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D5.2 - FRAMEWORK AND METHODS FOR THE MODALNET COMPUTATIONAL ENGINE

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF ABBREVIATIONS

Acronym	Description
API	Application Programming Interface
CEF	Connecting Europe Facility
CERL	Computational Engine for Resilient Logistics
C-ITS	Cooperative Intelligent Transport Systems
CO_2	Carbon dioxide
ConOps	Concept of Operations
CSS	Cascading Style Sheets
DFM	Digital Freight Matching
DRF	Django REST Framework
e-CMR	electronic Consignment note
EtA	Estimated time of Arrival
EtD	Estimated time of Departure
ETP	European Technology Platform
JSON	JavaScript Object Notation
HTTP	Hypertext Transfer Protocol
ICT	Information and communication technology
ID	Identification
IT	Information Technology
LCL	Less-than-container load
LSP (s)	Logistics Service Provider(s)
LTL	Less-than-truckload
ML	Machine Learning
NVOCC	Non-Vessel Operating Common Carrier
ORM	Object-Relational Mapping
PTN	Proximity Terminal Network
SaaS	Software as a Service
SMEs	Small and Medium-sized Enterprises
SPAs	Single Page Applications
SSS	Short Sea Shipping
TEU	Twenty-foot Equivalent Unit
ToT	Turnover Time
URI	Uniform Resource Identifier
VAT	Value Added Tax
WP	Work Package

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EXECUTIVE SUMMARY

The Computational Engine for Resilient Logistics (CERL) is a key component of ModalNET and represents one of the innovations developed during the SEAMLESS project. CERL is designed to facilitate route planning and match-making services by analysing data from shippers, transport operators, and other logistics service providers. By evaluating transport options across multiple modes—road, rail, and short-sea shipping—CERL supports cargo consolidation, optimizes backhaul traffic, and improves decision-making in logistics operations.

A key motivation for developing CERL is addressing gaps in current logistics tools, which often focus on single transport modes, lack integration across stakeholders, and provide unreliable transport estimations. Many existing platforms primarily serve road transport, leaving short-sea shipping and multimodal logistics underutilized.

The core functionality of CERL is built around a match-making engine, which processes transport requests from end users, identifies optimal routes, and facilitates cargo bundling opportunities. The system is designed to operate as both a standalone tool and an integrated component within the ModalNET platform, ensuring compatibility with other logistics solutions. Key stakeholders include shippers, carriers, freight forwarders, shipping lines, port authorities, and warehouse operators, each benefiting from improved transport planning and coordination.

CERL's technical architecture consists of a front-end module for user interactions, a storage/database module for storing all collected resources and intermediate results, a back-end matching module where search and matching algorithms are executed and an integration layer to allow interactions with external systems. Additionally, the engine adheres to strict security and privacy requirements, leveraging authentication mechanisms to protect sensitive logistics data.

This document serves as a foundational guide to the development and implementation of CERL, highlighting its potential to enhance resilience and efficiency in logistics operations.

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1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

Considering the ConOps and requirements derived in T2.5, and the specifications in T5.1, ModalNET will exploit real-time information from all entities (physical/digital) in the supply chain to support logistics planning, timely identification of disruptions, faults and failures, and the optimisation of supply chain risk control measures. The task will develop the computational engine to be implemented in T5.4 based on advanced frameworks for optimisation and network mapping considering criteria that contribute towards the resilience of the supply chain and the SEAMLESS feeder loop service.

This deliverable provides a detailed exploration of the logic underpinning the Computational Engine for Resilient Logistics (CERL), focusing on key elements such as the current state-of-the-art, stakeholder involvement and architectural design.

The document opens with an in-depth review of existing matchmaking engines, relevant products, and contemporary initiatives in the logistics sector. Through this state-of-the-art analysis, the report identifies critical gaps, barriers, and insights, which inform CERL's development. This ensures the platform aligns with current industry standards, leverages best practices, and addresses previously unmet challenges. These are then transfigured into CERL’s business concept, which is also presented in detail.

Another primary focus of this report is to identify and document the various stakeholders associated with CERL, classifying them into distinct groups and pinpointing those who could serve as potential users of both CERL and the broader ModalNET platform. This classification is essential for understanding how CERL can be tailored to meet the diverse needs of its user base and integrate seamlessly into the existing logistics ecosystem.

This deliverable also details the architectural design of CERL, providing a blueprint for its development and implementation. This design is structured to ensure that CERL not only fulfills its intended purpose but also adheres to best practices in security and privacy standards.

The deliverable concludes with a summary of the significant outcomes of this process, emphasizing the steps taken to align CERL with its intended purpose and the needs of its stakeholders.

In summary, this report serves as a foundational reference for the development and deployment of CERL, offering insights into its business logic, stakeholder engagement, and architectural framework required to achieve its objectives. Through this comprehensive approach, the deliverable supports CERL’s role as a key innovation within the SEAMLESS project and its contribution to the ModalNET platform.

1.2 INTENDED READERSHIP

This deliverable is publicly available and is intended for all readers with an interest in the SEAMLESS project, addressed to both members of the SEAMLESS Consortium and a broad spectrum of external stakeholders. External stakeholders may encompass a diverse range of entities, including

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professionals and organizations within the logistics industry, policymakers shaping regulations and frameworks, academic and research institutions exploring related fields, and prospective users of CERL and the ModalNET platform. By making this deliverable accessible, the SEAMLESS project aims to foster awareness, collaboration, and engagement among stakeholders who can benefit from or contribute to the development and implementation of CERL and ModalNET.

1.3 DOCUMENT STRUCTURE

The document is organized into four main sections, each serving a specific purpose in presenting the concept, design, and framework of the Computational Engine for Resilient Logistics (CERL):

Section 1 - INTRODUCTION: This section outlines the purpose and scope of the document, providing context for the content that follows. It also defines the intended readership, highlighting the target audience within and beyond the SEAMLESS Consortium. Additionally, this section describes the structure of the document, offering a roadmap for readers to navigate its contents effectively.

Section 2 - COMPUTATIONAL ENGINE FOR RESILIENT LOGISTICS: This section introduces the CERL concept, presenting a comprehensive overview that includes a state-of-the-art analysis of existing technologies and initiatives in the logistics domain. It details the business logic and conceptual framework of CERL, focusing on its innovative approach to matchmaking services. Furthermore, it identifies and classifies the core stakeholders associated with CERL, emphasizing their roles and potential engagement with the system.

Section 3 - CERL DESIGN: This section delves into the architectural design of CERL, providing a detailed framework for its technical implementation. It also addresses the critical aspects of security and privacy, outlining the requirements necessary to ensure compliance with regulatory standards and the protection of sensitive data. Specific attention has been given to make it compatible with the implementing and delectation acts of the eFTI regulation and ensure that when the relative implementation specifications are defined by September 2025, to be easily configurable to comply with them and operated either independently or as part of a generic logistics platform certified by eFTI.

Section 4 - CONCLUSIONS: The final section summarizes the key findings and outcomes discussed throughout the document. It reflects on the frameworks, methods, and innovations introduced for CERL, setting the stage for future developments and the broader application of the CERL and ModalNET platform.

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2 COMPUTATIONAL ENGINE FOR RESILIENT LOGISTICS

This section provides an in-depth overview of the Computational Engine for Resilient Logistics (CERL), including its conceptual foundation, a state-of-the-art analysis of related platforms and initiatives, and an outline of its business logic. Additionally, it identifies the stakeholder groups associated with CERL, their potential roles in the engine's development and utilization.

2.1 OVERVIEW

The Computational Engine for Resilient Logistics (CERL) is designed to facilitate digital and horizontal collaboration between shippers and carriers, with the goal of enhancing synchromodality, optimizing backhaul traffic, and contributing to the resilient dynamic management of supply chains. By leveraging advanced technology, CERL aims to address critical challenges in logistics, such as inefficiencies in cargo allocation and the reduction of the environmental impact of transportation. Currently under development, CERL will function as a cloud-based digital marketplace, employing sophisticated matchmaking logic to allocate cargo optimally and providing analytical tools tailored to the needs of various stakeholder groups. The matchmaking mechanism is intended to maximize load factors in both directions of travel, thereby reducing costs and minimizing the environmental footprint of logistics operations. Even though the CERL can operate as a stand-alone entity providing route-planning and transport matchmaking services, it includes an integration layer based on an application programming interface (API) that allows it to interact with other platforms and systems for data exchange. Its design allows it to operate in two modes, either as part of a federation by using the authentication/authorisation model and service brokerage defined by the federation or as a standalone solution using its own authentication/authorisation and role-based access control model.

In recent years, many engines, platforms, and initiatives have emerged to bridge the gap between supply and demand in the logistics sector. These tools aim to optimize shipping processes by connecting shippers and carriers, automating communication, and streamlining operations. However, CERL distinguishes itself by incorporating state-of-the-art advancements such as route discovery, cargo consolidation options, multimodal support and standardized modular units, as well as addressing gaps left by existing solutions.

The following sections present a detailed state-of-the-art analysis, examining existing tools and initiatives that have been developed to enhance logistics operations. This analysis highlights best practices and lessons learned from these tools, providing a foundation for identifying innovations and improvements that can be adopted and further developed in CERL. Building on this analysis, the business logic of CERL is defined, showcasing its unique features and advancements compared to existing tools and practices. Furthermore, relevant stakeholder groups are identified, detailing their roles and potential interactions with the engine. This stakeholder identification informs the definition of system requirements, ensuring that CERL is tailored to address the specific needs of its users and drive forward the goals of synchromodal and resilient logistics.

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2.2 STATE-OF-THE-ART ANALYSIS

In order to consider CERL effective, it must be functional, valuable to its stakeholders, and competitive when compared to existing tools and platforms in the logistics domain. To ensure these objectives are met, a state-of-the-art analysis has been conducted. This analysis focuses on evaluating current tools and initiatives, assessing their performance, identifying their strengths, and uncovering any gaps or limitations that present opportunities for innovation and further development. The outcomes of this state-of-the-art analysis serve as the foundation for defining CERL's business concept, ensuring that it addresses existing challenges and builds upon proven strategies. These findings are further elaborated in Section 2.3, where the business logic and unique value proposition of CERL are detailed. By leveraging this comprehensive analysis, CERL is positioned to offer innovative solutions that meet the needs of its stakeholders and stand out in a competitive landscape.

2.2.1 Existing Matchmaking Engines & Initiatives

AEOLIX[1] - Architecture for EurOpean Logistics Information eXchange:

AEOLIX is a tool to improve the interoperability of digital information systems. The idea is that through the use of electronic consignment notes (or e-CMR), logistics data can be fully integrated across national borders and IT platforms. The tool is comprised of a centralised cloud-based IT platform that optimises cargo flows and supply chain management. AEOLIX streamlines logistics decision-making, therefore enabling the sustainable and efficient transport of goods across Europe and increasing visibility across the supply chain for all the actors involved. The AEOLIX Platform represents a critical way forward of supply chain visibility and interoperability through decentralized information sharing. AEOLIX cloud services provide connectivity to multi-actor data and in-house or cloud-based applications, processes and services, thus enhancing collaboration and interoperability, potentially across the entire transport and logistics sector. AEOLIX provides also a comprehensive architecture to enable a digitally secure and regulated logistics services and information sharing through a platform[2].

ALICE[3] roadmaps:

The European Technology Platform (ETP) ALICE is set-up to develop a comprehensive industry lead strategy for research, innovation and market deployment of logistics and supply chain management in Europe. A key activity of ALICE is the development of research and innovation strategies, roadmaps, and priorities, collaboratively agreed by all stakeholders, to realize the "ETP on Logistics" vision. To advance its mission and vision, ALICE has established five distinct thematic groups, each dedicated to promoting research and innovation within the logistics sector. Thematic group 3 "Systems & Technologies for Interconnected Logistics" is dedicated to achieving real-time (re)configurable supply chains in (global) supply chain networks with available and affordable ICT solutions for all types of companies and participants. Supply Network Collaboration deals with

[1] https://www.iru.org/eu-research-innovation-projects/aeolix
[2] https://cordis.europa.eu/project/id/690797/reporting
[3] https://www.etp-logistics.eu/about-alice/

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maximizing resources utilization, such as vehicle and infrastructure capacity, by matching demand from multiple shippers with available transport and logistics services from different modes and service providers (see ALICE Roadmap Towards Zero Emission Logistics Transport modes are smartly used and combined and fleets and assets are shared and used to the max). Both coordination and collaboration can produce significant gains in terms of efficiency and sustainability and represent a big step towards the Physical Internet, leading the transition from individually managed supply chains to open supply networks enabling structural collaboration.

Bridge[4] - Trade Solutions:

Trade Solution's Bridge platform is a collaborative solution tailored for the Norwegian grocery industry, aiming to streamline interactions among purchasers, suppliers, transport buyers, and carriers. It offers a centralized hub for managing orders, discrepancies, transportation, waste, returns, and settlements, thereby enhancing operational efficiency. Bridge serves as a collaboration marketplace that streamlines interactions among supply chain stakeholders, facilitating operational efficiency through modular services, while CERL focuses on advanced matchmaking functionality, leveraging digital and horizontal collaboration to optimize cargo allocation, enhance synchromodality, and minimize environmental impact in logistics.

CargoStream[5] - Clusters2.0 project:

CargoStream is an independent pan-European platform developed as part of the Clusters 2.0 project. CargoStream functions as a collaborative logistics platform designed to enable horizontal collaboration among shippers, carriers, and other stakeholders within logistics clusters. The platform facilitates the pooling and sharing of resources, such as transport capacities, to achieve better efficiency and cost-effectiveness while reducing the environmental impact of logistics operations. CargoStream allows multiple shippers and carriers to coordinate and optimize their logistics activities by sharing routes, capacities, and schedules. It is also designed to reduce empty runs and improve load factors, maximizing the utilization of available transport resources. It also incorporates advanced algorithms to match supply (transport providers) with demand (shippers), ensuring that logistics resources are optimally allocated.

Cluster Community System[6] – Clusters2.0 project

The Cluster Community System (CluCS) is an IT platform developed as part of the EU-funded Clusters 2.0 research programme, designed to manage resources within logistics clusters and synchronize operations across a network of hubs, terminals, and warehouses. CluCS enables shippers to visualize and book services, while allowing logistics service providers (LSPs) to publish and offer their services. In addition to supporting service bookings, CluCS facilitates cargo bundling at the cluster level by integrating transport services with terminal operations and value-added activities. It offers capabilities for real-time monitoring, notifications of unexpected events, and dynamic re-planning and execution, ensuring seamless logistics operations. CluCS is often

[4] https://tradesolution.no/tjenester/bridge/
[5] https://cordis.europa.eu/project/id/723265/reporting
[6] http://www.clusters20.eu/

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described as a “physical platform” because it delivers services directly related to physical facilities within the defined geographical scope of a Proximity Terminal Network (PTN). Its primary beneficiaries include shippers, LSPs, freight forwarders, and other companies operating within the cluster, particularly small and medium-sized enterprises (SMEs). For SMEs, CluCS provides the critical advantage of digitizing their transport chains, enhancing competitiveness and operational efficiency. By coordinating and optimizing logistics resources and infrastructure, CluCS enables cooperative booking and planning for transport, handling, and related services. This results in several key benefits, including: reduced logistics costs through shipment consolidation; shorter lead times via synchronized multimodal solutions; increased shipment volumes due to improved operational efficiency; greater reliability through enhanced visibility and monitoring at the cluster level.

DTLF[7] - CEF projects:

The Digital Transport and Logistics Forum (DTLF) is an expert group that unites stakeholders from various transport and logistics sectors, including both private and public entities, to develop a shared vision and roadmap for digitalizing transport and logistics. The DTLF also plays a key role in identifying the need for EU-level measures and supporting their development and implementation where appropriate. To bring the concepts developed by the DTLF into practice, two Connecting Europe Facility (CEF) projects have been funded: FEDeRATED and FENIX. FEDeRATED[8] is an EU initiative focused on fostering digital collaboration by establishing the foundations for a secure, interoperable infrastructure for business and administrative data-sharing within freight transport and logistics. FENIX[9] is an EU project dedicated to creating a federated data-sharing architecture to serve the European logistics community, including shippers, logistics service providers, infrastructure operators, cities, and authorities. Its goal is to enable interoperability across existing and future platforms, facilitating seamless data exchange throughout the logistics ecosystem.

Usyncro[10] (previously eCustoms):

Usyncro is a digital logistics platform that streamlines international shipping by synchronizing all involved parties, transactions, and documents in a single location. Leveraging blockchain technology and artificial intelligence, it enhances transparency, efficiency, and security in supply chain operations. It facilitates efficient data sharing and documentation management, driving digital transformation in logistics operations and simplifying the customs clearance process. The platform serves a diverse clientele, including shippers, logistics service providers, freight forwarders, and other entities involved in international trade. By digitizing customs clearance processes and simplifying information flow among stakeholders, Usyncro aims to make global trade operations more efficient and transparent.

ARRIVAL[11] - ENTRANCE EU:

[7] https://transport.ec.europa.eu/transport-themes/digital-transport-and-logistics-forum-dtlf_en
[8] https://www.federatedplatforms.eu/
[9] https://fenix-network.eu/
[10] https://www.usyncro.com/en/ecustoms/
[11] https://www.entrance-platform.eu/

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The ARRIVAL platform, previously referred to as the ENTRANCE matchmaking platform, is a distinctive platform designed for the entire European transport and mobility sector. It will continue to operate beyond the project's conclusion. The platform brings together a wide range of key stakeholders from the "supply-demand-finance" triangle across the transport and mobility industries, encompassing all types of transport modes and means. ARRIVAL is an open-access platform, ensuring equal accessibility for all buyers and solution providers in the Transport, Mobility, and Logistics sectors.

MIXMOVE[12]:

The MIXMOVE platform is an innovative Software as a Service (SaaS) solution designed to enhance supply chain collaboration by integrating multiple suppliers and logistics service providers into an open cooperation network. By reimagining traditional logistics practices, it enables more cost-effective and environmentally friendly transportation while improving margins for both suppliers and logistics service providers. This is achieved through hyper-connectivity, stakeholder collaboration, and cargo consolidation. The platform offers resource optimization through both horizontal and vertical collaboration, logistics network optimization, and last-mile distribution efficiency. MIXMOVE delivers comprehensive supply chain control and visibility, including stock visibility across locations, loading unit optimization, and performance monitoring for shippers. For transport hubs, it provides transport management, contract logistics, cross-docking, and receiving planning and scheduling services. Additionally, it supports bookings, customer service, operations control, mobility, claims, linehauls, and other services for carriers.

Naviporta[13]:

Naviporta is an open and neutral platform that leverages blockchain technology to enhance the efficiency and transparency of global trade. By integrating physical, informational, and financial flows, Naviporta enables secure and seamless data sharing among stakeholders in the supply chain, including suppliers, buyers, logistics providers, and financial institutions. This integration reduces reliance on paper-based processes, mitigates fraud risks, and accelerates transaction times. Notably, the platform has been utilized to develop services like Quay Connect, which automates customs clearance between the Netherlands and the UK, resulting in significant cost savings and improved processing efficiency.

NEXTRUST[14]:

The primary goal of the EU-funded NEXTRUST research program was to enhance the efficiency and sustainability of European logistics by creating interconnected, trusted collaborative networks across the entire supply chain. These networks, developed both horizontally and vertically, integrate shippers, logistics service providers (LSPs), and intermodal operators as equal partners. The program developed a cloud-based C-ITS smart visibility software, which facilitates the re-engineering of these networks and improves the real-time utilization of transport assets. Using this

[12] https://mixmove.io/
[13] https://www.etp-logistics.eu/wp-content/uploads/2021/04/BLOCKC1.pdf
[14] https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-transport/logistics/nextrust

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tool, freight volumes are not only consolidated but also diverted from road transport to intermodal rail and waterways, promoting greater sustainability.

SELIS[15]:

The EU-funded SELIS research program aimed to create a "platform for pan-European logistics applications." The result was the development of the Shared European Logistics Intelligent Information Space (SELIS), a network of shared intelligent information spaces known as SELIS Community Nodes (SCNs), specific to various logistics communities. These communities establish SCNs to enable the next generation of collaborative, responsive, and sustainable transportation chains. SCNs connect with participants' existing systems via a secure infrastructure, offering shared information and tools for data acquisition and usage, based on a 'cooperation agreement.' The interconnected nodes form a distributed, common communication and navigation platform for pan-European logistics applications. Each node has the autonomy to decide which information it wishes to publish and what data it wants to subscribe to.

TradeLens[16] platform:

TradeLens is an open and neutral supply chain platform built on blockchain technology. It facilitates data sharing and collaboration across supply chains, with the goal of fostering industry innovation, reducing trade barriers, and promoting global commerce. TradeLens is designed for traders, freight forwarders, inland transportation providers, ports and terminals, ocean carriers, customs authorities, and other government entities, supporting their collaboration while enabling the digitization and automation of cross-organizational business processes. Nevertheless, the reluctance of stakeholders to join the initiative lead by MAERSK and IBM and issues that arose relative to the governance model and data exchange agreements, resulted to a seize of activities of the platform.

2.2.2 Results and Barriers

Over the past few years, a range of tools, platforms and initiatives has been developed and implemented with the aim of enhancing the shipping process and improving logistics efficiency. As the digitalization of shipping and logistics procedures is still a relatively new and intricate undertaking, these efforts represent foundational steps toward creating advanced tools and automated solutions that elevate the performance and role of the supply chain. However, many of these platforms focus narrowly on specific issues or procedures within the supply chain, neglecting other critical aspects and services that significantly impact overall logistics performance.

A notable limitation of current tools and initiatives is their lack of integration with Short Sea Shipping (SSS) services and the corresponding transportation requirements. Existing freight-exchange platforms primarily cater to road transport, rendering them unsuitable for addressing the specific needs of SSS. According to the state-of-the-art analysis, although there is a growing trend in research projects and commercial products to foster cargo consolidation and collaboration among logistics stakeholders, these efforts predominantly concentrate on road and rail transport. While

[15] https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-transport/logistics/selis
[16] https://www.tradelens.com/

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horizontal collaboration among shippers, carriers, and distributors aims to optimize long-term freight consolidation, water-based transport modes and the unique characteristics of SSS remain largely overlooked.

Additionally, many of the tools developed are tailored to specific stakeholder groups, offering services that cater to their individual needs but failing to facilitate effective communication and collaboration across different stakeholder categories. This fragmented approach results in a degradation of service quality, as users are compelled to rely on multiple tools to complete their tasks or revert to manual processes. The development of an integrated tool that acts as a single communication hub, supporting all necessary activities for diverse stakeholder groups, would greatly benefit the logistics industry by enhancing efficiency and overall performance.

Furthermore, the majority of current tools and initiatives lack combined and multimodal transportation options. This limitation stems from the inherent complexity of integrating and automating processes across multiple transport modes. Consequently, most tools and platforms are designed to provide information about services associated with a single mode of transport. However, multimodality - the seamless integration of various transportation methods - holds immense potential for transforming supply chain flow, productivity, and capacity.

In summary, by fostering cooperation among logistics stakeholders, multimodal solutions can significantly lower transportation costs and time, enhance supply chain efficiency, and improve environmental sustainability through reduced carbon emissions. This underscores the critical need for tools that can effectively address the complexities of multimodal logistics.

2.3 Business Concept

The Computational Engine for Resilient Logistics (CERL), currently under development, is envisioned as a transformative digital collaboration and matchmaking engine. Its primary goal is to enhance synchromodality within the container supply chain by intelligently matching cargo demand and supply among logistics stakeholders through the use of advanced, data-driven analytics. CERL is designed to dynamically adapt to shifting freight flows, improve the cost-effectiveness of partial cargo loads, and strengthen last-mile as well as just-in-time connections across multiple transport modes, including backhaul traffic. This innovative tool promises significant benefits to its users by fostering collaboration and optimization, delivering measurable improvements for all involved stakeholders.

CERL distinguishes itself from current state-of-the-art tools with several ground-breaking features. At its core, it supports cargo consolidation at the different standardised modular units level (i.e. 20/40/45ft containers, standard pallet, euro pallet), maximizing the bundling potential among diverse shippers to promote multimodal transport routes. It acts as a centralized communication hub for shippers and carriers, streamlining negotiations and enabling ad-hoc and long-term shipment planning. By addressing fragmentation in communication, CERL ensures that stakeholders have access to a unified solution, reducing inefficiencies and improving decision-making.

Rather than generating new data, CERL's primary function is to analyse and assess existing datasets from various logistics stakeholders, including shippers, carriers, freight forwarders, and

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shipping lines. This approach enables CERL to extract actionable insights that enhance logistics processes. The analysis yields multimodal transportation options, combining diverse transportation modes and means to reduce overall delivery time and costs. Moreover, the integration of multimodal transport with cargo bundling increases transport operators' efficiency and improves the management of empty containers - a persistent challenge in the industry. By optimizing asset utilization, CERL contributes to reduce costs and environmental impacts.

Users will be able to use CERL via ModalNET, but a highly customizable user interface, currently under development, will also be available. This interface enables users to sort and filter available options based on personalized criteria, such as cost, delivery time, or environmental footprint. Users can apply specific constraints—like a desired cost range or delivery time window—to streamline their search for the optimal solution. Results are presented with detailed attributes, including the associated environmental footprint, the number of transshipments, estimated times of arrival and departure (EtA and EtD), and turnover time (ToT). This granularity empowers users to sort and assess options effectively, ensuring they can identify the most suitable solutions with ease.

Another significant advancement is CERL's ability to provide accurate and reliable transport estimations. It calculates estimated times of arrival, boarding, and departure while accounting for transshipment windows and buffer times required for each transport mode and stakeholder group. This results in more precise scheduling and dependable transport options, addressing a key gap in current logistics tools and platforms.

In addition to its operational capabilities, CERL is designed for interoperability. The engine can seamlessly interact with federated logistics platforms and public authorities, enabling the exchange of critical information. This interoperability not only enhances its usability but also positions CERL as an essential tool in the digital transformation of the logistics industry, supporting stakeholders across the supply chain in achieving greater efficiency, sustainability, and resilience.

2.4 STAKEHOLDERS

To identify the direct and indirect stakeholders of the Computational Engine for Resilient Logistics (CERL), key stakeholder categories from the shipping industry were initially selected to form the core ecosystem of the computational engine. These primary groups were further analysed to determine potential users of the computational engine. The identified stakeholders include shippers, carriers and transport operators, freight forwarders, shipping lines, operators of connecting transport modes, local SMEs, and industry stakeholders, among others. These groups form the foundation for defining CERL's concept, as they stand to benefit significantly from its functionalities and services.

CERL is envisioned as a transformative tool to enhance horizontal collaboration among shippers, liner agents, freight forwarders, and carriers. The engine is expected to address increasing demands in the logistics sector while simultaneously managing and balancing backhaul traffic. By enabling stakeholders to consolidate and match cargo flows in both directions, CERL will foster better coordination and improved operational efficiency across the supply chain.

The computational engine will also serve as a valuable resource for logistics stakeholders within the entire supply chain. It will support them in the decision-making process relative to the booking

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process among shippers and freight forwarders, communicate freight costs, and arrange and track movements seamlessly.

This chapter provides a detailed description of the core stakeholder groups involved in CERL, offering insights into their roles, responsibilities, and specific needs. These details are essential for guiding the engine's development, ensuring it meets the demands of its users and enhances collaboration, efficiency, and performance across the logistics ecosystem.

2.4.1 Shippers

A shipper plays a pivotal role in the logistics and transportation sector, bearing the primary responsibility for ensuring the seamless movement of goods from origin to destination. As the owner or consignor of the cargo, the shipper's duties encompass a range of administrative, operational, and compliance-related tasks to facilitate efficient and lawful transportation.

Key Responsibilities of a Shipper:

- **Transport Booking and Coordination:** The shipper initiates the shipping process by arranging transportation, either directly with carriers or through freight forwarders, ensuring that the logistics align with delivery schedules and requirements[17].
- **Cargo Preparation and Packaging:** Ensuring that goods are appropriately packaged to withstand transit is a critical duty. This includes selecting suitable containers, especially for hazardous materials, to comply with safety standards and prevent damage[18].
- **Documentation and Compliance:** The shipper is responsible for providing the information for the preparation of essential shipping documents, such as the bill of lading, which serves as a contract of carriage and a receipt of goods. Accurate documentation is vital for customs clearance and legal compliance[19].
- **Customs Clearance and Regulatory Adherence:** Navigating the complexities of customs regulations falls within the shipper's purview. This involves ensuring that all necessary documentation is in order and that any applicable duties and taxes are prepared for, facilitating smooth customs clearance[20].
- **Coordination of Loading and Stowage:** The shipper ensures that goods are correctly labeled and that incompatible items are not stowed together, adhering to safety regulations to prevent hazards during transportation[21].

[17] https://www.dashdoc.com/en/blog/shipper-definition
[18] https://www.magellanlogistics.com.au/what-are-the-shippers-responsibilities
[19] https://www.maersk.com/logistics-explained/shipping-documentation
[20] https://www.inboundlogistics.com/articles/customs-clearance/
[21] https://www.ups.com/media/en/shippers_responsibilities_01012005.pdf

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- **Communication of Freight Costs:** Transparent communication regarding freight costs with all parties involved is essential for budgeting and financial planning within the supply chain[22].
- **Ensuring Proper Labeling and Hazard Identification:** Accurate labeling, including hazard identification for dangerous goods, is crucial to comply with international shipping regulations and ensure safety during transit[23].

By diligently executing these responsibilities, shippers play an integral role in maintaining the efficiency, safety, and reliability of the global supply chain, contributing to goods reaching their destinations in a timely and secure manner.

2.4.2 Carriers/Transport Operators/LSPs

A Carrier, also known as a Transport Operator or Logistics Service Provider (LSP), is an individual or company legally authorized and responsible for transporting cargo from one location to another. This transportation is achieved through various modes of transportation, including feeder vessels, rail systems, trucks, and other road transport systems, either directly or via third-party arrangements. Carriers typically own and operate transportation equipment and offer essential logistics services to facilitate the seamless movement of goods. Depending on the transportation mode employed, carriers may be trucking companies and railroads to airlines, steamship lines, and parcel or express delivery services. In the shipping industry, cargo transportation predominantly occurs by water[24], and carriers typically fall into the following categories:

1. **Terminal Operators:** Terminal operators are companies that contract with port authorities to manage cargo movement through ports. Their responsibilities include handling the transfer of containers between cargo ships, trucks, and freight trains while optimizing customs processes to minimize ship docking times and port delays. Terminal operators oversee container receipt and delivery for both landside (road or rail) and seaside (barge or ship) partners. Additionally, they manage container storage, supervise incoming and outgoing shipments, conduct quality control, ensure terminal equipment functionality, and oversee administrative tasks like paperwork, leases, safety, and port security[25].
2. **Trucking Companies:** Trucking companies manage the movement of cargo before and after its main journey. Local truckers manage the first leg of the journey, by collecting freight from warehouses and transporting it to processing points like ports. They are also responsible for the final leg of transportation, moving goods from vessels to logistics hubs or customer destinations[26].
3. **Logistics Operators:** Logistics operators are companies that design, manage, optimize and control supply chains for other companies. Their involvement can span supply, transport,

[22] https://www.dashdoc.com/en/blog/shipper-definition
[23] https://www.magellanlogistics.com.au/what-are-the-shippers-responsibilities
[24] https://unctad.org/publication/review-maritime-transport-2021
[25] https://documents1.worldbank.org/curated/ar/767451507184005691/pdf/pdf
[26] https://www.iru.org/

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storage, and distribution, depending on the agreed-upon commercial terms. They streamline operations to ensure cost-efficiency and timely deliveries[27].

4. **Liner Agents:** A liner agent is an individual or company that represents a shipping line or ship operator in a specific geographic area or port. Their primary role is to act as a local representative of the shipping line, providing a range of services to ensure the smooth operation of cargo shipments. Liner agents are responsible for securing cargo for the shipping line and supporting shippers with various logistics-related and administrative tasks[28].

5. **Brokers:** Brokers are individuals or companies that act as intermediaries between shipowners and cargo owners, coordinating negotiations to arrange ocean transport of goods. They are also involved in ship sales and purchases, overseeing transaction details and ensuring agreements are met[29].

2.4.3 Freight Forwarders

A freight forwarder, also known as a forwarding agent or a non-vessel operating common carrier (NVOCC), is a person or organization specializing in arranging and managing the logistics and transportation of goods on behalf of the shipper individuals, manufacturers, or other corporations. Their primary responsibility is to ensure that goods are efficiently transported from their point of origin, such as a manufacturer or producer, to a market, customer, or final distribution destination. While freight forwarders do not physically move the goods themselves, they play a critical role in coordinating logistics by leveraging their expertise in the complex supply chain network. They act as intermediaries between shippers and carriers, negotiating and contracting transportation services to secure the most economical, reliable, and time-efficient routes. Freight forwarders manage the entire shipment process, from storage and packaging to the actual transport, making them essential facilitators of global trade. Freight forwarders typically examine documents such as the commercial invoice, shipper's export declaration, bill of lading, and other records mandated by carriers or the exporting, importing, or transshipment countries. Increasingly, this process is conducted in a digital, paperless environment, enhancing efficiency and accuracy[30].

2.4.4 Shipping Lines

A shipping line is a company or organization that owns and operates vessels, ensuring the efficient transportation of cargo aboard their ships. These entities manage cargo movement from its origin to its destination, primarily operating port-to-port along established routes on fixed schedules using their own fleet. Shipping lines can function as carriers when utilizing their own containers but also offer leasing services to other carriers, enabling them to transport cargo on the shipping line's

[27] https://acrosslogistics.com/blog/en/logistics-operator
[28] https://www.ics-shipping.org/
[29] https://www.alchemygts.com/Ship-Broker-jobs
[30] https://worldclassshipping.com/international-freight-forwarder/

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vessels. Additionally, they support freight forwarders by providing services such as space allocation, favourable credit terms, and consistent communication[31].

2.4.5 Operators of connecting transport modes

Operators of connecting transport modes, commonly referred to as multimodal transport operators, represent a specialized category within the carrier - transport operator stakeholder group. These operators provide integrated transportation services that combine two or more modes of transport—such as shipping, trucking, and rail—to facilitate seamless cargo movement. As defined by the Convention on International Multimodal Transport[32], "international multimodal transport" involves the carriage of goods using at least two distinct modes of transport under a single multimodal transport contract, from a designated location in one country where the operator takes charge of the goods, to a specified delivery point in a different country. Notably, operations limited to pick-up and delivery under a unimodal transport contract do not qualify as international multimodal transport.

By leveraging multiple transportation modes, multimodal transport operators can manage individual segments of the logistics process or oversee the entire cargo transfer, optimizing costs and reducing delivery times. The responsibilities of multimodal transport operators may be fulfilled by freight forwarders or carriers specializing in logistics across trucking, rail, air, sea, or inland waterways. Although these operators may subcontract portions of their services to other carriers, they retain full accountability for the goods, ensuring their integrity, addressing any damages, and resolving transport-related issues[33].

2.4.6 Port/Airport authorities

Port authorities, usually public or semi-public entities, are tasked with the management, regulation, and enhancement of port areas. Their responsibilities typically include constructing and maintaining port infrastructure, leasing or granting concessions of this infrastructure to private companies, and fostering the growth and competitiveness of the port cluster[34]. These authorities oversee a wide array of services and activities, such as vessel traffic management, enhancement of navigational safety, legal oversight, and the implementation of security and environmental protocols within national waters. They play a pivotal role in ensuring the smooth operation of ports, aligning their functionality with the economic and regulatory demands of the region.

Airport authorities are generally independent entities charged with the operation, oversight, and development of one or more airports[35]. Their primary focus is on maintaining compliance with international security agreements, facilitating the safe and efficient movement of passengers and cargo, and ensuring that airport facilities meet global aviation standards.

[31] https://www.lotus-containers.com/en/difference-between-container-owners-and-shipping-lines/
[32] https://unctad.org/system/files/official-document/tdmtconf17_en.pdf
[33] https://www.shiphub.co/multimodal-transport/
[34] https://www.mdpi.com/2071-1050/13/5/2795
[35] https://doi.org/10.1016/j.jairtraman.2023.102423

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Both port and airport authorities serve critical roles in the broader logistics and shipping process. Port authorities are responsible for managing infrastructure and ensuring safe, secure, and efficient port operations, while airport authorities ensure compliance with aviation protocols and secure the seamless operation of air transport. Together, these entities handle essential administrative and operational issues, acting as key decision-makers and facilitators within their respective domains.

2.4.7 Warehouse operators

Warehouse operators play a crucial role in the supply chain by ensuring the proper storage, handling, and dispatch of goods. Warehousing itself involves not just the storage of finished goods but also activities such as packing, order processing, and shipping. A warehouse operator oversees the smooth functioning of these processes, ensuring goods are stored safely, processed efficiently, and delivered promptly. The primary responsibilities of a warehouse operator include the movement of goods in and out of a warehouse or depot. This entails tasks such as loading and unloading products, preparing outgoing stock for delivery, and reviewing incoming shipments. Operators use equipment like forklifts and order-picking machines to retrieve and store items, especially those placed at high levels. They are also tasked with scanning and tracking both incoming and outgoing orders to maintain an accurate inventory flow. Beyond handling the physical movement of goods, warehouse operators ensure that incoming inventory matches manifest documents and inspect deliveries for defects, damages, or missing items. They maintain meticulous records of all materials received and shipped, which includes developing mailing labels and preparing essential shipping documents. Moreover, warehouse operators contribute to the efficiency of the logistics chain by ensuring that goods are stored in a manner that maximizes space and facilitates quick access when needed. Their role extends to maintaining safety standards within the warehouse, such as ensuring proper storage conditions for sensitive goods and adhering to workplace safety regulations. Warehouse operators support the overall supply chain by minimizing delays, optimizing inventory management, and ensuring customer satisfaction through the accurate and timely fulfilment of orders[36].

2.4.8 Other

Other stakeholder groups that may indirectly benefit from CERL include individuals, organizations, and companies influenced by its functionalities. These stakeholders encompass administrative bodies, public authorities, statistical organisations, and customs agencies, each contributing uniquely to the logistics ecosystem.

Administrative bodies and public authorities establish and maintain the policy framework that governs the logistics sector. Their responsibilities include providing regulatory support, fostering industry development, overseeing contractual agreements, and offering advisory services. These entities ensure that the logistics industry operates within a structured and compliant environment.

Statistical organisations gather and analyse data across logistics and related domains. Their work involves interpreting data to produce valuable insights, such as market trends, economic indicators,

[36] https://www.sugamgroup.com/the-role-of-warehousing-in-supply-chain-management/

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and industry benchmarks. This information aids in strategic decision-making, fostering efficiency and growth within the logistics sector.

Customs agencies are national authorities tasked with overseeing the movement of goods across international borders. They collect tariffs, monitor cargo traffic, and ensure compliance with trade laws. Customs duties are taxes levied on imported or exported goods, serving multiple purposes: safeguarding the domestic economy, protecting local industries, regulating the flow of restricted goods, and generating government revenue. Customs agencies also play a pivotal role in maintaining the legality of trade activities. Their duties include conducting customs inspections, calculating and collecting applicable taxes and duties (such as VAT and excise taxes), preventing smuggling, and combating customs fraud. These efforts ensure secure and lawful international trade while protecting the country's economic interests and societal well-being[37].

By addressing the needs of these diverse stakeholders, CERL has the potential to enhance not only logistics operations but also the overall efficiency and security of the supply chain ecosystem.

[37] https://www.aade.gr/en/teloneia/customs-service-general-directorate-customs-and-excise-duty-0

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3 CERL DESIGN

3.1 ARCHITECTURAL DESIGN

The computational engine for resilient logistics is structured into three primary modules: the front-end module, which serves as the user interface; the storage/database module, where all collected resources and intermediate results are securely stored; and the back-end module, which houses and executes the search and matching algorithms.

The architecture of CERL must align with stakeholders' needs, which are subsequently formalized into appropriate functional and non-functional requirements for the engine. The core components of CERL include the server, user interface, database, web-mapping component, and optimization component. These components are organized into three primary modules:

- **Front-End Module**: Comprising the user interface and the web-mapping component.
- **Storage/Database Module**: Responsible for storing all collected resources and intermediate results.
- **Back-End Module**: Includes the server and the optimization component, where search and matching algorithms are executed.
- **Integration Layer**: An API allowing external systems to interact and exchange data with the CERL

Each module is purposefully designed to cater to specific end-user needs and requirements. Depending on their role (outlined in the subsequent User Roles section), users must be able to perform various tasks. For instance, service providers should have the capability to upload or update data related to vessel schedules and availability, while end-users should be able to set the details of their transport requests. Additionally, all users expect relevant outputs, such as shipping and matching recommendations for end-users, and tools for interactively monitoring active transport schedules. These functionalities will be delivered through user interfaces that collectively form CERLS's front-end. Moreover, these inputs and outputs will also be integrated with ModalNET, via the API that allows it to interact with CERL. Users can provide inputs, such as transport requests or updates on schedules, directly into ModalNET, leveraging its centralized interface. Similarly, they can retrieve CERL's outputs—such as optimized matching recommendations, and multimodal transport routes—within the broader ModalNET environment. By embedding CERL within its ecosystem, ModalNET ensures a seamless and efficient flow of data and functionalities, enhancing the overall user experience and operational coordination across its integrated modules.

To calculate shipping schedules that align with transport request specifications, the engine requires a mathematical or algorithmic model of the underlying transport network. This model is constructed using data provided by service providers, such as vessel schedules, availability, and capacity, and is continuously updated with new information. The engine's back-end leverages this model to compute feasible routes that meet transport requests, ranking them based on the user-defined optimality criteria. These routes are stored and later utilized to identify potential matches between

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end-users. The model also incorporates business criteria that prevent the algorithm from considering routes that may be connecting two points but are not logical.

All user data, whether intermediate or final outputs such as recommended shipping schedules and matchings, are securely stored in dedicated databases. These databases ensure the seamless retrieval of information, either through the user interface or the back-end processes when required.

The subsequent chapters provide a comprehensive overview of CERL's main user roles, the primary and secondary inputs and outputs of the front-end, the storage and communication mechanisms, the back-end matching engine, and an illustrative use case scenario. It is worth noting that the following sections delve into technical details to thoroughly explain various facets of CERL's architecture.

3.1.1 User Roles

The computational engine identifies and serves two distinct user groups, each with specific roles and responsibilities within the logistics ecosystem:

1. **Logistics Services Supply Group (Service Providers):**

   This group comprises entities that own or manage transport assets such as ships, trains, and trucks, and provide transportation services. Service providers are responsible for offering their resources to facilitate the movement of goods across various stages of the supply chain.

2. **Logistics Services Demand Group (End Users):**

   This group includes the owners of cargo that needs to be containerized and transported. End users submit transportation requests, detailing their specific logistics requirements, to ensure their goods are moved efficiently from origin to destination.

The engine is meticulously designed to provide tailored functionalities for each user group, ensuring their unique needs are addressed effectively. These functionalities involve both inputs and outputs, with distinct capabilities assigned to each role.

For every user role, the engine distinguishes between **primary** and **secondary** inputs and outputs:

- **Primary inputs** refer to critical data and actions that drive the logistics operations, such as uploading transport schedules for service providers or submitting transport requests for end users.
- **Secondary inputs** include supplementary data that enhances operational efficiency, such as updates to existing schedules or adjustments to ongoing requests.

The subsequent sections delve into these functionalities, elaborating on how the engine caters to the needs of each user role, ensuring a seamless and efficient interaction between logistics services supply and demand.

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3.1.2 Front-end – Primary inputs & outputs

3.1.2.1 Primary Inputs

Service Providers

Primary inputs for service providers constitute the foundational data upon which the transport network model is developed. These inputs enable the computational engine to accurately map and optimize logistics operations.

Vessel and Rail Operators

Vessel and Rail operators can provide detailed information about their vessels, including:

- Stopping locations: Ports of call or designated stops for the upcoming period.
- Arrival and departure times: Scheduled dates and times for each stopping location.
- Remaining transport capacity: Available capacity for each modular unit type (i.e. containers, pallets) for transitions between two stops.
- Transportation costs: Costs incurred between consecutive stopping locations.
- CO_2 emissions data: Information such as emissions per hour at a specific speed and capacity level.

The computational engine also allows service providers to dynamically update and manage this data, including the ability to:

- Modify/update remaining transport capacity.
- Adjust arrival and departure times.
- Update transportation costs.
- Remove an entire vessel schedule.
- Add new vessel details.

Truck Operators

Truck operators, focusing on transport between ports and inland destinations, can upload:

- Location pairs: Routes in the format of (port → inland location) or (inland location → port).
- Associated data: Information such as transportation costs, CO_2 emissions, and estimated delivery times for each route.

Given the on-demand nature of trucking services and their irregular schedules, a comprehensive understanding of fleet capacities and integration with vessel availability is challenging and remains an area for further refinement.

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End Users

End users can input detailed specifications and preferences for their transport requests.

Request Specifications

These include the essential details that define a transport request, such as:

- Origin and destination points.
- Quantity of goods to be transported (in TEUs).
- Latest possible delivery date.

Additional specifications may include:

- Type of product to be transported.
- Specific container requirements (e.g., refrigerated, insulated).

Request Preferences

Preferences guide the optimization process, detailing criteria such as:

- Total cost.
- Transit time.
- Earliest possible delivery date.
- Environmental impact (e.g., CO_2 emissions).

End users are also empowered to manage their requests actively. They can:

- Modify order details.
- Cancel orders.
- Mark orders as completed or fulfilled.

By defining these primary inputs, the computational engine ensures that the transport network algorithms are appropriately parametrized, filtering results to meet user needs and delivering tailored logistics solutions.

3.1.2.2 Primary Outputs

The computational engine employs parameterized search algorithms on the transport network model to identify routes that satisfy end-user transport request specifications. These routes, referred to as **feasible routes**, are further processed based on user-defined preferences to prioritize them according to personalised optimality criteria such as cost, time, or environmental impact.

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Outputs for End Users

The computational engine generates tailored transport and matching suggestions for each end user, designed to meet their specific requirements. These suggestions are structured as follows:

(Headhaul Shipping Schedule, Backhaul Shipping Schedule, Matching Shippers)

1. Headhaul and Backhaul Shipping Schedules:

   Each shipping schedule provides a sequential breakdown of logistics details for each leg of the journey, including:

   1. Leg Details: Identifier, type (ship, train, or truck), and owner of the transport vessel involved in the leg.

   2. Leg Locations: Origin and destination points for the leg.

   3. Timing:

      - For ships or trains: Departure time from the origin and arrival time at the destination.

      - For trucks: The time required to reach the destination.

   4. Total Cost: The cumulative cost of the schedule for the end user.

   5. CO_2 Emissions: Environmental impact of the shipping schedule.

2. Matching Shippers:

   This field lists other end users whose requests align with the current user's request. Matches are classified into two categories:

   - Headhaul Matching: Requests share the same origin, destination, and closely aligned shipping/delivery schedules, allowing multiple users to share the same transport resources. If end users match in the headhaul context, the Headhaul Shipping Schedule provides comprehensive details of a proposed shipping itinerary that satisfies their requests. This includes information such as the vessels involved, stopping locations, arrival and departure times, and CO_2 emissions. In such cases, the Backhaul Shipping Schedule remains empty.

   - Backhaul Matching: After delivering one user's cargo, the same transport resources (e.g., empty containers) are used to fulfill another user's request. For a backhaul match, the destination of the first user becomes the origin of the second, and their timelines align closely. If the end users match in the backhaul context, the Headhaul Shipping Schedule includes details of a proposed shipping itinerary that fulfills the first end user's requests. The Backhaul Shipping Schedule then provides information about a shipping plan that utilizes the empty containers from the first user's order to fulfill the second end user's requirements once the first order has been delivered.

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Notifications:

The computational engine ensures real-time updates to users:

- Notifications are sent when a new transport request matches an existing input.
- Alerts are issued if a previously matched request is closed, fulfilled, or canceled.

By delivering these outputs, CERL not only enhances decision-making for end users but also promotes efficient and sustainable logistics operations.

3.1.3 Front-end – Secondary inputs & outputs

3.1.3.1 Secondary Inputs

The secondary inputs for the engine are dynamic updates and feedback provided by both end users and service providers to enhance the quality, reliability, and adaptability of the engine.

End Users

- **Confirmation of Adopted Transport Schedules**: Once matched end users and service providers finalize an agreement, end users confirm the transport schedule they have adopted. While the brokerage happens offline, confirmation of the trip needs to take place on CERL in order to adjust the relative transport capacities.
- **Service Feedback and Ratings**: End users can rate their respective service providers based on the quality of the services rendered. This feedback helps improve service standards and fosters transparency on the computational engine.

Service Providers

- **Schedule Monitoring and Updates**: Service providers are responsible for tracking the fulfillment of agreed transport schedules. They are required to update the engine with information regarding the successful completion of each leg of the route.
- **Handling Unexpected Events**: In case of unforeseen events that disrupt the schedule, service providers must promptly notify the engine and provide request routing plan alternatives.

3.1.3.2 Secondary outputs

End Users

- **Disruption Notifications and Alternative Routes Requests:** If unexpected events disrupt an ongoing transport schedule, affected end users are promptly notified. They are given the option to submit new requests for alternative routes to complete the remaining unfulfilled legs of the initial schedule.

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- **Activity Reports:** End users receive periodic reports summarizing their activity on the platform, including completed trips, service ratings given, and any alternative routing requests made.

Service Providers

- **Performance and Service Usage Reports:** Service providers receive periodic aggregated reports detailing their service usage on the platform, including the number of completed transport schedules, disruptions handled, and user feedback received.

3.1.4 Storage

The data resources critical to CERL's operations, such as vessel schedules and transport orders, are stored in a PostgreSQL database. Recognized as the world's most advanced open-source relational database, PostgreSQL offers a robust, reliable, and high-performance solution with over 35 years of active development[38]. Its rich feature set and scalability make it an ideal choice for handling CERL's diverse and dynamic datasets.

On top of this database layer, Django, a high-level Python web framework[39], is deployed. Django provides a database-abstraction API that allows seamless creation, retrieval, updating, and deletion of objects (records) in the database. This abstraction simplifies interactions with the database by employing an Object-Relational Mapping (ORM) layer, which plays a vital role in managing data and enabling smooth communication with CERL and ModalNET.

Further enhancing the framework is the Django REST Framework (DRF), a versatile toolkit for building robust and flexible web APIs[40]. DRF serializes data from the Django ORM and enables it to be accessed and updated through a RESTful API. These APIs can then be consumed by modern JavaScript frameworks such as Vue.js, Angular, or React, facilitating system extension, user interaction, and integration with external systems. The entire workflow, as described above, is illustrated in Figure 1.

[38] https://www.postgresql.org/
[39] https://www.djangoproject.com/
[40] https://www.django-rest-framework.org/

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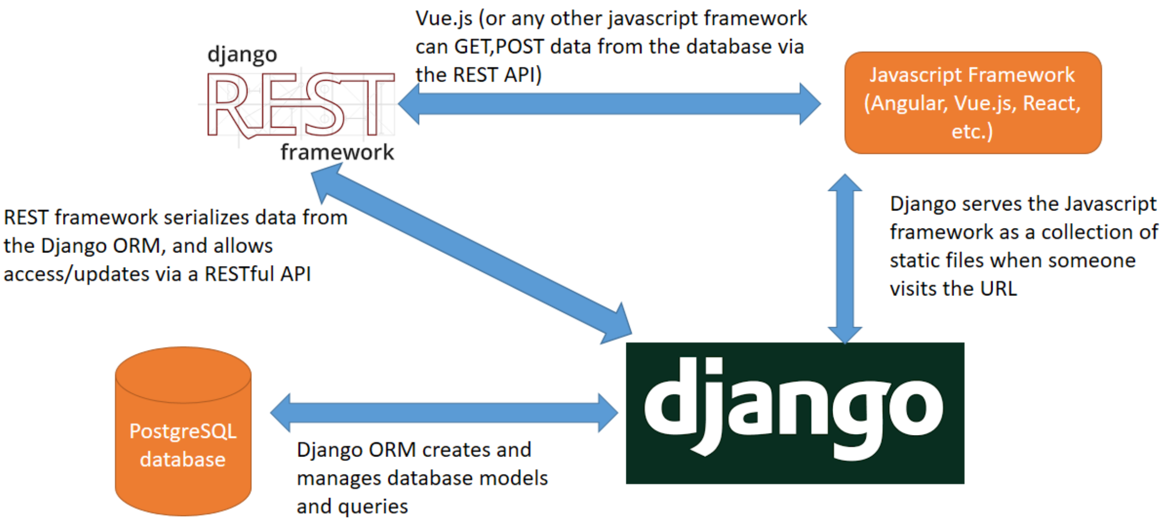

Figure 1 Interaction between the main components of CERL

The database schema of CERL adheres to a thoughtfully designed data model. This model organizes CERL's elements and establishes standard relationships among real-world entities, ensuring consistency and clarity. At its core, the model represents two primary entities: service providers and end users, complemented by additional elements that define their relationships with vessels, ports of call, transport orders, and more.

Each entity in the model corresponds to a table in the PostgreSQL database, with attributes represented as columns. Relationships between entities are materialised using foreign keys, enabling efficient data organization and retrieval.

The main entities in CERL's database schema include:

1. Service Provider

- Represents logistics service providers offering transport services.
- **Attributes**: Name, address, phone number, and email. These attributes uniquely identify each service provider.

2. Vessel

- Captures details about a transport vehicle, which can be a ship, train, or truck.
- **Attributes**:
    - Type (e.g., ship, train, truck).

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- Name.
- CO_2 emissions data.
- Total capacity and current remaining capacity.
- Status (e.g., on sea, in port, out of service).

3. Location of Call

- Represents specific points where a vessel stops during its journey to load or discharge cargo.
- **Attributes**:
  - Arrival and departure dates.
  - Available remaining capacity before departure.
  - Status (e.g., departed, arrived, arriving).
  - Journey status (e.g., start, intermediate, end).
- This entity establishes a relationship between a vessel and a location, indicating that a specific vessel stopped at a given location at a particular time.

4. Location

- Describes registered locations within the system, such as ports or inland terminals.
- **Attributes**:
  - Name.
  - Geographical coordinates.

5. End User

- Represents individuals or organizations that own cargo and place transport orders.
- **Attributes**: Name, address, phone number, email.

6. Transport Order

- Defines a cargo transport request submitted by an end user.
- **Attributes**:
  - Origin location and destination location.
  - Product quantity to be transferred.
  - Product quantity expressed in TEUs.

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    - Latest allowable delivery date.
    - Product type and container type (e.g., refrigerated, insulated).
    - Status (e.g., fulfilled, canceled, open).
- This entity links to the End User entity and the Location entity, as the origin and destination attributes correspond to registered locations.

7. Suggested Shipping Schedule

- Represents proposed shipping schedules generated by the Transport Network model for a given transport order. These schedules are stored for reference, avoiding redundant recalculations.
- **Attributes**:
    - Transport Order: A foreign key linking to the corresponding transport order.
    - Locations of Call: A list of IDs representing the various stops along the shipping route.
    - Total Cost: The cumulative cost of the proposed schedule.
    - Total CO2 Emissions: Emissions associated with the schedule.
    - Matching Transport Orders: A list of IDs corresponding to other transport orders from different users that align with the given schedule.

3.1.5 Communications

The Python Django framework will be employed to enable seamless access to the database's content, facilitating interactions with both the front-end interface, any external clients that may need to connect to CERL as well as ModalNET. As previously detailed in section 3.1.4, the Django REST framework (DRF) will be used as the foundational library for building these APIs. This choice ensures the development of robust, flexible, and scalable web services capable of handling a variety of database operations.

The APIs will support several functionalities tailored to specific database tasks. For instance, HTTP POST methods will be used to create new entries in the database, such as adding a vessel or registering a transport order. HTTP PATCH methods will handle partial updates to existing records, enabling operations like modifying vessel schedules or updating the status of transport orders. HTTP DELETE methods will facilitate the removal of records from the database, such as deleting obsolete vessel entries.

All API interactions will maintain a consistent structure to ensure compatibility and ease of use. Path parameters will be used to identify specific resources within the database, while the request body will always be formatted in JSON. To comply with this requirement, the HTTP request header must

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explicitly include "Content-Type: application/json". Similarly, all responses returned by the APIs will be structured in JSON format, allowing for straightforward integration with the front-end and external systems.

By adopting this approach, CERL will ensure efficient, secure, and scalable interactions between the database and its users. This will promote a unified and reliable protocol for data exchange across the system, enhancing its overall functionality and user experience.

3.1.6 Back-end – Matching Engine

The back-end of CERL, referred to as the Matching Engine, is responsible for transforming the input data provided by shipping companies into a comprehensive model that represents the transport network as a graph. In this graph-based representation, ports serve as vertices, and the transitions of vessels between these ports act as edges. Each edge is characterized by specific attributes, including departure and arrival dates, available cargo capacity, and potentially other operational details. Alternatively, a different modelling approach, still under consideration, involves representing space-time points as vertices. In this configuration, each vertex would correspond to a specific port at a precise time point, adding a temporal dimension to the network.

Once the end users' transport orders are received, the graph undergoes processing using specialized graph topology algorithms. These algorithms analyse the graph to identify shipping schedules by determining feasible and optimal paths that align with the requirements of each transport order. These paths are computed based on criteria such as delivery deadlines, available capacity, and cost efficiency. The result is a set of candidate shipping schedules that fulfil the users' requests.

To enhance efficiency, the computed schedules are stored in an intermediate results database. This caching mechanism allows the engine to reuse previously generated schedules whenever a new transport order matches existing conditions, reducing computational overhead. These candidate schedules also serve as the foundation for the subsequent matching process. The engine facilitates matches between end users with complementary needs and between end users and service providers, ensuring optimal utilization of transport resources.

The matching results, once finalized, are stored in dedicated Matching Suggestions databases. From there, they are seamlessly integrated into the front-end user interface, making them accessible to users in a clear and organized manner. This back-end architecture not only ensures accurate and efficient processing of complex logistics data but also supports CERL's goal of providing a user-centric and responsive experience.

3.1.7 Indicative Use Case Scenario

CERL's operation begins with initialization using data provided by shipping companies. These companies are expected to supply vessel schedules covering at least a two-month rolling period. The schedules are anticipated to remain relatively stable over time. End users interact with the ModalNET platform or directly with CERL by placing transport orders and marking them as closed or fulfilled once an agreement with a service provider is reached.

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The workflow for an end user engaging with CERL involves a structured sequence of actions:

1. Whenever an end user places a transport order, the engine is activated to identify feasible and optimal transport schedules that meet the specifications of the order. This triggers the search for routes that align with the requested criteria.

2. The identified transport schedules, along with any previously calculated schedules stored as intermediate results, are analyzed to identify potential matches. Matching orders are identified based on complementary requirements, as previously outlined.

3. Once the engine determines suitable matches, the end user is promptly notified and can access the matched results. These may be downloaded directly or delivered through preferred communication channels.

4. Simultaneously, both service providers and other end users involved in the identified matches are notified about the relevant opportunities.

5. As long as the transport order remains active, CERL ensures ongoing engagement by providing regular updates. End users receive notifications if new orders that align with their requirements are discovered or if any of the previously matched orders are fulfilled, closed, or cancelled. This continuous monitoring and notification mechanism enhances CERL's utility and responsiveness.

6. CERL is designed to deliver responses in near real-time or on a periodic basis, ensuring timely communication and decision-making for all users. This systematic process ensures efficient matching, transparent notifications, and streamlined interactions between end users and service providers.

3.2 Security/Privacy Requirements

The back-end infrastructure of the computational engine, which stores critical resources such as data on vessels, service providers, transport orders, and other relevant information, will be secured to ensure only authorized users can access it. This security is enforced through the OAuth2 protocol, an open standard widely adopted for access delegation[41]. OAuth2 is designed to provide secure and delegated access to server resources without requiring users to share their passwords. Instead, users can authorise third-party applications to access their data through the issuance of access tokens.

OAuth2 operates by enabling a resource owner (e.g., a user or entity managing data) to authorize third-party applications without sharing login credentials. The protocol is tailored for Hypertext Transfer Protocol (HTTP), and it works by allowing authorization servers to issue access tokens to

[41] https://auth0.com/intro-to-iam/what-is-oauth-2

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clients (such as web applications). These tokens, approved by the resource owner, are then used to access protected resources hosted by a resource server.

In CERL, the front-end serves as the third-party client, while the back-end acts as the resource server that houses vital information such as transport orders, user profiles, and service provider details. The resource owners, in this case, are the end users and service providers who populate the database with shipping schedules, transport orders, and related content.

The interaction between these components is illustrated in Figure 2, which outlines how the front-end accesses protected resources through CERL's OAuth2 implementation. The process includes the following steps:

1. **Client Registration**: The front-end client registers itself with the CERL authorization services by providing necessary information such as a client ID and a redirect URI. This registration enables the client to participate in the OAuth2 workflow.

2. **User Login and Authorization**: When a user attempts to log in via the front-end, they are redirected to the CERL login page. The user provides their credentials, which are verified by the authorization server. Upon successful authentication, the authorization server issues an access token to the client.

3. **Resource Request and Validation**: Once logged in, the user may request a resource (e.g., searching for shipping schedules) through the front-end. The client forwards the access token to the CERL resource server (back-end) as part of the request. The resource server validates the token to ensure it is valid and authorized.

4. **Resource Delivery**: Upon successful validation, the resource server retrieves the requested data and sends it to the client. The user can then view the requested information, such as shipping schedule details, via the front-end interface.

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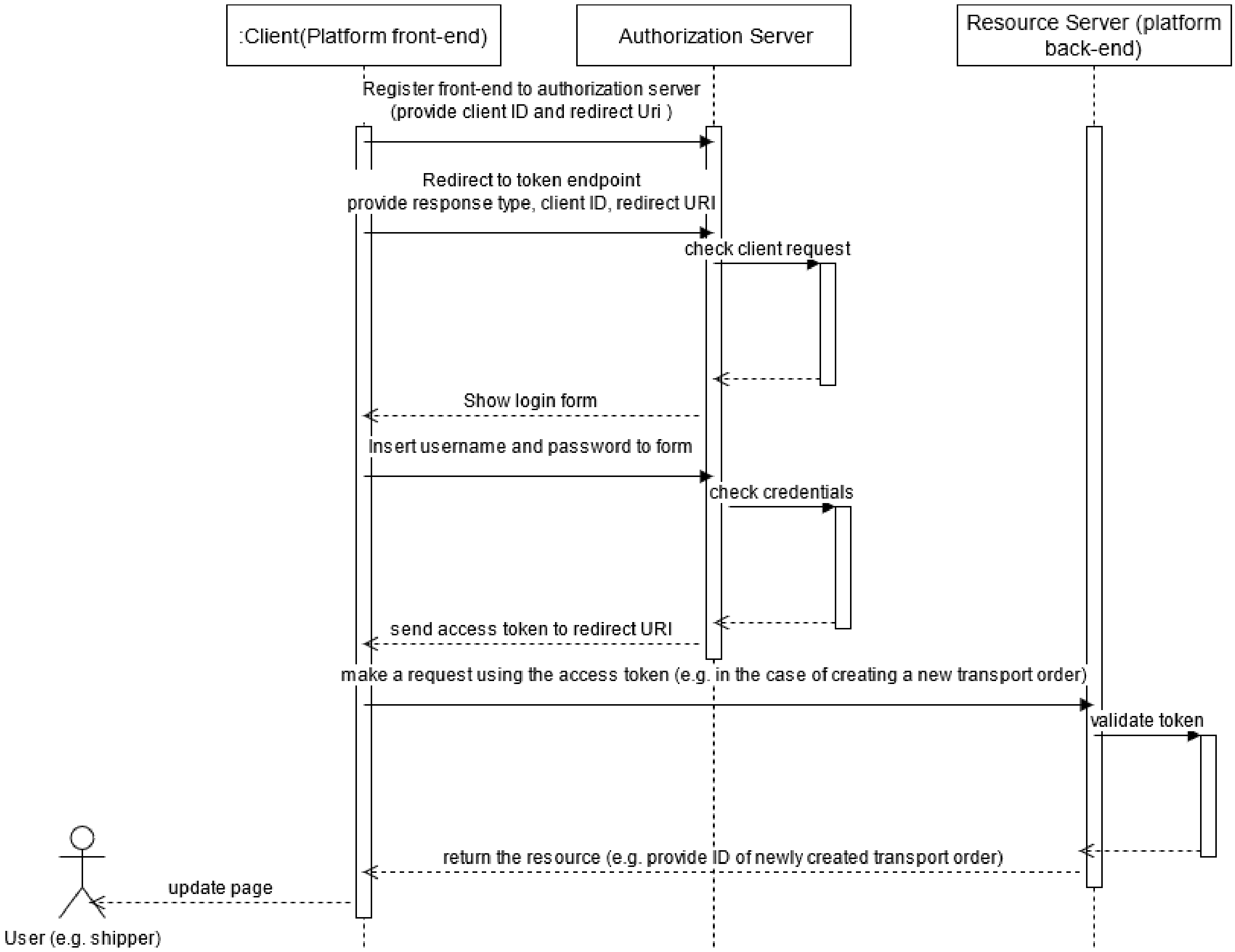

Figure 2 Sequential diagram depicting CERL front-end, Authorisation server and resource server (back-end) interactions

Since CERL front-end is built using the Python Django framework, which integrates JavaScript, CSS, and image files (static content), Django's built-in authentication methods will be employed to manage user permissions effectively. After a user logs in, the access token is immediately provided to the front-end and is used to maintain the user's session throughout their interaction with the platform.

This workflow is particularly well-suited for Single Page Applications (SPAs), where it is challenging to keep sensitive information like the "client_secret" confidential. By leveraging OAuth2 and Django's authentication mechanisms, the CERL platform ensures robust security, seamless user experiences, and secure access to protected resources.

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4 CONCLUSIONS

This document provides a comprehensive analysis of the computational engine for resilient logistics, focusing on its business logic and underlying methodology, as well as CERL's architecture. The approach taken involved a step-by-step examination, identifying and studying potential sources of information to extract key features and functionalities. An in-depth review of current platforms and initiatives was conducted, offering insights into existing barriers. The analysis revealed several critical barriers, including the tendency of most initiatives to concentrate on isolated issues or specific procedures, often overlooking essential aspects of the broader supply chain, such as focusing solely on road transport. This limitation makes them ill-suited to address the unique challenges of multimodal transport. Another significant barrier identified is the lack of communication and collaboration among stakeholders, compounded by the absence of integrated, multimodal services.

The document also provided a detailed overview of the platform's business concept, outlining the main stakeholder groups involved in the logistics process and describing their respective roles. Additionally, the architectural design of CERL was presented, detailing its three primary modules—the front-end, storage/database, and back-end modules— as well as an integration layer, while highlighting how these components interact and support the platform's overall functionality, and how the system architecture aligns with stakeholder needs. Finally, it was presented how security and privacy requirements are addressed in CERL.

Looking ahead, the next steps for CERL include the release of its first prototype, which will feature an alpha version, using inputs from Tasks T2.5 and T5.3, along with a subset of relevant data. This will pave the way for the platform's further implementation in Task 5.4.

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