely on IoT for real-time data collection, big data analytics for actionable insights, cloud computing for scalable data processing, AI for predictive analytics and automated decision-making, and strong cybersecurity measures to protect data integrity.

The impact of these digital platforms is profound. They enhance operational efficiency by providing real-time insights and optimization recommendations, leading to reduced fuel consumption, lower operating costs, and improved vessel performance. Sustainability is greatly improved, as optimized energy systems and routes lead to reductions in greenhouse gas emissions and pollutants, helping the maritime industry comply with environmental regulations and sustainability goals. Safety and reliability are also enhanced through predictive analytics and real-time data sharing, which help identify potential issues before they escalate, enabling proactive maintenance and minimizing the risk of accidents. Additionally, these platforms promote seamless communication and data sharing among stakeholders, fostering collaboration, transparency, and coordinated decision-making.

However, the NEMOSHIP digital platform brings several unique advantages. It integrates advanced Digital Twin models and machine learning algorithms specifically designed for optimizing large battery energy storage systems (BESS) on ships. Additionally, its modular and scalable architecture allows for seamless adaptation to a wide range of maritime environments. NEMOSHIP's focus on real-time data processing and predictive analytics further enhances its ability to improve both energy efficiency and safety in maritime operations, setting it apart from other solutions in the field.

3. Main modules and communication

The proposed NEMOSHIP Digital platform, designed as modular platform, embodies the principles of distributed computing and microservices architecture. Each module within this platform is designed to fulfil a distinct and specialized role, contributing a unique piece to the collective functionality of the system (Figure 1). This modular design not only enhances the system's flexibility and scalability but also facilitates maintenance and upgrades by allowing individual modules to be modified or replaced independently.

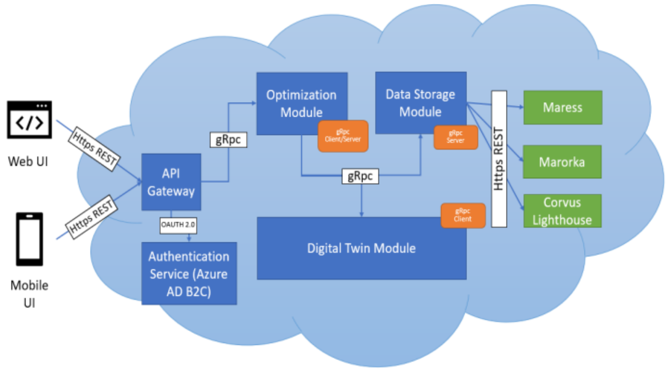

Figure 1 - Module communication

In such a modular environment, effective communication is paramount, both between the modules themselves and with external entities like users and data providers. Since the entire platform is cloud-deployed, network-based communication protocols are employed to facilitate this interaction. The selection of these protocols is critical to the efficiency, security and reliability of the system's communication framework. The platform predominantly utilizes two main communication protocols: Representational State Transfer (REST) and gRPC Remote Procedure Calls (gRPC). REST's simplicity is used for external communications, while gRPC manages data-intensive internal communications with its efficiency. This combination ensures the platform remains robust, efficient, and scalable.

In the following sections, details about the key components of the environment, including Digital Twin Module, Optimization Module, Data Storage Module, and the external components are highlighted.

3.1. The Digital Twin module

The Digital Twin (DT) module's role is to simulate to a high degree of accuracy of the real-world ships it is designed to digitally replicate (Figure 2). To achieve this, it needs to rely on state-of-the-art simulation software like Simcenter Amesim [20]. A typical DT is a replica of a physical system that is connected to and receives updates from its real-world counterpart via a bi-directional data link. The Maritime Digital Twin Architecture is introduced to systematize DT's features, aiming to improve overall knowledge and application of DTs.

The Digital Twin Interface is a webAPI cloud service that coordinates access to module components and returns responses in a standardized format. Each Simulation Service is a deployment of a simulation platform like Simcenter Amesim or Matlab Simulink in the cloud with an exposed API that can be accessed by the Digital Twin Interface. Through this API the Digital Twin Interface needs to be able to change simulation parameters, start/stop simulations and extract simulation results when the simulation has finished.

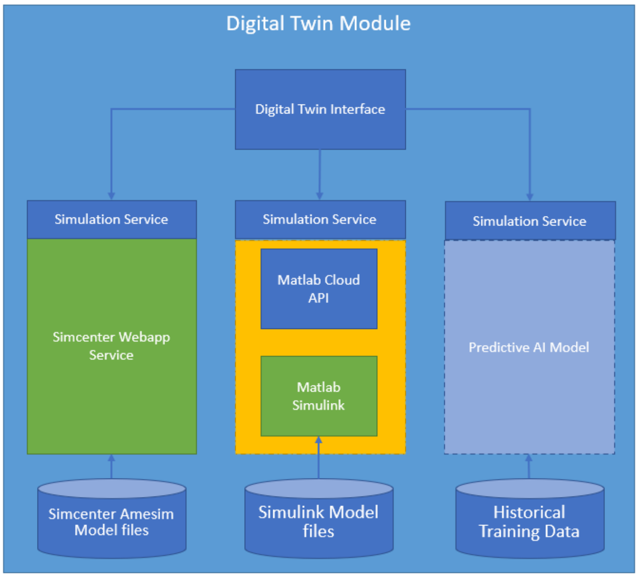

Figure 2 - Digital Twin module

3.2. The Optimization module

The proposed Optimization module is composed of two main services:

- The Optimization Management Service oversees all tasks required to derive crew guidance data from user input. It consists of three main components designed to facilitate this process, see Figure 3. The Optimization Module API handles receiving all the inputs from the user interface and transfers it to the Optimization Engine Manager. The Optimization Engine Manager decides if it needs to start up a new instance of an Optimization Engine Service or reuse an existing one and process and pass the correct parameters to it. It also handles receiving the output from the Optimization Engine services and passing it to the Crew Guidance Extractor. The Crew Guidance Extractor interprets the results from the optimization Engine Service and converts it to a format that can be used by the User Interface to display the guidance to the user.
- The Optimization Engine Service is responsible for receiving optimization parameters and determining optimized values for variable parameters while maintaining fixed parameters constant. The Optimization Engine Service utilizes three key components: (i) The Optimization Engine API, which communicates with the Optimization Engine Manager to receive parameters for optimization; (ii) The AI Optimization Engine, trained on historical data, identifies optimal values based on fixed parameters and simulation results, iterating through multiple attempts to achieve satisfactory outcomes; (iii) The Digital Twin Broker manages the DT simulation by sending simulation parameters identified by the AI Optimization Engine and retrieving the results to pass back for further analysis.

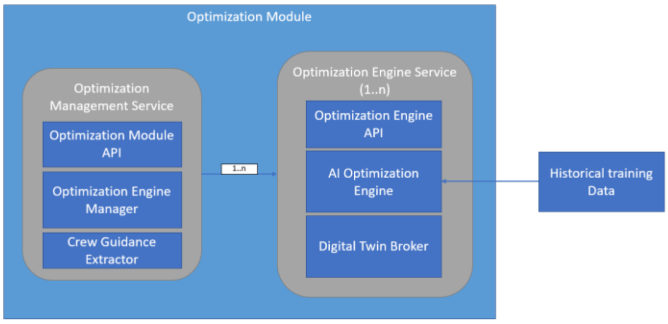

Figure 3 - Optimization module

3.3. The Data Storage module

The Data Storage module (Figure 4) has one main component, the Data Adapter Service. This service exposes a gRPC interface (Data Adapter Service API) that allows it to communicate to the other modules. It contains subcomponent adapters for each data provider in the project with the possibility to always add more. The Data Adapter subcomponents are responsible for all the communication, retrieval and formatting of the data for their respective provider. The Data is then passed to the Data Correlator in a common format which will normalize the data from a duration perspective and correlate the data from all the providers. Once correlated the data is passed back to the interface API which sends it back to the client.

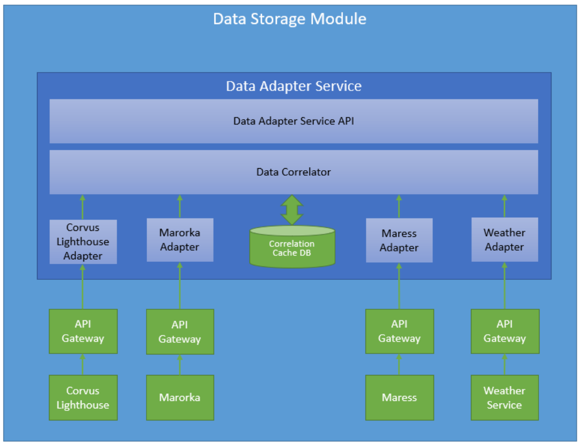

Figure 4 – Data storage module

3.4. External components

External components refer to elements of the NEMOSHIP Digital Platform that are either part of the partners' existing portfolios or widely used software within the maritime industry. This subsection will focus on a selection of these components that are representative of their respective categories.

3.4.1. Ascenz Marorka

The Ascenz Marorka Web API [21] is a sophisticated interface designed to facilitate access to data stored within Ascenz Marorka's extensive data center. This API is a critical component for external systems and software tools that require interaction with Ascenz Marorka's data repositories. It provides a standardized, well-documented set of methods, allowing for seamless and secure data retrieval and manipulation.

3.4.2. Corvus Lighthouse

The Lighthouse is a data logger that collects data from the Corvus Energy BESS interpack communications network, aggregates it in an efficient format for transfer and then sends the data up to the cloud-based storage for storage and later processing. The main interfaces to the Lighthouse are:

- Ethernet connection via RJ45 port – Inter-pack communications network
- Ethernet connection via RJ45 port – Internet connection (onboard the vessel)
- DC power connection
- Micro SD card slot for additional storage

The Lighthouse plays a non-critical role in the operation of the Orca ESS and the ESS can operate without a Lighthouse connected to the system because it only passively monitors ethernet data on the interpack network. Lighthouse is delivered with all deliveries of Corvus Energy BESS systems.

3.4.3. Webapp Cloud Platform (powered by Simcenter Amesim)

The Simcenter Webapp Server is a versatile and advanced tool designed to democratize the access to system simulation models across an organization. Simcenter Webapp Server is an innovative solution that offers simplicity, cost-effectiveness, and a range of features that enhance the accessibility, customization, and security of system simulations in a web-based environment. These capabilities make it a valuable tool for organizations looking to leverage system simulation models across different departments and user types.

An overview of the proposed NEMOSHIP Digital Platform architecture is illustrated in Figure 5, highlighting the general structure and key components of the system.

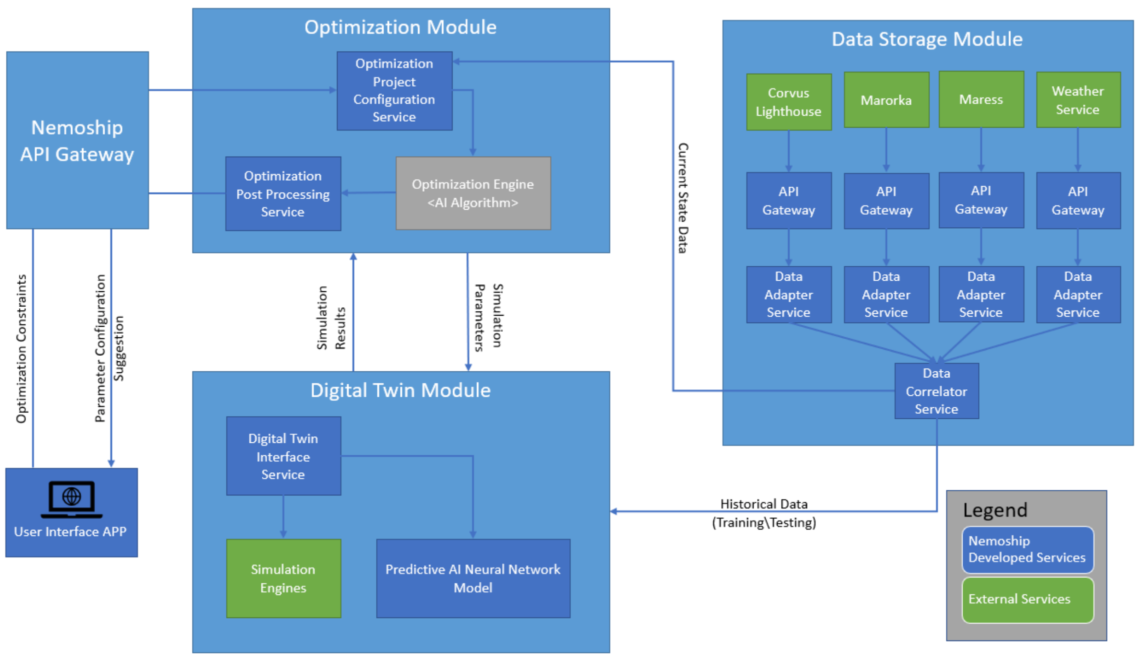

Figure 5 – Proposed NEMOSHIP Digital Platform architecture

4. SUPPORTED USE-CASES

In this section, three distinct modules are presented, demonstrating the platform's capability to support a range of practical applications and illustrating its versatility. For all supported use-cases, the initial step involves user authentication. After successful authentication, users gain access to the platform's tools and configuration options.

4.1. Battery usage optimization during trip planning

This module allows the user to import or define all the parameters of a trip in the NEMOSHIP Digital Platform interface and see the recommended guidance values for all the vessel optimization parameters available in the DT. The user can import a route, add state changes by specifying a waypoint and optionally a time difference. The purpose of this module is not to replace existing and established maritime trip planning software, instead it will be a complementary addition of features that are needed to optimize battery usage, reduce fuel consumptions and emissions. Therefore, the platform will support importing waypoints and other data from the existing maritime platforms and services, analyze historical data for similar routes and provide recommendations for Power Management System. It also provides a set of pages to assist in mapping out the voyage from the ship energy management perspective.

4.2. At sea battery usage optimization

In this module, using system's adaptability and dynamic functionality, the pages delivered by module A transform to reflect real-time conditions and requirements. This dynamic shift is critical for effective battery efficiency management. The vessel's position is updated continuously, ensuring accurate and current location data is always available. In this mode, the system smartly filters and displays only the relevant waypoints and state changes pertinent to the current leg of the journey. This selective visualization ensures that the crew is not overwhelmed with unnecessary information, enabling them to focus on immediate priorities.

4.3. At sea scenario prediction

In the scope of maritime operations, the implementation of DT technology marks a significant advancement, particularly in the context of this module The DT becomes an invaluable tool during the vessel's deployment at sea, enabling a multitude of simulated scenarios that offer deep insights into vessel behavior under varying conditions. This technology not only simulates real-time operations but also extends to hypothesize numerous 'what-if' situations, thereby providing a robust platform for strategic decision-making and operational optimization.

At the core of this application is the ability to simulate the vessel's behavior using a range of input parameters and scenarios. This simulation is not a mere theoretical exercise; it is a sophisticated engineering analysis that incorporates varying environmental conditions, operational modes, and functional parameters. By manipulating these variables within the DT framework, the system can forecast the vessel's performance, considering factors such as fuel efficiency, emissions, speed, maneuverability, and safety.

One of the most notable features of this technology is its comparative analysis capability. The system can run parallel simulations, each varying in certain parameters, and then juxtapose these scenarios against each other. This comparison is crucial for understanding how specific changes in operational modes or functional parameters can significantly impact key performance indicators (KPIs). For instance, by adjusting variables like engine speed, navigation route, or weather conditions, the system can demonstrate the resultant effects on fuel consumption and carbon emissions. Such analysis is invaluable for enhancing operational efficiency and environmental sustainability.

5. CONCLUSIONS

The application of DT technology within the NEMOSHIP Digital Platform exemplifies a significant advancement beyond traditional simulation methods. By integrating real-time predictive capabilities with retrospective analysis, the platform offers a multifaceted approach to maritime operations. The Digital Platform modules illustrate the system's adaptability across various voyage phases, from detailed pre-voyage planning to real-time adjustments at sea. This dual capability not only enhances battery efficiency, safety, and decision-making accuracy but also drives forward-looking simulation and backward-looking analysis. As a result, the DT emerges as a key tool in modern maritime operations, fostering greater efficiency, sustainability, and strategic decision-making in response to dynamic sea conditions and evolving operational demands.

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