Designing a dynamic platform for the next generation of multi-modal logistics

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***Abstract*—The FOR-FREIGHT (Flexible, multi-mOdal and Robust FREIGHt Transport) project represents a pioneering initiative aimed at revolutionizing multimodal logistics by optimizing transport capacity and enhancing sustainability and efficiency. This paper delves into the project's overarching objectives, methodologies, and anticipated impacts. With a primary focus on developing innovative solutions seamlessly integrated into existing logistics systems, FOR-FREIGHT strives to diminish the average cost of freight transport. The project's unique approach encompasses a comprehensive, end-to-end optimization of multimodal logistics services, addressing challenges prevalent in airports, ports, inland terminals, and logistics nodes. Central to FOR-FREIGHT's success is the creation of a cloud-based platform, combining IoT, AI/ML, and Big Data Management, designed to streamline logistics processes and facilitate decision-making. The paper also emphasizes the integration of legacy systems, ensuring the project's applicability to real-world scenarios. Furthermore, FOR-FREIGHT envisions an open marketplace and standardized interfaces, fostering collaboration and interoperability across diverse stakeholders. As the project advances, it promises to not only redefine multimodal logistics practices but also contribute to the establishment of sustainable and efficient standards within the industry.**

Keywords—Transport & Logistics; AI; Solvers; multi-modal transport

I. Introduction

The FOR-FREIGHT project is geared towards optimizing the utilization of multimodal freight transport capacity, striving to achieve competitive sustainability coupled with heightened efficiency. The primary objective is to diminish the average cost of freight transport by introducing innovative solutions seamlessly integrated with existing logistics systems. [1] This comprehensive approach is designed to facilitate more effective and sustainable management of goods and freight flows across diverse transportation hubs, including airports, ports, inland terminals, and various logistics nodes.

The project considers the requirements and interests of all stakeholders, ensuring a well-rounded perspective that incorporates economic, environmental, and social aspects. By doing so, FOR-FREIGHT aims to address the complex web of challenges associated with modern freight logistics. The innovative solutions developed under FOR-FREIGHT will target the end-to-end optimisation of multimodal and multi-stakeholder logistics processes. One of the key focuses to enhance accessibility to transhipment services, thereby streamlining the movement of goods across various transportation modes and logistics nodes. The project's Unique Value Propositions are devised to revolutionise the freight transport landscape, encompassing a spectrum of benefits for both industry players and society at large. Through a concerted effort to integrate novel technologies and methodologies, FOR-FREIGHT seeks to usher in a new era of sustainable and efficient freight management. FOR-FREIGHT employs a structured methodology, encompassing several key directions to achieve its overarching objectives. The initial phase involves the establishment of three multimodal Transport and Logistics (T&L) trial sites strategically positioned within operational environments. This foundational step sets the stage for subsequent developments aimed at enhancing the efficiency and sustainability of freight transport.

Integrating diverse legacy systems and ensuring seamless interoperability poses a significant challenge, requiring robust solutions to bridge compatibility gaps. Additionally, the adoption of advanced technologies like AI/ML and IoT necessitates substantial investment in infrastructure and expertise, potentially impeding progress. Regulatory hurdles, including compliance with data privacy laws and transportation regulations, add another layer of complexity, requiring meticulous navigation to ensure adherence while innovating.

Logistically, coordinating stakeholders across the multimodal transportation network presents challenges in aligning interests, standards, and processes, particularly in heterogeneous environments. Overcoming these obstacles demands a holistic approach, involving stakeholder collaboration, regulatory compliance frameworks, and innovative technological solutions tailored to the intricacies of the logistics landscape.

A pivotal aspect of FOR-FREIGHT's methodology is the integration of the three trial sites' functionalities under a unified cloud-based experimentation platform. This platform serves as a comprehensive hub, providing seamless access, monitoring, and evaluation capabilities. This integration not only fosters a cohesive approach but also facilitates the systematic testing and validation of the proposed multimodal logistics services, ensuring their viability in real-world applications.

Extensive trials are a crucial component of the methodology, designed to rigorously assess and validate the effectiveness of the proposed multimodal logistics services [2]. These trials serve as a practical benchmark, offering valuable insights into the operational dynamics and potential improvements that can be incorporated into the evolving FOR-FREIGHT framework.

An integral focus of FOR-FREIGHT's methodology is the development of sustainable business models and collaborative, multimodal T&L service plans. This strategic approach aims to establish a robust foundation for long-term success, fostering cooperation among stakeholders and ensuring the economic viability of the proposed logistics solutions [3].

Furthermore, FOR-FREIGHT envisions the creation and evolution of a multimodal logistics ecosystem. This initiative is geared towards promoting the widespread adoption of the innovative solutions developed within the project. By optimizing multimodal freight transport capacity, our solution minimizes empty journeys and maximizes resource utilization, thereby reducing carbon emissions and environmental impact. By fostering an ecosystem that encourages collaboration and embraces novel technologies, FOR-FREIGHT seeks to catalyze a paradigm shift in the freight transport landscape [4].

The overall concept and envisioned platform architecture of FOR-FREIGHT are represented in Figure 1, emphasizing the logistics solutions to be developed and demonstrated. The project's use cases (UCs) and real-life field trials are strategically designed to address three complementary intermodal transport scenarios: seaport-to-city (last mile) utilizing the subway network, seaport-to-airport employing trucks, and inland (river) port-to-mainland through rail transport. This comprehensive approach covers a broad spectrum of functionalities, accommodating the diverse requirements of the majority of T&L stakeholders. By promoting end-to-end optimization and sustainability considerations across the logistics network, the FOR-FREIGHT solution ultimately drives down costs, improves operational performance, and contributes to a more environmentally conscious and resilient logistics industry.

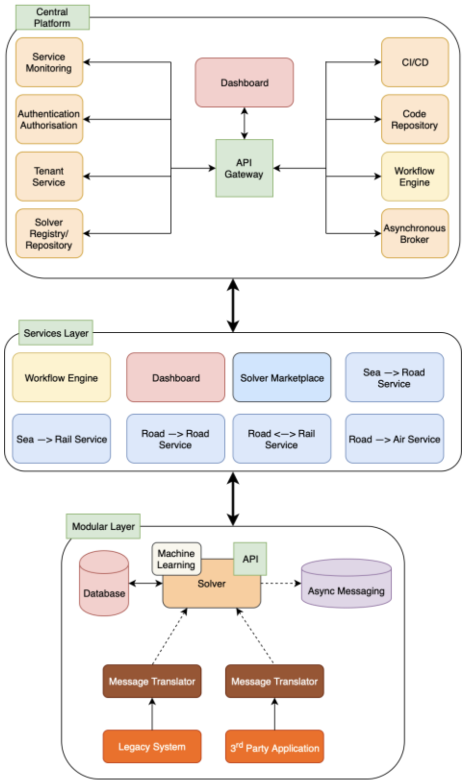

Figure 1 High-level architecture of the FOR-FREIGHT platform

II. FOR-FREIGHT Platform Architecture

The FOR-FREIGHT platform represents a cloud-based system characterized by objective customization and role-based design, aiming to deliver operational benefits to all participants involved in the project's scope. With a diverse array of technical solutions ranging from IoT and AI/ML to Big Data Management, the platform is strategically crafted to address challenges identified in the Spanish, Greek, and Romanian UCs within the three trial sites.

Within the FOR-FREIGHT framework, the architectural design places emphasis on prioritised functionalities. Firstly, it involves the modelling of the logistics network based on operational specifications. Secondly, the system translates Key Performance Indicators (KPIs) and operational expectations into technical challenges, encompassing elements such as prediction, simulation, optimisation, decision support, and recommendation. Thirdly, the platform proposes the integration of technical modules to guide multi-modal logistics services towards their predefined goals and expectations. To optimize efforts, the platform collaborates with existing assets, including legacy systems, internal technical providers' expertise, and third-party applications.

Furthermore, the FOR-FREIGHT platform orchestrates the operation of the integrated solutions, covering aspects such as monitoring, life cycle management, and data exchange. It provides support for tracking, visualization, output viewing, and exportation of all functionalities included in a user-role-based manner.

The international association "Terminal Industry Committee – TIC4.0" joined the project to help with the standardisation of FOR-FREIGHT's outcomes. Established in 2018, TIC4.0 aims to unite companies in the terminal operators' industry, port equipment manufacturers, and suppliers to develop industry standards for data exchange protocols and formats. Through its efforts, TIC4.0 has created a standardized "common language" with defined semantics and data models, adaptable to various logistics processes. Our project plans to utilize TIC4.0's data model to achieve standardized data representation across solver-legacy system and solver-output data layers. This involves using TIC4.0's data model as the foundation for both input and output data, with specialized APIs for accurate translation and interpretation. A successful pilot application has already demonstrated the feasibility of this approach, where legacy system data was transformed into the common language, processed by the solver, and structured according to TIC4.0's standards.

The design philosophy of the platform is anchored in a lightweight approach. The construction process begins with maximal intersections among all UCs, laying the groundwork for a versatile prototype. Subsequently, tailor-made components specific to each UC are implemented atop this underlying prototype, ensuring a flexible and efficient system that caters to the unique requirements of each scenario.

The project incorporates a **Services Layer**, defining an end-to-end pipeline of interconnected logistics entities characterized by predefined KPIs. These services encompass nodes and edge functions represented in a graph-based structure, serving as interfaces that provide functionalities throughout various stages of UC scenarios. For instance, optimizing transportation time between a seaport and a city involves strategically located Distribution Centers and depots. Through this layer, services within UCs from Spanish, Greek, or Romanian trial sites can select modules from the repository to construct their end-to-end operational T&L pipeline and link them with appropriate input/output elements like end-devices and vehicles.

The **Modular Layer** serves as the backbone component, housing a repository of modules invoked by services towards their goals. This includes legacy systems, core solvers, and third-party applications. Legacy systems represent existing practices and management systems, while core solvers integrate information and operations for supply chain efficiency. Third-party applications contribute data and tooling for weather, traffic, and simulations, enhancing the centralized use of standardized data from these systems.

III. SOLVERS DESIGN

Within the context of the FOR-FREIGHT project, we propose a range of functional modules designed to address the technical demands posed by three distinct UCs, which have hitherto remained unaddressed or inadequately resolved by the legacy systems. Our overarching strategy involves generalizing these solvers to effectively address common bottlenecks and thereby alleviate implementation challenges. Our approach leverages synergies derived from various initiatives, spanning Deep Learning, Machine Learning, Simulation models, real-time tracking, IoT, and Blockchain techniques, all directed towards optimizing dynamic end-to-end logistics networks.

The formulated solvers encompass a broad spectrum of functionalities, addressing key aspects of multimodal logistics optimization. These modules include an Estimated Time of Arrivals (ETA) Predictor for forecasting cargo arrival times, a Dwelling Time or Duration Stay Predictor for predicting total stay duration at logistics hubs, and a per-sub-route Transport Cost and Emission Predictor for forecasting costs and environmental impacts. Additionally, there are modules such as the Resource Capacity or Demand Predictor, Routing Recommender, Real-time Re-planner, and Next Transport Mode Recommender, focusing on anticipating resource capacity, optimizing routes, dynamically recalculating plans in real-time, and advising on the next transport mode. Further functionalities include the Warehouse Planning Optimizer for maximizing truck utilization, the Localizer for freight tracking, and the Data Analyzer for extracting insights from diverse datasets to enhance logistical operations' efficiency and accuracy.

Historical and real-time operational data shared by port facilities, warehouses, depots, trucking companies, and metro companies are utilized to train predictive models. Additionally, internal stakeholders contribute IoT technologies for end-to-end freight tracking, ensuring the ongoing accuracy of predictive indicators. Starting from legacy systems, the service must be equipped with several functions (solvers), including data analysis for anomaly detection (Data Analyzer), ETA prediction, route optimization for minimal transport time (Time Optimizer), and real-time plan adjustments based on road incidents (Real-time Recommender). Furthermore, these solvers require additional data sources to enhance accuracy, such as Weather and Traffic forecasting. Notably, due to the absence of historical records for truck travel between distribution centres and metro depots, simulated data is essential for the time predictor on this specific sub-route. Furthermore, Weather, Traffic, and Simulator functionalities are sourced externally (third-party applications) to supplement the functional implementation of this service.

IV. USE CASES FOR VALIDATION

The FOR-FREIGHT project employs the Spanish, Greek, and Romanian UCs as integral components to validate the platform's capabilities and overarching concept. The integration of existing legacy systems and technologies within these UCs serves as a practical testing ground, showcasing the adaptability of the FOR-FREIGHT platform to the complex and varied landscapes of modern logistics infrastructures. The real-world challenges presented by the integration of legacy systems from diverse stakeholders in each UC exemplify the platform's ability to seamlessly incorporate and harmonize various components, from transportation modes to data management tools. The focus on creating cohesive ecosystems within the supply chain, where data and insights flow seamlessly, underlines the importance of interoperability and efficient data exchange, contributing to overcoming information silos. By harnessing advanced technologies such as Digital Twins, AI/ML, Blockchain, and IoT components, the UCs demonstrate the platform's versatility and efficacy in enhancing decision-making, optimizing routes, and reducing environmental impacts. Each UC has a unique emphasis, be it on end-to-end multi-modal optimization, innovative last-mile solutions, or continuous process optimization, collectively showcases the platform's commitment to addressing diverse logistics challenges and staying adaptive over time. The successful validation across these UCs establishes the credibility and applicability of the FOR-FREIGHT platform within the multifaceted landscape of modern, multimodal transportation and logistics environments.

A. Spanish Use Case

The Spanish trial site concentrates on the seamless integration of seaport, road (truck/train), and subway (last mile) transport modes, aiming to achieve end-to-end multi-modal transport optimization to improve forecast planning by >15%, increase document digitalization by >20%, Reduce container staying at the port by >15% and reduce GHG emissions by >15%. This trial site encompasses two distinct scenarios: In Valencia Port, the primary focus is on the efficient unloading and loading of freight from vessels onto trucks or trains destined for DHL's warehouse. In Madrid, the focus shifts to activities from DHL's warehouse up to last-mile distribution through the Metro de Madrid network, introducing an innovative aspect by leveraging Metro de Madrid (MDM) depots, stations and trains to distribute the parcels to be retrieved by end customers at station lockers rather than traditional last-mile hubs and transport modes. The overarching objective is to develop a sophisticated decision support system (DSS) tailored to multimodal logistics, emphasizing improved decision-making, optimized routes, and reduced greenhouse gas emissions through advanced technologies like Digital Twins, Blockchain, Artificial Intelligence/Machine Learning (AI/ML) and IoT components. These technologies provide valuable insights into T&L processes, enabling real-time decision-making, predictive analytics, and automation.

The trial site strongly emphasizes achieving end-to-end multimodal optimization. Digitalization and automation are key components, aimed at eliminating labour-intensive tasks, enhancing cargo visibility, reducing errors, minimizing congestion, and improving interoperability between stakeholders. The overarching goal is to minimize inefficiencies and bottlenecks, ensuring swift and cost-effective delivery of goods to their final destinations.

A foundational element of the development plan for the Spanish trial site revolves around the integration of existing legacy systems and technologies. Given the intricate nature of contemporary logistics, there is a compelling need to harmonize diverse components, ranging from transportation modes to data management tools. More specifically, the integration efforts will be concentrated on gathering and extracting historical data, thus forming a rich repository of information that will prove essential for feeding the different solutions within FOR-FREIGHT, facilitating interoperability among different stakeholders, surpassing existing information silos that hinder efficient information exchange processes, and promoting a more collaborative and efficient logistics ecosystem.

The FOR-FREIGHT operational framework aligns with this objective by developing a set of solutions, known as solvers, to address these various challenges encountered in the Spanish UC. The designed solvers for the Spanish UC aim to: 1) predict the Estimated Time of Arrival (ETA) of transport means, the stay of the cargo at the port and the capacity of MDM; 2) recommend the optimal route planning based on time, cost and emission factors; 3) estimate resource requirements and their optimal allocation; 4) provide real-time cargo visibility; 5) offer a decentralized system for sharing T&L data and documents. In this way, although each of the solvers focuses on specific requirements and has particular functionalities, the ultimate goal is to maximize the efficiency, visibility and control of the processes and operations in the T&L chain.

Continuous process optimization is integral to the Spanish UC, where although the process flow remains largely unchanged, the focus shifts to enhancing data visibility. Through the utilization of Digital Twins and AI-based Machine Learning, transport planning becomes more efficient, ensuring a dynamic and adaptive approach to logistics operations, while the real-time access to estimated and actual information from the different actors involved in the process, and the optimization and secure tracking of transactions between stakeholders, is raised through a blockchain solution. Finally, selected logistics events will be validated through IoT devices connected to the cargo and/or logistics assets, while others will be estimated using data analytics and predictive models that forecast cargo arrivals and departures within the Spanish UC logistics nodes.

As a result, the integration of legacy systems will significantly enhance the capabilities and value propositions of the project.

The strategic focus of FOR-FREIGHT involves eliminating information silos and strengthening communication channels among stakeholders. This is achieved through the use of the FOR-FREIGHT platform and its associated solvers, which aim to improve efficiency, increase visibility, and promote sustainability in the project's multifaceted operations.

B. Romanian Use Case

The Romanian trial site aims to optimize the logistics chain and multimodal transport services, end to end, between the Danube River port of Galati and the railway infrastructure. The trial site aims to reduce container idle time by 25%, reduce routing errors by 20%, reduce accidents by 30%, increase end-to-end capacity due to optimization of resource utilization by 20%, and decrease loading/unloading time by 20%.

Developing connections with other modes of transportation is a continuous challenge for each port. Considering this, the general objective is to develop a functional decision support system (DSS) adapted to multimodal logistics, emphasizing decision-making based on data obtained in real-time from the field, optimized routes, and reduced greenhouse gas emissions using the most advanced available technologies.

The primary objective of river transport and trade remains to ensure the secure and timely movement of goods at national and international levels while maintaining economic efficiency. Unlike maritime ports, river transport conditions are subject to an increased number of variables, such as changes in routes or blockage of waterways, changing water levels, the occurrence of frost in winter, and other elements that can influence traffic and, implicitly, the time of the vessels arriving at the port.

Regarding the Romanian UC, we intend to collect and process all the data necessary to streamline freight transport operations and integrate the legacy systems of the interested parties with a modern collaborative platform. The historical data that we already have represents a step ahead in achieving the critical indicators proposed through the FOR-FREIGHT project.

Key legacy systems integrated into UC Galati include EuRIS, which provides the Danube River vessel location, water level, and waterway data. That data is available online and can be accessed for free by the interested parties. Making data available to all operators, creating an ecosystem, and digitizing operations will lead to reaching all the milestones of progress that we have proposed.

In the Romanian trial site, we will use top technologies, such as IoT components for determining weather and air quality conditions, trackers for locating containers, Digital Twins, AI/ML, and Blockchain. These technologies provide valuable insights into transportation and logistics (T&L) processes, enabling real-time decision-making, predictive analytics, and automation.

Digitization and automation are vital components to eliminate labor-intensive tasks, improve cargo visibility, reduce errors, minimize congestion, and improve interoperability between stakeholders. The trial site focuses on optimizing end-to-end multimodal transport, from river ports on the Danube to customers on the railway infrastructure. The general goal is to minimize inefficiency and blockages, ensuring the fast and cost-effective delivery of goods to their final destinations and, implicitly, the possibility of replicating the solution offered by the FOR-FREIGHT project at the other Danube ports.

Using Digital Twins and Machine Learning based on artificial intelligence, transport planning becomes more efficient, ensuring a dynamic and adaptive approach to logistics operations. Implementing the solution resulting from the project will lead to the correct estimation of the arrival times of the river vessels in the port, the time required, and the planning of the loading/unloading activities, the accommodation, and the planning of the railway transport.

Also, the FOR-FREIGHT platform will provide recommendations regarding the need for resources that must be allocated for operations, carbon footprint assessment, estimates of the necessary costs, and real-time tracking of containers.

C. Greek Use Case

The strategic roadmap for the Greek UC is tailored to implement a diverse array of functionalities along the seaport-to-airport T&L line, aiming to establish a cutting-edge multimodal and transhipment ITU logistic T&L line to reduce the container idle time at the port by 25%, reduce the container idle time at the airport by 25%, reduce the customs clearance process time by 20%, reduce errors by 20%, increase efficiency of the storage space by 15% , and increase end-to-end capacity due to optimization of resource utilization by 20%. The Piraeus port in Athens is the natural gateway for delivering good from the Far East not only inside Greece but also to European, Middle East and African countries, which offers immediate access to road, rail and air transport. Various logistics operators ship their cargo to Piraeus via international vessels/container ships, where they are reloaded/reshipped using various modes of transportation. As a result, a significant ongoing logistics chain exists between the Piraeus port's terminal and logistics operators and the Athens International Airport (AIA), as well as the respective cargo handlers and customs authorities that operate within AIA.

This comprehensive approach involves the exploitation of advanced technologies, such as AI/ML tools, IoT devices, Big data and Cloud technology to optimize and automate cargo services. The endeavour encompasses the revitalization, expansion, and modernization of existing infrastructure and legacy systems. The ultimate goal is the seamless connection of the Piraeus COSCO terminal to the AIA warehouse lots, followed by onboarding onto designated airplanes and foster highly collaborative and cooperative logistics operations with a significant degree of automation.

Also, many different stakeholders are involved in the end-to-end process, and currently, the alignment among them takes place manually, which leads to inefficacies, errors and time-consuming procedures. The envisioned T&L architecture strives to revolutionize the landscape by establishing a scalable and sustainable multimodal logistics ecosystem. Prioritising interoperability, efficiency, and seamless connectivity, the plan incorporates innovative features to elevate logistics operations. The optimisation of multimodal logistics services stands as a focal point, benefiting both stakeholders and customers by embracing state-of-the-art technological advancements.

The revolutionary innovation introduced at the Greek trial site revolves around the implementation of an Aircraft Automated Booking/Next Aircraft Recommender system, marking a pivotal shift in the management of aircraft-involved T&L operations. This unique integrated system aggregates and processes information from multiple management systems of distinct stakeholders and delivers an end-to-end real-time view of multimodal freight transport. Additionally, this advanced system seamlessly integrates automation, efficiency, and intelligent decision-making, streamlining the aircraft booking process and optimizing resource allocation. By harnessing predictive analytics and real-time data, the Next Aircraft Recommender dynamically recommends the most suitable aircraft for upcoming flights, adapting to changes in real-time. The system ensures economic efficiency and cost savings through automated processes, resource allocation, and its intelligent decision-making capabilities significantly reduce errors associated with manual procedures, speed up loading/unloading, customs clearance and transport processes thereby enhancing overall reliability, automation, and security in T&L operations.

The implementation methodology adopts a dual-pronged approach, with a primary focus on evaluating and optimizing legacy systems and concurrently leveraging historical data. Reports and historical data from the relevant stakeholders will be used as a baseline for benchmarking, concerning the cargo/container idle time, average customs clearance and delivery time and storage capacity. This strategy runs in parallel with strict adherence to logistics standards and a keen consideration of end-user needs. The exploitation of historical data is a cornerstone in the architecture of solutions serving as a robust foundation for algorithmic training and subsequently to the creation of predictors and DSS. The integration of legacy system data is crucial for capturing key events that mark significant operations within the T&L line. The user-centric character of the envisioned solutions highlights their enduring usability, marking a substantial advancement in the seaport-to-airport T&L landscape drawing an impact which extends beyond solutions.

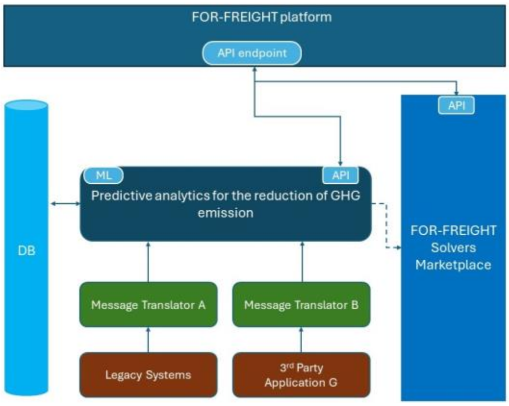

Figure 2. Representation of the connectivity of GHG reduction solver with the FOR-FREIGHT platform.

The envisioned solvers for the Greek UC are integral prerequisites for developing the aforementioned innovative solutions and target various clusters within the T&L chain. Thus, there are three main categories of clusters related to: 1) the optimization of warehouse processes, 2) the reduction of GHGs emissions, and 3) the establishment of an integrated predictive logistics intelligence suite. For instance, the second cluster utilizes data analytics to monitor carbon emissions, predictive modeling for forecasting based on historical data, and supply chain optimization. Figure 2 depicts an example of the connectivity of GHG reduction solver with the FOR-FREIGHT platform utilization all of the essential components for a seamless integration of the solver to the FOR-FREIGHT platform.

The upcoming deployment at the Greek trial site involves a suite of systems, including Goldfreight (GOLD's WMS), COEL's legacy systems, on-board units, parking sensors, and the WINGS Chariot platform. This strategic integration of existing and innovative systems is designed to facilitate improved communication and collaboration among stakeholders, dismantling information silos and nurturing a more cohesive and efficient logistics ecosystem.

V. Conclusions

FOR-FREIGHT represents a groundbreaking initiative in the field of multimodal logistics, strategically crafted to tackle the evolving challenges of contemporary freight transport. With a holistic approach focused on enhancing efficiency and sustainability, FOR-FREIGHT aims to transform the industry by introducing innovative solutions seamlessly integrated into existing logistics systems. The project's commitment to delivering operational benefits to all participants is evident through the incorporation of technical modules, collaboration with existing assets, and support for tracking and visualization. The proposed solvers within FOR-FREIGHT, categorized and equipped with specific functionalities, outline a high-level strategy to meet technical demands unaddressed by legacy systems. This forms a robust suite of tools designed to optimize dynamic end-to-end logistics networks, making FOR-FREIGHT standing at the forefront of innovation in the logistics industry, ready to usher in a new era of sustainable and efficient freight management. The combination of advanced technologies, standardized frameworks, and real-world validation through diverse use UCs positions FOR-FREIGHT as a pioneering effort with the potential to reshape the future of multimodal logistics. Through collaborative efforts and industry partnerships, FOR-FREIGHT sets the stage for a more interconnected, efficient, and sustainable logistics ecosystem.

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