D1.1

Needs analysis of relevant stakeholders for the European multimodal transport network

FIR at RWTH Aachen University

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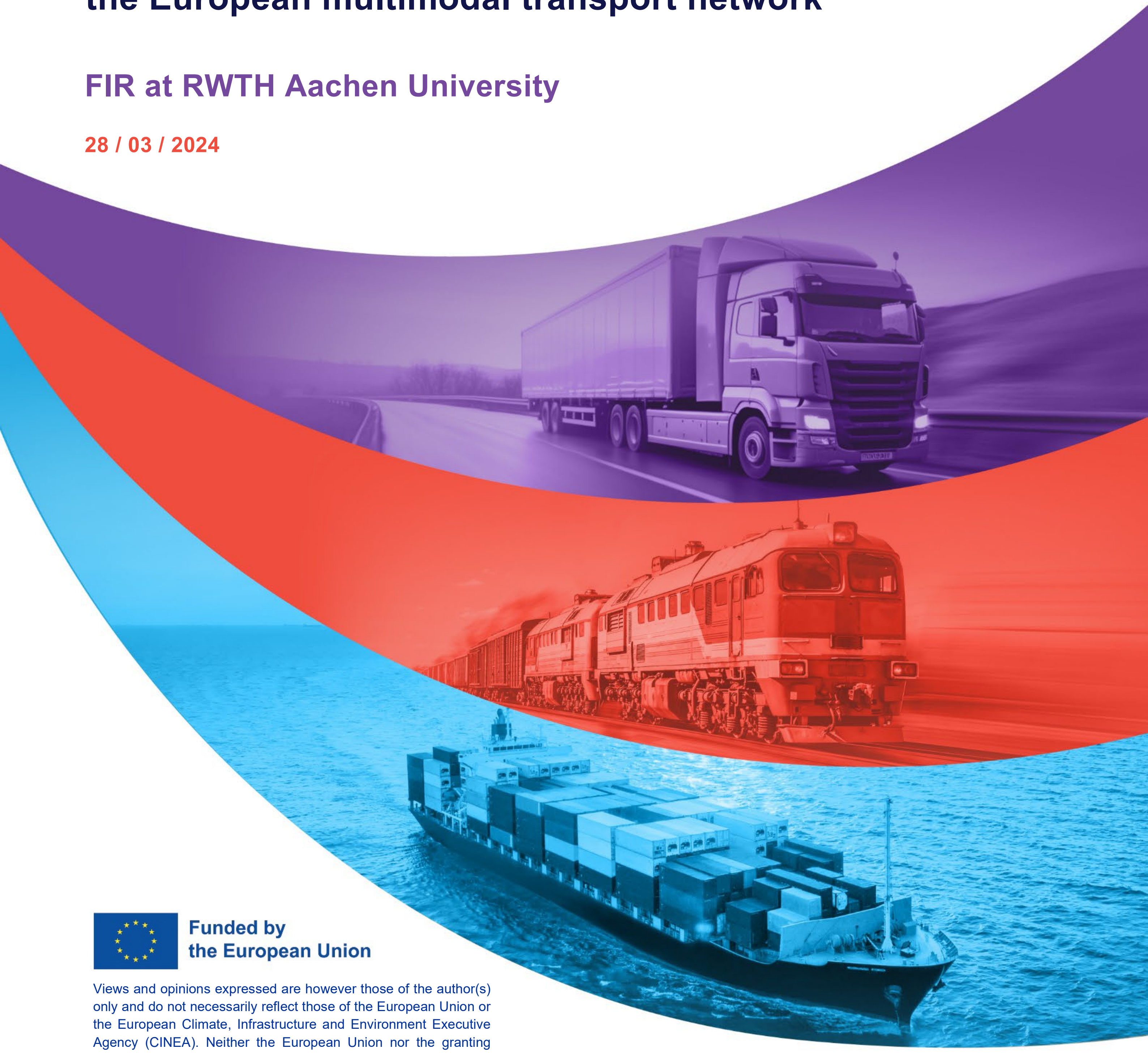

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ABBREVIATIONS

ABBR.	PHRASE
1PL	First-Party Logistics
2PL	Second-Party Logistics
3PL	Third-Party Logistics
4PL	Fourth-Party Logistics
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
API	Application Programming Interface
CHA	Challenges
CRM	Customer Relationship Management
CSV	Comma Separated Values
DEM	Demographics
DIS	Disruptions
DLSP	Digital logistics service provider
ECMT	European Conference of Ministers of Transport
ERP	Enterprise Resource Planning
ERTMS	European Rail Traffic Management System
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
EVA	Evaluation
FMEA	Failure Mode and Effects Analysis
GDP	Gross Domestic Product
ICT	Information and Communication Technology

ABBR.	PHRASE
IT	Information Technology
ITU	Intermodal Transport Units
IWW	Inland Waterways
LLP	Lead Logistics Provider
LOG	Logistics
LSP	Logistics Service Provider
MS	Microsoft
NUTS	Nomenclature des unités territoriales statistiques
OCAP	Out of Control Action Plan
PAR	Participation
PI	Physical Internet
R&I	Research & Innovation
ReMuNet	Resilient Multimodal Freight Transport Network
RES	Resilience
RRT	Rail-Road-Terminals
RU	Railway Undertaker
SARIL	Sustainability And Resilience for Infrastructure and Logistics networks
SCM	Supply Chain Management
SME	Small and Medium Enterprises
SOL	Solutions
TEN-T	Trans-European Transport Network
TMS	Transport Management System

ABBR.	PHRASE
TOS	Terminal Operating System
VFM	Value Flow Model
WMS	Warehouse Management Systems
WP	Work Package
XML	eXtensible Markup Language

1 INTRODUCTION

ReMuNet - Resilient Multimodal Freight Transport Network - is financed by the European Commission through the European Union's Horizon Europe research and innovation program under Grant Agreement No 101104072. It has been proposed by a consortium of 15 beneficiaries coordinated by FIR at RWTH Aachen University and will be lasting 36 months, having started in July 2023. The content of the project and the aim of the deliverable will be presented in the following.

1.1 Project Background

ReMuNet is tasked with identifying and signalling disruptive events while assessing their impact on transport corridors. By communicating alternative multimodal transport routes to logistics operators and subsequently to truck drivers, train drivers, and barge captains, it facilitates a more rapid network response. Furthermore, ReMuNet orchestrates route and capacity utilisation and enables synchromodal relay transport.

Additionally, ReMuNet is responsible for establishing comprehensive standards for the transnational description of multimodal nodes and transport routes, including infrastructure elements and their parameters. This forms the basis for a unified modelling language. To ensure maximum practical applicability and acceptance, these standards are developed by evaluating and consolidating existing description standards, supplementing technical and sustainability related descriptive attributes, and engaging in close collaboration with European transport companies, associations, and institutions.

ReMuNet's collaborative platform reduces entry barriers for regional transport companies, encouraging participation in multimodal transport, known for its lower average emissions compared to road freight transport. Intelligent routing algorithms prioritise low emission routes and modes of transport, enhancing transport efficiency and significantly cutting emissions. ReMuNet explores the integration of alternative drives to further support sustainability goals, aiding political and economic decision-makers in expanding and maintaining vital transport infrastructure.

ReMuNet's algorithm considers the impacts of disruptive events and strategically plans route distribution to maximise the efficiency of the multimodal transport network. Within the project a comprehensive Transport Failure Mode and Effects Analysis (FMEA) is conducted, including detailed risk analysis of disruptive events and potential transport disruptions, to transparently assess short and long-term effects on the multimodal transport infrastructure. ReMuNet's data pool expedites internal decision-making, supporting the development of business capabilities necessary to manage disruptions.

ReMuNet maintains a catalogue of transport Out of Control Action Plans (OCAP), containing quick reaction strategies to respond to potential transport collapses. Synchromodal relay transport is tested as the preferred transport mode to bridge failed transport routes.

ReMuNet's algorithm provides real-time status updates on functioning transport nodes and edges, enabling flexible route adjustments. The algorithm calculates failure probabilities for transport routes and minimises congestion on alternative routes through intelligent distribution.

ReMuNet's collaborative platform treats small and large companies equally, aiming to integrate local players and connecting freight forwarders, carriers, terminal operators, and other key players in the multimodal transport sector. It enables the digitalisation of communication, contracts, handover protocols, and booking processes, and orchestration of synchromodal relay transport. Continuous interactive improvement is achieved through algorithm testing and validation using historical disruptive event data. The platform provides transparent and user-friendly access for small and medium enterprises (SME) to route network structures, scheduling, operators, and capacity booking in road, rail, and barge transport.

The platform's infrastructure includes basic backend functionalities, such as master data management, user administration, roles, rights, and user-friendly application programming interfaces (API) and interfaces to existing systems and data sources. ReMuNet provides an AI-supported transport system model capable of depicting the effects and impact intensities of various disruptive events on the transport infrastructure, recognising patterns, deriving failure probabilities, identifying bottlenecks, and evaluating alternative courses of action, thus reducing reaction time, and offering sustainable, event-based route alternatives and scenarios.

ReMuNet strives to integrate civil protection organisations into the collaborative platform, matching them with freight transporters, and using real-time data to display the status of functioning and failing transport infrastructure, enabling faster and more targeted aid transportation.

By integrating all relevant stakeholders via interfaces into ReMuNet, a wide variety of anonymous planning data is refined to create the necessary basis for decision-making. Clear data governance structures and data handling processes that comply with privacy policy specifications ensure secure and trusted information exchange. External data inputs are obtained through APIs and interfaces from multiple sources, enabling participatory planning.

1.2 Key Objectives of the ReMuNet Project

The concept of the Physical Internet foresees a seamless network where resources and assets can be shared openly and efficiently. ReMuNet's **main objective is to support the achievement of this vision by giving the transport network the ability to prepare, respond, and adapt to disruptive events**.

In practice, ReMuNet uses digital technologies to holistically improve the resilience of the logistics and freight transport network. This includes making planning more robust and secure, reducing response times, and speeding up system recovery. ReMuNet also takes environmental aspects into account and aims to provide synchromodal transport options with the lowest emissions. This contributes to the implementation of the Physical Internet and helps to reduce the environmental impact of freight transport.

ReMuNet's key objectives are to:

Lay the foundation for a common standard to describe sustainable European multimodal transport networks for all stakeholders: ReMuNet creates comprehensive standards for the transnational description of multimodal nodes and transport routes including infrastructure elements and their parameters. This will lay the foundation for a uniform modelling language. To ensure maximum practice orientation and acceptance, the standards are developed by evaluating and consolidating existing description standards, supplementing technical and sustainability relevant descriptive attributes, and closely collaborating with European transport companies, associations, and institutions.

Reduce European inland transport emissions on the main run by over 50% in the long term: ReMuNet's collaborative platform lowers entry barriers for regional transport companies to participate in multimodal transport, thus facilitating combined transport which on average produces fewer emissions than road freight transport. Intelligent routing algorithms prefer low emission routes and modes of transport and increase transport efficiency, in turn significantly reducing emissions. To further contribute to sustainability goals, possibilities to integrate alternative drives are explored. Insights support political and economic decision-makers in expanding and maintaining the necessary transport infrastructures.

Enable the multimodal freight network to react and respond 20% more quickly to disruptive events until 2026 (in comparison to 2021): The algorithm considers the impacts of disruptive events and plans a robust route distribution to maximise the efficiency of multimodal transport system utilisation. Transport FMEA including risk analysis of disruptive events and potential transport collapses is conducted to make the short and long-term effects of disruptive events on the multimodal transport infrastructure transparent. A shared data pool accelerates internal decision-making and supports the development of business capabilities necessary to cope with disruptions. Catalogue of transport OCAPs containing quick reaction strategies to (upcoming) transport collapses ensure the ability to (re-)act. Synchromodal relay transport will be tested as the preferred type of transport mode to bridge failed transport routes.

Provide 50% more alternative transport routes in the face of disruptive events and make multimodal route planning 10-20% more accurate and efficient until 2026 (in comparison to 2021): The algorithm displaying the real-time status of functioning transport nodes and edges allows for flexible adjustment of route suggestions. Routes are calculated and forwarded to freight forwarders and navigation systems to ensure communication with drivers and barge captains. The algorithm determines failure probabilities of transport ways and minimises congestion on alternative routes via intelligent route distribution. A collaborative platform connects freight forwarders, carriers, and terminal operators, as well as other key players in the multimodal transport sector to gather real-time data and digitalise communication, contracts, handover protocols, and booking processes and orchestrate synchromodal relay transport. Continuous interactive improvement will be achieved by simulative algorithm testing and validation with historical data of disruptive events.

Create new approaches for benefit-sharing cost-efficient business models and integrate 30% more companies (>50% SMEs) into the multimodal freight transport ecosystem: ReMuNet offers an open collaborative data platform, which does not differentiate between small and large companies and integrates local players. The platform provides user-friendly access for SMEs to route network structures, scheduling, operators, and capacity booking in road, rail, and barge transport. The platform infrastructure includes basic backend functionalities, e.g., master data management, user administration, roles, and rights as well as user-friendly APIs and interfaces that connect the platform to other systems and data sources.

Predict the impact of disruptive events on multimodal transport corridors with a 90% higher accuracy until 2026 (in comparison to 2021): ReMuNet provides an AI-supported transport system model able to depict the effects and impact intensities of various disruptive events on the transport infrastructure, recognise patterns, derive failure probabilities, identify bottlenecks, and evaluate alternative courses of action. This will lead to shortening reaction time by offering sustainable, event-based route alternatives and scenarios.

Enable civil protection organisations to set up aid delivery logistics for crisis areas 25% faster in 2026 (in comparison to 2021): ReMuNet integrates civil protection organisations into the collaborative platform and matches them with freight transport companies. The network status will stay updated by using real-time to display functioning and failing transport infrastructure while taking new makeshift transport ways into account. This approach will enabling a faster and more focused aid transportation into crisis areas.

Create a unified data pool that portrays the real-time utilisation of multi-modal European transport infrastructure in compliance with data protection regulations: By integrating all relevant stakeholders via interfaces into the ReMuNet, a wide variety of anonymous planning data will be refined to create the necessary base for decision making. Clear data governance structures and secure data handling processes will be implemented to meet privacy policy specifications. External data input is pulled via APIs and interfaces from multiple different sources enabling participatory planning.

1.3 Relation with other Research Projects

The ReMuNet-Project is part of the 2020 Horizon Europe Call which is meant to shape competitive and reliable technologies for a European industry leading in key areas and enable production and consumption in a sustainable and effective way. Besides ReMuNet there are plenty other EU-projects that tackle similar problems, that are shown in Table 1.

Table 1: List of synergies with other EU research projects

RELATED PROJECTS	SYNERGIES WITH REMUNET
SARIL https://saril-project.eu/	SARIL and ReMuNet share a goal of improving transport resilience and sustainability. Their collaboration has involved joint surveys and discussions on related topics. SARIL's focus on incorporating environmental considerations into resilience complements ReMuNet's focus on handling disruptions and optimising routes. By utilising SARIL's expertise, ReMuNet can further refine its approach to developing sustainable and resilient transport networks.
PhysICAL https://physical-project.at/	PhysICAL and ReMuNet share goals of improving transport efficiency and sustainability. Their collaboration allows ReMuNet to adopt PhysICAL's initiatives to better manage disruptions and enhance sustainable transport networks.
Core/Heros https://www.euproject-core.eu/	CORE aims to mitigate the impact of disasters on vulnerable populations, aligning with ReMuNet's goal of enhancing transport resilience. Collaboration can lead to comprehensive strategies for managing disruptive events and promoting resilient transport networks.
Clusters 2.0 https://cordis.europa.eu/project/id/723265	Clusters 2.0 aims to improve logistics efficiency and reduce environmental impact with Europe's open network logistic clusters, aligning with ReMuNet's sustainable transport goals. Collaboration may lead to integrating these clusters into ReMuNet's strategies, enhancing infrastructure, economic growth, and optimising transport operations through a hyper-connected logistics network, fostering stakeholder collaboration.
FEDeRATED https://www.federatedplatforms.eu/	The projects share goals of optimising asset capacity, reducing environmental impact, and encouraging digital technology use in logistics. Utilising FEDeRATED's tools and infrastructure can enhance ReMuNet's pursuit of sustainable and efficient EU transport systems.
DISCO https://discoprojecteu.com/	DISCO complements ReMuNet's objectives by using the Physical Internet to improve logistics, emphasising decentralised data sharing and scalability to boost supply chain efficiency and sustainability. Merging DISCO's digital solutions into ReMuNet's plans can foster innovation in sustainable logistics and planning.
UNCHAIN https://unchainproject.eu/contact/	UNCHAIN, focused on transforming logistics for sustainability and safety, aligns with ReMuNet's objectives. It works on urban transport efficiency and environmental improvements, indirectly aiding sustainable freight goals. Their collaboration could boost transport efficiency and supply chain optimisation efforts.
DELPHI https://delphi-project.eu/	DELPHI and ReMuNet focus on integrating transport modes and seamless data sharing to optimise freight transport. Both leverage AI technologies to improve transport management. Collaborating could lead to knowledge sharing and innovative solutions for efficient, sustainable transport.

RELATED PROJECTS	SYNERGIES WITH REMUNET
KEYSTONE https://www.keystone-project.com/	KEYSTONE and ReMuNet aim to enhance transport sustainability and efficiency through data sharing and compliance in a digital ecosystem. Their collaboration will leverage KEYSTONE's expertise in API standards and digital solutions to optimise freight systems and promote sustainability.
SETO https://setoproject.eu/	SETO's digital platform, focused on improving transport enforcement through data integration, complements ReMuNet's efficiency goals. Collaboration allows ReMuNet to share its data security and integration expertise, aligning with SETO's objectives to streamline information access and enhance data security.
SUM https://sum-project.eu/	The SUM project aims to transform European mobility by merging shared modes with transport systems, prioritising innovation, and sustainability. Its collaboration with ReMuNet, which focuses on freight optimisation, could enhance efforts to cut emissions and boost transport efficiency.
GEMINI https://www.geminiproject.eu/	GEMINI's sustainable models and mobility services complement ReMuNet's transport optimisation goal. With digital tools and shared mobility, GEMINI addresses emissions and safety challenges. Collaboration with ReMuNet could boost stakeholder cooperation and public-private partnerships.
ADMIRAL https://www.admiral-project.eu/	ADMIRAL's digital marketplace for logistics supports ReMuNet's aim to boost freight efficiency and sustainability. By managing supply chains and emissions, ADMIRAL aids ReMuNet's environmental goals. Collaboration can enhance knowledge sharing and innovation adoption in supply chain management.
eFTI4EU https://efti4eu.eu/what-is-efti4eu/	eFTI4EU's digital freight information initiative aligns with ReMuNet's efficiency and digitalisation goals. It supports seamless transport by promoting EU-wide interoperability, mirroring ReMuNet's aims. Their collaboration can drive the standardisation of digital platforms, easing administrative processes and fostering sustainable transport.
ACUMEN https://acumen-project.eu/	ACUMEN's efforts in multimodal transport management complement ReMuNet's logistics optimisation goal. With its focus on secure data sharing, advanced monitoring, and decision-making tools, ACUMEN supports ReMuNet's mission to improve transportation efficiency and sustainability, fostering a seamless transport network.

1.4 Objective of Deliverable 1.1

The first work package of ReMuNet establishes the theoretical foundation for the project by investigating the impact of disruptive events on transport chains and analysing mitigation options. It lays the foundation for common standards to describe sustainable European multimodal transport networks for all stakeholders and presents a requirements-based reference for the technical development of the digital solution components, such as the collaborative platform and the routing algorithm.

As integral part of the first work package Task 1.1 aims to develop an in-depth understanding of the relevant stakeholders within the multimodal transport ecosystem. It is led by FIR Institute for Industrial Management at RWTH-Aachen in collaboration with Humlog Institute at Hanken School of Economics, MANSIO GmbH, Fraunhofer Austria, Hafen Wien GmbH, White Research SRL, UIRR s.c.r.l., Vediafi Oy, Danish Red Cross, and ETP-ALICE. The research undertaken in this task uncovers the existing impediments that actors within multimodal transport encounter in the event of disruptions. Drawing from stakeholders' experience with previous disruptions Deliverable 1.1 explores existing strategies and contingency plans and deduces specific stakeholder needs to increase preparedness for future events. Understanding the needs of multimodal transport stakeholders will help shape the outcome of the ReMuNet project by addressing technological requirements, business-related concerns, and regulatory constraints. In addition, the sustainability efforts of various stakeholders are highlighted and the potential for reducing emissions through the comprehensive use of digital tools is analysed.

The findings outlined in Deliverable 1.1, "Needs analysis of relevant stakeholders for the European multimodal transport network," are crucial for the development of digital modules. Recognising and meeting the requirements of key stakeholder groups is fundamental to ensuring the ReMuNet solution is practical, sustainable, and widely accepted.

The stakeholder analysis was conducted using desk research, surveys, and semi-structured interviews with experts to evaluate the value generated by key stakeholders, pinpoint challenges, and ascertain their roles within the multimodal ecosystem. In addition, collaborative digital and physical workshops have been organised involving industry experts and consortium partners. The workshops served as a platform for in-depth discussions, and offered the opportunity to challenge assumptions, and refine project details. The gathered insights include information from representatives involved in the immediate transport chain such as freight forwarders carriers, terminal operators, and other relevant entities. Additionally, adjacent stakeholder groups including government bodies, industry associations, and non-governmental organisations such as environmental groups, have been examined.

Given ReMuNet's piloting focus on the Trans-European Transport Network (TEN-T) corridors North Sea-Baltic (CORR 2) and Rhine-Danube (CORR 9) within work package five, particular emphasis was placed on stakeholders operating in these geographical areas. Based on studies conducted on European intermodal freight transport a methodology has been developed to estimate the intermodal potential of TEN-T corridors. Supplemented with up-to-date corridor-specific data on freight volumes, modal splits, transport infrastructure etc. this methodology enables the estimation of freight volumes that could be transported intermodally, and consequently the potential for emission reduction.

1.5 Structure of the Deliverable

The structure of this document is designed to provide a comprehensive overview of the ReMuNet project, its objectives, methodologies, and key findings.

Following the introduction of the objectives for both the ReMuNet project and Task 1.1, the document explores the theoretical bases crucial for refining the research area and building a solid understanding of the project's context and theoretical framework. It covers various fundamental concepts such as the Physical Internet, transport modalism, disruptive events, resilience of freight transport systems, and the TEN-T concept. After presenting the TEN-T concept, the document offers brief overviews of the focal corridors, North Sea-Baltic, and Rhine-Danube.

Following the presentation of the TEN-T concept and focus corridors, the next section outlines the developed methodology for estimating their specific intermodal potential. The methodology, grounded in desk research proposes a straightforward, practical approach to evaluating corridors in terms of their intermodal capability, estimating the proportion of freight that could be transported intermodally and calculating potential emission reductions.

Subsequent sections of Deliverable 1.1 focus on the needs analysis of relevant stakeholders in the European multimodal freight transport ecosystem. The methodology in Chapter 4 outlines the research problem, research plan, data collection, and analytical methods used in Task 1.1, offering clarity on the research approach, and affirming the credibility and accuracy of the results. The research methodology builds on a multifaceted information gathering process including desk research, focus workshops, a survey, and expert interviews with key stakeholders. This method ensures a high level of objectivity, reliability, and validity in the outcomes. The extensive analysis of both primary and secondary information sources, combined with the holistic view of the ecosystem and its participants, further guarantees that the findings are highly representative, shedding light on current challenges and solutions from perspectives. The different information-gathering methods are explained in detail, including desk research procedures, workshop concepts, the survey design, and the guidelines for the semi-structured interviews.

Following the methodology chapter the document presents the results drawn from the stakeholder analysis. In Chapter 5 the insights from the information-gathering process feed into the development of a description model for the European multimodal freight transport ecosystem. Utilising the value flow modelling approach, a generalisable core process for multimodal transport is presented, highlighting the interrelationships among the key stakeholder groups engaged in the multimodal transport chain. In addition to illustrating the key stakeholder groups, the value flow model identifies and visualises the exchange relationships between them. A Table 6 in Section 5.3 provides a detailed overview of exchange relationships, documenting the types of information stakeholders receive from and provide to other ecosystem partners.

Building on the value stream model the following section provides detailed descriptions of the European multimodal freight transport ecosystem's stereotypical stakeholder roles, based on insights from the stakeholder analysis.

Following the clarification of each stakeholder role, their contributions, dependencies, and information exchanges, Deliverable 1.1 focuses on outlining the challenges stakeholders encounter during or in preparation for disruptive events. For this, different types of disruptive events impairing multimodal freight transportation are analysed in terms of operational layer, place of occurrence and possible impact. This includes an examination of stakeholders' experiences with disruptions, their impacts on business operations, and strategies like contingency planning and digital technology adoption aimed at mitigating disruption effects and enhancing resilience. Subsequently, the identified challenges are consolidated into categories to highlight the principal concerns affecting individual stakeholder groups as well as the entire ecosystem.

Chapter 6 tackles key challenges, contrasting them with existing strategies and technologies. By comparing current major obstacles to implemented measures, stakeholder needs are identified and categorised. Building on challenges and stakeholder needs Chapter 7 evaluates the functional aspects of digital technologies, assessing their potential to enhance efficiency, sustainability, and resilience.

Finally, Deliverable 1.1 concludes by summarising the key findings from the stakeholder analysis and their implications to evaluate how they can be incorporated into the ReMuNet solution’s conceptional framework. It offers recommendations for future initiatives and research trajectories within the ReMuNet project, guiding subsequent efforts towards addressing identified challenges and leveraging opportunities.

2 THEORETICAL BACKGROUND

This chapter serves as a theoretical basis for the stakeholder analysis of ReMuNet and the subsequent research contributions. By presenting theoretical concepts, principles, and assumptions necessary for the delimitation of the study area and the research approach it creates a uniform understanding throughout the project.

As a trailblazer project for the Physical Internet (PI) ReMuNet pursues the vision to enable and incentivise synchromodal relay-transportation on European rail, road, and inland waterways to increase the holistic network resilience. The PI, which represents a fundamental concept for the research contributions within the framework of ReMuNet will be explained in Section 2.1 shedding light on interrelationships and shared objectives with ReMuNet.

Due to ReMuNet focusing on multimodal freight transport using road and rail infrastructure as well as inland waterways, defining the terminology for the different modes of transport is crucial to create a common understanding throughout the project. Therefore, the terms, “intermodalism”, “multimodalism”, “synchromodalism” and “transmodalism” are introduced, defined, and distinguished from one another.

ReMuNet aims to reduce economic losses caused by transport disruptions while also promoting sustainability. Therefore, it is important to understand the probabilities and potential impacts of different disruptive events. To achieve maximum practical benefit, ReMuNet will focus on events that have a significant impact and can be predicted and planned for to some extent. To characterise disruptive events, the typology developed in Deliverable 1.3 (cf. Kulkarni et al., 2023) with the 'swan analogy' coined by mathematician Nassim Taleb in 2007 (cf. Taleb, 2007).

Building on the understanding of disruptive events and their potential impact on the multimodal freight transport network the concept of resilience is introduced in Section 2.4. ReMuNet understands the resilience of transport networks as the minimisation of disruption-induced impacts on network performance, in both intensity and duration, along with minimising the system recovery time.

To delineate the geographical scope for ReMuNet, Section 2.5 describes the TEN-T, with particular emphasis on the Rhine-Danube and North Sea-Baltic transport corridors. These corridors are designated for the pilot implementation of the ReMuNet solution in later project stages.

2.1 Physical Internet

The Physical Internet (PI) is a concept in transport logistics that aims to maximise efficiency and sustainability. It involves consolidating freight flows and pooling resources in interconnected networks to effectively fulfil customer requirements. By using digital technologies and promoting the seamless networking of logistics services, the use of resources is optimised and a smooth process is made possible (Ballot et al., 2020; Hoa Tran-Dang et al.).

Open and interconnected logistics services and networks, which constitute the development of the PI, aim to optimise capacity utilisation to meet present and future demands. Emphasising efficiency-driven value creation can accelerate the shift towards greener and cleaner assets, contrasting with price reductions and margin erosion stemming from current asset usage. Achieving identified efficiency potentials could accommodate a projected 300% increase in transport demand with only a 50% rise in assets as the European Technology Platform ALICE (Alliance for Logistics Innovation through Collaboration in Europe), states in their "Roadmap to the Physical Internet" (Ballot et al., 2020).

Furthermore, ALICE identifies 5 main development fields to enable PI-driven green logistics (Ballot et al., 2020):

1. From logistics nodes to PI nodes

In logistics, nodes serve various functions such as consumption, storage, transformation, and transshipment of goods between different transport modes. The PI aims to transform these logistics nodes into standardised PI nodes. PI nodes will utilise a range of interoperable modular load units and offer digitally accessible services for planning, booking, and executing operations.

2. From logistics networks to PI networks

Logistics networks encompass both logistics nodes and the transportation services linking them to their destinations. These networks are typically managed by a single entity. PI networks aspire to establish seamless, flexible, and resilient door-to-door services. They consolidate and deconsolidate shipments within the logistics network, ensuring that all assets, capabilities, and resources are visible, accessible, and usable to optimise efficiency.

3. Developing the system of logistics networks towards the PI

The System of Logistics Networks, integral to the Physical Internet, consists of interconnected individual logistics networks. This setup enables all network owners to access the assets, services, and resources of other networks. It serves as the foundation for efficient, secure, and extensible services facilitating the flow of goods, information, and finances across these interconnected networks.

4. Access and adaption

This section outlines the primary requirements for accessing the PI via a logistics network, along with the necessary steps and mindset shift needed to embrace PI concepts.

5. Governance

Governance encompasses the necessary advancements to transition logistics nodes, logistics networks, and the system of logistics networks into the PI. This involves establishing rules by stakeholders involved in forming or utilising these networks, as well as implementing trust-building processes and mechanisms.

Using the framework from Figure 1 ReMuNet will contribute to this vision by providing the transport network with the core ability to prepare, respond, and adapt for disruptive events. Against this backdrop, ReMuNet uses digital technologies for holistically improving logistic and freight transport network resilience - from more robust participatory planning processes to shorter response times and quicker system recovery. Considering environmental aspects, ReMuNet further contributes to the implementation of the PI and thus aims for synchromodal transport options with the lowest emissions utilising the asset sharing concept of relay transportation.

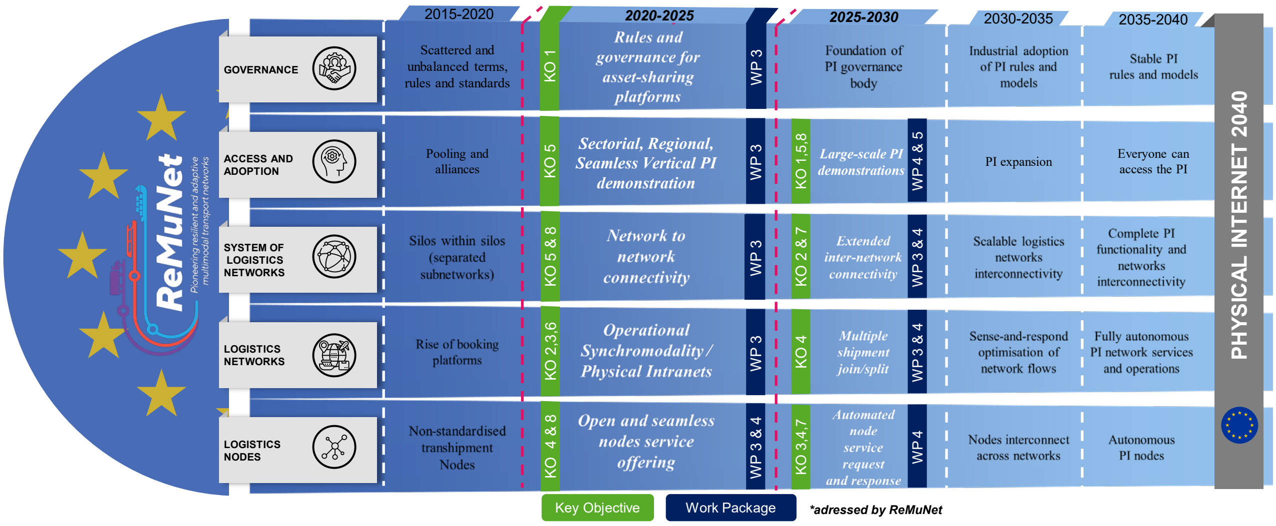


Figure 1: ReMuNet framework for the Physical Internet

2.2 Freight Transport Modalisms

Intermodalism, transmodalism, multimodalism, and synchromodalism are three key approaches to optimising the transportation of goods and passengers across different modes of transportation. Each approach offers distinct advantages and serves varying purposes in the complex field of logistics.

Intermodalism, the “utilisation and thus combination of different modes of transportation along a route” (Nobis, 2014), involves the organisation of a sequence of modes between an origin and destination, including the transfer between the modes. Its main goal is to connect transportation systems that could not be connected otherwise because they are not servicing the same market areas due to their technical characteristics. In intermodalism, each segment is subject to a separate ticket (for passengers) or a contract (for freight) that must be negotiated and settled. This approach allows for the integration of different modes while maintaining separate contracts or tickets for each leg of the journey (Gronalt et al., 2019; Posset et al., 2020; Rodrigue, 2018).

Multimodalism, the “use of different modes of transportation within a different time frame” (Nobis, 2014), is essentially an extension of intermodalism, where all the transport and terminal sequences are subject to a single ticket or contract (bill of lading) that can be assumed by a single integrated carrier. This means that the entire journey is covered by a single agreement, offering a more streamlined and simplified experience for the end user. While this can appear more efficient due to reduced transactional costs, it may not always be the most efficient and sustainable option. A multimodal service provider may prioritise the use of its own routes and facilities, which may not always be the most convenient for the user. The main objective of such an integrated carrier is to maximise the use of its assets, which could sometimes conflict with the user's needs (Gronalt et al., 2019; Posset et al., 2020; Rodrigue, 2018).

Synchromodalism enhances logistics by optimising processes throughout the entire transport network, promoting deeper integration between information and goods flow, and increasing flexibility. The primary objective of synchromodality is to lower costs, emissions, and delivery times without compromising the quality of supply chain services (Giusti et al., 2019). Unlike traditional transport systems, synchromodal logistics allow for adaptable chains that can be modified during transport, with the ability to automatically select the optimal transport mode at the right time. Unlike intermodal transport, synchromodal systems enable switching between modes at any point in the chain, but effective collaboration among partners is essential (Posset et al., 2020).

Transmodalism “involves connecting different segments of the same mode between an origin and a destination” (Rodrigue, 2020). It aims to reconcile different modal services on the same network. Whether transmodalism occurs under a single or separate ticket or contract can vary depending on the specific context. Transmodalism is particularly common in air transportation, where passengers can easily book a ticket between two locations, even if it involves transiting through an intermediary airport and using separate carriers. Air carriers have strategically employed transmodalism by establishing major hubs that maximise the number of city pairs serviced and implementing code-sharing agreements. In contrast, transmodalism in freight transportation is more challenging, as switching load units within the same mode can be complex due to the large amount of handling required (Rodrigue, 2018).

Figure 2 provides a visual overview of the different modalisms in freight transportation.

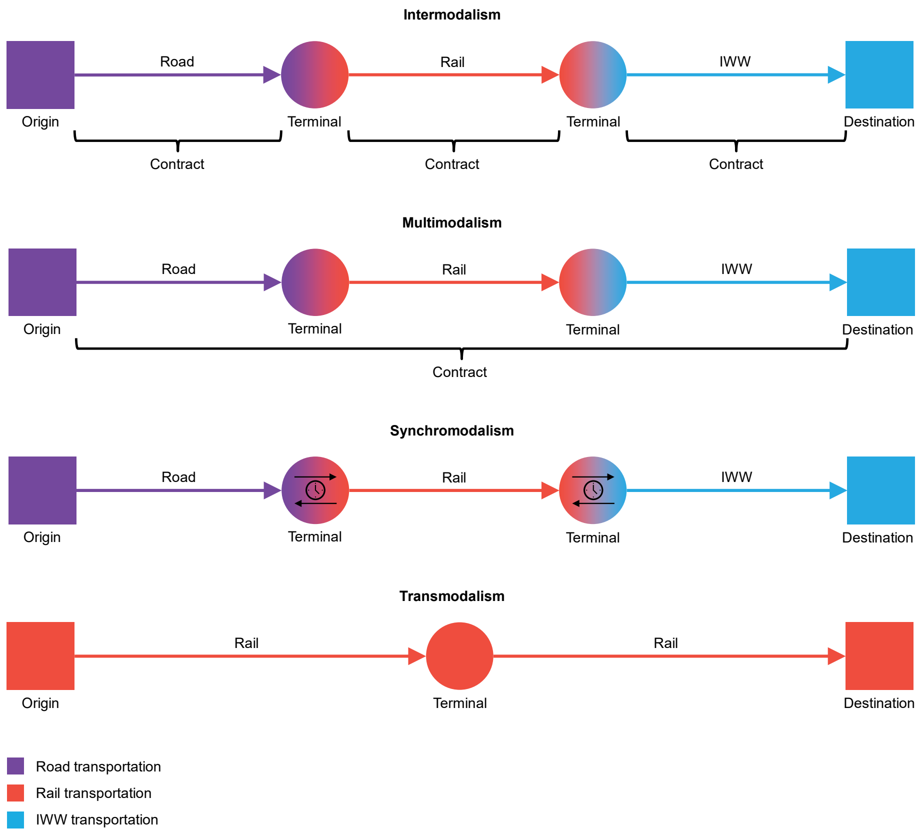


Figure 2: Modalisms in freight transport (own delineation based on Rodrigue, 2018)

Within the project context of ReMuNet no distinction will be made between intermodal and multimodal transports. To ensure continuous transportation amidst disruptions, ReMuNet considers all regional transportation options across road, rail, and inland waterways. It identifies optimal transport combinations tailored to the specific conditions of the event, including relay transport strategies to circumvent compromised infrastructure sections. The project does not differentiate between existing multimodal or intermodal contracts, despite implications from its name. The resilience and sustainability of these modal combinations, potentially incorporating transmodal segments, are thoroughly evaluated. Enhancing transport network transparency, the collection and analysis of (real-time) data from sensors and telematics systems plays a crucial role, facilitating the shift towards synchromodal transport. Embodying the principles of the PI, ReMuNet pioneers cross-stakeholder communication within the European transport sector, aiming to lower emissions and foster a more efficient, resilient transport network.

2.3 Disruptive Events

"A **disruptive event** can be defined as any interruption or change, planned or unplanned, in the operations of a transport network, creating effects, such as delays, blockages or closures." (Kulkarni et al., 2023)

Based on the typology developed in Deliverable 1.3 disruptive events can be classified based on their operational layer, cause, and impact. The operational layer is divided into the information layer and the physical layer. The distinction by operational layer differentiates between disruptions primarily affecting the physical environment, e. g. physical transport infrastructure, and disruptions primarily affecting the information and communication level, e. g. (digital) data exchange between logistics players and adjacent stakeholder groups. The causes of disruptive events encompass natural disasters, technological failures, regulatory changes, security incidents, accidents, health emergencies, capacity shortages, geopolitical crises, extreme weather conditions, and economic slowdowns. These determinants were discerned through an analysis of historical events and discussed in focus groups and expert interviews. It should be noted that the disruptive events categorised by cause can have an impact on both the physical layer and the information layer. The impact of these events can vary in terms of time duration (short-term, medium-term, long-term) and geographical extent (narrow-spread or wide-reaching). Understanding these classification possibilities is crucial for developing strategies to enhance the resilience and responsiveness of multimodal networks by supporting logistics stakeholders to manage the challenges they encounter in the face of disruptive events (Kulkarni et al., 2023).

An alternate framework providing further insights into the different classifications and approaches on disruptive events is the “swan theory” first introduced in 2007 by the financial mathematician Nassim Nicholas Taleb in his book “The Black Swan”. Following this framework disruptive events might be distinguished into three categories, a white swan, a black swan and ultimately a grey swan.

> “A **white swan** is a highly assured event with three principal qualities: it is certain; its impact can easily be projected; and, after the event, we make a portrayal of the event which can be well recognised, and any mistakes in judgment are related to ambiguity in decision making“ (Devarajan et al., 2023)

Conversely, a **black swan** event lies outside the realm of human anticipation, with its probability of occurrence incalculable and the magnitude of its impact inestimable due to the lack of any historical precedent or indication of future likelihood.

> “First, it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Second, it carries an extreme impact. Third, in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making a **black swan** explainable and predictable” (Taleb, 2007).

Many events with high impact and a limited predictability due to low probability of occurrence fall into the category of **grey swans**.

> “A **grey swan** is a metaphor for a large-impact and rare event that’s somewhat predictable, yet many overlook it. It’s the ‘known unknown’, a rare event that some know is possible, but no one knows when or whether it will occur” (Hole & Netland, 2010)

As natural catastrophes multiply in the wake of climate change, the risks of pandemics and geopolitical conflicts are omnipresent, the threat of disruptive events to the European transport network grows ever greater. The frequency of supply disruptions has increased by 33 % since 2022 resulting in an average economic loss of 75 million € per company (interos, 2023). A key objective of the ReMuNet project is to enable the multimodal freight network to react and respond more quickly to disruptive events, improving resilience of the whole transport chain and reducing disruption related costs.

For greater practical benefit, ReMuNet will focus on events that are not only impactful but also possess a degree of predictability and manageability. Understanding the probabilities of occurrence and the potential impact of major disruptive events is critical to developing countermeasures that help reduce response times and speed up system recovery. Thus, ReMuNet focuses on disruptions that can be categorised white swan events such as seasonal weather events, accidents or strikes and to a limited extent on grey swan events like major geopolitical crises and their subsequent effects. Due to the great uncertainty regarding black swan events, these are not considered in the design of the ReMuNet solution.

2.4 Resilience of Freight Transport Systems

Resilience is a versatile term with various applications that has evolved into a veritable buzzword in the last years. The multitude of definitions to be found in the literature does not allow for a complete grasp and delimitation of the term, according to which the term must always be tailored to the context (Mayar et al., 2022).

The term "resilience" is derived from the Latin word "resiliere", which means "to spring back" or "to bounce back". The term was originally used in ecological systems, where it was distinguished from stability (Holling, 1973). Since then, the concept has spread to numerous disciplines, including organisation (Sheffi, 2005), economics (Rose & Liao, 2005), social sciences (Adger, 2000), supply chains (Raj et al., 2015; J. W. Wang et al., 2013; J. Wang et al., 2018) and engineering (Hollnagel & Woods, 2006; J. W. Wang et al., 2019; Xu et al., 2018). According to the Oxford Languages Dictionary, resilience is defined as "the ability of people or things to recover quickly after something unpleasant, such as shock or injury" (Oxford Dictionary). Another definition by Home and Orr (1997) describes resilience as “a fundamental quality of individuals, groups and organisations, and systems as a whole to respond productively to significant change that disrupts the expected pattern of events without engaging in an extended period of regressive behaviour” (Home & Orr, 1997). In recent years, the term resilience has commonly been used in the context of disaster to describe a system’s ability to maintain an acceptable level of efficiency in the face of disruptive events, such as the COVID-19 pandemic at the end of 2019 (Liao et al., 2023). Although the term "resilience" can be interpreted differently according to the context, it generally refers to the ability of a system to return to its normal state after a disruption (Hosseini et al., 2016; Zhou et al., 2019).

In the context of supply chains, resilience can be defined as an organisation’s capacity to mitigate disruptions and achieve swift recovery through strategies that enhance transparency and communication within the supply chain. Given the increasing complexity of global supply chains and transit times, the need for resilient transport systems has become more prominent (Pitera & Goodchild, 2009).

Resilience in freight transportation systems is important for supporting economic activity and production. Disruptions can have severe economic consequences, making resilience crucial in minimising negative impacts. Resilient transportation systems ensure the smooth functioning of supply chains, enabling timely delivery of goods and reducing costs (Pitera & Goodchild, 2009). Most definitions suggest that resilience encompasses qualities like flexibility and elasticity, which is crucial for sustainable transport systems. Analysing interactions between transport modes can lead to strategies that are both economically sound and resilient, focusing on specific geographic and functional areas of freight movement. By integrating mode and route optimisation with a resilience framework, the most effective strategies that align with the unique features of local and regional logistics operations and network infrastructure can be identified, thereby reducing disruption impacts (Arabi et al., 2021). Adaptability and flexibility are key elements of resilience, allowing the transportation system to adjust to changing conditions, technologies, regulations, and market dynamics. A resilient system can recover more quickly, find alternative routes or modes of transport, and maintain service levels (Arabi et al., 2021). Ta et al. have proposed an approach to defining freight transportation system resilience, describing it as the ability of the system to withstand and recover from disruptions, whether they are caused by natural disasters, technological failures, or another unforeseen events (Ta et al., 2009).

Taking previous definitions into account the following working definition for “resilience of freight transport networks “has been derived for ReMuNet:

A **resilient freight transport network** minimises disruption-induced impacts on network performance, in both intensity and duration, along with minimising the system recovery time.

A resilient freight transport network progresses through three chronological stages: pre-disruption, during disruption, and post-disruption. Within the strategic pre-disruption phase, actions focused on increasing resilience aim to mitigate the impact of disruptions and enhance preparedness. During this phase, strategies contingent on specific scenarios are formulated to guide the orchestration and execution of transports in response to disruptions, employing a "what-if" logic approach. Strategies within this period may involve prioritising users of the freight system in expectation of constrained infrastructure capabilities and developing robust information-sharing mechanisms to enable users to make well-informed choices regarding the use of infrastructure capacity. During disruptions, actions are taken to respond quickly and minimise negative impacts, such as rapidly disseminating information about the disruption and reallocating resources. Lastly, actions taken post-disruption aim to promote resilience by learning from the disruption and its underlying causes to reduce long-term impact (Sheffi & Rice Jr., 2005). The learning process involves re-evaluating decisions made and actions taken, with the intention of incorporating constructive insights back into the contingency planning before the next disruption.

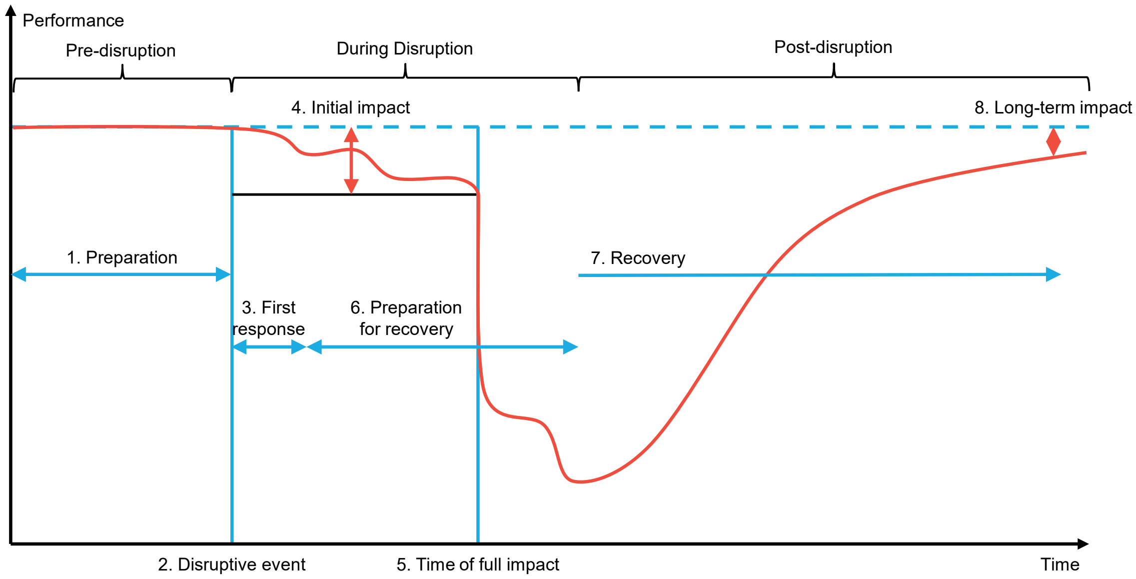


Figure 3: Impact of disruptions on performance over time
(own delineation based on Sheffi & Rice Jr., 2005)

To gain a deeper understanding of freight transportation system resilience, Ta et al. (2009) identified six properties of resilience through an extensive review of the literature. These properties include redundancy (having multiple resources to fulfil system functions), autonomy of components/stakeholders (components or stakeholders that can operate independently), collaboration (engaging stakeholders and users to foster interaction, idea sharing, trust-building, and routine communication), efficiency adaptability (system flexibility and the capacity to learn from past experiences through reinforcement learning), and interdependence (the interconnectedness of system components and dimensions). These properties contribute to the overall ability of the freight transportation system to effectively respond to and recover from disruptions at the managing organisation, infrastructure, or user levels.

By implementing four core functionalities the ReMuNet solution aims to increase transport network resilience and to boost corridor efficiency. The basic functionalities consist of a common standard describing multimodal transport networks and disruptive events, an algorithm calculating and allocating possible multimodal transport routes in the face of disruptive events, a collaborative platform to connect relevant stakeholders and enable event-based synchromodal relay transport and ultimately an AI-model forming the basis for self-learning multimodal transport networks. These four modules respond to the delineated stages of resilient freight transport systems, culminating in an enhanced disruption profile (See Figure 4). Improved efficiency leads to quicker reaction times to disruptions, facilitating a swifter return to baseline performance levels. Through collaborative resolution of disruptions via the ReMuNet platform, the severity and duration of disruptions are significantly reduced, thereby diminishing economic losses and potential environmental damage ensuing from such events.

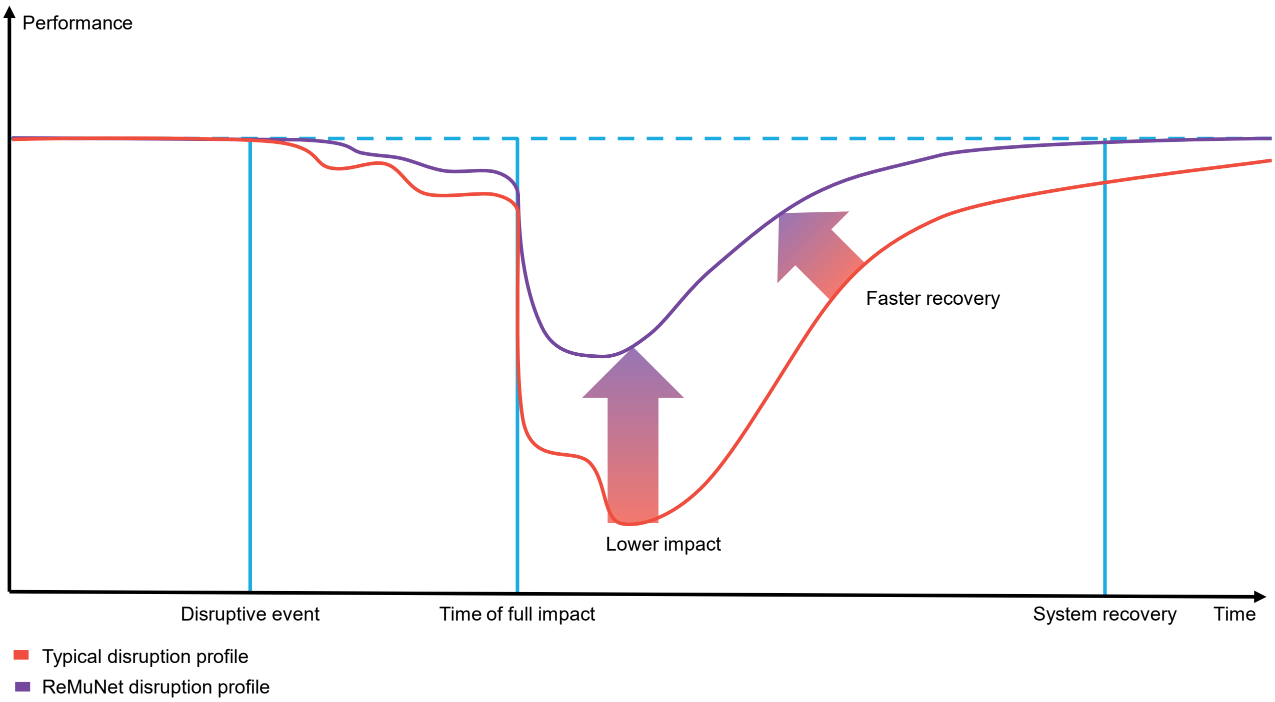


Figure 4: ReMuNet disruption profile

2.5 TEN-T Concept

The Trans-European Transport Network, also known as TEN-T, is a vast transportation network that spans Europe, connecting various transportation modes such as roads, railways, aviation, and waterways. The network's primary objective is to enhance the efficiency, safety, and sustainability of transportation systems across the member states of the European Union while facilitating the seamless flow of goods and people across international borders (European Commission, 2024; Regulation (EU) No 1315/2013, 2013).

On October 17, 2013, the European Union announced the selection of nine core network corridors, which replaced the initial 30 TEN-T priority projects to increase connectivity across Europe while increasing the resilience and sustainability of the transport system. Identification and development measures of the core network within the comprehensive network are due by 2030 (European Commission, 2013; Regulation (EU) No 1315/2013, 2013). The development and expansion of the TEN-T network is guided by European Union policies and assisted by the EU via financial support to promote economic growth, territorial cohesion, and environmental sustainability within the European transport sector. This should ultimately challenge the obstacle of missing links across border sections and fragmented transport infrastructure (European Commission, 2013).

Table 2: TEN-T core network corridors
(European Commission, 2024)

CORR 1	**BALTIC-ADRIATIC**	On of the key trans-European-road and railway networks in central Europe connecting northern member states with southern states of Italy and Slovenia.
CORR 2	**NORTH SEA-BALTIC**	Links the north-west EU member states with the northeast states. Since 2021 including Finland, parts of Sweden and Poland up to the border of Ukraine.
CORR 3	**MEDITERRANEAN**	The main east-west freight transport corridor south of the Alps. Focusing on road and rail the corridor connects mediterranean ports with the centre of the EU.
CORR 4	**ORIENT/EAST-MEDITERRANEAN**	Connects major ports of North, Baltic, Back and Mediterranean Sea via road transportation.
CORR 5	**SCANDINAVIAN-MEDITERRANEAN**	Key north-south connection spanning from Finland and Sweden to Malta.
CORR 6	**RHINE-ALPINE**	Connecting Belgium and Netherlands along the Rhine through the Rhine-Ruhr and Rhine-Neckar regions with the Alps and northern Italy.
CORR 7	**ATLANTIC**	The corridor connects the Iberian Peninsula with northern France and western Germany utilising all modes of transport.
CORR 8	**NORTH SEA-MEDITERRANEAN**	Main connection between Ireland through the centre of Europe to southern France including main ports of Ireland, France, and Netherlands.
CORR 9	**RHINE-DANUBE**	Main east-west transport corridor across Continental Europe along the rivers Rhine and Danube.

TEN-T consists of two layers, the core network corridors, strategically identified routes linking major cities and nodes, and comprehensive network sections that cover broader geographical regions (see Figure 5). Each TEN-T corridor contains at least three transport modes, three EU-Member states and two cross-border sections (European Commission, 2013, 2024; Regulation (EU) No 1315/2013, 2013).

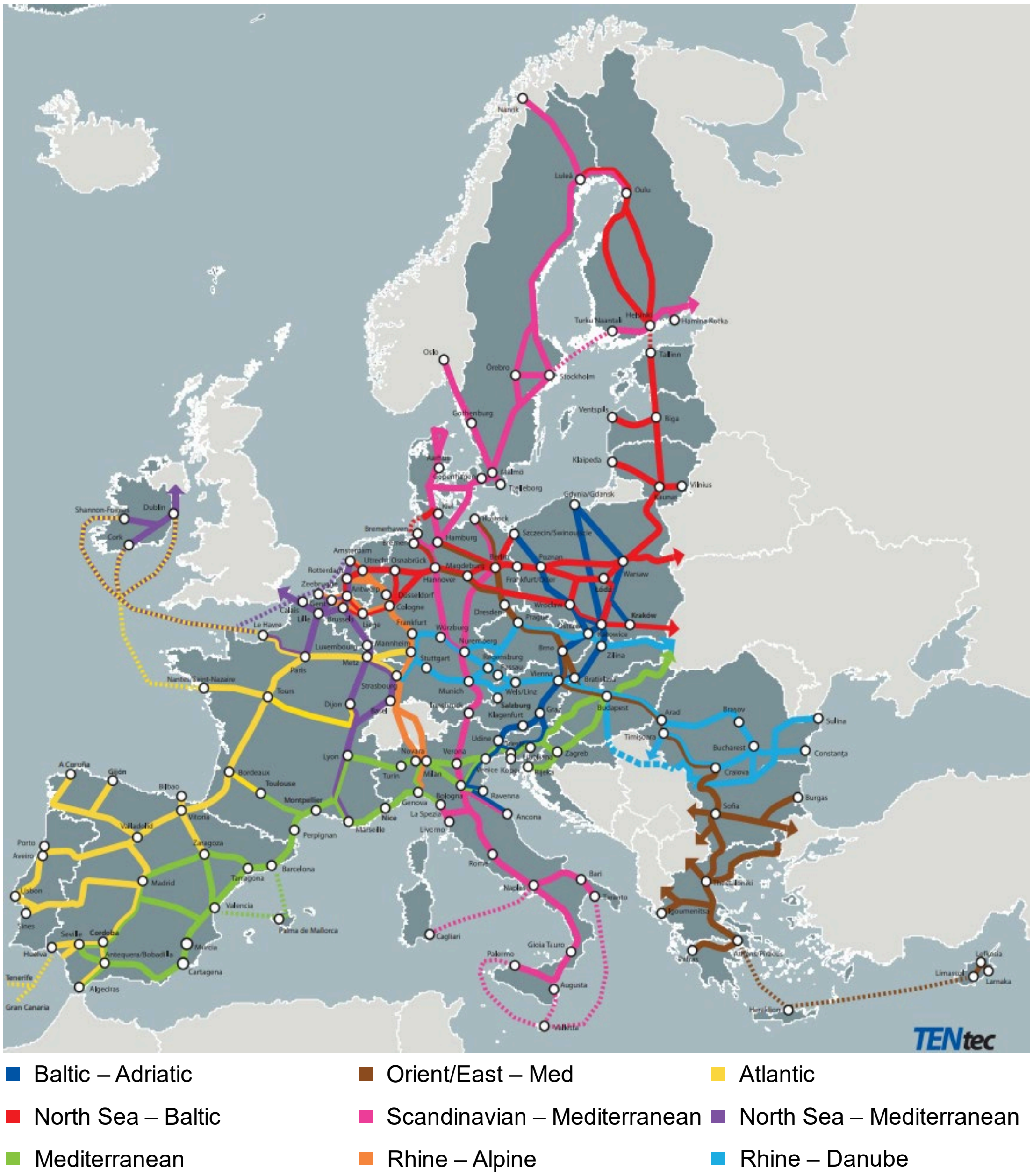


Figure 5: Trans-European transport network (European Commission, 2021) (European Commission, 2021)

The major goals of TEN-T, improving multimodal freight transportation in Europe and improving economic and environmental sustainability along the freight transport chain, align with the key objectives of the ReMuNet project. The Rhine-Danube corridor and the North Sea-Baltic corridor have been chosen for piloting the ReMuNet solution at a later stage of the project (WP5).

2.5.1 TEN-T Corridor Rhine-Danube

The Rhine-Danube Corridor provides the main east-west link across Continental Europe (European Commission, 2017b). Tracing its route along the Danube River, it connects

Strasbourg and Southern Germany with the Central European cities of Vienna, Bratislava, and Budapest, before passing through the Romanian capital Bucharest to culminate at the Black Sea port of Constanta. A second branch of the corridor tracks a path from Frankfurt to the Slovakian/Ukrainian border, linking Munich, Prague, Zilina and Kosice. Linked Countries are France, Germany, Austria, the Czech Republic, Slovakia, Croatia, Bulgaria, Romania and touching the not EU-member states of Switzerland, Ukraine, Serbia and Bosnia (European Commission, 2024).

The Corridor comprises 4,488 kilometres of roads that connect the capitals of all the Member States on the Corridor, which will be all extended to motorways by 2030 (European Commission, 2017b).

The Rhine-Danube Corridor includes a rail-network of overall 5,715 kilometres of which are 91% electrified (European Commission, 2017b).

The inland waterway network within the Rhine-Danube Corridor spans approximately 2,400 kilometres along the Danube, comprising the largest portion. Additionally, it encompasses sections of other rivers such as the Rhine, Main, and Sava. Altogether, this network totals 3,650 kilometres of inland waterways, linked to 19 inland ports (European Commission, 2017b).

Table 3: Basic information on the TEN-T Rhine-Danube Corridor. (European Commission, 2017b)

MEMBER STATES	France, Germany, Czech Republic, Slovakia, Austria, Hungary, Romania
URBAN NODES	Strasbourg (FR), Mannheim (GER), Frankfurt/M (GER), Nürnberg (GER), Stuttgart (GER), München (GER), Ostrava (CZ), Praha (CZ), Bratislava (SK), Wien (AT), Budapest (HU), Timişoara (RO) and București (RO)
POPULATION	94.43 Mio (2014)
GROSS DOMESTIC PRODUCT (GDP)	2,009 billion € (estimated for 2014)
EMPLOYMENT	43.21 Mio (2014)
FREIGHT TRANSPORT VOLUME	149 billion tkm (2017)

2.5.2 TEN-T Corridor North Sea-Baltic

The North Sea-Baltic TEN-T corridor is the main connection of the northern European countries and represents an important connection of northwest and northeast of Europe (European Commission, 2024).

The Corridor encompasses a network of 4,092 kilometres of roads linking the capitals of all the Member States along its route (European Commission, 2017a), which have been extended in 2021 to 6,934 kilometres spanning from Finland and norther Sweden all the way through Poland to the borders of Ukraine (European Commission, 2024).

The total railway network of the Corridor is 8,828 kilometres long (European Commission). Noteworthy is the issue being that some sections of the rail network in the Baltic member states are not electrified and also have a different track gauge (European Commission, 2017a).

The 2839 kilometres long inland waterway network of the North Sea-Baltic TEN-T freight transport corridor connects the North Sea ports of northern France, Netherlands and Germany with Berlin (European Commission, 2024).

Table 4: Basic information on the TEN-T Rhine-Danube Corridor.
(European Commission, 2017a)

MEMBER STATES	Belgium, Netherlands, Germany, Poland, Estonia, Latvia, Lithuania, Finland, Sweden
URBAN NODES	Antwerp (BEL), Brussels (BEL), Amsterdam (NL), Rotterdam (NL), Berlin (GER), Bielefeld (GER), Bremen (GER), Cologne (GER), Hamburg (GER), Hannover (GER), Warsaw (PL), Lodz (PL), Poznan (PL), Vilnius (LITH), Riga (LATV), Tallinn (EST), Helsinki (FIN)
POPULATION	89.86 million (2014)
GDP	2,702.05 billion € (2014)
EMPLOYMENT	41.09 million (2014)
FREIGHT TRANSPORT VOLUME	213 billion tkm (2015)

3 INTERMODAL POTENTIAL

The following section introduces a methodology for estimating the intermodal potential as a means for analysing and examining TEN-T freight transport corridors regarding their multimodal aspects. The intermodal potential estimation aims to shed light on the status quo of the intermodal capabilities of current freight transport networks. It combines infrastructural aspects with freight-related aspects and reveals potential areas where the intermodal capability of a transport corridor can be improved.

This methodology serves as a basic description of the idea of intermodal potential and suggests different ways in which the methodology could be extended.

3.1 Motivation

Analysing the multimodal freight transport network's stakeholder needs requires a clear understanding of the transport chain's current state, involving the identification and analysis of transport corridors. Following the EU in their initiative to harmonise the transport sector and increase resilience and efficiency of trans-European logistics the two TEN-T corridors relevant for piloting the ReMuNet solution were chosen to be analysed in detail. The Rhine-Danube Corridor is the main east-west connection of Continental Europe (European Commission). The Nort Sea-Baltic is the main transport axis connecting all northern European member states (European Commission).

A significant challenge in generating detailed and current corridor profiles is the scarcity of accurate, up-to-date information on characteristics, potential, and bottlenecks of each corridor. Most recent analyses of the TEN-T corridors are based on studies from 2017, utilising data from 2010 to 2014 (European Commission, 2017a, 2017b). The lack of consistency in methodologies across these studies complicates the creation of standardised corridor profiles and their subsequent analysis. To address this, a methodology for estimating intermodal potential will be introduced, alongside recommendations for data collection strategies to facilitate comprehensive analysis of TEN-T freight transport corridors through intermodal potentials.

To offer more detailed insights into the current state of intermodal transport data in Europe, ReMuNet partner UIRR leads a meta-analysis within Task 1.2 of the first work package. This task aggregates recent intermodal transport data from key member states and pinpoints data collection requirements. Utilising this data, the methodology for estimating intermodal potential will yield a more precise depiction of the present intermodal freight transport network.

The development of the methodology for the estimation of intermodal potential follows a three-step framework shown in Figure 6.

Figure 6: Development of the methodology for determining intermodal potential

Desk research, focusing on studies related to the Rhine-Danube and North Sea-Baltic TEN-T freight transport corridors, forms the foundation for establishing detailed corridor profiles that characterise these geographical areas in terms of their freight transportation features.

Corridor profiles include data on population, GDP, employment, and freight volume within or traversing a TEN-T corridor. They may also detail terminal listings within a corridor, including the associated urban node, types of served transportation modes, infrastructural access points, and the proportion of intermodal transport units utilised for freight shipment within or across the corridor. These profiles highlight key multimodal features of each corridor, including routes, carriers, and infrastructure. Given the absence of detailed and standardised data, these profiles serve as preliminary overviews of the transport corridors, with further elaboration planned in later stages of the ReMuNet project.

The intermodal potential methodology facilitates the analysis of TEN-T freight transport corridor profiles, emphasising their multimodal transportation capabilities. However, its current utility is constrained by the availability of accurate data. With the potential for future enhancement, this methodology could become a comprehensive tool for analysing TEN-T corridors and their intermodal freight transport capacities.

3.2 Discussion on Collected Information

Prior desk research for developing corridor profiles concentrated on the TEN-T Rhine-Danube and North Sea-Baltic corridors, targeted for ReMuNet solution pilots in Work Package 5. The primary sources of multimodal transport system information were EU-commissioned studies from December 2017, offering mode-specific analysis. However, the relevance and accuracy of these studies are now questionable due to their age. Moreover, they provide limited details on multimodal aspects such as freight modal splits, terminal features, transport unit usage, and overall freight data within or across the corridors, resulting in underdeveloped multimodal profiles. The studies employ varying methodologies for data collection and presentation, complicating comparative analysis. For instance, the Rhine-Danube study details terminals within urban nodes differently from the North Sea-Baltic study, which treats each urban node as a single terminal, even when multiple terminals are available. Accurate analysis of a corridor's intermodal potential requires detailed data on the quantity and characteristics of each terminal within the corridor.

To organise and categorise the gathered data for generating standardised corridor profiles - amenable to future expansion - several Key Performance Indicators (KPIs) were established, as outlined in Table 5. These KPIs underpin the foundation for calculating intermodal potential, leveraging their interrelations. They may be characterised as ‘basic information’, ‘intermodal transport information’, ‘advanced intermodal transport information’, which will be calculated from the ‘intermodal transport information’, and the ‘intermodal potential’.

Table 5: Listing of KPIs for the estimation of the intermodal potential

INDICATOR	ABBR.	UNIT	DESCRIPTION	FORMULA
Population	Pop	-	Population along the corridor.	-
Employment	Emp	-	Employment along the corridor.	-
Gross domestic product	GDP	€	GDP produced in the corridor.	-
Freight volume	FV	tkm	The freight volume being transported within or through the corridor.	-
Freight modal split	FMS	%	The share of freight, which is being transported either on road, rail or IWW	-
Share of ITUs	SITU	%	Share of ITUs being used to ship freight within or through the corridor.	-
Terminals	T	-	The number of Terminals within a corridor.	-
Intermodal terminals	IMT	-	The number of terminals capable of intermodal transshipments within the corridor.	-
Share of intermodal terminals	SIMT	%	Share of intermodal terminals among the total number terminals.	SIMT = IMT/T
Network Length	NL	km	The length either of the road, rail or IWW network within a corridor.	-
Network Compliance	C	%	Compliance of the road, rail or IWW network regarding the TEN-T regulations.	C_Road = MW C_Rail = Min(E; LS; AL; TL; TG) C_IWW = Min(IWWR; D; H)
Express / Motorway	MW	%	Road network sections which are classified as express or motorway.	-
Electrification	E	%	Rail network sections which are electrified.	-
Line speed	LS	%	Rail network sections which fulfil line speed ≥ 100 km/h.	-

INDICATOR	ABBR.	UNIT	DESCRIPTION	FORMULA
Axle load	AL	%	Rail network sections which fulfil Axle load ≥ 22.5 t.	-
Train length	TL	%	Rail network sections which fulfil Train length ≥ 740 m.	-
Track gauge	TG	%	Rail network sections which fulfil Track gauge = 1,435 mm.	-
IWW requirements	IWWR	%	IWW network sections which fulfil CEMT requirements for class IV IWW.	-
Draught	D	%	IWW network sections which fulfil permissible draught (min 2.5 m).	-
Height under bridges	H	%	IWW network sections which fulfil the permissible height under bridges (min. 5.25 m).	-
Expansion capability of transport network	ECN	%	Percentage of not TEN-T compliant network sections.	ECN = 1 - C
Intermodal potential	IMP	%	The intermodal potential a transport corridor has.	IMP = Min(1-SIMT; 1-SITU; ECN)

3.3 Methodology to Estimate Intermodal Potential

The intermodal potential serves as a tool to analyse and evaluate KPIs of a TEN-T freight transport corridor. The value estimated represents the potential a transport corridor might have to handle its freight via intermodal means of transport. The intermodal potential combines infrastructural aspects such as terminals and regulatory compliance of networks with freight aspects such as the usage of ITUs among common TUs. This methodology is a fundamental framework which aims to be extended in future research. The KPI list presented in the previous sections forms the bare minimum of data needed to estimate the intermodal potential. The data collected needs to be accurate, complete, and up to date.

The intermodal is estimated as shown in Figure 7 by the combination of three key aspects of intermodal transportation: the share of multimodal terminals, the share of ITUs and the compliance of the transport network regarding TEN-T regulations.

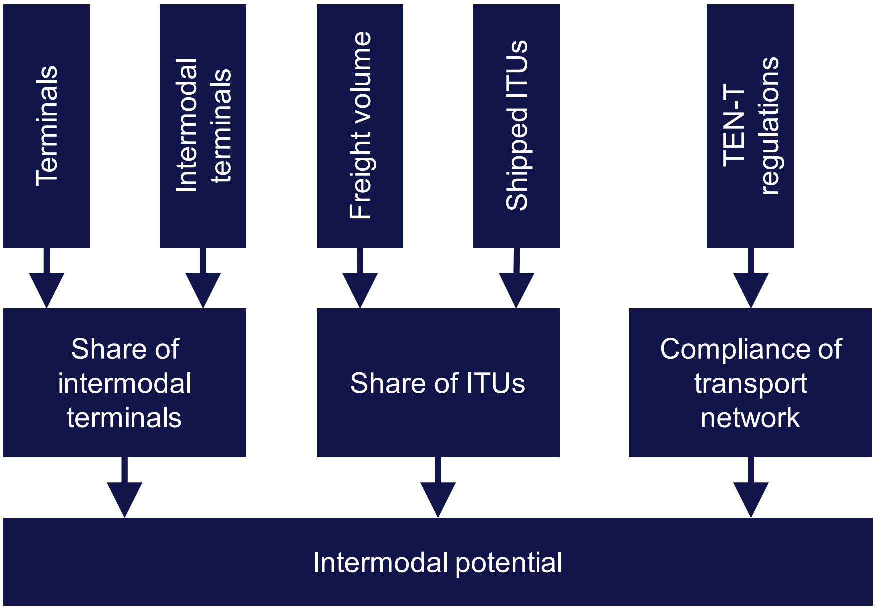


Figure 7: Framework for estimating the intermodal potential

The share of intermodal terminals results from the percentage share of intermodal terminals of common terminals or not usable for intermodal transportation, such as road-road-terminals, within the TEN-T freight transport corridor. Intermodal terminals are those that serve at least two modes of transportation or have infrastructural access to at least to means of transport such as bi- and trimodal terminals. Road-road-terminals do not serve the idea of transshipment to a different mode of transportation and are therefore not considered intermodal terminals.

The share of ITUs results from the percentage share of ITUs used for transportation within the TEN-T freight transport corridor. An ITUs is defined as “Container, swap body or semi-trailer/goods road motor vehicle suitable for intermodal transport” (eurostat et al., 2010).

The compliance of the transport network regarding TEN-T regulations is defined by distinct aspects regarding the character of the freight transport network for a certain mode of transport (road, rail or IWW). For road transport this is the availability of express or motorways. For rail networks the compliance is determined by the amount of electrification, network sections with a possible line speed over 100 km/h, the possibility of axle loads over 22,5 t, manageable train lengths over 740 m and a track gauge of 1.435 mm. For inland waterways (IWW) the compliance is determined by the European Conference of Ministers of Transport (ECMT) requirements for class IV IWW, the permissible draught, and the permissible height under bridges. If a network is not fully compliant with the regulations, it shows potential for expansion in the non-compliant categories and might improve intermodal freight transportation within a TEN-T corridor.

Ultimately, the intermodal potential is estimated by choosing the minimum of the three advanced KPIs and subtracting it from 100%.

The methodology for assessing intermodal potential employs a straightforward analysis of TEN-T freight corridors using specific KPIs related to intermodal features. This approach primarily gauges the corridor's capacity for enhancing intermodal transport, thus aiding in assessing the multimodal transport network's current operational efficiency. Furthermore, it facilitates the evaluation of cost and emission reductions within a corridor's transport sector, aligning with ReMuNet's objectives. However, to refine this methodology, the availability of detailed multimodal data in line with the specified KPIs must be enhanced.

4 RESEARCH DESIGN AND DATA COLLECTION

Understanding the European freight transport network requires more than just identifying the characteristics of geographical corridors; a critical analysis of stakeholders, their value contributions, challenges, and needs is essential. This comprehensive approach enhances the understanding of the network and clarifies the roles and issues key stakeholders face, which ReMuNet aims to address. ReMuNet's primary goal is to enhance the network's resilience by meeting stakeholders' needs, thereby increasing efficiency, reducing economic losses, and enhancing ecological sustainability. To mitigate the impact of disruptions and improve responsiveness, it is necessary to connect identified action areas to specific transport chain roles and clarify actor collaboration for a cohesive multimodal transport approach. In addition to examining the impacts and responses to disruptive events, it is crucial to comprehend the existing data exchanges among key actors and the information and communication technologies employed. This report aims to assess the needs of stakeholders within the multimodal freight network, explore ReMuNet's potential to meet these needs, and identify emerging research opportunities.

This chapter outlines how the stakeholder needs analysis was conducted. It explains the steps taken to gather and analyse data in a structured and systematic way. In this part, the research design and data collection methods are detailed. It is explained how participants were selected and how the data was analysed.

By synthesising existing scholarly works through desk research, leveraging the expertise of consortium partners in workshops, conducting an online survey, and performing expert interviews it was possible to obtain a comprehensive understanding of the challenges and needs encountered by stakeholders of the European multimodal transport network in the face of disruptive events (see Figure 8).

Figure 8: Research design for the stakeholder analysis

The stakeholder analysis was initiated by extensive desk research to analyse the multimodal transport chain. Examining key academic and industrial literature on intermodal freight transport logistics provided a detailed understanding of the current ecosystem and involved stakeholders, laying the foundation for further exploratory research. The initial stage's findings significantly aided in establishing a consensus on technical terminology and definitions across the ReMuNet project ultimately leading to the development of a project glossary (see).

Building on desk research outcomes, identified topics were elaborated on and discussed in both physical and digital interactive workshops. The workshops convened industry experts, consortium partners, and Industry Board members to intensively explore the multimodal transport ecosystem, revisiting initial assumptions and enriching early data collection. Serving as a knowledge exchange format, these interactive sessions enhanced understanding of the industry's complexities by examining the transport process and the roles of various entities within it.

Questions from the desk research and workshop discussions informed the creation of a combined questionnaire with ReMuNet's sister project, “Sustainability And Resilience for Infrastructure and Logistics networks” (SARIL).

The survey aimed at gathering insights from a broad spectrum of industry stakeholders, reaching out to over 100 participants to collect a wealth of information, pinpoint potential interview candidates and collaborators, and cover diverse knowledge areas. The survey focused on collecting essential information on stakeholder needs, challenges, and expectations within intermodal transport chains, especially in the face of disruptive events. It sought to offer an insight into the industry's current state and stakeholder perspectives on digital, operational, and financial obstacles. The survey created the basis for subsequent in-depth expert interviews to understand the identified challenges, needs and potential solutions in greater detail.

This semi-structured interviews with industry experts followed a standardised interview framework and was conducted using a digital whiteboard to achieve higher quality results through (See Annex II). The interviews contributed massively to creating standardisable ecosystem role profiles and to gaining an understanding of how different companies manage disruptions and define their requirements. The interviews aimed to deliver detailed, high-quality insights into the industry's unique demands and processes, thus enhancing the overall depth and breadth of the stakeholder analysis. The combination of the survey and in-depth semi-structured expert interviews, ensures comprehensive coverage of the study area and a representative result of the stakeholder analysis (see Figure 9).

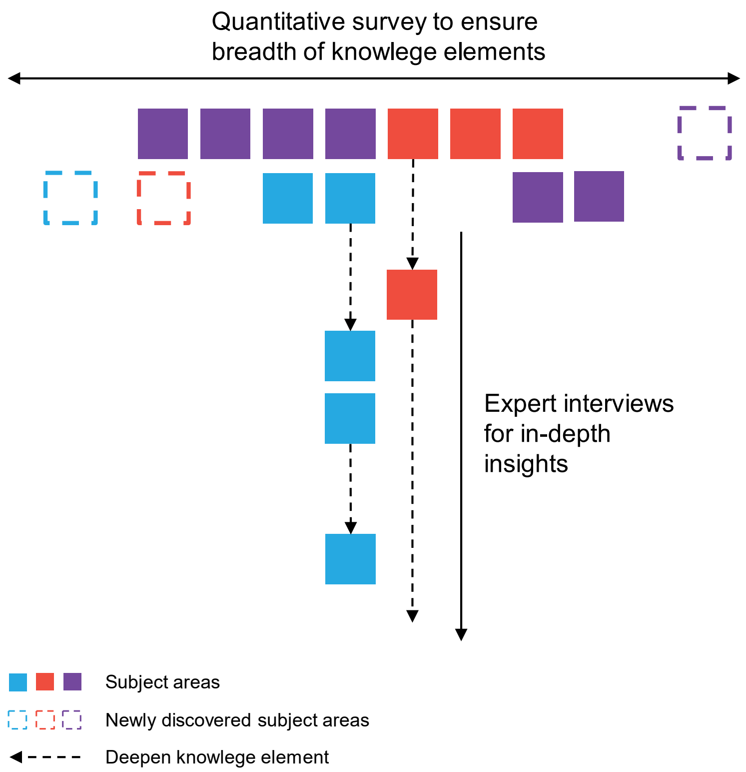


Figure 9: Framework for the survey and interview design

Subsections 4.1 and 4.2 provide additional details on the survey and expert interviews, respectively.

4.1 Online Survey

The following subsection provides an overview of the digital stakeholder survey conducted between December 2023 and January 2024. The findings from the literature review provide the basis for the current state of intermodal logistics and the identification of practical challenges. The survey is the initial stage of expert involvement in the research process. It combines the analysis of the multimodal transport process (Section 5.2), the roles involved (Section 5.4), and the TEN-T corridors (Section 2.5) with stakeholder needs identification in practice (Chapter 6). This creates a theoretically sound yet practically relevant interview guideline for subsequent expert interviews. Following Fink's guidelines (Fink, 2003), the survey's objectives are to assess the relevance of the literature research results and identify additional interview topics based on practical work experience. The survey is presented as supportive of the expert interviews, which are the focus of the data collection.

The validation of the content derived from literature review requires a deductive approach. to examine their practical relevance. Their relevance is verified or falsified as topics for the subsequent expert interviews (Saunders et al., 2019). The questionnaire method is widely used in science due to its broad and simple applicability (Mummendey & Grau, 2014). It allows for the collection of valuable data from a large group of respondents in an economic way. Data collected via questionnaires can be easily analysed using descriptive and inferential statistical methods, leading to valid results.

The survey was coordinated and conducted in collaboratively with ReMuNet's sister research project SARIL to recruit a high number of participants and obtain valid statements. SARIL aims to expand the traditional definition of resilience, which concentrates on threat prevention, robustness, and system recovery, by incorporating green aspects (Sustainability And Resilience for Infrastructure and Logistics networks [SARIL]. The questionnaire and data collection for the online survey were jointly developed and conducted between December 2023 and January 2024. Subsequently, data was collected separately for each project based on its specific requirements.

Participants were recruited through the consortium and industry board partners associated with the ReMuNet and SARIL projects, as well as personal networks, the projects' LinkedIn pages, topic-specific LinkedIn groups, and collaborations with other EU research initiatives focusing on multimodal logistics. The aim of this selection was to attract individuals with expertise in multimodal transportation, particularly those who have worked or are currently working within the multimodal logistics industry. For ReMuNet, the survey serves as a building block for identifying and analysing key stakeholders' needs. While the results of the survey serve as the first round of a two-stage Delphi study (cf. Dalkey & Helmer, 1963) for SARIL, ReMuNet is not planning any further rounds in the survey of participants.

The survey questionnaire adheres to the structure proposed by Mummendey and Grau (2014), beginning with an introduction, followed by contextual questions, and concluding with a closing section. The content-specific part consists of eight sections reflecting the research foci of both ReMuNet and SARIL.

- The participant **Demographics** (DEM) section serves to collect necessary information about the individuals involved and their interactions within multimodal freight transportation. This segment clarifies the roles and regional operations of the participants, as well as their methods of data exchange. This information is critical for ReMuNet, as it provides insights into the working environments and needs of the stakeholders.
- The next section, **Logistics** (LOG), provides a detailed analysis of the participants' roles in multimodal freight transport, including their operational regions and data exchange practices. This analysis is essential for comprehending the sector's dynamics and requirements.
- The third section, **Challenges** (CHA), examines the various obstacles encountered in intermodal transportation. By prioritising and evaluating these challenges, it is possible to identify significant issues that require attention and action in subsequent project phases.
- ReMuNet's objective is to improve network resilience to potential disruptions. Therefore, it is crucial to understand current response strategies to such disruptions. The

'Disruptions' section (DIS) addresses this by posing a series of questions related to the impact of disruptions and the effectiveness of existing management strategies.

- The **Evaluation** (EVA) section assesses the significance of various environmental factors in relation to management strategies, laying the groundwork for improvements in this area.
- The **Resilience** (RES) section discusses attributes that enhance the participants' ability to withstand disruptions, providing valuable information for enhancing overall system resilience.
- The chapter on potential **Solutions** (SOL) requests participants' insights and requirements for a digital solution that aims to reduce disruptions in intermodal transportation, reflecting a proactive problem-solving approach.
- The survey concludes with a section on further **Participation** (PAR), inviting experts to contribute to the ongoing efforts of SARIL and ReMuNet, thereby fostering a collaborative and inclusive approach to addressing the challenges within the industry.

In surveys, questions can be categorised according to their response standardisation and purpose. A distinction is usually made between open (non-standardised), closed (standardised) and semi-open (partially standardised) questions (Kromrey, 2002). This categorisation reflects the degree of freedom given to respondents in choosing their answers. Closed questions are those that present all possible answers within the questionnaire, limiting respondents to the choices provided. Conversely, open questions allow respondents complete freedom in formulating their answers. Semi-open questions represent a middle ground, providing pre-defined answers while also providing space for respondents to formulate their own answers (Hollenberg, 2016). All three types of questions are used in the survey to ensure rigorous validation and to elicit additional insights from practitioners. To address the issue of none of the response options provided being appropriate, a 'not relevant' option has been included. In addition, certain questions are marked as optional to streamline the questionnaire and allow for anonymous participation.

To meet SARIL's requirements for the upcoming iteration of the Delphi study, both projects shared access to the digital survey platform “Welphi”. This platform improves the traditional Delphi method by automating it and enabling asynchronous participation from individuals located in different geographical areas. Welphi facilitates the iterative process by enabling anonymous, multi-round feedback, empowering participants to refine their views based on the collective perspective. Key automated functions include computing statistical data, aggregating participant comments, and providing communication tools to foster ongoing engagement. Welphi is designed to streamline consensus-building and decision-making processes, making it particularly advantageous for extensive, dispersed, or time-constrained participant groups (Welphi, 2023). Figure 10 to Figure 13 show exemplary screenshots of the survey conducted with the Welphi tool.

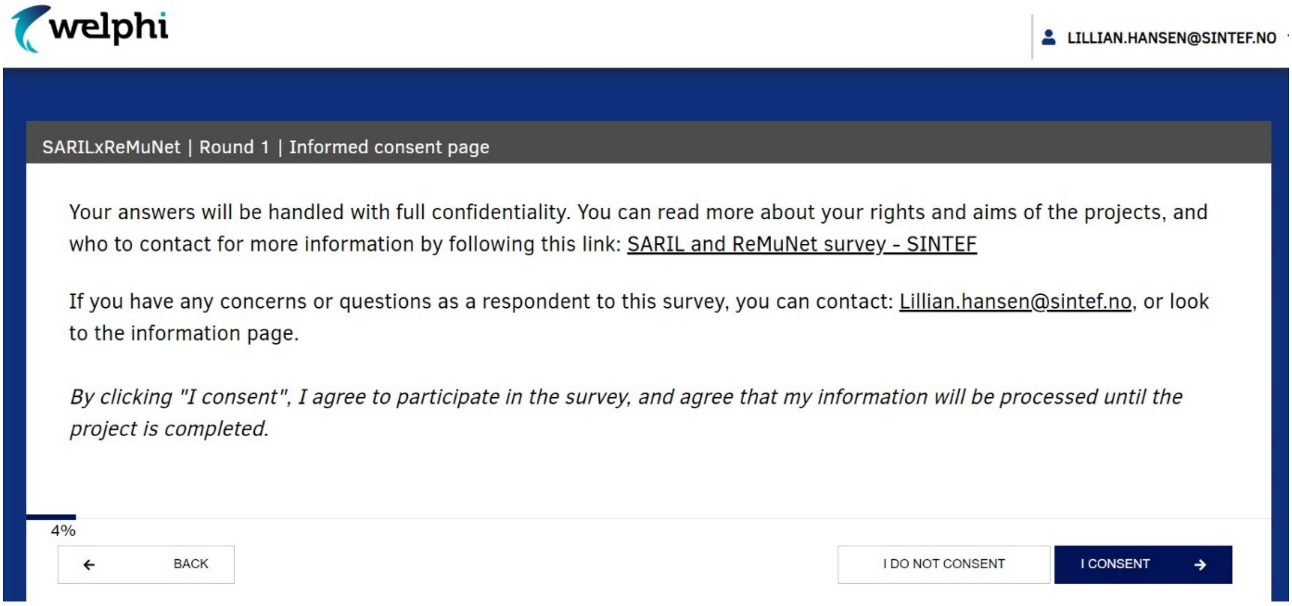


Figure 10: Welcome screen of the survey

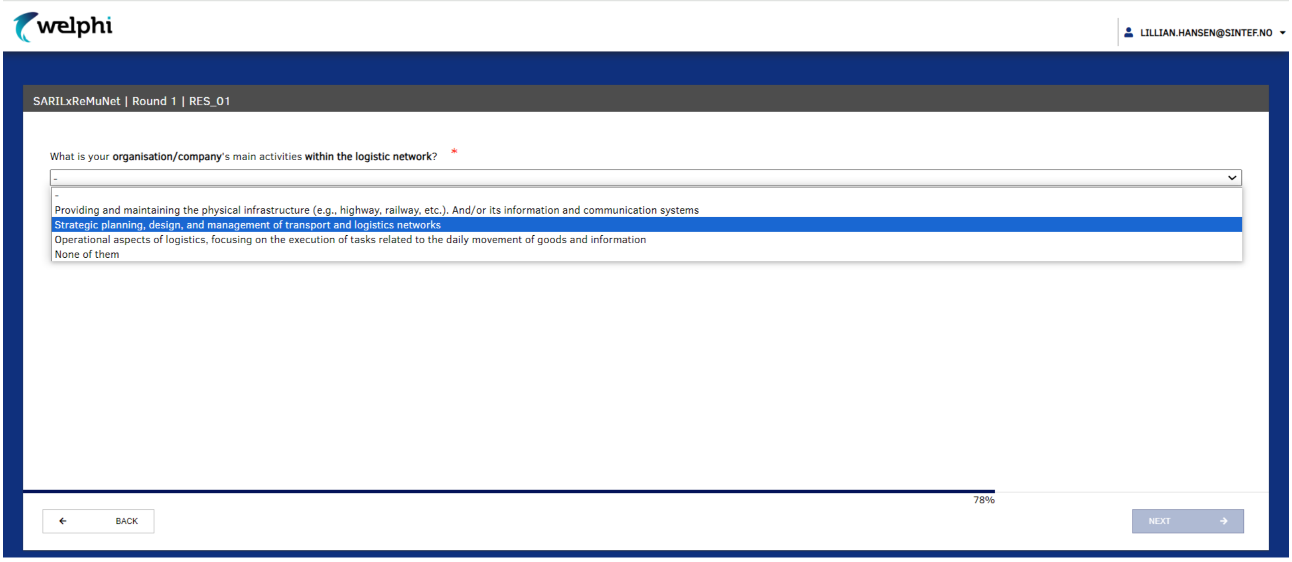


Figure 11: Exemplary single choice question of the survey

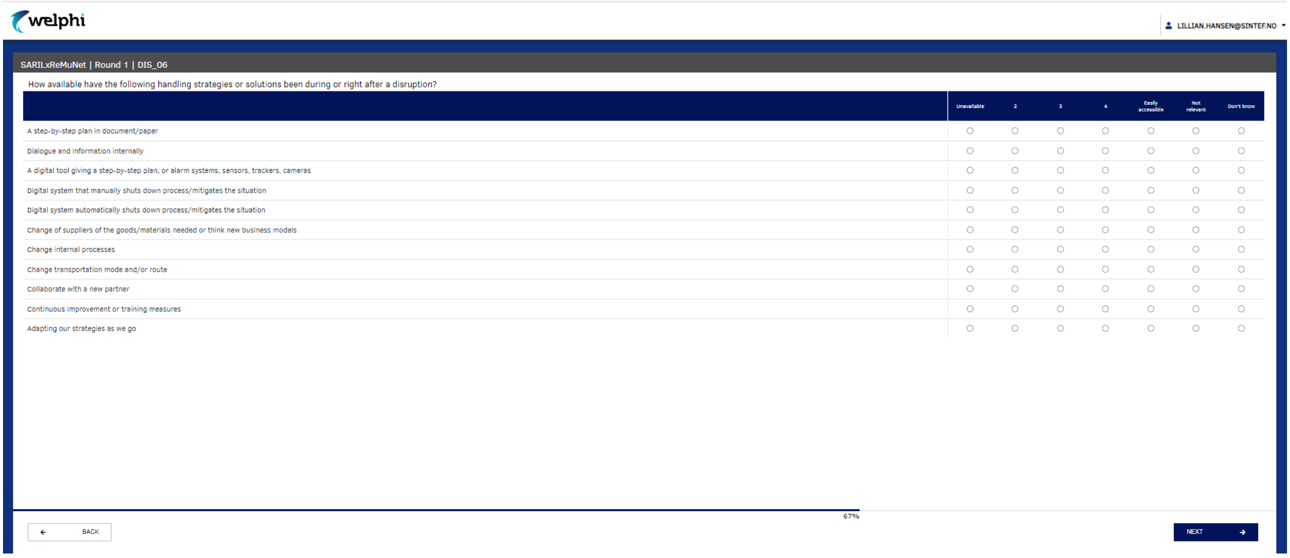


Figure 12: Bulk question in matrix format of the survey

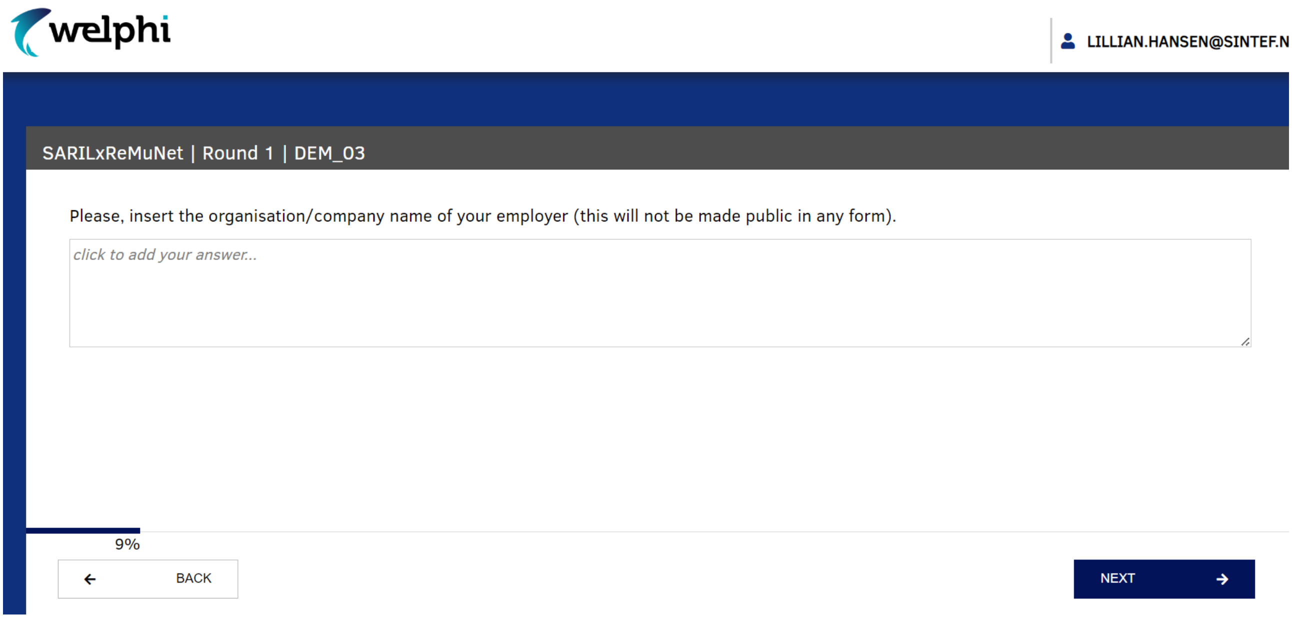


Figure 13: Free form question of the survey

For the ReMuNet project the subsequent cleaning and analysis of the exported comma-separated values (.csv) were conducted using Microsoft Excel.

During the survey period spanning December 2023, to January 2024, a total of 71 participants registered to take part in the survey, of which 61 completed the survey in full or in part. Figure 14 provides a detailed overview of the response rates for each section of the survey.

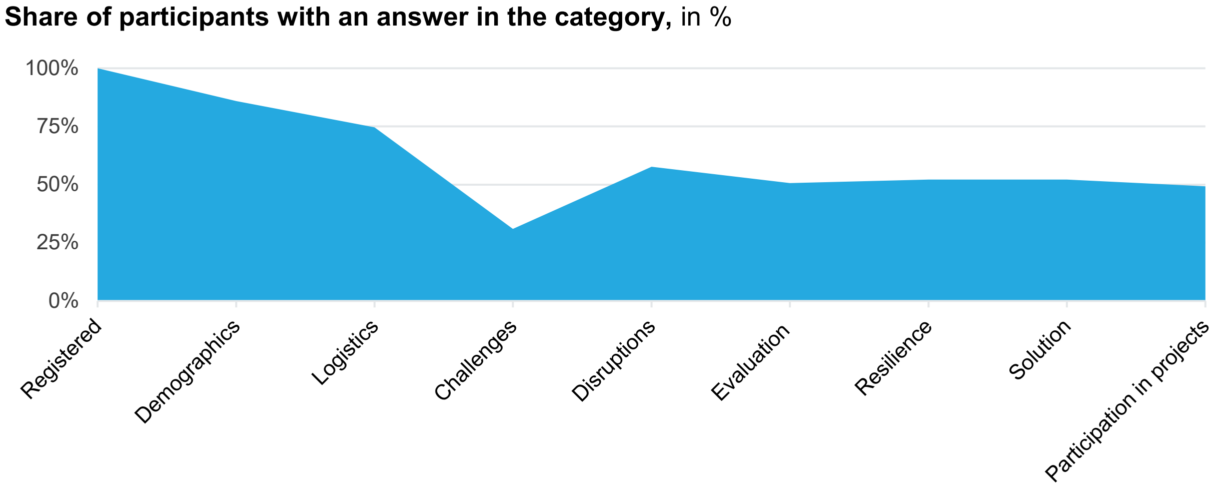


Figure 14: Response rate of survey participants over various steps of the questionnaire

The obtained results of the survey were subsequently used to develop the semi-structured interview guide used for the expert interviews. Survey results were thus incorporated into the creation of stakeholder role profiles in Section 5.4, and used for the analysis stakeholder challenges in Chapter 6 and the identification of stakeholder needs and technological potentials in Chapter 7.

4.2 Expert Interviews

While the desk research and survey serve as foundational sources of comprehensive information, the expert interviews are designed to further explore specific elements and in detail, particularly focusing on disruptions and challenges impacting stakeholders within the multimodal freight transport network. Ultimately, the identification of stakeholder needs is facilitated by understanding the implications of disruptions and challenges, thereby revealing essential requirements for the ReMuNet solution and its functional modules in addressing these needs effectively.

To comprehensively derive stakeholder needs based on challenges encountered in the face of disruptive events a structured approach was adopted. This entailed carrying out 24 semi-structured interviews, with representative industry experts to explore the complex challenges and needs of stakeholders. To achieve sufficient comparability of the data and to lay the foundation for a subsequent content analysis the interviews were conducted using a semi-structured interview guide (Annex II). The interview guide has been developed following desk research insights and adjusted according to the online survey responses.

The semi-structured interviews were designed around six key questions, tailored to extract detailed information regarding the stakeholders' perspectives on disruptions, challenges, and requisite solutions within the multimodal freight transport network.

1. What are the main activities of the company and what are its economic key value propositions?
2. Which customer segments does the company serve and what data is exchanged?
3. What contribution does the company make to sustainability in day-to-day business, but also regarding incidents?
4. What are the main challenges that the company faces in its operations and how have they been addressed so far?
5. Which disruptions affect the company the most or most frequently and what challenges does it face in overcoming them?
6. How can digital solutions contribute to better disruption management and what has hindered implementation so far?

Each interview session was planned, with a duration of approximately one hour allotted to ensure in-depth exploration of the subject matter. The interviews were facilitated via video calls, allowing for efficient communication and engagement between the interviewers and the participants. Typically, one to two interviewers conducted the sessions, fostering a conducive environment for open dialogue and information exchange. While most interviews involved one interviewee, certain sessions accommodated multiple participants to capture diverse viewpoints and insights.

The selection of interviewees spanned across 10 different European countries, ensuring representation from various geographical regions within Europe. This diverse sampling approach enriched the study by incorporating perspectives from stakeholders operating within different regulatory, infrastructural, and market contexts.

Furthermore, the selection criteria for stakeholders were designed to encompass individuals holding essential roles in European intermodal transport logistics. This targeted selection ensured that the insights gathered were reflective of the experiences and challenges encountered by key stakeholders actively involved in shaping the European freight transport ecosystem. Annex II provides an overview of the stakeholders that participated in the expert interviews.

During the interviews, a structured approach was employed to capture stakeholders' statements effectively while ensuring accuracy and clarity of information. To facilitate this, a digital whiteboard (Mural) was utilised, enabling real-time visualisation of stakeholders' statements as they were articulated. This interactive tool allowed interviewees to actively participate in the documentation process by making corrections or additions to their comments. After the interviews, the processed mural boards were shared with the participants, ensuring transparency, and fostering a common understanding of the interview content.

Using the digital whiteboard enhanced the interview process in several ways. It allowed for instant feedback and validation from interviewees, enabling immediate adjustments or clarifications, reducing misunderstandings. This real-time interaction ensured information accuracy and fostered active engagement and collaboration between interviewers and participants. Additionally, visualised inscriptions acted as a record of interview discussions, offering a structured and clear depiction of stakeholders' viewpoints. This visual record supported data organisation and synthesis and served as a reference for further analysis and interpretation.

All interviews were recorded, after receiving a verbal declaration of consent by the interviewee. Additionally, the built-in transcription tool of Microsoft teams was used. Following the interviews, the transcription was checked against the recording and meticulously edited and analysed by hand to extract key themes, patterns, and insights. After final transcription, the recorded interviews were promptly deleted as part of data privacy and confidentiality protocols, ensuring the security and integrity of participants' information.

Following the manual transcription of the interview recordings, the data underwent a content analysis process aimed at extracting key insights and understanding the nuances of stakeholders' perspectives on disruptive events and challenges within the European intermodal freight transport sector. The analysis commenced with the systematic examination of the transcripts, wherein interview responses were checked to identify recurring themes, patterns, and key statements. This process involved categorising various aspects of the stakeholders' discussions, including their perspectives on disruptions, challenges, and needs. Furthermore, the analysis encompassed both qualitative and quantitative evaluation methods, with particular emphasis on disruptions and challenges faced by stakeholders. Qualitative evaluation involved a detailed examination of stakeholders' statements, allowing for an exploration of their experiences and perceptions. Quantitative evaluation, on the other hand, focused on numerical data and metrics, providing additional insights into the prevalence and impact of specific disruptions and challenges within the industry.

The identified disruptions were categorised based on the typology from Deliverable 1.3 by Kulkarni et al. (2023). The results give insights on which types of disruptive events are the most widespread among different actors within the multimodal freight transport network and which roles are being affected the most. Furthermore, differentiating between the operational impact levels, specifically the information and physical layers, enables the assessment of effects and the subsequent identification of potential solutions. After categorising relevant disruption types, specific challenges were identified that make dealing with disruptive events more difficult. This analysis was as well conducted from both role-specific and industry-wide viewpoints.

As a direct response to the challenges in dealing with transport disruptions, requirements were derived together with the interviewees. The interviewees were asked about missing solution modules in the sense of a gap analysis and a possible role specificity of the identified need was discussed subsequently. At the conclusion of the interviews, contributions to sustainability and technological potentials were highlighted, which could potentially be integrated into ReMuNet's solution design.

Due to the semi-structured nature of the expert survey, the topics were surveyed with varying intensity depending on the company-specific fields of expertise. For the derivation of standardisable role profiles, it should also be noted that, depending on the activities carried out, a company can fulfil several roles within the multimodal freight transport ecosystem.

5 MULTIMODAL FREIGHT TRANSPORT ECOSYSTEM

This chapter presents and consolidates findings derived from the desk research, workshops, survey, and expert interviews.

Firstly, a core multimodal transport process is depicted using the Value Flow Model proposed by den Ouden (Section 5.1). This model serves as a conceptual framework to analyse the flow of value within the intermodal transport network, providing a structured basis for understanding the dynamics of the system. The process introduced in Section 5.2 is based on results obtained from desk research and a partner workshop conducted at ReMuNet's kick-off meeting.

Additionally, the core process is supplemented with insights obtained from desk research and additional workshops to develop a comprehensive model to visualise the flow of information within the network (Section 5.3) and the distinct role profiles (Section 5.4). These additional insights offer a nuanced understanding of how information is exchanged and utilised among stakeholders in the industry.

5.1 Value Flow Model

The Value Flow Model (VFM) serves as a structured framework utilised for the analysis and visualisation of value exchanges within ecosystems. The VFM extends beyond conventional business model design by integrating insights from various disciplines, including socio-technical systems and value creation models (den Ouden, 2012).

Fundamentally, the VFM is geared toward comprehending the generation, dissemination, and allocation of value across diverse actors within intricate networks of relationships. It offers a methodical approach to delineating the progression of value from its conceptualisation in the initial value proposition to its realisation and distribution among end-users (den Ouden, 2012).

The VFM consists of five fundamental elements (den Ouden, 2012):

1. **Actors:** These entities include participants within the ecosystem, encompassing a spectrum of stakeholders such as customers, enterprises, suppliers, regulators, and other relevant parties. Initially conceptualised as roles rather than specific entities, this allows for flexibility and adaptability within the model.
2. **Motivations:** Each actor harbours unique interests, intentions, and objectives guiding their involvement in the ecosystem. The discernment of these motivations assumes significance in evaluating alignment and congruence with the overarching value proposition.

3. **Compatibility and influence:** This facet assesses the extent to which the motivations of different actors converge with one another and with the central value proposition. Additionally, it examines the influence wielded by each actor on decision-making processes within the ecosystem.
4. **Investments and throughput time:** Estimating investments for each business actor's contribution to the value proposition aids in understanding the balance between investment and revenue streams. Similarly, indicating throughput times facilitates discussions on alternative strategies and fosters trust among potential partners, allowing for early mitigation of uncertainties in the planning process.
5. **Transactions:** Transactions represent the conduit for the exchange of goods, services, money, information, and intangible assets amongst actors within the ecosystem. They serve as illustrative depictions of how value traverses between entities, thereby contributing to the overarching value creation process.

The VFM splits the ecosystem into four delineated sectors: the central value proposition, complementary offerings, supplying and enabling network, and other stakeholders. Each sector has a specific role in the creation and distribution of value, with the central segment of the value supply being pivotal for value creation and dissemination to the end consumer (den Ouden, 2012).

Within the ReMuNet project, the VFM serves as a methodological basis for recording the current ecosystem. Therefore, an initial simplified version of the VFM representing the intermodal freight transport core process will be presented in the following section. This will be basis and starting point for further detailing, as it is part of T3.2 of the ReMuNet project.

5.2 Intermodal Freight Transport Process

Intermodal supply or transport chains represent a standardisable process within the realm of multimodal transportation, integrating various modes of transport to efficiently move goods. This approach enables seamless transhipment of complete intermodal loading units between different modes of transport without the need to redistribute individual loads. Typically, intermodal transport includes road transportation for initial and final legs of the journey, with rail or inland waterway segments in between (Gronalt et al., 2019; Posset et al., 2020; UN/ECE, 2001).

The intermodal freight transport core process encompasses a network of interconnected activities facilitated by various actors across diverse modes of transportation. The intricate connections between these actors and their roles shown in Figure 15 provide a comprehensive understanding of this process.

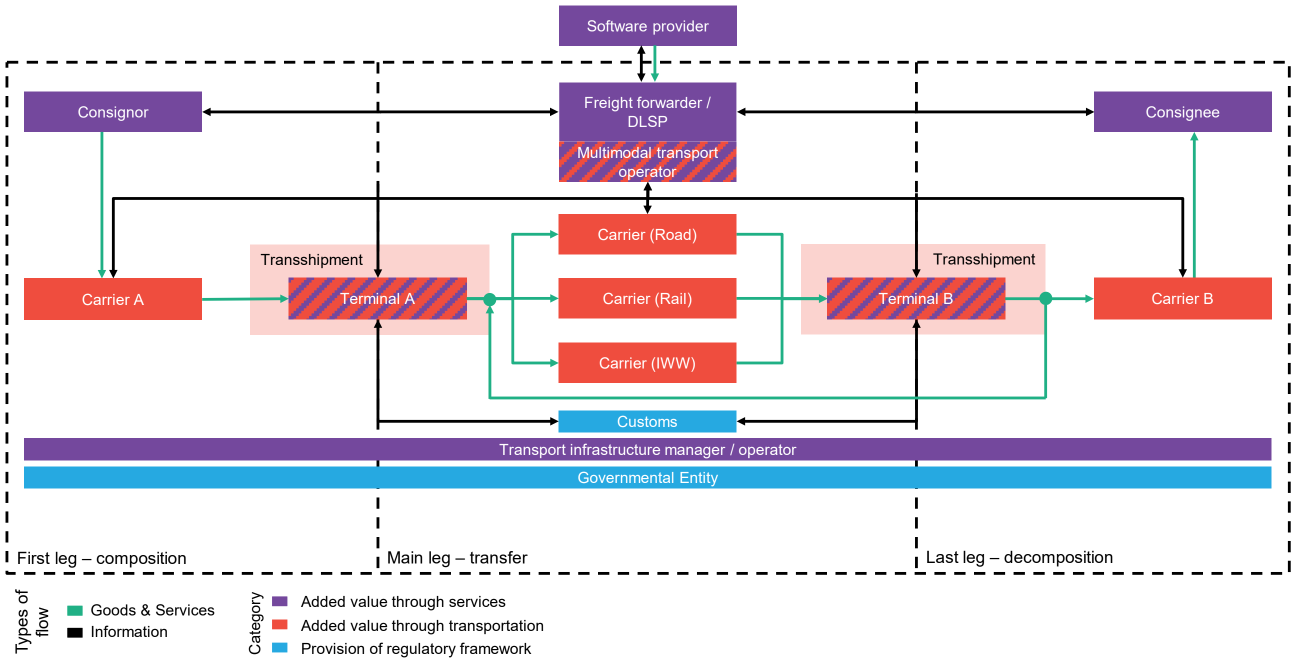


Figure 15: Visualisation of the intermodal transportation core process

Firstly, the actors can be categorised into three principal groups based on the value they contribute: those involved in adding value through service and transportation, and entities that support the process by providing regulation.

Typical intermodal freight transport roles like software providers, consignors/shippers, freight forwarders and multimodal transport operators, (digital) logistics service provider (LSP), and consignees are pivotal **service providers** for orchestrating logistics and ensuring smooth transitions between different stages.

In the domain of **transportation and transshipment**, carriers along with terminal operators play significant roles in physically moving goods from one location to another. Employing various modes of transport and logistic operations, they ensure timely and secure delivery.

Roles contributing value through **regulation**, like infrastructure managers e. g. federal railway authorities as well as customs and other government bodies, manage the overall infrastructure of the transportation network and ensure compliance with regulatory standards. They provide the framework in which the intermodal transport process operates.

The standard intermodal freight process can be further examined by dissecting it into its constituent legs. In the composition phase, goods are prepared and packaged for transportation by the consignor, often in collaboration with the consignee. Within the process model, Carrier A starts of transporting goods to Terminal A by road, because consignors mostly do not have direct access to other modes of transport at their dispatching location and are therefore dependent on road transport to cover the first leg.

After the first leg, transshipment occurs vertically or horizontally at Terminal A. Once customs clearance is obtained, goods are transported by carriers via road (under the regulations of federal road authorities, rail (under the regulations of federal railway authority), or barge (under the regulation of federal waterway and shipping administration) to Terminal B. Here, transshipment occurs again, initiating either a new transportation phase or proceeding to the final leg, decomposition.

In the decomposition phase, goods are transported by Carrier B via road to the consignee. Throughout this transportation process, (digital) logistics service providers, freight forwarders, combi operators, and software providers play crucial roles in managing operations, while governmental or authority regulations govern the entire process.

5.3 Flow of Information

The flow of information within systems includes both upstream and downstream communication, with data being received from preceding logistics players (upstream) and forwarded to successive actors (downstream). Additionally, information can be categorised as either static, thus constant over time, or dynamic, thus constantly evolving. Static information includes order details describing the shipped goods, shipping specifications on the transportation conditions, and regulatory guidelines. Dynamic information on the other hand includes the status of the shipping information, forecasting data, track-and-trace updates, and terminal information.

The exchange of both static and dynamic information is crucial for maintaining smooth coordination and efficient operations throughout the intermodal supply chain. By sharing relevant and up-to-date information, stakeholders can make timely and informed decisions.

Table 6 offers a rough outline of the information exchange among stakeholders in multimodal freight transportation, depicting the current state without delving into specifics regarding information accuracy or associated challenges.

Table 6: Flow of information between the roles in intermodal freight transport

ROLE	UPSTREAM		DOWNSTREAM	
	STATIC	DYNAMIC	STATIC	DYNAMIC
Consignor	Regulatory and compliance requirements Cargo preparation instructions Transport equipment Transport insurance Documentation requirements Booking confirmation	Carrier availability and schedules Freight rates and contract information ETD	Transport order Shipment specifications Transport origin and destination Booking confirmation Billing instructions Contact details Tracking requirements Preferred mode of transport Handling instructions	Pick-up time Loading bay
Consignee	Customs and clearance documentation Handling instructions Transport documents	ETA Tracking information Delivery scheduling Change notifications Condition reports	Contact details Unloading equipment Invoicing Return shipping instructions Documentation needs Handling instructions	Delivery preferences Service Feedback
Carrier	Origin and destination Shipment details Booking and reservation Loading unit Regulations and compliance Additional instructions	Timetables Routing Tracking and tracing Handling duration	Received cargo documentation Regulations and compliance documentation Billing and invoicing Sustainability indicators (CO_2 equivalents)	Tracking and tracing updates ETA In-transit reporting Incident and exception reporting Feedback requests
Terminal	Shipment information Loading unit Safety and compliance requirements Booking information Transport schedules Handling instructions	Routing information Pre-arrival notifications ETA Handling documentation	Handling/transshipment rates Transshipment equipment Storage rates Transshipment track Terminal specifications Sustainability indicators (CO_2 equivalents)	(Un)loading schedules Cargo status updates Documentation of transfers Condition reports Incident reports
Freight Forwarder or DLSP	Regulatory and compliance information Documentation requirements Shipment information Freight rates Pick-up and delivery instructions Handling requirements Booking confirmation	Change notifications Availability of transport vehicles and transshipment points Routing information Cargo tracking and status updates Transport schedules	Cargo specifications Transport and customs documentation Shipping information Regulatory and compliance information Booking information Handling instructions Rate and payment information Delivery instructions	Track-and-Trace information Change notifications Evaluation requests Emission tracking
Infrastructure Operator/Manger	Cargo specifications Compliance and regulatory information	Traffic volume forecasts Routing information Maintenance and repair requests Technology integration requests Environmental and sustainability data	Infrastructure access and usage fees Regulatory and compliance information Planning and development information	Infrastructure availability Operational changes Capacity constraints Safety and security updates Weather conditions

5.4 Multimodal Freight Transport Roles

This section provides an overview of the key roles in the multimodal freight transport process, offering a broad understanding of the topic. Identifying and characterising crucial roles of the intermodal freight transport chain is essential to understand the ecosystem according to the VFM after den Ouden. The insights obtained from the survey and interview results directly contribute to the stakeholder role profiles by investigating the different value creation contributions, pain points, and the stakeholder’s positioning in the multimodal transport value chain multimodal. The role profiles form the basis for designing a new intermodal freight transport ecosystem in work package 3, integrating the new digital solutions developed in ReMuNet. Analysing the current state of the ecosystem with all essential roles will be crucial to identifying pressing needs and pain points and shed light on promising technological potentials that will contribute to a digitalised and sustainable European transport industry.

The following subsections provide a detailed description of the roles involved in the flow of goods based on the core process introduced in Section 5.2.

5.4.1 Consignor

“A person or company that sends goods to someone, usually the person who is buying them.” (O'Shea, 2011)

The consignor, also known as the shipper, initiates the transport chain by providing the consignment to be shipped. Consignors typically enter a transport contract with freight forwarders and multimodal transport operators that are responsible for ensuring a successful delivery of the shipment to the consignee or receiver. Apart from delegating the responsibility to logistics service providers the consignor can also act as the direct transporting entity, however, this is more an exception than a norm, given the complexity of international supply chains. In general, the consignor or shipper is not responsible for coordinating transport across various modes. This responsibility lies with the multimodal transport operator or combi operator (Clarke et al., 2005; Gronalt et al., 2019; Posset et al., 2020; Sarder, 2021).

The consignor/shipper is responsible for ensuring the accuracy of static freight data such as the goods' type, marks, number, weight, quantity, and, if applicable, hazard warnings of the shipment. Additionally, consignors may be required to pack and consolidate the goods for shipping.

5.4.2 Consignee

“The person or company to whom goods or documents are officially sent or delivered.” (O'Shea, 2011)

The consignee or receiver initiates the shipment by placing an order with the consignor or shipper and receives the goods sent by them. The consignees have the right to receive the goods as described in the transport documents. Additionally, the consignee can exercise certain rights under the transportation contract, such as determining the place of delivery and providing instructions to the carrier (Clarke et al., 2005; Gronalt et al., 2019; Posset et al., 2020). These instructions may include, for example, the choice of sustainable modes of transport. Against the backdrop of progressing climate change, the sustainability of transport is becoming increasingly important for consignors. In this context, multimodal transport, utilising climate-friendly transport options like rail or inland waterways for the main leg, can serve as an effective lever for sustainability.

5.4.3 Logistics Service Provider

"A company whose main activity is the provision of logistics services for other companies." (Wallenburg, 2004)

Logistics Service Providers (LSPs) are entities within the supply chain management domain that offer a variety of services and access to essential analytics and expertise in emerging industry technologies. These services typically include warehousing, commissioning, packaging, and value-added supply chain activities. As technological development progresses, digital services are playing an increasingly important role in the service portfolio of LSPs. Business analytics, route planning, fleet management, supply chain optimisation and many other services have been offered for many years by LSPs that have no physical assets such as warehouses or vehicles. In the ReMuNet project, these LSPs are referred to as Digital Logistic Service Providers (DLSPs).

Based on their scope of responsibility, activities, and involvement in the transport process, it is also common to differentiate LSPs according to the "n^{th} PL" categorisation for "n^{th} Party Logistics Provider". Based on their operational scope LSPs can be categorised into different types (Table 8).

Table 7: Characterisation of Logistics Service Providers

SERVICE CHARACTERISTICS OF LSPs	1PL	2PL	3PL	4PL	DLSP
Self-management of logistics function (own assets)	X	X			
Lease of own transportation (asset-based logistics services)		X	X		
Transportation and freight forwarding		(X)	X	X	(X)
Warehousing, including inventory management		(X)	X	X	
Picking, packing, and labelling		(X)	X	X	
Reverse logistics (returns), customer relationship management			X	X	X
Project management (PM), sourcing and negotiations				X	(X)
Consultancy function				X	X

SERVICE CHARACTERISTICS OF LSPs	1PL	2PL	3PL	4PL	DLSP
End-to-end integration				X	(X)
Logistics planning and control				X	X
Transport management (3PL management)				X	X
Main activity: Provision of digital logistics services				(X)	X

In the context of ReMuNet, the term 'logistics service provider' will be used exclusively for 3PLs and above, distinguishing them from freight forwarders and multimodal transport operators.

In most instances, 3PLs and 4PLs embody DLSPs. Their distinction from pure software providers lies in executing coordinating activities utilising various software solutions, not solely selling, or providing these solutions. Additionally, other LSPs, such as container service providers, maintenance providers, and warehousing service providers, though not within the primary focus of ReMuNet, remain significant contributors to the logistics landscape.

3PLs primarily handle basic logistics activities and coordinate various entities such as carriers, logistics intermediary firms, and other service providers. Their services span across transportation, warehousing, inventory management, order processing, information systems, and packaging.

4PLs are responsible for the development and maintenance of logistics projects in a more strategic manner. While they perform similar tasks as 3PLs, 4PLs focus on enhancing, managing, and improving the company's supply chain without physical assets, serving as asset-free logistics intermediaries.

A notable distinction between LSPs and freight forwarders is their role in the supply chain. Freight forwarders act as intermediaries between goods owners and carriers, whereas LSPs encompass a broader spectrum of logistics activities and services. (Evangelista et al., 2013; Mathauer & Hofmann, 2019; Skender et al., 2016; Stefansson, 2006)

Carrier

"Independent logistics service providers to execute [...] transport. [...] it operates in the so-called hire or reward [..] mode." (Schönberger, 2005)

The carrier is responsible for transporting goods from one node in the supply chain to another. Carriers utilise various modes of transport, including road, rail, inland waterway, air, and sea. However, for the specific investigation within the scope of ReMuNet, the focus lies solely on the first three modes: road, rail, and inland waterways. Carriers may be contracted directly by the consignor or by intermediaries such as forwarders. Goods are typically consolidated into ITUs, known as (intermodal) transport units.

In intermodal operations, carriers primarily operate between terminals or between terminals and the consignor or consignee. The transportation stage involving the consignor is termed the "first leg", while the stage towards the consignee is termed the "last leg". These legs often involve road transportation due to infrastructural considerations unless direct access to rail or waterway is available to the consignor or consignee.

Carriers may be classified as common carriers or contract carriers. Common carriers offer transportation services to multiple parties and are more flexible in their operations. In contrast, contract carriers provide services exclusively to specific consignors/shippers or forwarders under long-term contracts (Gronalt et al., 2019; Posset et al., 2020; Sarder, 2021; Solvay et al., 2016).

Freight Forwarder

"Companies that arrange the dispatch of goods for third parties after concluding a forwarding contract are called freight forwarders [..]. The central task of a freight forwarder is to organise the transport." (Geiger, 2013)

A freight forwarder operates as a service provider within the transportation and logistics sector, responsible for managing shipments initiated by the consignor or shipper. These professionals offer various transport-related services and act as intermediaries between shippers and carriers. Key responsibilities of freight forwarders include tendering and contracting carriers, monitoring all in-transit movements, and consolidating small shipments into more cost-effective sizes. Additionally, they play a role in route selection, consolidation services, and coordination with third parties to facilitate the movement of goods (Posset et al., 2020).

The primary focus of freight forwarding services is on transportation. However, freight forwarders may also offer ancillary services such as packaging, warehousing organisation, documentation processing, insurance arrangement, and payment facilitation (Murphy et al., 1992; Posset et al., 2020).

Multimodal Transport Operator

“The [multimodal transport] process is carried out and coordinated by one operator – the Multimodal Transportation Operator. [...] Moreover, the entire process of international multimodal transport is covered by a single contract signed between the MTO and the consigner.” (Poliak & Salamakhina, 2023)

A multimodal transport operator may act as the freight forwarder in the multimodal transport chain servicing not only one mode of transport as it is common for traditional freight forwarders, but multiple or even all of them. Freight forwarders in the context of multimodal transportation, multimodal transport operator or combi operator, can be categorised into different types (Saeed, 2013), including:

1. MTOs (ocean-based Multimodal Transport Operators), which handle sea-based transportation,

2. VO-MTOs (Vessel Operating Multimodal Transport Operators), responsible for vessel operations, and
3. NVO-MTOs (Non-Vessel Operating Multimodal Transport Operators), light asset operators, which arrange shipping services without owning vessels.

Digital Logistics Service and Software Provider

Evolving towards a supply chain in the context of Industry 4.0, digital Logistics Service Providers (DLSPs) are LSPs, who do not use any physical assets to perform their logistics services. Instead DLSPs focus on the usage of digital solutions to manage and orchestrate a transport assignment. Technologies used by DLSPs are cloud computing, digital twins, IoT, big-data analytics, and blockchains (Dahibhate et al., 2022). In many cases they do not develop software themselves but use solutions provided by software providers.

Software providers offer a variety of software solutions tailored for logistics service providers, including transport management and warehouse management software. These solutions are typically available in standardised and customised formats to meet the diverse needs of clients (Evangelista et al., 2013; Gunasekaran et al., 2017).

Support Services and Consulting

Support services and consulting services provided by logistics service providers have undergone transformation over time, reflecting shifts in market dynamics and technological advancements within the freight transport sector. Traditionally, industrial distributors were perceived as full-service intermediaries, offering a wide range of supporting services such as delivery, credit, technical advice, repair service, assembly, and promotion to customers. However, this all-inclusive approach has been subject to challenge by the emergence of functional specialists focusing on specific activities within information and material flows (Gadde & Hulthen, 2009).

In response to these shifting paradigms, specialised support service and consulting firms within the freight transport sector have emerged. These entities offer tailored consulting logistics-service models aimed at helping companies navigate challenges unique to freight transport operations. Unlike standardised modular service portfolios, which may not fully address the nuanced needs of companies, the consulting model adopts an analysis-driven approach. This approach leverages insights derived from industry benchmarks, key performance indicators, and in-depth client consultations to develop customised solutions.

Specifically, within the realm of freight transport, these support and consulting services provide expertise in areas such as route optimisation, efficiency enhancement in warehousing and distribution, inventory management optimisation, and implementation of advanced tracking and tracing systems to monitor cargo movements. By offering tailored solutions grounded in data-driven analysis and industry expertise, these specialised firms enable companies to address logistical challenges effectively and optimise their freight transport operations (Soino et al., 2012).

5.4.4 Terminals

"Place equipped for transhipment and storage of intermodal transport units [..] between modes." (eurostat et al., 2010)

Terminals, also referred to as nodes or hubs, serve as key components of the transportation network, facilitating shunting and transshipment processes necessary for modal shift, a key aspect of intermodality (Gronalt et al., 2019; Posset et al., 2020; Studiengesellschaft für den Kombinierten Verkehr e.V., 2023).

In general, terminals can be distinguished regarding their handling equipment into structural and semi structural transshipment facilities. Structural transshipment facilities are the commonly known terminals with standard equipment necessary for transshipment and shunting operations.

Semi structural transshipment facilities offer access points to rail freight transport without requiring specialised infrastructure or stationary handling equipment. Instead, the necessary transshipment equipment is affixed to the means of transport itself, allowing for flexible and efficient freight transfer operations (Gronalt et al., 2019).

Besides, their equipment terminals might also be distinguished regarding their infrastructural aspects especially their access points and operated modes of transportation.

Terminals with two infrastructural access points to modes of transport such as road and rail or road and waterway are classified as bimodal terminals. Terminals with access to all three types of transport (road, rail, and waterway) are called trimodal terminals. In addition to bimodal and trimodal terminals, there are also unimodal terminals, which cater exclusively to a single mode of transportation, such as road terminals (Ahmadinejad & Langeroodi, 2023; Gronalt et al., 2019; Studiengesellschaft für den Kombinierten Verkehr e.V., 2023).

Shunting and transshipment processes are fundamental to terminal operations, facilitating the rearrangement of routes and the transition between transportation modes, respectively. These processes are meticulously organised and executed by terminal operators using a range of specialised equipment, including gantry cranes, reach stackers, straddle carriers, and transport vehicles (Gronalt et al., 2019).

Shunting primarily involves the arrangement and formation of train wagons, encompassing tasks such as provision, collection, formation, and control of freight wagons. In contrast, transshipment entails the change of transportation mode and can be categorised into vertical and Horizontal transshipment, depending on the type of equipment employed. Vertical transshipment is the most common way of transshipment for all craneable transportation units, utilising equipment such as cranes, forklifts, or straddle carriers. Horizontal transshipment, on the other hand, is mainly used for non-craneable transport units like semi-trailers, particularly in combined rail and road transport (Angelini et al., 2019; Brooks, 2004; Posset et al., 2020).

Additionally, various subprocesses besides shunting and transshipment are executed at terminals to ensure operational functionality and service provision. These include commissioning, emergency services, repair and maintenance, security, licensing, customs handling, entry and exit handling, warehousing, and documentation (Angelini et al., 2019).

5.4.5 Infrastructure Operator and Manager

Infrastructure operators and managers are responsible for the development, operation, and maintenance of transportation networks and facilities. Their duties involve facilitating the movement of vehicles, passengers, and goods, along with managing retail and real estate activities within the transportation infrastructure. For example, in the railway sector, a railway operator must secure a train path from a railway infrastructure company to operate a train on its tracks, necessitating a clear distinction between a "train path" and a "time slot" (Posset et al., 2020).

Additionally, transport infrastructure operators and managers oversee the comprehensive management of transport infrastructure. Their responsibilities include planning, construction, maintenance, operation, and overall management of transport facilities. Also, they may engage in road asset management, vehicle load control, setting performance standards, bridge management, facilitating self-regulation among heavy vehicles, and implementing systems to handle abnormal loads, all aimed at ensuring the safe and efficient operation of transportation networks (European Commission, 2023; Gronalt et al., 2019; Posset et al., 2020).

In detail, there is a distinct difference between transport infrastructure operators and managers, which mainly is based on the ownership of infrastructure facilities, but will not be further discussed, because it does not further contribute to the understanding of the core process.

5.4.6 Governmental Entities

Governmental entities and authorities are actively engaged in the formulation and implementation of transportation policies and regulations. Their primary objective is to develop strategies and actions aimed at improving efficiency, services, and sustainability within the transport sector while ensuring the smooth flow of transportation.

The legal framework governing transportation encompasses a wide array of concepts and policies, including international harmonisation efforts and specific regulations such as those pertaining to the European Union. These regulations cover various aspects, including liability issues and document requirements, to ensure consistency and compliance across jurisdictions (Anastasiia et al., 2022; Eftestol-Wilhelmsson et al., 2014).

6 STAKEHOLDER CHALLENGES IN THE FACE OF DISRUPTIVE EVENTS

This chapter presents the main findings from the stakeholder survey (Section 6.1) and expert interviews (Section 6.2). Both sections start with an introduction of the respective audiences, followed by an analysis of the challenges faced by stakeholders in the multimodal transport ecosystem.

The results contribute to information breadth by providing an overview of the current state of the multimodal transport network. They offer valuable insights into prevalent trends, challenges, and stakeholder perspectives, enriching the analysis and providing context for further exploration.

Moreover, the results from expert interviews are analysed, focusing on several key aspects. Firstly, disruptions encountered within the industry are delved into, identifying major factors that impede the smooth operation of the transport network. Secondly, the challenges faced by stakeholders are examined, shedding light on obstacles that hinder their efficiency and productivity especially in the face of disruptive events. Subsequently, in Chapter 7 the needs of stakeholders will be derived from the findings on disruptive events and challenges, highlighting their requirements and expectations for improving the transport network. In a final step in Chapter 8, requirements for the ReMuNet solution and its functional modules will be derived based on the identified needs, aiming to develop tailored solutions that address stakeholders' concerns effectively.

6.1 Initial Results from the Survey

The survey section is structured as follows: Firstly, it outlines the demographic composition of survey participants and their roles within the multimodal logistics ecosystem (Subsection 6.1.1). This is followed by an analysis of primary challenges (Subsection 6.1.2), which leads into an evaluation of how disruptions affect the business operations of the respondents (Subsection 6.1.3).

6.1.1 Survey Participants and their Role in Multimodal Logistics

The opening segment of the survey conducted also provides a concise overview of the participants' demographics and position in the intermodal transportation ecosystem. About two-thirds of the respondents hold positions in management or strategy, as depicted in Figure 16, with half of these individuals employed in the private sector, as further detailed in Figure 17.

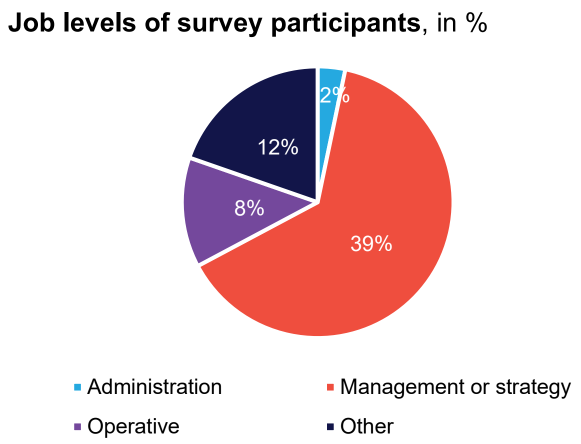


Figure 16: Results from question DEM_01
What is your role in the organisation/company you work for?

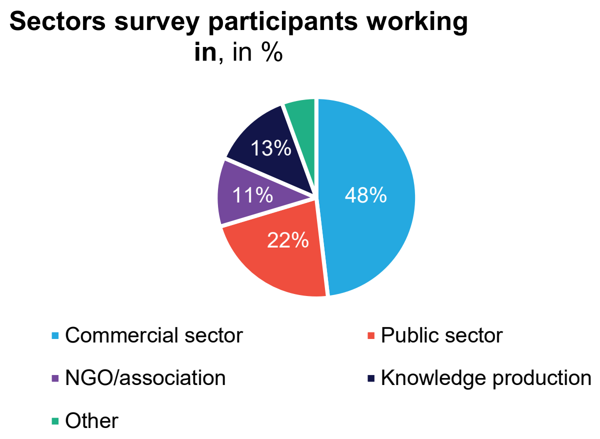


Figure 17: Results from question DEM_05
What main sector does your organisation/company work in?

Within this subgroup from the private sector, half are associated with terminal operators or LSPs (see Figure 18). Meanwhile, public sector respondents span all administrative levels, with a minor skew towards participants from port authorities, as illustrated in the accompanying Figure 19.

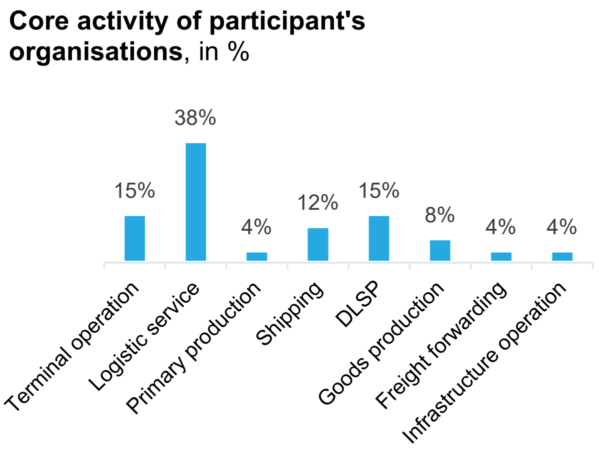


Figure 18: Results from question DEM_06
What is the main activity of your organisation/company?

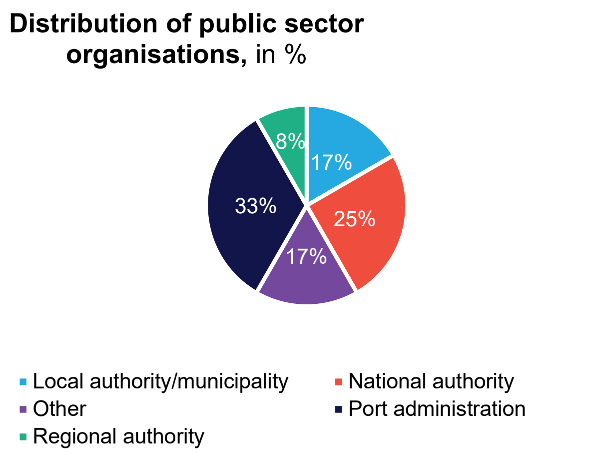


Figure 19: Results from question DEM_08
Please specify the type of public sector you are in.

Entities involved in the core process of multimodal logistics, as illustrated in Figure 20, are typical customers or roles in the downstream segment of the value chain. Within the surveyed group, carriers engaged in road freight transportation are overrepresented relative to other transport modes. Conversely, those involved in inland waterway transport are underrepresented.

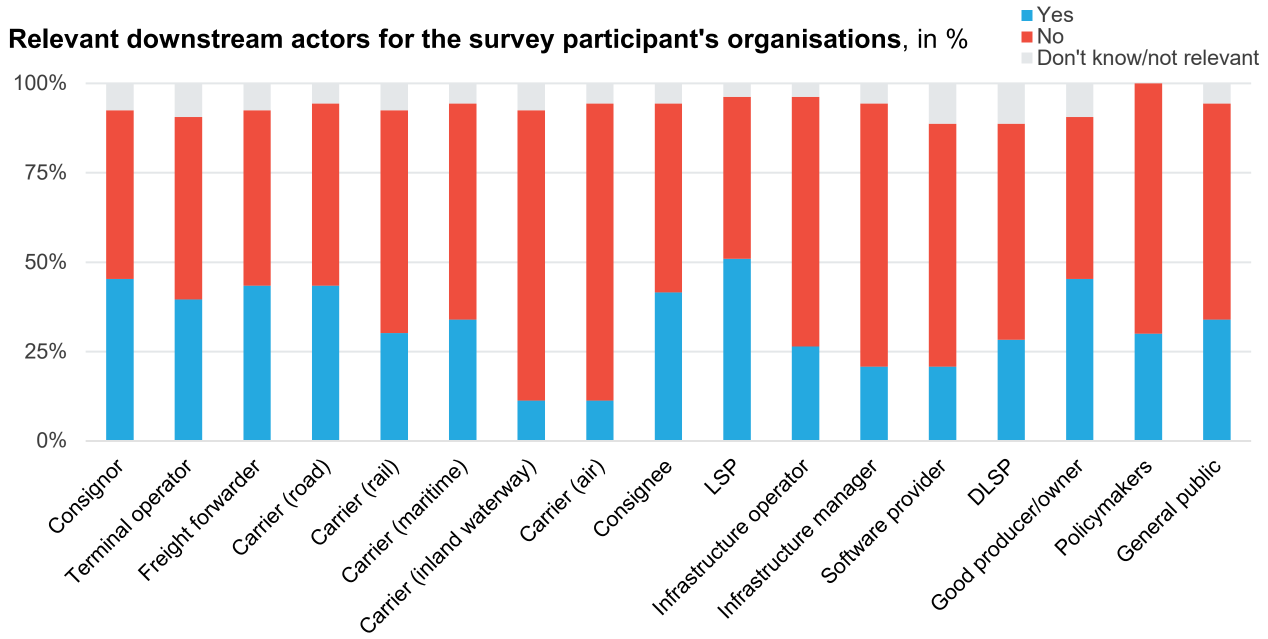


Figure 20: Results from question DEM_09
Are any of the following actors your main customer/clients?

As expected for the target audience, the participants are either dependent on logistics services enabling them to create their own value or provide transportation by themselves. Most of the participants offer booking/planning or loading and transhipment-as-a-service in multimodal freight transport (Figure 21).

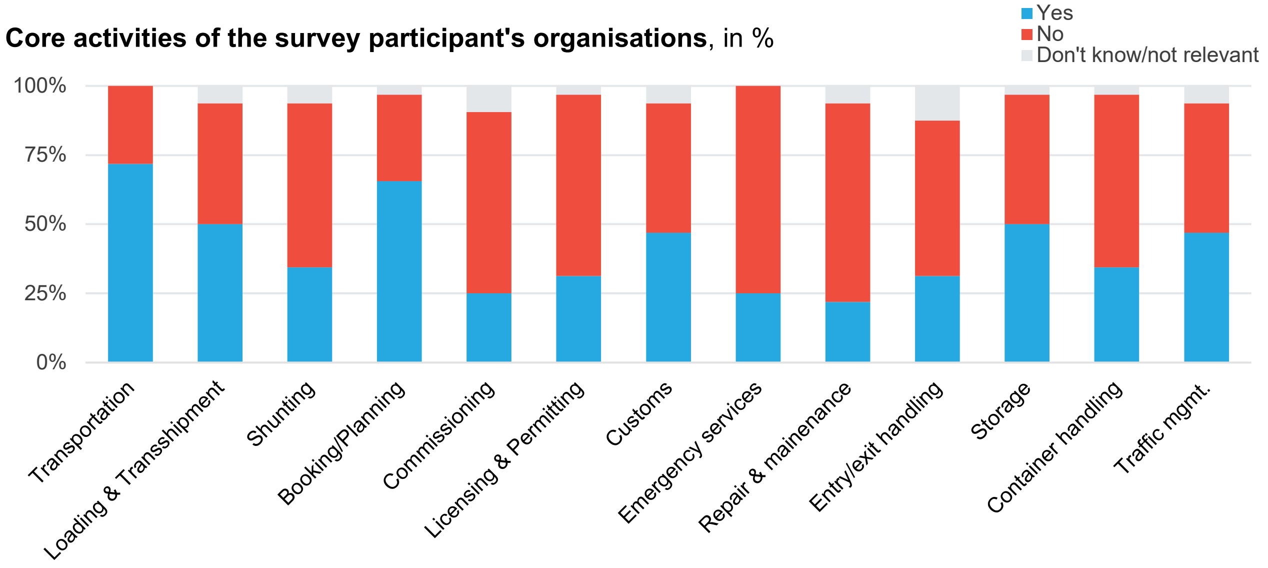


Figure 21: Results from question LOG_02
Does your organisation offer any of the following activities or process steps in multimodal logistics?

Figure 22 shows that the most important modes of transport are road and rail, followed by maritime. Inland waterways and air are less important. This is consistent with the results from question DEM_09, which also indicate the same order of relevance.

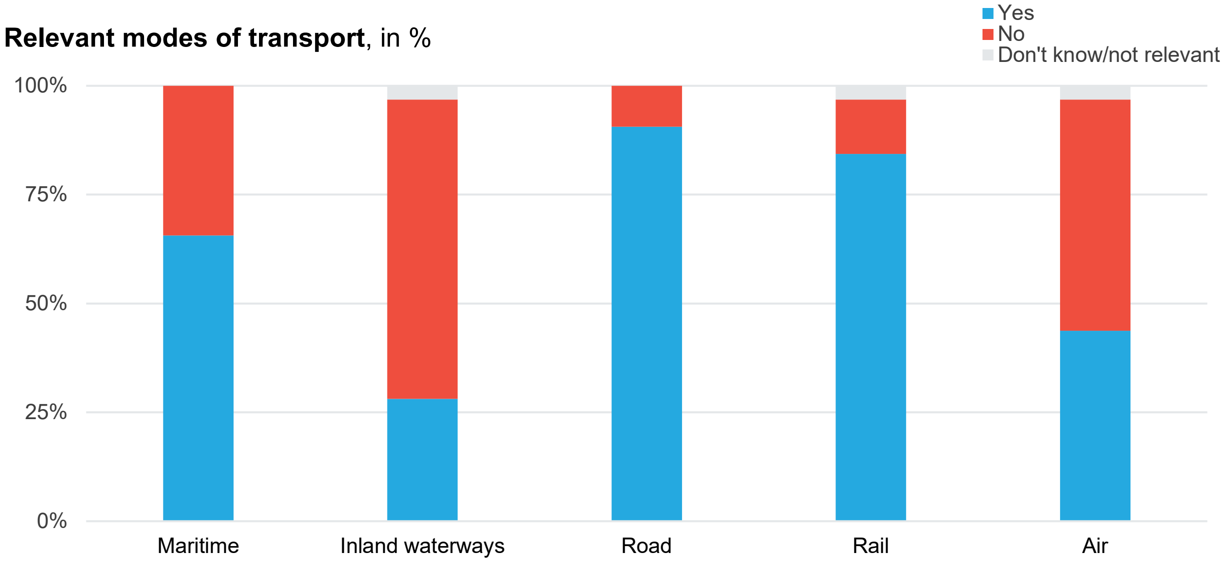


Figure 22: Results from question LOG_03
Are any of the following modes of transport relevant to your organisation?

The goods most frequently transported are containers, general cargo, and industrial goods (Figure 23).

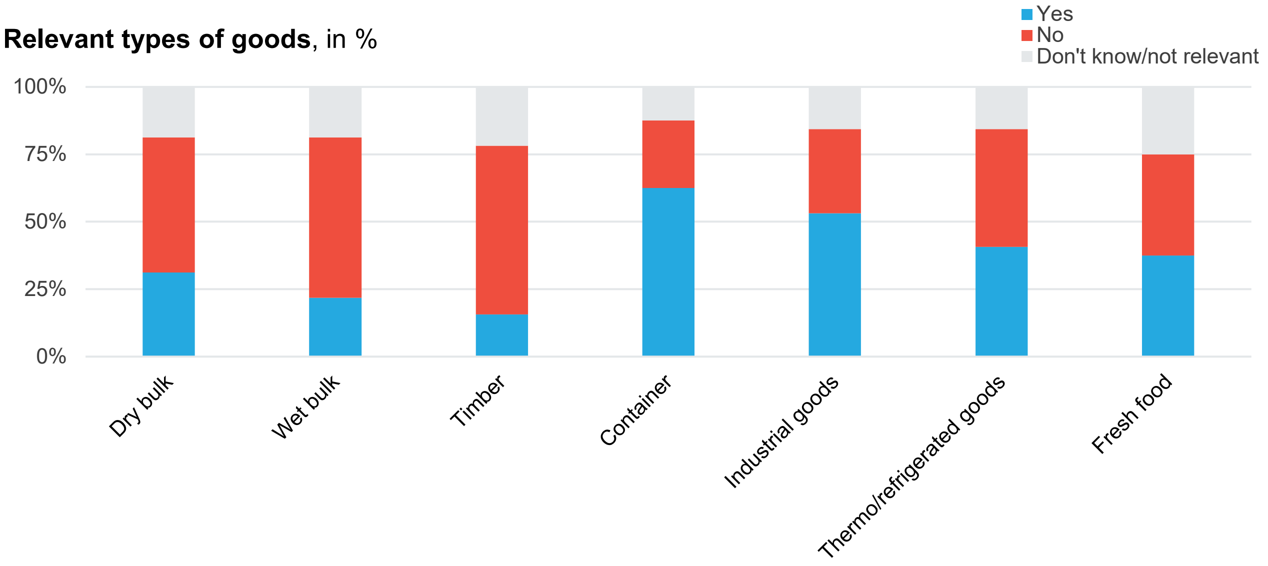


Figure 23: Results from question LOG_04
In general, do you often transport any of the following goods?

The organisation's activities are primarily focused on Central and Western Europe[1], followed by Northern and Eastern Europe (Figure 24).

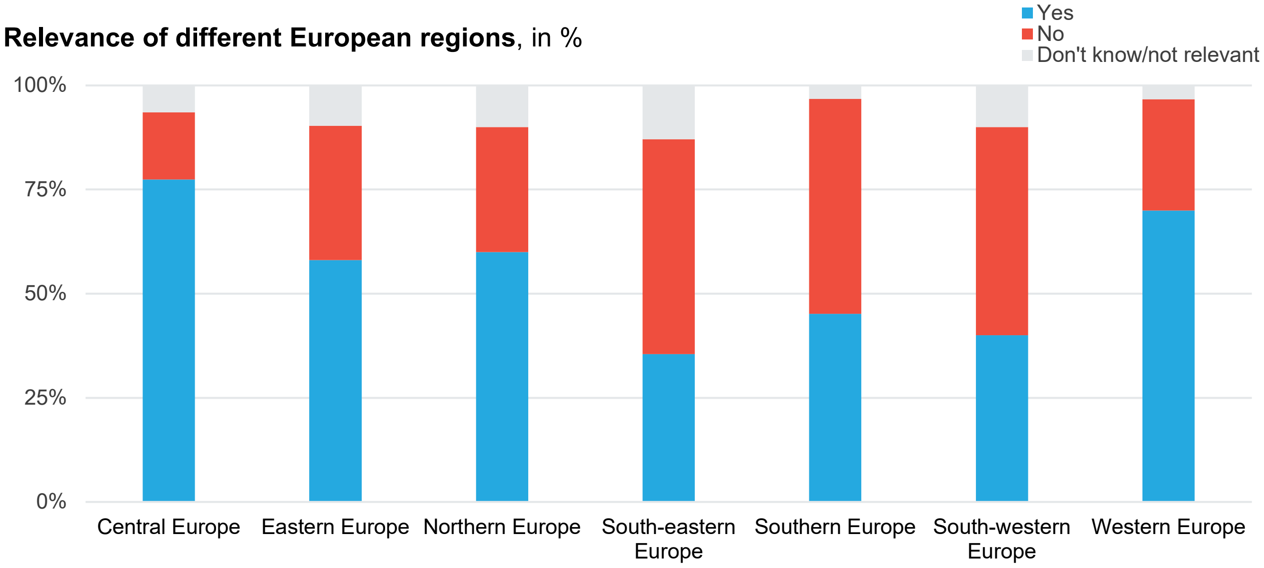


Figure 24: Results from question LOG_07
Do your organisation's activities target any of the following European regions

Trucks, trains, and ships are the primary modes of transportation for goods, as investigated in LOG_03. Route planning decisions are typically made by third-party logistics providers or logistics managers within the company. Central decisions factors are direct costs, delivery time, and distance. Sustainability criteria such as emissions and energy consumption play a secondary role in the decision-making process (s. Figure 25).

[1] The geographical breakdown of the European continent is based on the *The World Factbook* (Central Intelligence Agency (CIA) 2024).

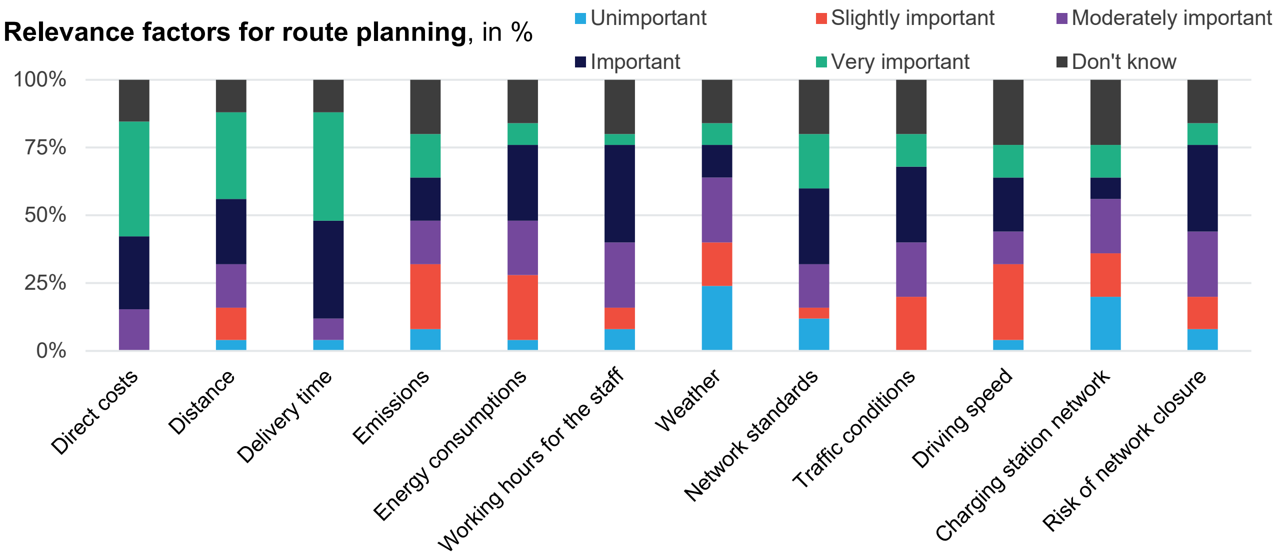


Figure 25: Results from question LOG_12
How important are the following factors to choose a route?

In the area of IT systems, a variety of platforms are used, with communication and collaboration systems being the most frequently cited, followed by data analysis and reporting systems, TOS, and ERP systems. Overall, the use of IT systems in the logistics process is low compared to other industries. Innovative technologies such as blockchain-based systems are only used sporadically (Figure 26).

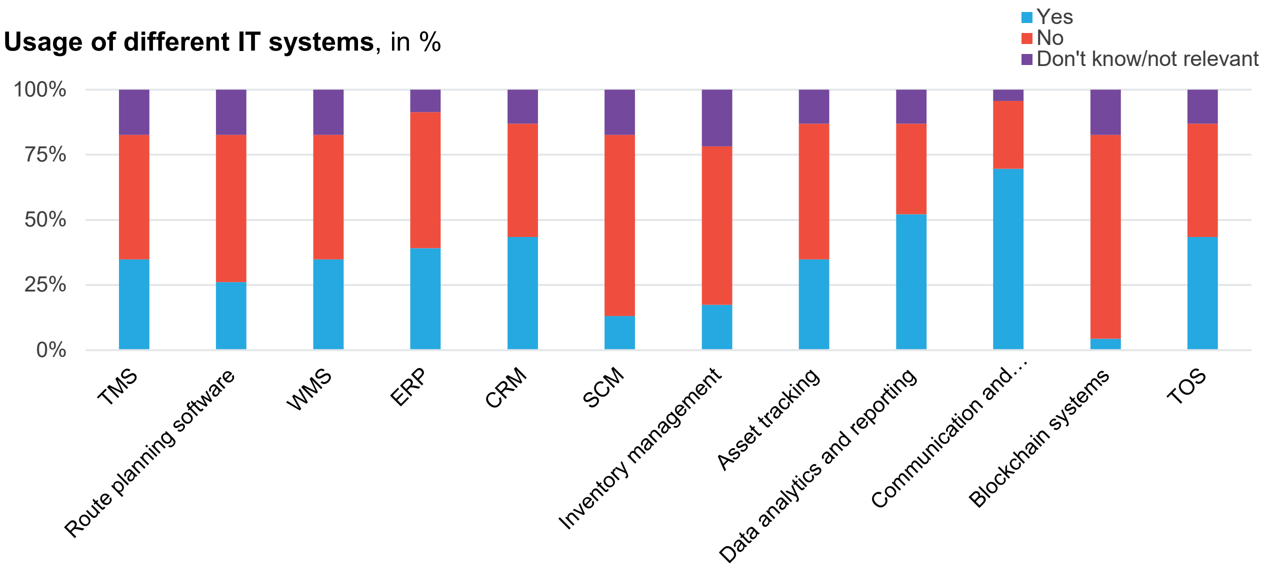


Figure 26: Results from question LOG_13
Do you use any of the following IT systems as part of your logistics process?

Despite the low prevalence of TMS in the logistics process (Figure 26), a large proportion of the functions of such a system are mapped manually by those involved, using other IT systems or workarounds (Figure 27). As might be expected given the heterogeneous nature of the survey respondents, general functions that are relevant to a wide range of users in various forms, such as document management, order management or reporting/business analysis, are used more frequently than more specific functions such as material master data management.

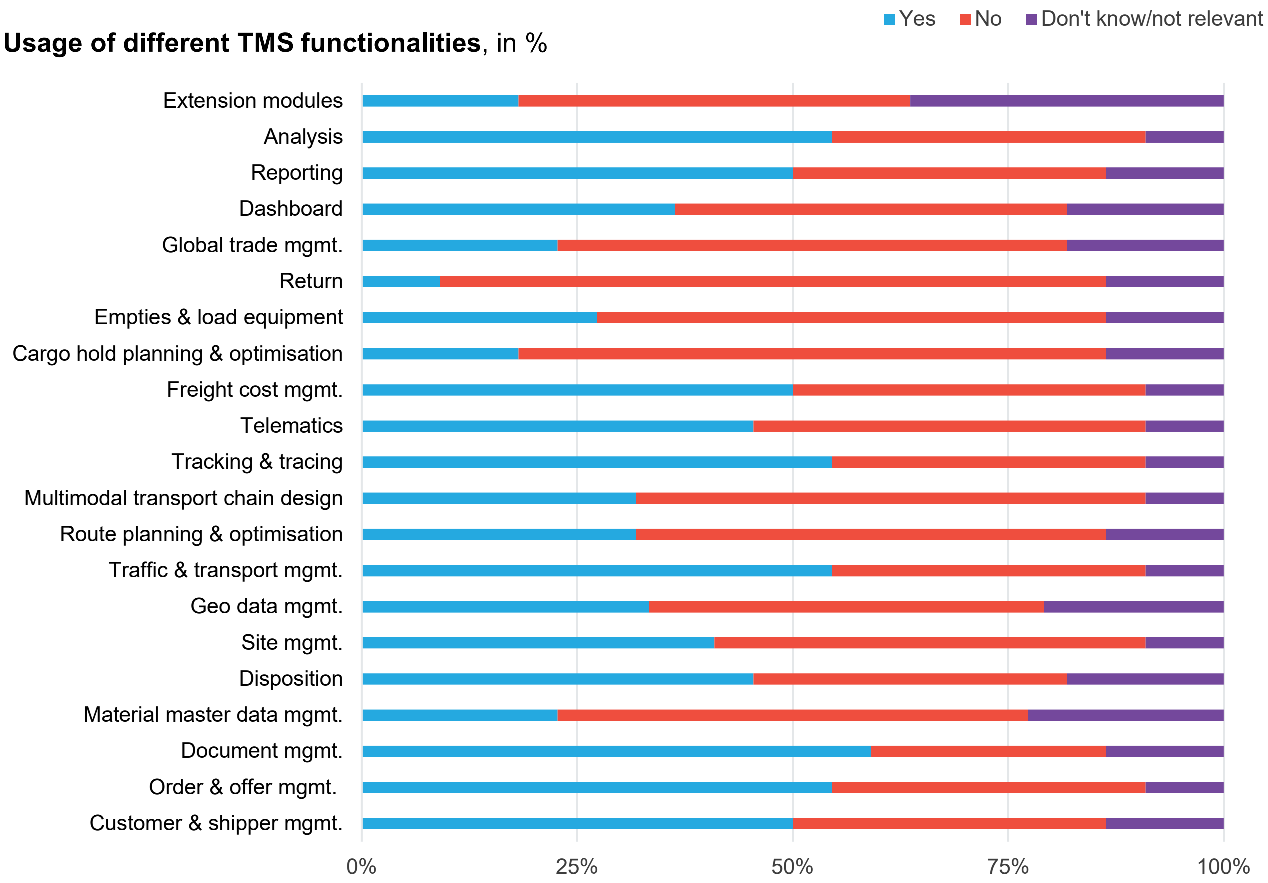


Figure 27: Results from question LOG_14
Does your organisation use any of the following functions of a TMS system?

PDFs and emails are the most used formats for data exchange, alongside Microsoft (MS) Office formats (such as docx, xlsx and pptx) and standardised Electronic Data Interchange

(EDI) formats. For asynchronous data exchange, digital media are mainly used, except for fax and paper-based communication (Figure 28).

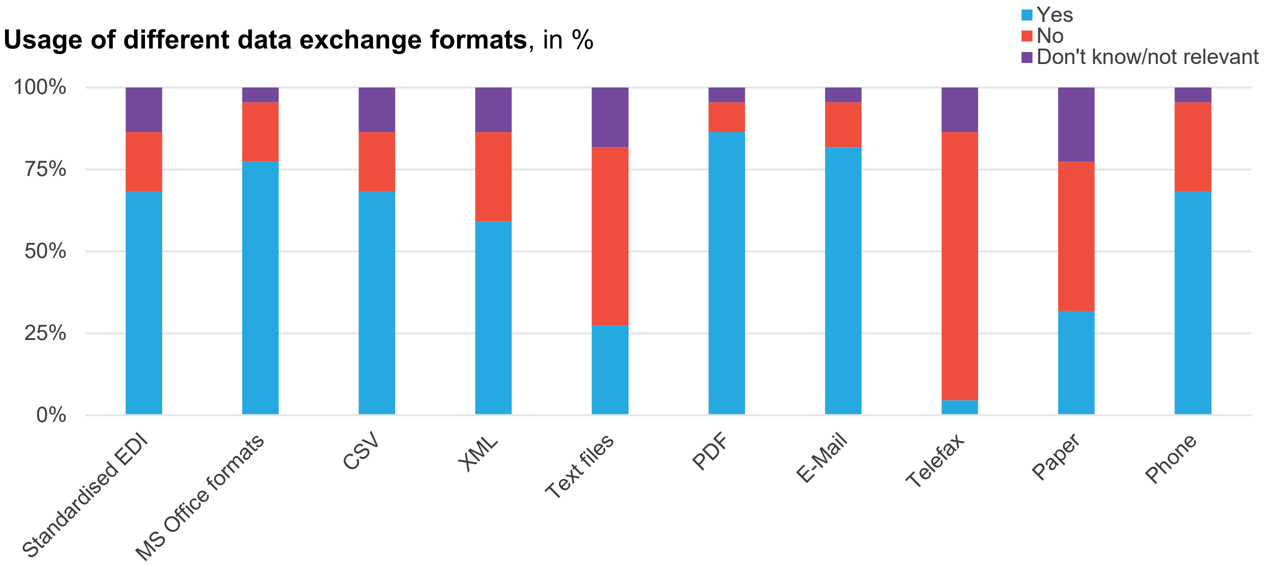


Figure 28: Results from question LOG_15
Does your organisation use any of the following formats to exchange data?

6.1.2 Challenges of the Survey Participants

During the initial conception of the survey, seven categories of challenges were identified. The categories serve as a framework for investigation of the challenges perceived by the stakeholders (Figure 29 to Figure 34 with the corresponding questions CHA_01 to CHA_07).

In terms of infrastructural challenges, respondents identified the impact of infrastructural capacities and demand, as well as the continuous development of multimodal transport infrastructure and construction activities that affect the infrastructure, as the most pressing issues (Figure 29).

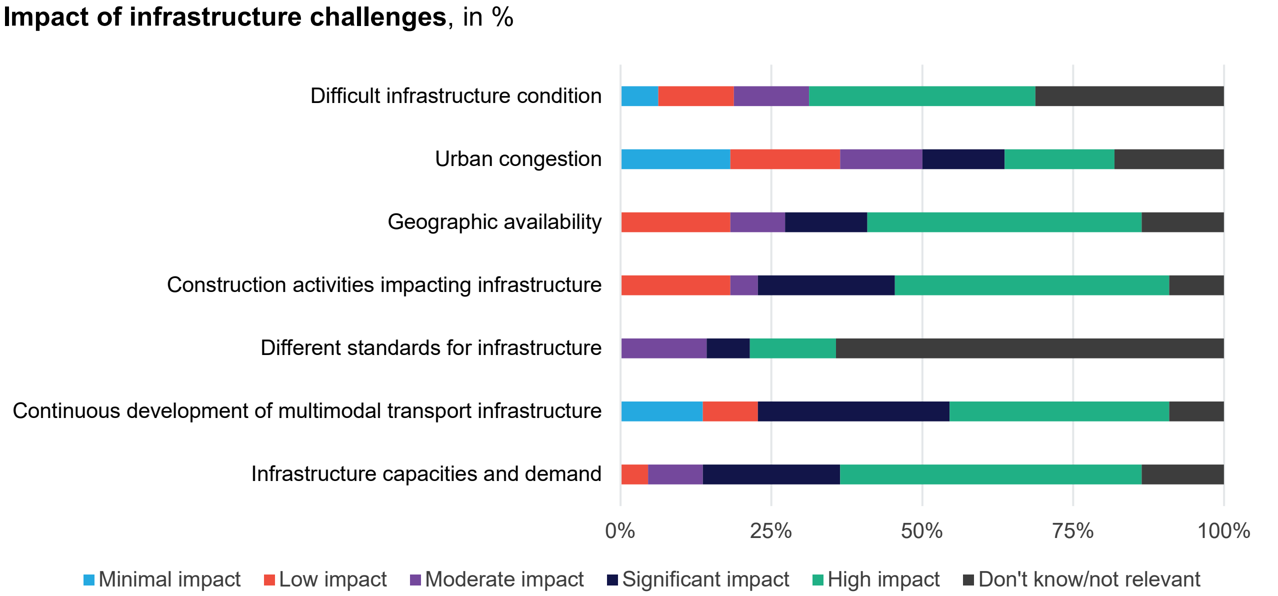


Figure 29: Results from question CHA_01
Please rate the impact of the following infrastructure challenges on your organisation.

The survey respondents identified real-time data management and end-to-end visibility as the most significant challenges related to digital technology, as visualised in Figure 30. Additionally, threats to cybersecurity are seen as another challenge, albeit not as frequently mentioned as the others.

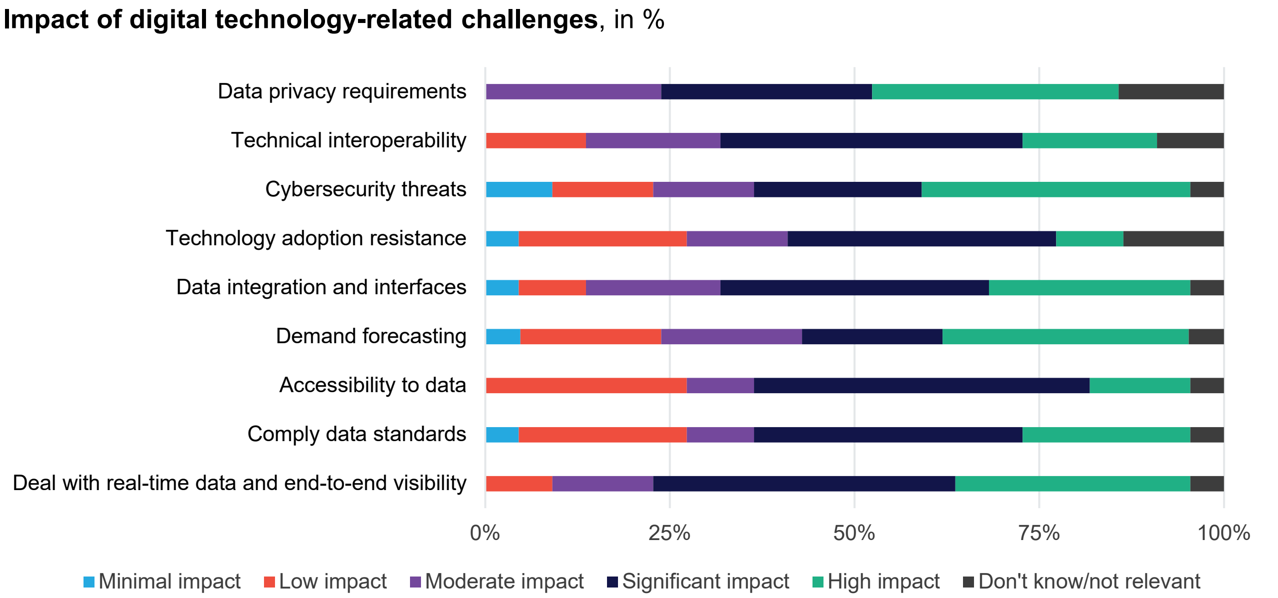


Figure 30: Results from question CHA_02
Please rate the impact that the following digital technology-related challenges have on your organisation.

From an operational perspective, all the challenges examined were rated as having at least a 'moderate' impact, with respondents highlighting the management of disruptive events and collaboration/coordination between stakeholders as particularly challenging (Figure 31).

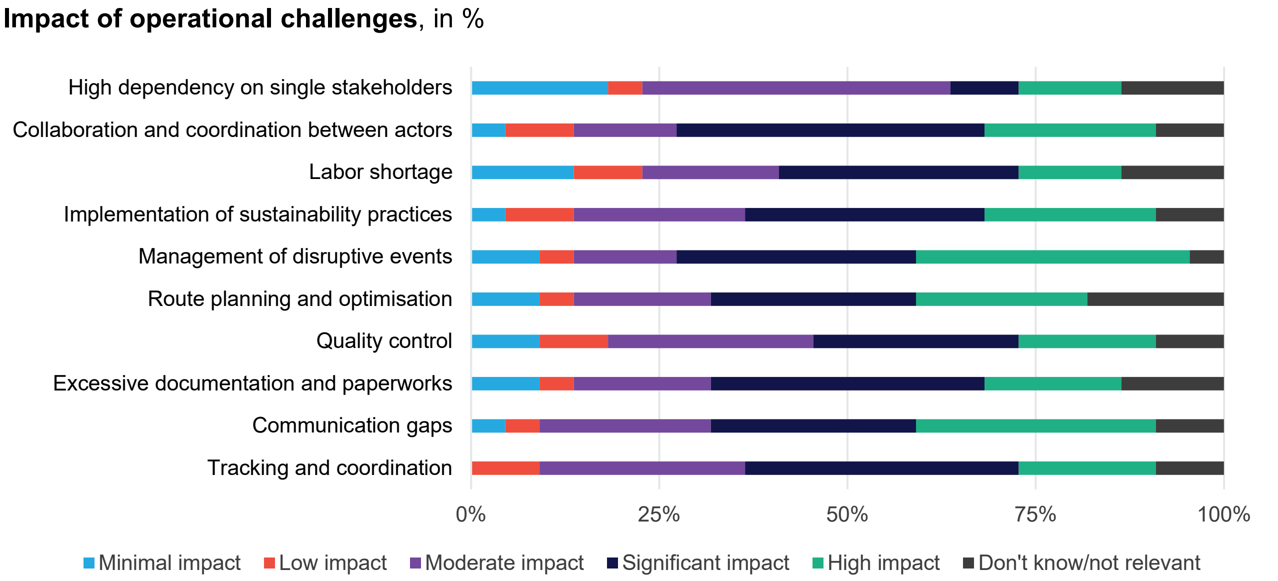


Figure 31: Results from question CHA_03
Please rate the impact of the following operational challenges on your organisation.

Respondents identified overall inefficiencies in their organisation's operations as the central challenge on the cost side (Figure 32). Fuel, energy, and labour costs were also identified as significant challenges.

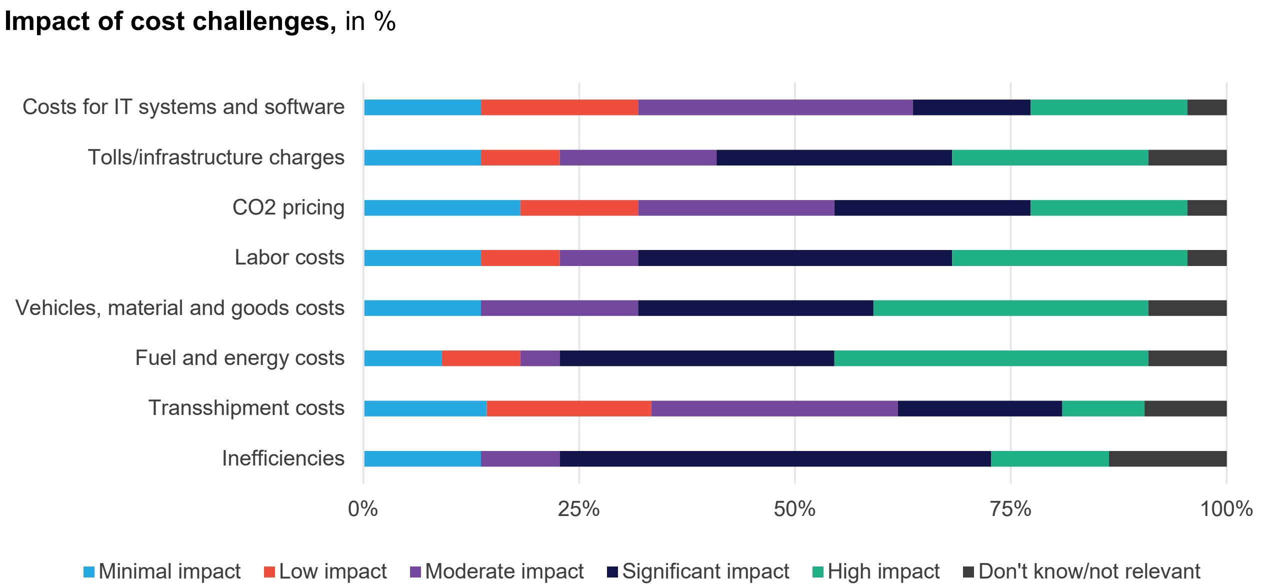


Figure 32: Results from question CHA_04
Please rate the impact of the following cost challenges on your organisation.

When considering regulatory or legal challenges, no specific challenge stands out (Figure 33). However, the most significant issues are customer and regulatory compliance, as well as an updated legal framework.

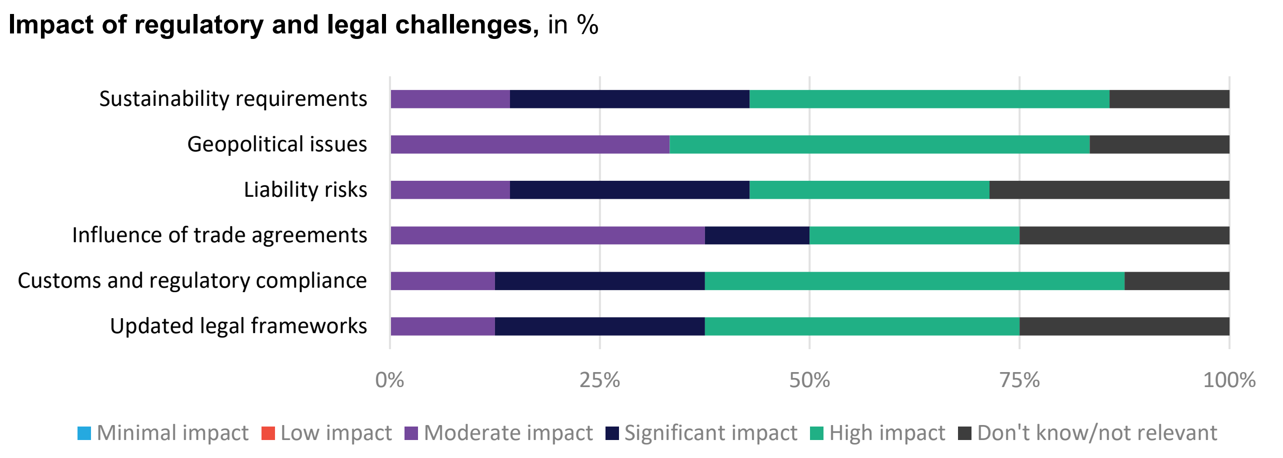


Figure 33: Results from question CHA_05
Please rate the impact of the following regulatory or legal challenges on your organisation.

Finally, when asked about the importance of market challenges, the most significant challenge identified was fluctuations in consumer demand (Figure 34).

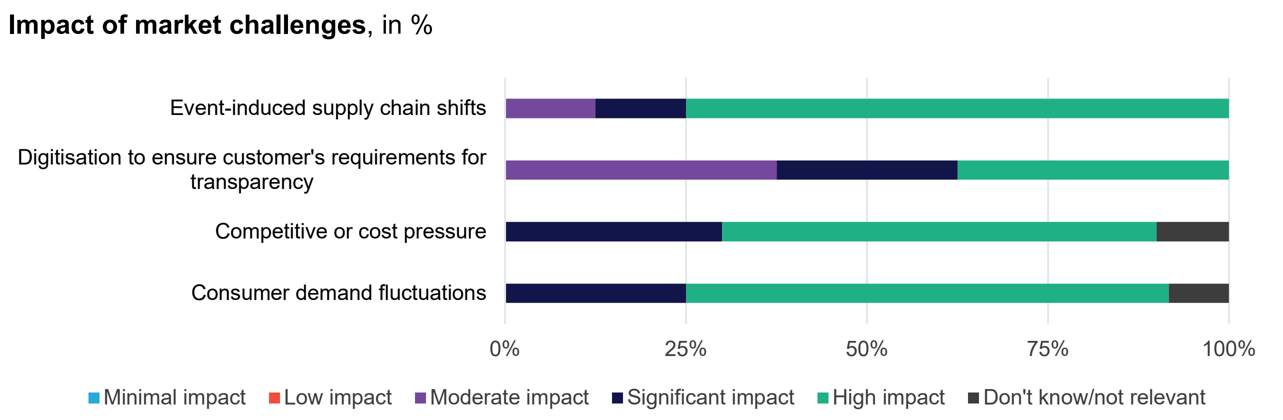


Figure 34: Results from question CHA_07
Please rate the impact of the following market challenges on your organisation.

6.1.3 Impact of Disruptive Events and Handling of Disruptions

When analysing the most impactful disruptions experienced by the participants over the past five years, health emergencies or pandemics and regulatory changes related to such crises were found to have the most pronounced effect on daily work (Figure 35). In contrast, the impact of localised natural disasters such as landslides, avalanches, or sinkholes has been more varied but generally moderate.

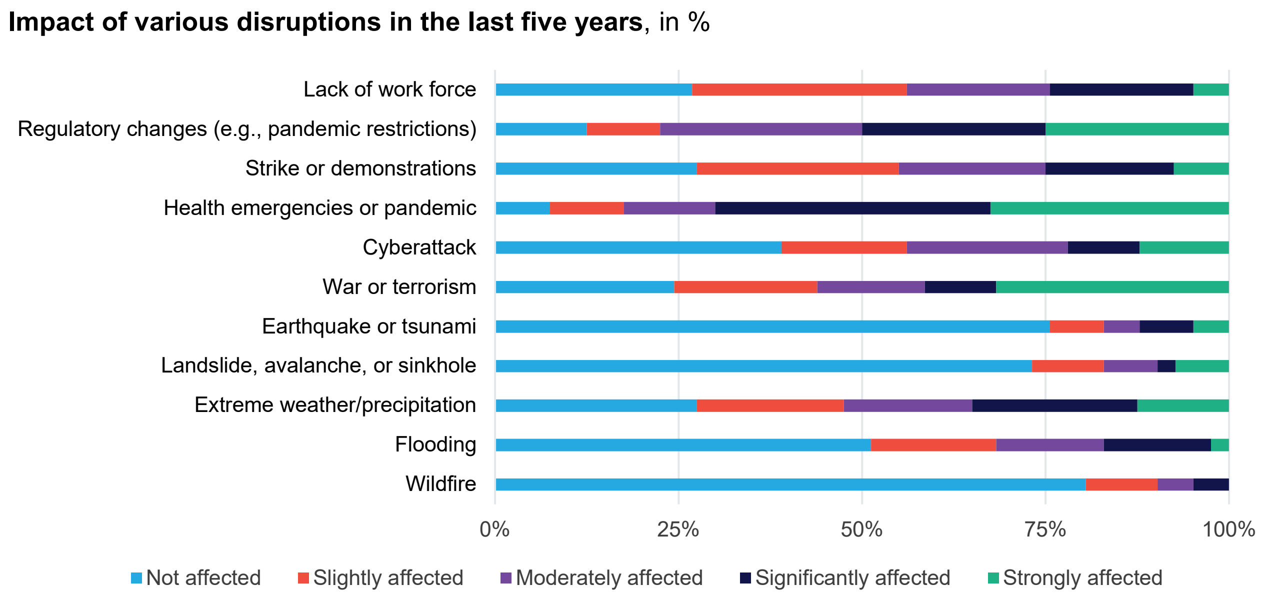


Figure 35: Results from question DIS_01
In your opinion, how much have the following disruptions affected your daily work in the last 5 years?

The survey participants reported facing severe disruptions such as shortages of products or raw materials, lack of personnel, and cost increases (Figure 36). These findings highlight the significant impact of supply chain disruptions and human resource limitations on operational efficiency. The severity of disruptions varies across different types, highlighting the complexity that organisations must navigate. This emphasises the need for comprehensive risk management strategies.

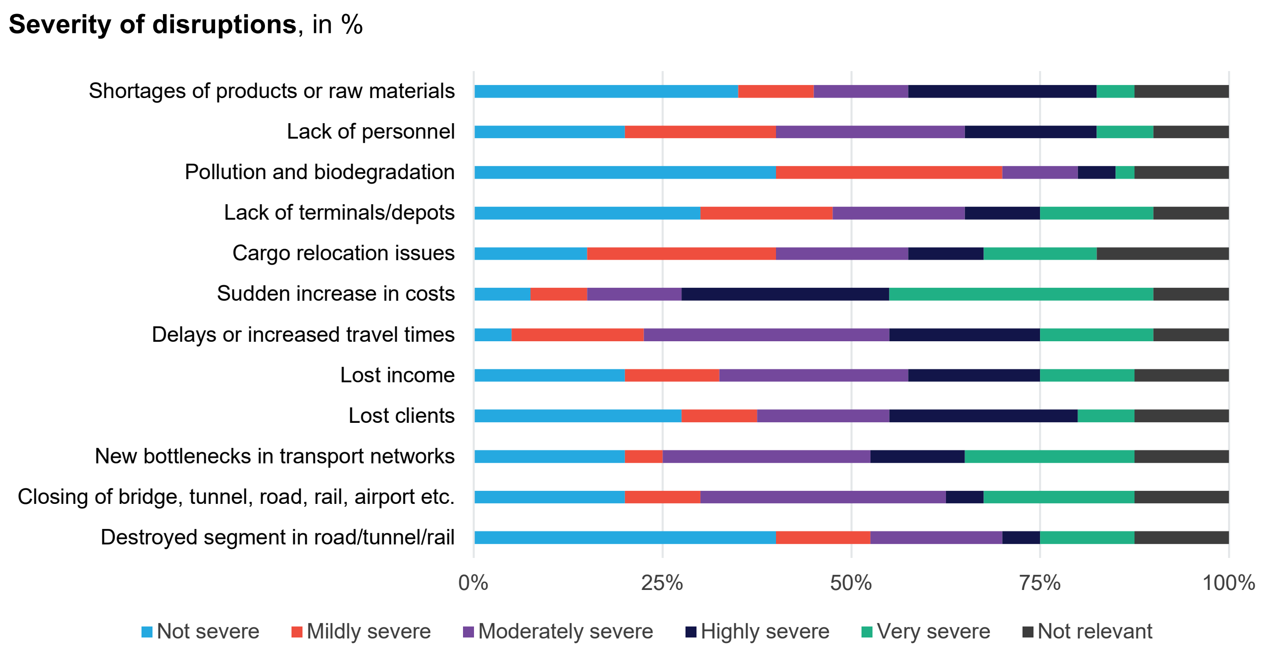


Figure 36: Results from question DIS_03
Think about the type of disruption you were affected most by. Of the following potential consequences, how severe have they been?

Based on Figure 37, just over half of the surveyed organisations have established systems to manage disruptions. This highlights a potential vulnerability in the preparedness of 47% of the participants. The almost equal distribution between those with and without such systems indicates a gap in how organisations handle disruption management, indicating the need for improvement in institutionalising response mechanisms. Figure 38 illustrates the availability of various handling strategies, including adaptive strategies, continuous improvement, and changes in partners, routes, or modes, as the most accessible handling strategies for organisations facing disruptions. The varying accessibility of different strategies suggests differences in organisational resilience and preparedness. Flexibility and strategic partnerships are highlighted as key assets in navigating disruptions.

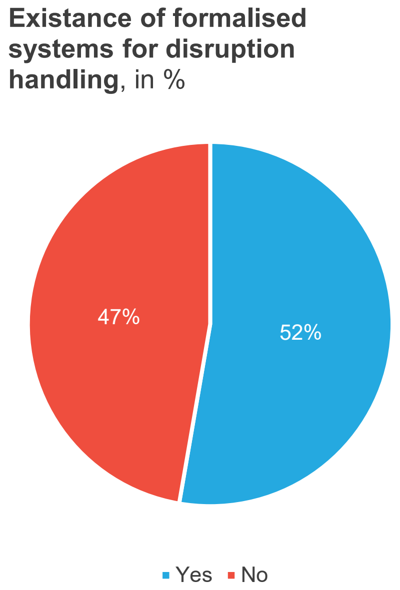


Figure 37: Results from question DIS_05
Does your organisation have a formalised system to handle disruptions in place?

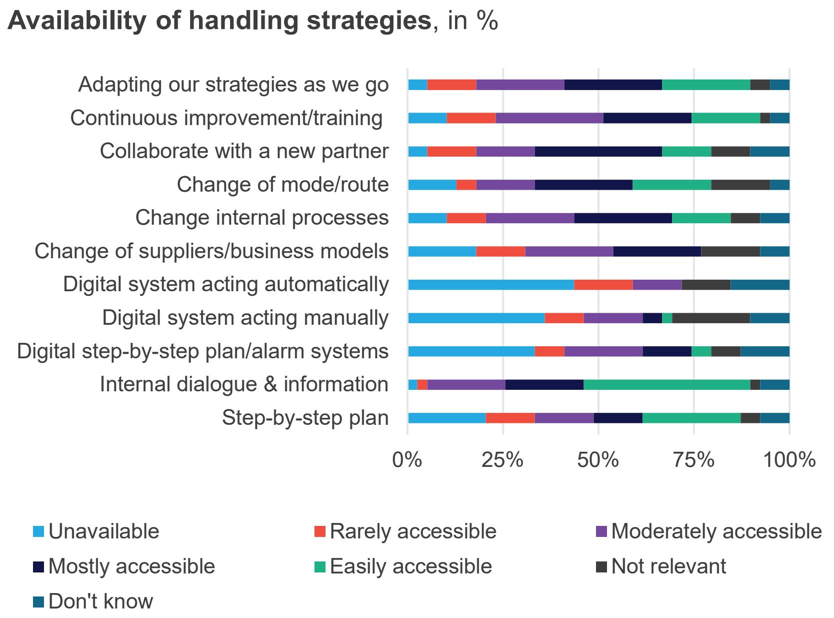


Figure 38: Results from question DIS_06
How available have the following handling strategies or solutions been during or right after a disruption?

Figure 39 shows that the most significant barriers to effective disruption response are the lack of personnel or human resources, poor stakeholder collaboration, and unclear organisational vision. These findings highlight the critical importance of human and organisational factors in disruption management. Addressing these barriers could significantly enhance an organisation's ability to respond to and recover from disruptions. This highlights the importance of strategic focus on both internal and external collaboration, as well as clear strategic direction.

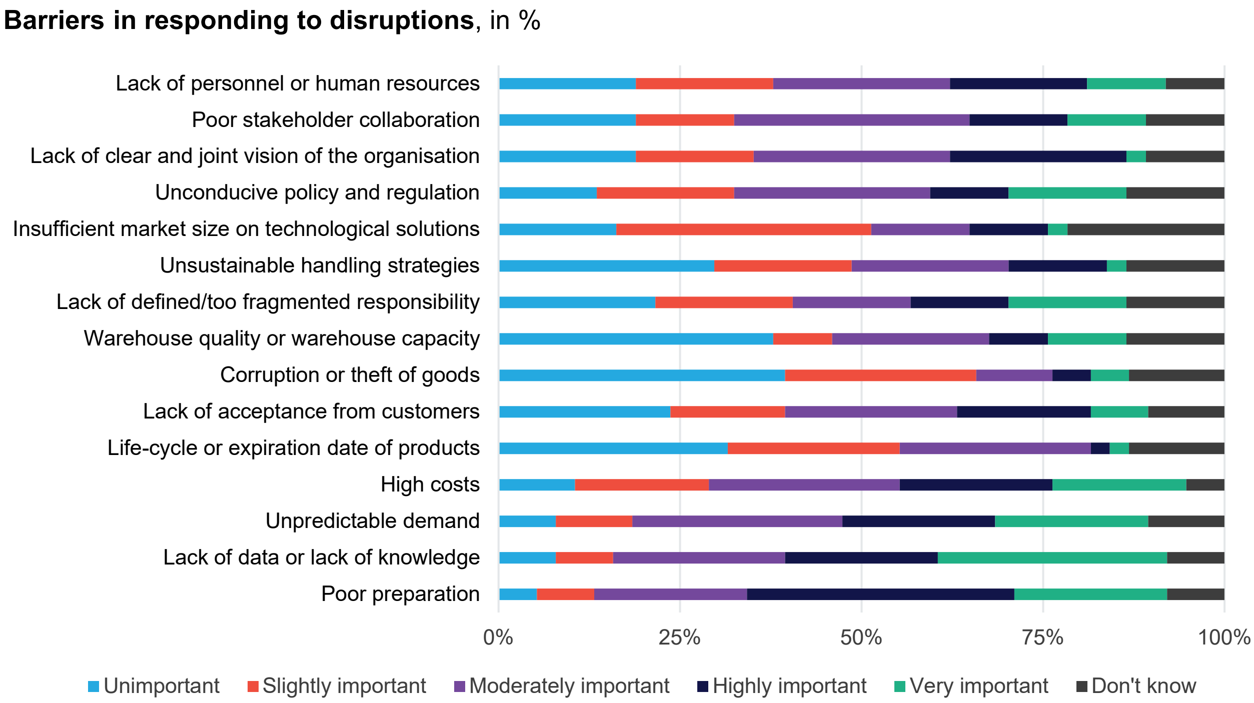


Figure 39: Results from question DIS_07
Thinking back on the disruption that affected your daily work the most, how important are the following barriers in responding to disruptions?

6.2 In-depth Results from the Expert Interviews

The expert interviewees face both routine operational obstacles and challenges that arise during disruptive events. In a first step in Subsection 6.2.1 the interview participants will be characterised followed by a classification of disruptive events evident in the industry. In the final Subsections 6.2.3 and 6.2.4 the findings from the interviews are presented and further analysed.

The ReMuNet research project's chronological sequence and parallel progress allow for supplementary analysis of the challenges identified in the interviews, based on the results from Deliverable 1.3 (cf. Kulkarni et al., 2023), for the analysis and systematisation of the interview results.

6.2.1 Expert Interview Participants

To analyse the challenges faced by stakeholders during disruptive events, 24 stakeholders from the freight transport network were interviewed. A detailed description of the interview partners, their role, and activities as well as the reasoning why they have been chosen for as representative experts for ReMuNet can be found in Annex IV. While these stakeholders represent the multimodal freight transport roles introduced in Section 5.4, in most cases, the activities of the interviewed stakeholders cannot be clearly assigned to one archetypal role. Rather, some organisations fulfil several roles with their service portfolio. (see Figure 40).

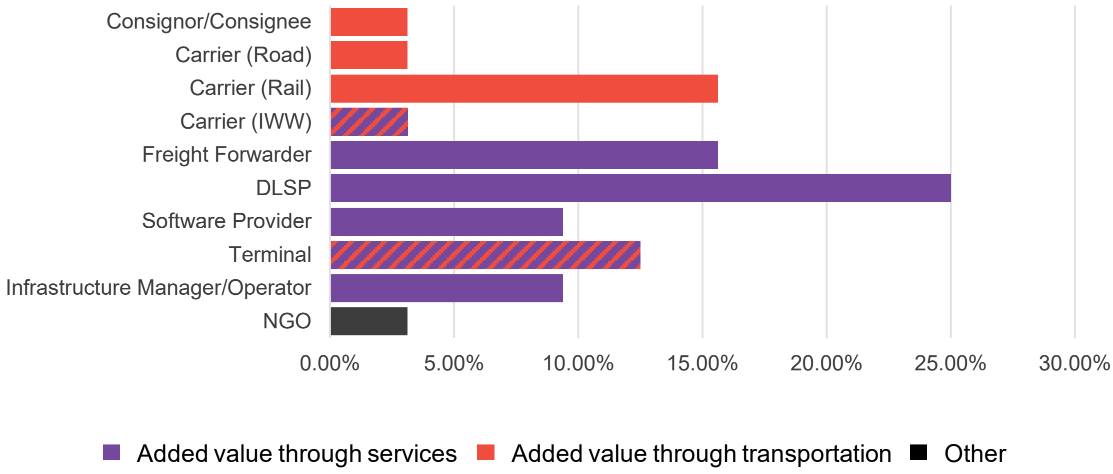


Figure 40: Shares of interview partners by role

6.2.2 Categories of Disruptions

Kulkarni et al. (2023) classify disruptions in the transportation sector into two distinct layers based on their impact area: the physical layer and the information technology layer (see Figure 41). This dual classification highlights the multifaceted nature of transportation disruptions, emphasising their impact on both tangible infrastructure and (digital) information systems. This study suggests that the physical layer is more susceptible to disruptions than the information layer. This is supported by nineteen mentions of the physical layer compared to six distinct types of disruptions primarily affecting the information layer.

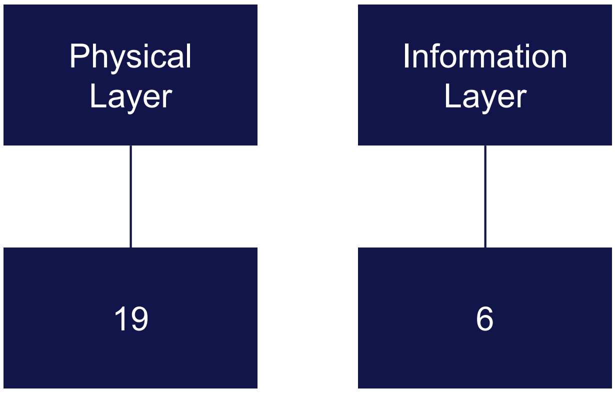


Figure 41: Disruption categories based on area of impact

Disruptions within the transport sector can have extensive repercussions, affecting every link within the transport chain. To develop a standardised approach for managing various disruptions, data obtained from interviews will be classified into nine main segments: natural disasters, technological failures, regulatory changes, security incidents, accidents, health emergencies, capacity shortages, geopolitical crises, and extreme weather conditions. Each category has unique characteristics that significantly impact the transport sector. The following section provides a detailed overview of each category and explains how various disruptions are allocated across different roles.

Natural disasters, such as floodings and avalanches, can severely disrupt transport networks by causing extensive damage to infrastructure and interrupting the flow of goods. The logistics performance of nations is closely tied to the impact of natural disasters within their borders.

Similarly, **technological failures**, including signal malfunctions, are a relevant category of disruptions. The growing importance of informational components in transport logistics makes systems vulnerable to breakdowns. Failures in the freight transport network can cause significant delays and misrouting of freight, which can impede network efficiency.

Regulatory changes, such as the adoption of climate-friendly propulsion systems or the imposition of truck driving restrictions, can significantly impact the European freight transport system. This has been demonstrated by the consequences of Brexit. These changes often require adjustments to operational procedures, which can cause temporary slowdowns and potential congestion at border checkpoints.

Security incidents, such as cargo theft or attacks on ships, pose threats to physical infrastructure and information systems. They can lead to the shutdown of critical transport hubs, cause delays due to enhanced security measures, and create uncertainty that disrupts the flow of goods.

Accidents are also a highly visible source of disruption. Immediate and localised disruptions can be caused by events such as compromised cargo integrity or vehicular collisions. These occurrences may result in the temporary closure of transport routes and redirection of freight traffic, which could have ripple effects throughout the wider network.

Health emergencies, such as pandemics, can impact freight transport by inducing labour shortages and necessitating the adoption of new health and safety protocols. These dynamics can create operational challenges and major delays within the freight network.

The category of **capacity shortages** encompasses events such as strikes, traffic congestion, flat tyres, or roadworks. These incidents become particularly critical during times of heightened demand or when the transport network faces additional pressure from other disruptive events.

Geopolitical crises, such as the war on Ukraine or the consequences of Brexit, may result in border closures, restricted access to certain routes, increased scrutiny of goods, and often lead to extended transit times, freight redirection, and heightened operational costs.

The list of challenges can be concluded **by extreme weather conditions**, such as low tides, significant rainfall or snowfall, and storms. Extreme weather events can cause significant damage to infrastructure and reduce the capacity of transport routes.

6.2.3 Disruptions impacting Multimodal Transportation

Figure 42 shows the categories of disruption outlined by Kulkarni et al. (2023), which are connected to the causes of disruptions identified in interviews conducted within ReMuNet's Task 1.3. The findings show the total number of disruptions mentioned, categorised according to the described typology, as reported by all interviewed stakeholders.

Categories	Natural Disasters	Technological Failure	Regulatory Changes	Security Incidents	Accidents	Health Emergencies	Capacity Shortages	Geopolitical Crisis	Extreme Weather
Quantity	2	6	8	5	12	10	20	11	27

Figure 42: Interview results on the causes of disruptions

Assigning these categories to the dual layer approach mentioned above, contributes to the assumption that disruptive events mainly impact the physical layer (Figure 43). However, disruptions within the freight transport sector sometimes affect both the physical and information layers. This is particularly evident in cases of technological failures, which can result from both hardware malfunctions and lapses in information systems. Certain types of disruption are difficult to classify as either physical or informational. Notably, the analysis shows that no disruption types are solely attributed to the information layer, highlighting the interconnectivity between digital and physical domains of disruptions.

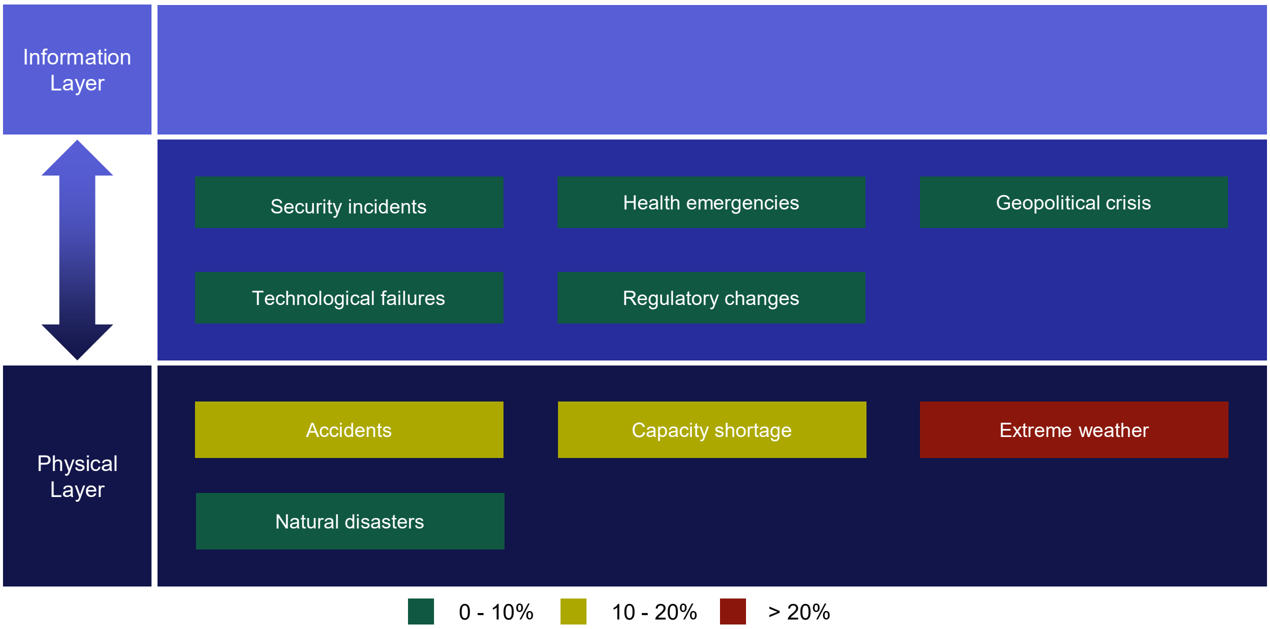


Figure 43: Disruption-Layer-Heat-Map

Analysing the actors being affected by disruptive events, carriers, predominantly rail carriers but also those in road and inland waterways sectors, bear the brunt of disruptions within the transportation and logistics sector, accounting for 50% of the share (Figure 44). While carriers primarily contribute value through transportation, disruptions also affect other stakeholders, albeit to a slightly lesser extent. This is because disruptions typically strike the physical layer first and, thus, more often affect the role that primarily executes the operational process of transportation.

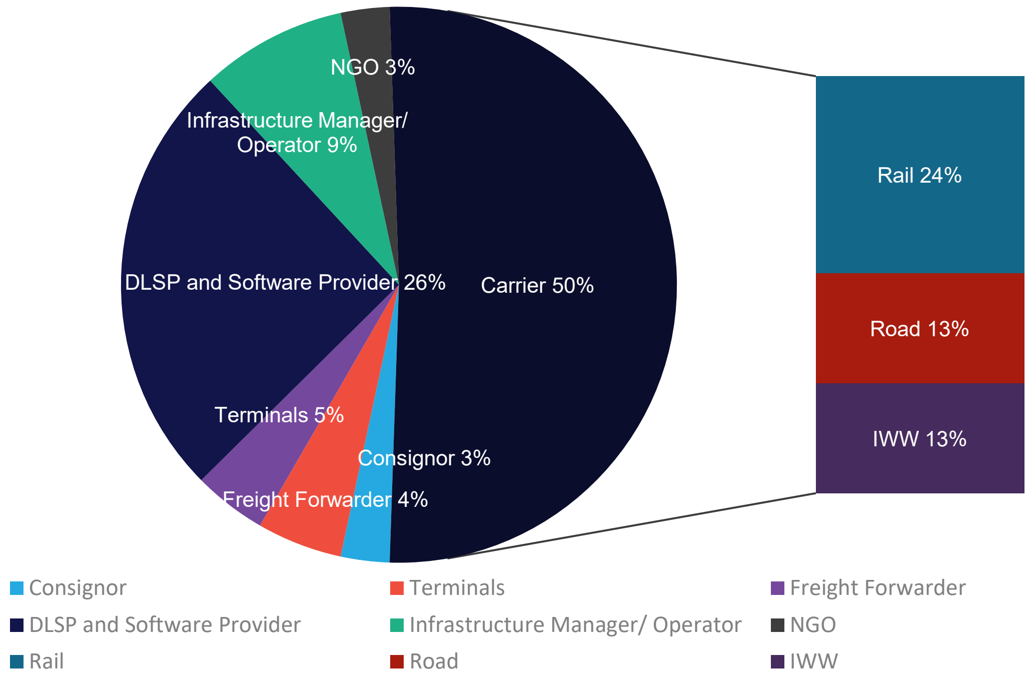


Figure 44: Share of disruptions per role

Aligning the identified categorised disruptions with the role profiles of key stakeholders of the multimodal freight transport network, the interview results initially have been analysed from an industry-wide perspective following by the role specific analysis of challenges.

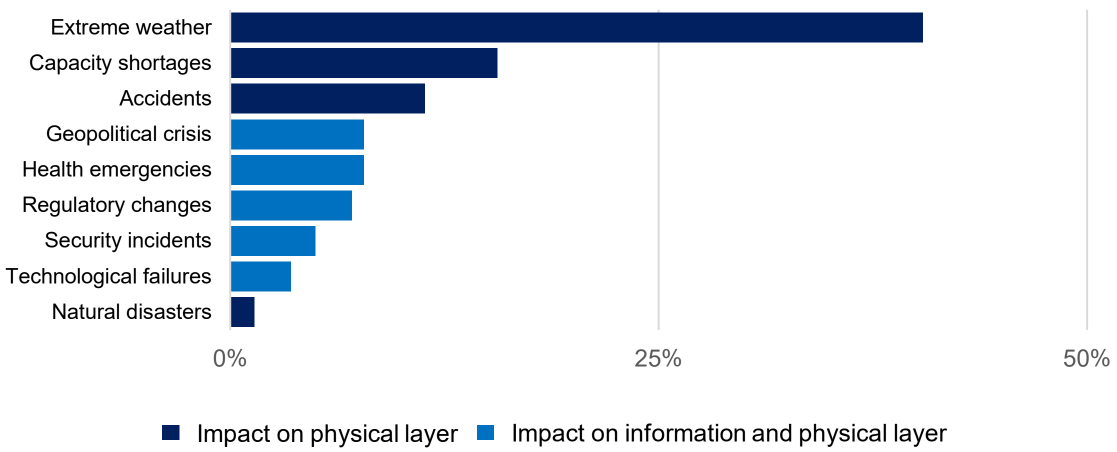


Figure 45: Industry-wide disruptions

Disruptions in the freight transport network can arise from various factors, including extreme weather events, capacity shortages, and accidents. Extreme weather events, such as storms and heavy rainfall, can make roads impassable, shut down ports, and disrupt railway operations by damaging tracks or scattering debris. This can result in shipment delays, cargo rerouting, and an increased risk of goods being damaged. Due to their unpredictability and potential severity, these events also pose safety risks to transport personnel.

Capacity shortages may occur when freight demand exceeds the available capacity of transport carriers and infrastructure, leading to shipping delays and higher costs for shippers. These shortages may stem from strikes, congested traffic, or unexpected detours, making it difficult to acquire transport services.

Furthermore, incidents involving freight transportation, such as trucks, trains, ships, or aircraft, can cause significant disruptions to the transportation network.

Other disruptions that can significantly impact the interaction among stakeholders across different countries include geopolitical crises, health emergencies, changes in regulatory frameworks affecting customs procedures, security incidents, technological breakdowns, and natural disasters. It is crucial to approach these topics objectively, recognising their complexity and broad impact on the freight transport network.

Disruptions affecting Consignors and Consignees

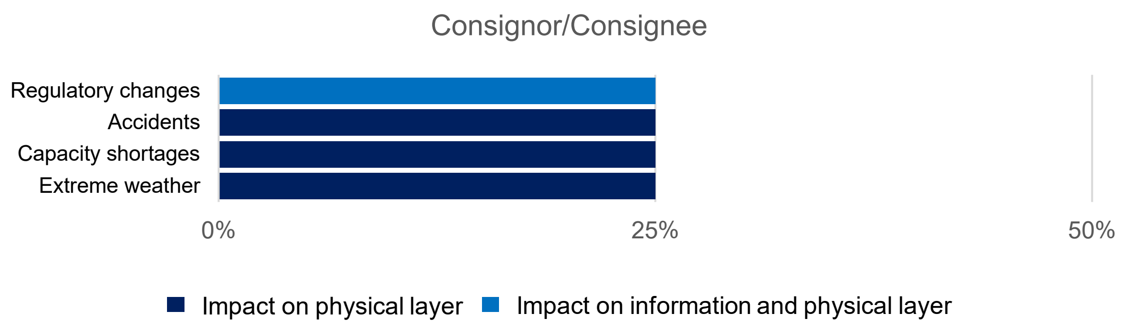


Figure 46: Disruptions affecting Consignor/Consignee

In logistics, disruptions can affect the stability and efficiency of the supply chain for both consignors and consignees. As one stakeholder noted, "The system is very sensitive. Small problems rapidly result in large-scale outages" (IP 2, 2023). These disruptions include border delays due to regulatory changes, accidents that damage cargo, capacity deficits caused by strikes, and severe weather events. They can threaten the timely and intact delivery of goods, potentially damaging customer relations and economic performance.

The disruptions for carriers can be divided into the three main modes of transportation under investigation in ReMuNet: Road, rail, and inland waterways.

Disruptions affecting Carriers

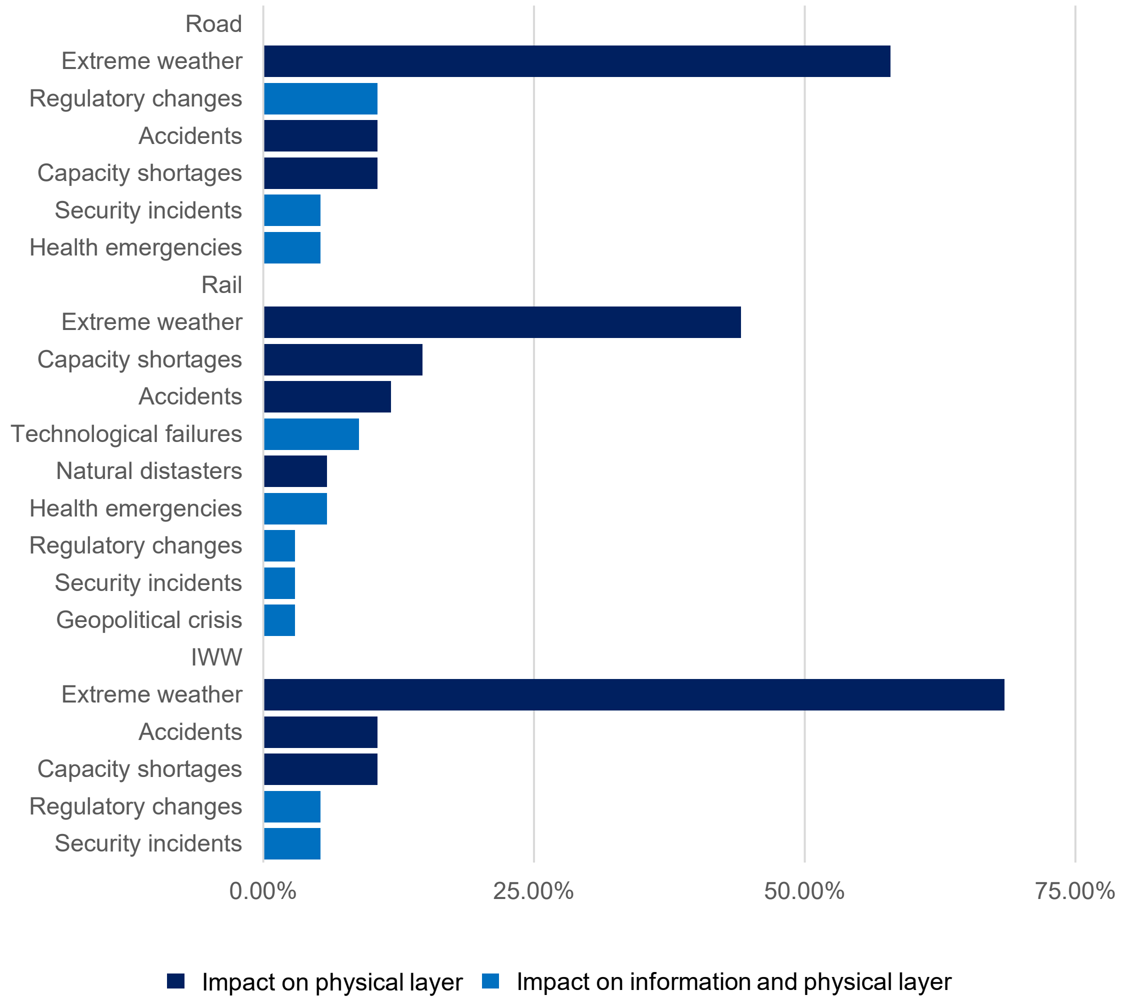


Figure 47: Disruptions affecting Carriers

Impact on Road Carriers

In road transport, carriers can be significantly impacted by disruptions such as driving bans for trucks, the use of alternative propulsion, stolen or damaged loads, accidents, driver illness, construction sites, tire failures, and weather conditions. These disruptions can result in cancellation, rescheduling and rerouting, creating considerable impact on the network's performance. The consequences are often direct delays in the supply chain and increased costs due to longer journey times or claims management.

Impact on Rail Carriers

In rail transportation, disruptions can be caused by various factors such as signal failures, accidents, stolen cargo, pandemic-related restrictions, capacity bottlenecks, and weather conditions. The rail system is static and has high-capacity utilisation by major players, resulting in low flexibility and increased dependency on the infrastructure. Efficiency can be further reduced due to disruptions on detour routes or construction work, leading to unavoidable empty runs.

Rail operators face a significant challenge with the inadequate flow of information during strikes. It is crucial for carriers to receive timely communication about impending strikes to enable them to adjust their operations and minimise the impact on their services. As one carrier stated, “If I know that in three days there will be a strike by the German railways and no train will be allowed, so the train we are counting on will be cancelled. […] If the information is currently available, please provide it […]” (IP 20, 2024). This emphasises the huge potential of disrupting transportation processes due to the lack of information exchange and timely communication.

Impact on IWW Carriers

Disruptions such as varying waterway conditions in neighbouring countries, construction sites, closures, blockades, and weather conditions are of great importance in inland shipping. These can cause detours and capacity problems. The transportation system's semi-static nature makes it vulnerable to infrastructure-related disruptions that directly affect the supply chain by limiting the availability of transport and storage capacity in inland shipping.

The critical role of inland waterway transport is underlined by a statement: "If I don't have the inland waterway vessel, the railway can't do much - let alone the truck. [...] You can't replace and divert certain modes of transport.” (IP 13, 2023) This highlights the unique capacity and capabilities of inland waterway transport, which cannot be easily replaced by rail or road in the event of disruption. The interdependence of different modes of transport and the potential for cascading effects if one mode experiences significant disruption is a critical consideration in supply chain resilience planning.

In summary, extreme weather conditions are seen as the regular main cause of disruptions, despite some variations in the individual disruptive events affecting the stakeholder's performance.

Disruptions affecting Freight Forwarders

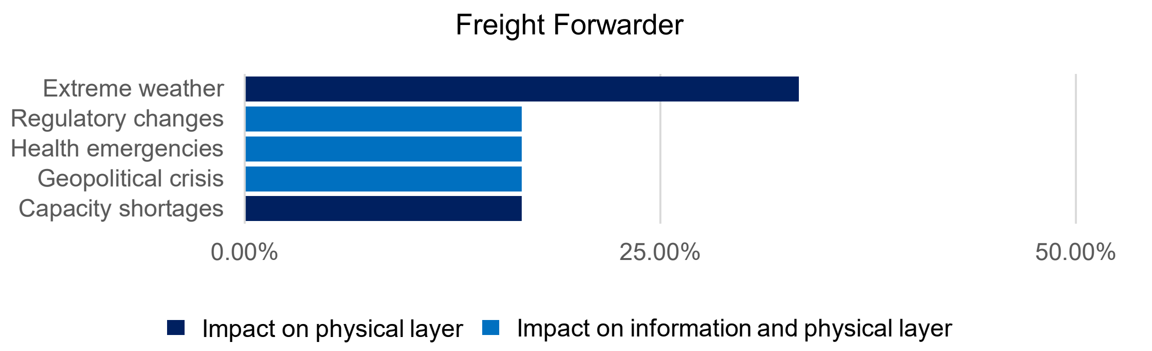


Figure 48: Disruptions affecting Freight Forwarders

Freight forwarders can experience disruptions that affect their efficiency and reliability. Extreme weather conditions are the most common disruptions and pose a significant threat. These weather events can cause delays, damage to goods, and disruptions in the supply chain, making transportation planning and execution much more difficult. As one expert explains, "[…] a line closure […] has an immediate impact on your punctuality. […] You have to check whether the train driver can drive the alternative route and whether the load parameters, the train parameters on the alternative route, are suitable." (IP 22, 2024). In such situations, freight forwarders must communicate with infrastructure operators to replan routes accordingly.

Another significant problem is the non-recognition of letters of credit due to changing regulations. This can lead to delays and additional costs as the security of payment and flow of goods are called into question.

Geopolitical crises, such as wars, e. g. the war on Ukraine, can cause significant financial disruption for freight forwarders who work with stakeholders in multiple countries. To mitigate these disruptions, detours and rescheduling may be necessary, which can result in drastic capacity shortages.

Disruptions affecting DLSPs and Software Providers

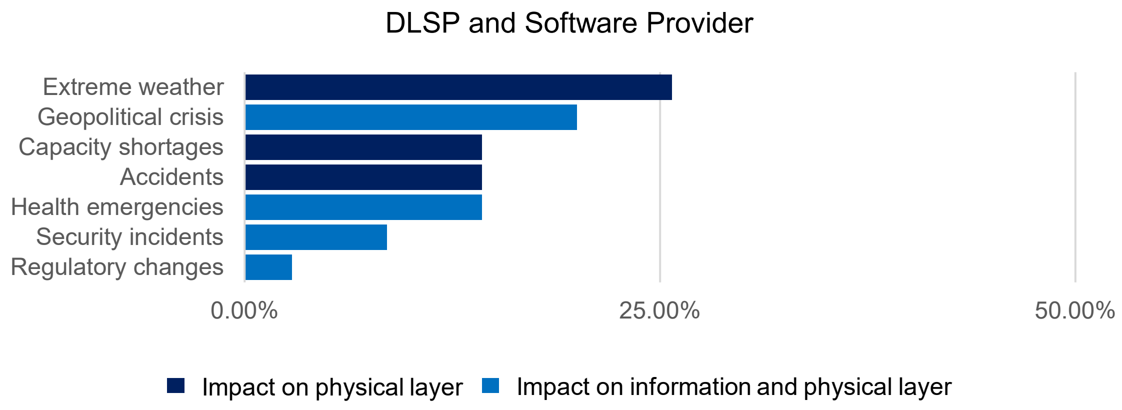


Figure 49: Disruptions affecting DLSPs and Software Providers

DLSP and software providers are crucial components of the supply chain and can be directly or indirectly impacted by various disruptions. Extreme weather conditions, for instance, can have an indirect yet significant impact on their operations, leading to delays, disruptions, and additional costs. Pandemics and other health-related disruptions may impact staff availability and lead to border closings and other major restrictions, making it challenging to maintain services and respond effectively to customer demands. Geopolitical conflicts can cause significant disruptions, affecting trade routes, customs procedures, and corridor availability.

One stakeholder noted that geopolitical crises often lead to further disruptions, citing the example of difficulties around Brexit and being understaffed. Failure to respond in a timely manner can result in a snowball effect, with problems piling up and requiring more work to resolve. The significance of proactive and adaptive strategies to mitigate the cascading effects of disruptions, particularly geopolitical crises, is emphasised.

Additionally, security incidents, such as cargo theft and accidents, pose a significant risk. Accidents that result in cargo damage can disrupt the supply chain and require prompt action to limit the impact on end customers.

Disruptions affecting Terminals

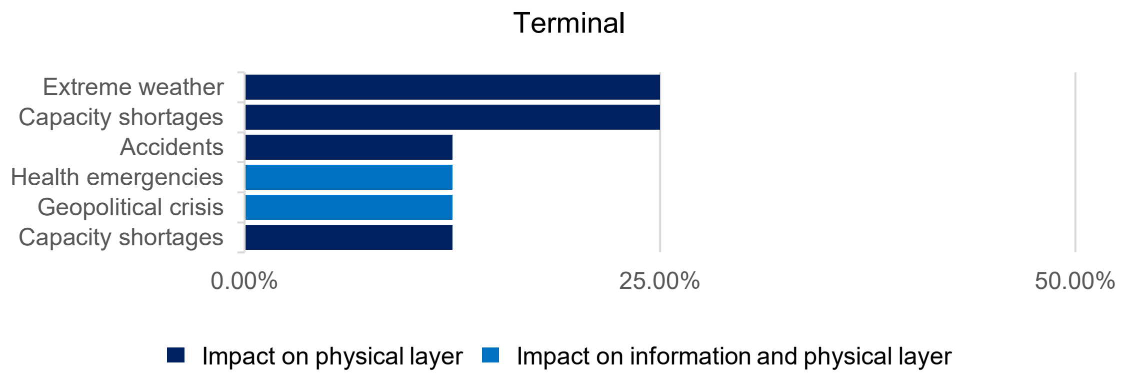


Figure 50: Disruptions affecting Terminals

Terminals are essential in the multimodal freight transport chain as they act as hubs for the transshipment and distribution of goods. They are susceptible to various disruptions that can impact their operations and have a far-reaching effect on the supply chain.

Weather conditions are a significant factor among these disruptions and pose a significant challenge to the stability and efficiency of terminal operations. As stated by a stakeholder in an interview highlighting “storms in seaports. [...] The cranes in the seaports could not load or unload the trains, or load or unload the ships at all, and as a result the trains could not be loaded or unloaded. Loading activities were restricted. [...] The ships also leave the port later or not with the desired cargo because they may not be able to be loaded due to the non-unloading” (IP 21, 2024). This insight illustrates how severe weather events can disrupt terminal operations, leading to delays affecting timetables and transport schedules, ultimately affecting the entire supply chain. Weather events can cause unexpected closures, which can jeopardise the safety of stored goods and affect the movement of goods within the terminal and on adjacent transport routes. As a hub connecting the edges of different transport routes, any accident or lack of capacity has a major impact on the entire freight transport network.

Geopolitical crises, along with global regulatory bodies, can significantly disrupt transnational transshipment processes as well.

Disruptions affecting Infrastructure Managers or Operators

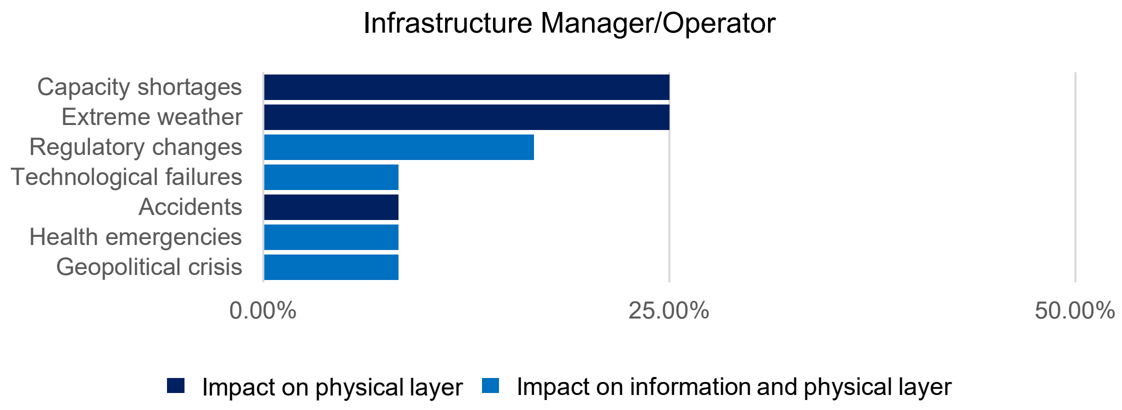


Figure 51: Disruptions affecting Infrastructure Managers/Operators

Infrastructure managers and operators play a crucial role in maintaining the supply chain as they are responsible for the operability of the transport infrastructure. However, they face various disruptions that can impact their operations, such as technological failures e. g. signal disruptions, regulatory changes, accidents, and health emergencies like pandemics, which an infrastructure operator has experienced first-hand: "What we as a [company] have felt, of course, is the Covid-19 pandemic with the complete collapse of lorry traffic." (IP 17, 2024).

To overcome these challenges, it is essential to have rapid response mechanisms and robust contingency plans in place. Capacity bottlenecks caused by construction sites, unavailable infrastructure, or planned renovations can be particularly problematic and require careful planning and coordination.

Geopolitical crises can cause border delays and affect trade routes, while extreme weather conditions can lead to detours and infrastructure closures. Therefore, it is essential to have robust contingency planning and the ability to respond quickly to changes.

Managing these disruptions effectively requires infrastructure managers and operators to combine forward planning, technological support, and close collaboration with all supply chain stakeholders.

Disruptions affecting NGOs

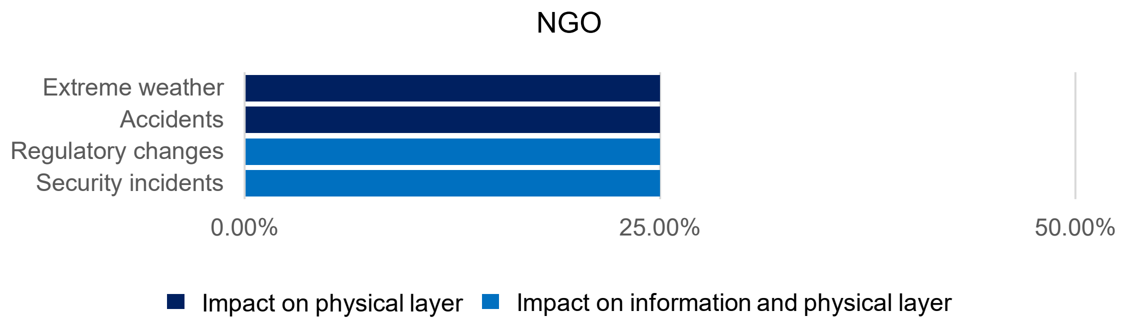


Figure 52: Disruptions affecting NGOs

NGOs operating in the humanitarian logistics sector may face various disruptions highlighting a special use case for transport logistics. Regulatory changes, such as those affecting customs clearance processes, can cause delays and additional bureaucratic hurdles. Security incidents, such as stolen cargo and accidents, pose risks that can affect both the security and efficiency of the supply chain. Extreme weather conditions also have the potential to disrupt NGO operations by blocking transportation routes or damaging infrastructure. As humanitarian aid organisations operate in crisis areas characterised by damaged or make-shift transport infrastructure, accidents occur regularly, which can impair operations significantly.

Conclusion

The analysis shows that most disruptions in the transportation and logistics primarily impact the physical layer rather than the information layer. This highlights the importance of addressing physical infrastructure vulnerabilities and operational contingencies. Nonetheless, they cause bullwhip-effects which can extend to the information layer. However, as repairs to the physical infrastructure often take a long time, it is all the more important to initiate effective, cross-stakeholder communication at an early stage in order to reschedule transports and reallocate capacities.

Because they operate directly on the physical transport infrastructure, carriers are most profoundly impacted by disruptions. Their pivotal role in facilitating the movement of goods positions them at the forefront of encountering and managing disruptions across various stages of the supply chain.

Disruptions affecting carriers encompass a spectrum of challenges, prominently including extreme weather conditions, accidents, and capacity shortages. Carriers' ability to maintain consistent and reliable transportation services is significantly impeded by disruptions, which are rooted in physical occurrences and operational constraints.

Extreme weather conditions are the most frequently cited challenge among the identified disruptions. The impact of extreme weather events on transportation networks is significant, causing delays, route diversions, and operational disruptions that affect the entire supply chain.

It is important to note that disruptions on the physical layer are more common, but disruptions on the information layer, such as regulatory changes and geopolitical crises, can also have a significant impact on the complete transport network. These disruptions, although influenced by external political and regulatory dynamics, often involve complex challenges in managing information.

6.2.4 Challenges impacting Multimodal Transportation

In addition to the disruptions already outlined, the stakeholders in the multimodal freight network face various additional challenges. While these challenges are closely linked to disruptive events, they represent obstacles that need to be addressed independently. If significant challenges already exist in normal operations, these only intensify in the event of a disruption. Addressing challenges of the transport network will improve network resilience and increase operational efficiency. The following section outlines the main challenges faced by the stakeholders interviewed and places them in a context that serves as a basis for analysing the stakeholders' requirements for increasing the resilience of the freight transport network.

Following the distinction of disruptions into the physical and the information layer, Figure 53 provides a concise overview on the categorisation of challenges faced by transport network stakeholders. As can be seen, the information layer outweighs the physical layer, with almost twice as many challenges as the physical layer. This imbalance highlights an important aspect of the difficulties in the transport sector. Many of the problems are not caused by purely physical barriers, but by the limited ability or willingness to share information.

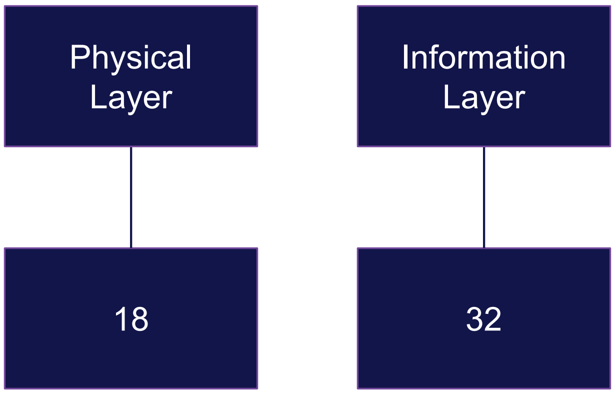


Figure 53: The different layers of challenges

Figure 54 provides a comprehensive overview of the challenges identified in the logistics sector, structured into four main dimensions and a total of eight sub-categories. This classification encompasses the entire spectrum of challenges derived from the interviews, with each challenge being uniquely counted within its respective sub-category. The main dimensions, Socio-economic Factors, Technology, Regulatory Factors, and Infrastructure-related Factors, encompass major areas where challenges in the logistics sector emerge. Notably, there is no sub-category under Regulatory Factors as it broadly covers all aspects of regulations, laws, and authorities, thus making further subdivision unnecessary. Each main dimension is broken down into sub-categories for a more detailed analysis. For instance, within the Socio-economic Factors, challenges regarding costs and economic factors as well as human resource-related challenges have different effects on the logistics sector. A brief examination of the numbers reveals that the infrastructure-related factors dimension holds many unique challenges, with Capacity Management being the predominant concern.

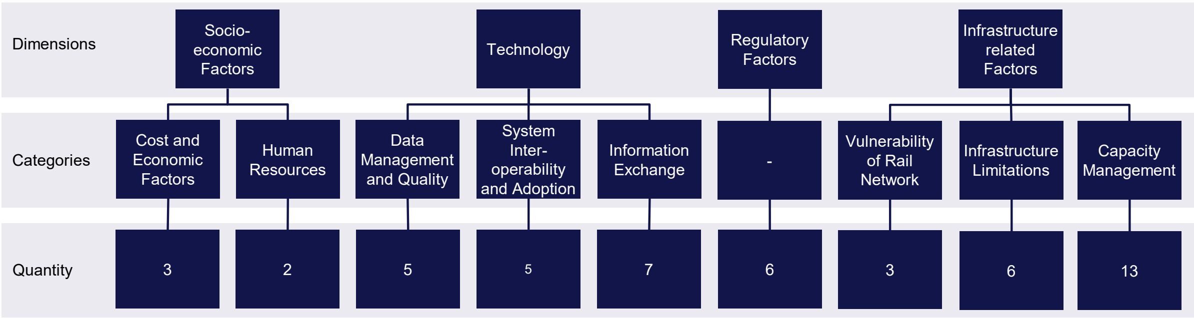


Figure 54: Interview results on the category of challenges

Although the Physical Layer's Infrastructure-related factors present the highest count of unique challenges, the Information Layer contains the most frequently mentioned challenges. The Technology category, specifically the Data Management and Quality subcategory, has been identified as one of the most cited challenges by interviewees, as shown in Figure 55, which presents a quantitative analysis where each category's mentions are calculated as a proportion of the total mentions for all categories. These proportions are then converted into percentages to provide a clear visual representation of the data. The colour gradient is particularly informative: light red indicates challenges mentioned with lower frequency (0-10%), standard red denotes medium frequency (10-20%), and deep red signifies high frequency (>20%). This analysis highlights the importance of technological proficiency in managing data quality and integrity within the logistics sector. It emphasises the need for solutions that target the digital aspects of logistics.

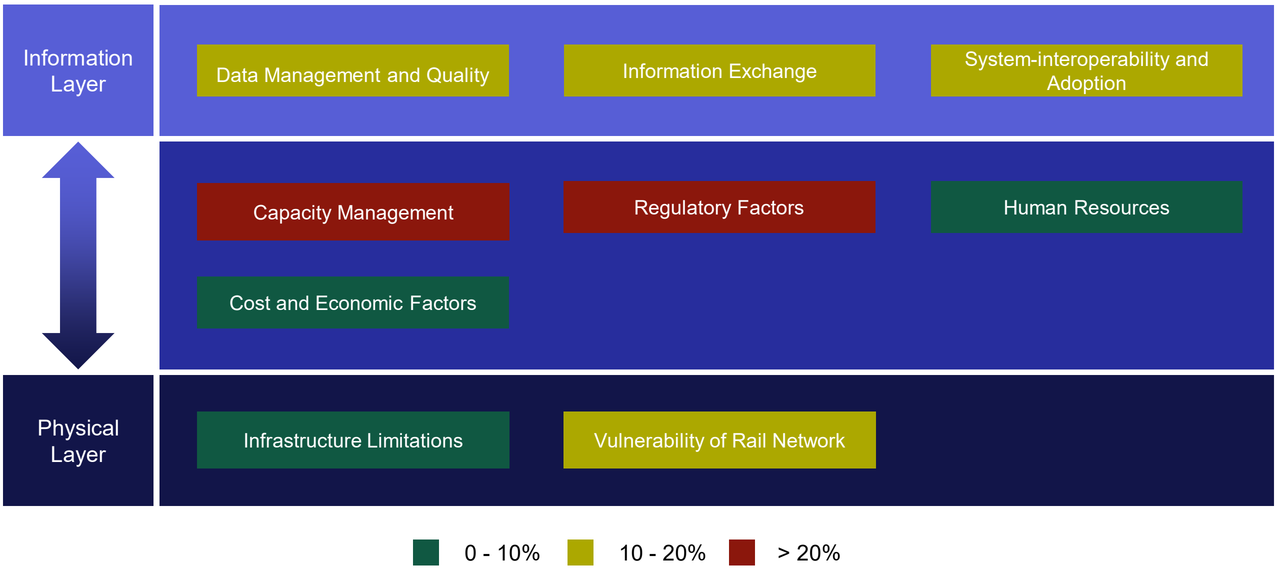


Figure 55: Challenge-Layer-Heat-Map

Figure 56 presents the proportion of challenges per role. The largest part of the graph, 43%, is represented by the carriers, which identifies them as the actors affected by the most challenges being the actors predominantly operating the transport processes itself. Furthermore, rail carriers are the group of carriers most affected by challenges.

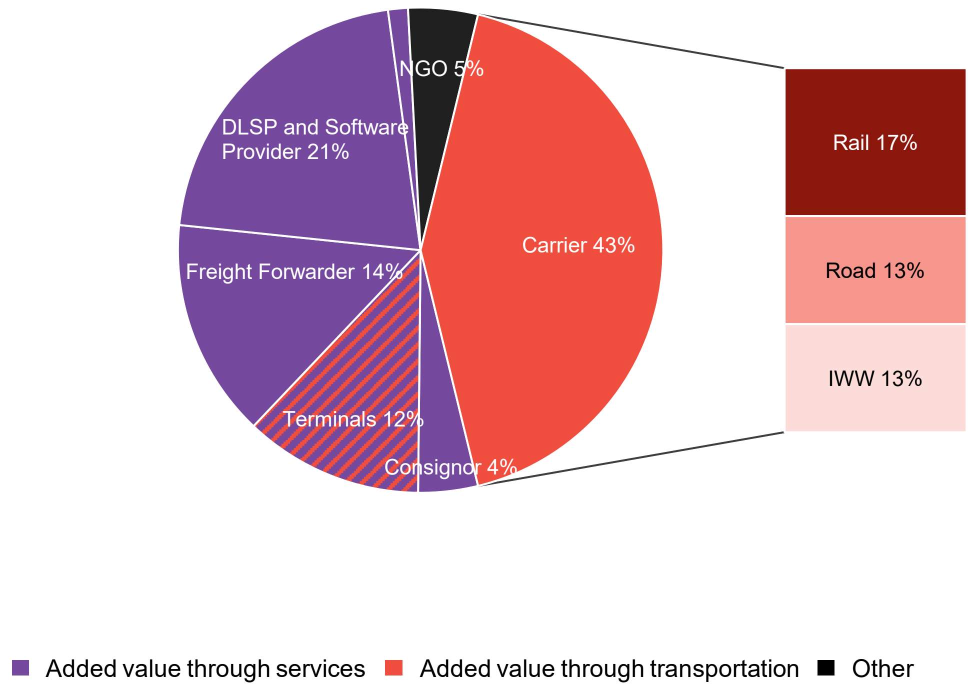


Figure 56: Share of challenges per role

Industry-wide challenges

To align the identified challenges with specific roles, the interview results have been analysed to discern how these challenges are distributed across different stakeholder positions. This next section investigates which roles encounter which challenges within the sector.

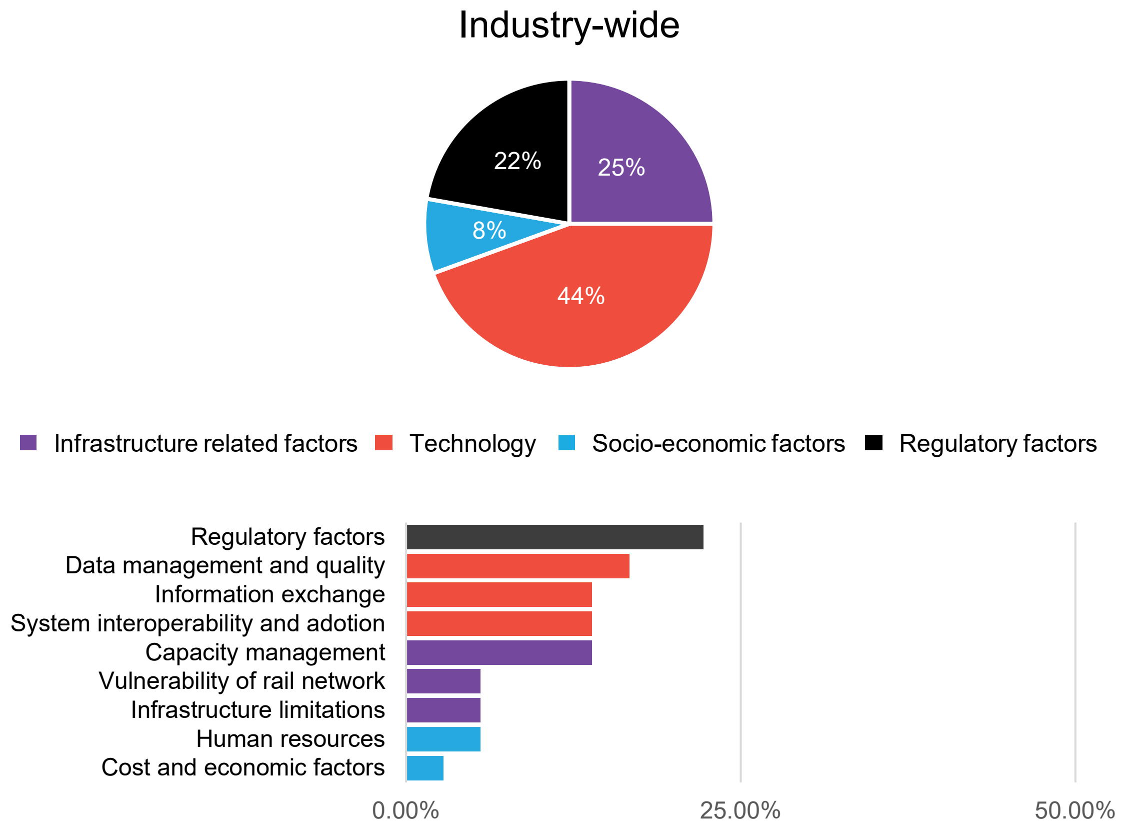


Figure 57: Industry-wide challenges

The multimodal transport network faces numerous industry-wide challenges that significantly affect its efficiency and resilience. Among them, three key challenges stand out: regulatory challenges, poor data management and quality and lacking information exchange:

Technological Factors

Data quality is a critical and widespread issue in the transport sector, impacting all involved parties. Problems with insufficient data accuracy or outdated information disrupt the smooth functioning of operations and make effective planning difficult. The lack of standardised formats and a unified tracking and management system worsens these issues, causing supply chain inefficiencies and confusion.

The core concern, echoed by most stakeholders, revolves around the "data challenge", with data quality varying greatly described by one as ranging "from a minor to a major disaster" (IP 12, 2023). Another significant issue is data accessibility, with stakeholders highlighting the considerable waste of resources and complications arising from poor data quality and ineffective sharing mechanisms (IP 2, 2023).

Information exchange is intimately connected to the problem of data quality. Poor communication, manual process dependencies, and a reluctance to share critical data lead to operational bottlenecks. Technological hurdles, such as incompatible systems and slow digital adoption, further impede efficient data exchange and collaboration. Additionally, some stakeholders deliberately withhold data for competitive reasons or due to data sharing imbalances. As transport logistics is typically a low-margin business and subject to strong cost pressure, the willingness to share information is limited. "The unwillingness to share data is certainly a big obstacle to making our system more efficient" (IP 8, 2023). Trust is an important prerequisite for sharing data and collaborative business models also promise higher sales in logistics. Although many stakeholders recognise the great benefits of collaborative business models, there are enormous reservations when it comes to practical implementation, which can often be traced back to perceived trust issues. This reluctance results in a scarcity of essential data like pricing and terminal details, causing suboptimal capacity planning: "Participants are extremely reluctant to share data... we have to plan with the insufficient data available" (IP 12, 2023).

Hence, many stakeholders express a critical need for the establishment of industry-wide digital and data quality standards to instil trust and operability and make relevant information widely accessible. Such standards would enable process improvements and boost operational efficiency across the board.

Infrastructure-related Factors

The multimodal transport network is currently facing significant challenges related to its physical infrastructure. These challenges essentially include issues of capacity management and the vulnerability of rail networks, which are crucial to ensuring efficient and reliable transport services.

Capacity management is a key concern as many parts of the network are operating at or near capacity limit. The excessive use of resources results in bottlenecks, delays, and ultimately higher costs and lower reliability within the supply chain. Managing and optimising the use of existing capacity is critical to solving these problems.

Vulnerability of the rail network is another key challenge. It refers to disruptions due to network weaknesses. The vulnerability of transport infrastructure has a direct impact on the stability and reliability of supply chains and is therefore a priority for all stakeholders in the industry. An illustrative example provided by one interviewee underscores the significance of resilience: "Then, of course, short-term or unplanned events, such as major accidents that cause closures of several hours [...]" (IP 14, 2023). This highlights the direct impact that unexpected incidents can have on the entire network's performance.

Regulatory Factors

Regulatory factors play an important role in shaping the operational landscape of the multimodal transport network and present both challenges and opportunities for stakeholders. While regulations are essential to ensure safety, fairness in competition, and environmental protection, they can also create complexities that impact efficiency and cost effectiveness.

One of the biggest regulatory challenges is the diversity and inconsistency of rules across regions and modes of transport. This inconsistency leads to high bureaucratic efforts and can make cross-border transport more difficult as stakeholders must navigate a patchwork of legislation, which can lead to delays and higher operating costs. In addition, the dynamic nature of the legal framework means that companies must keep up with changes in order to comply with regulations, making logistical planning and implementation even more difficult.

Efforts to harmonise regulations and promote standardisation across borders and modes of transport could significantly reduce these challenges.

Interconnection of the Challenges

The challenges faced by the multimodal transport network are closely intertwined and form a complex landscape in which stakeholders must navigate to ensure efficient and resilient freight transport.

At the centre of this is the issue of data quality and availability, which not only embodies the technological challenges, but also has a profound impact on infrastructure usage and capacity management. Missing or poor data not only affects operational efficiency by leading to sub-optimal use of transport infrastructure such as roads, railways and inland waterways, but also makes it difficult to comply with regulatory standards that require accurate reporting and tracking of goods.

This is because technological challenges, particularly in the area of data quality and information exchange, have a direct impact on the utilisation of infrastructure. Poor data quality and limited data availability can lead to poor decisions in the development and maintenance of infrastructure, which can result in under- or over-utilisation of assets. For example, without accurate and timely data, it is difficult to accurately predict traffic flows, leading to congestion on roads or railways and underutilisation of ports or terminals. This inefficiency not only puts a strain on existing infrastructure, but also has an impact on strategic decisions.

Regulatory factors also play a crucial role in the introduction of technologies and the development of infrastructures. For example, regulatory discrepancies between regions can lead to a fragmented landscape, making it difficult to deploy standardised technology solutions and further complicating the challenges at the interface of technology and infrastructure. The lack of regulations or clear guidelines from the state, especially in the event of a disruption, can also lead to difficulties, as each player then interprets the regulations differently, so that a standardised transfer of information is no longer guaranteed, which in turn significantly impairs data quality.

Challenges affecting Consignors and Consignees

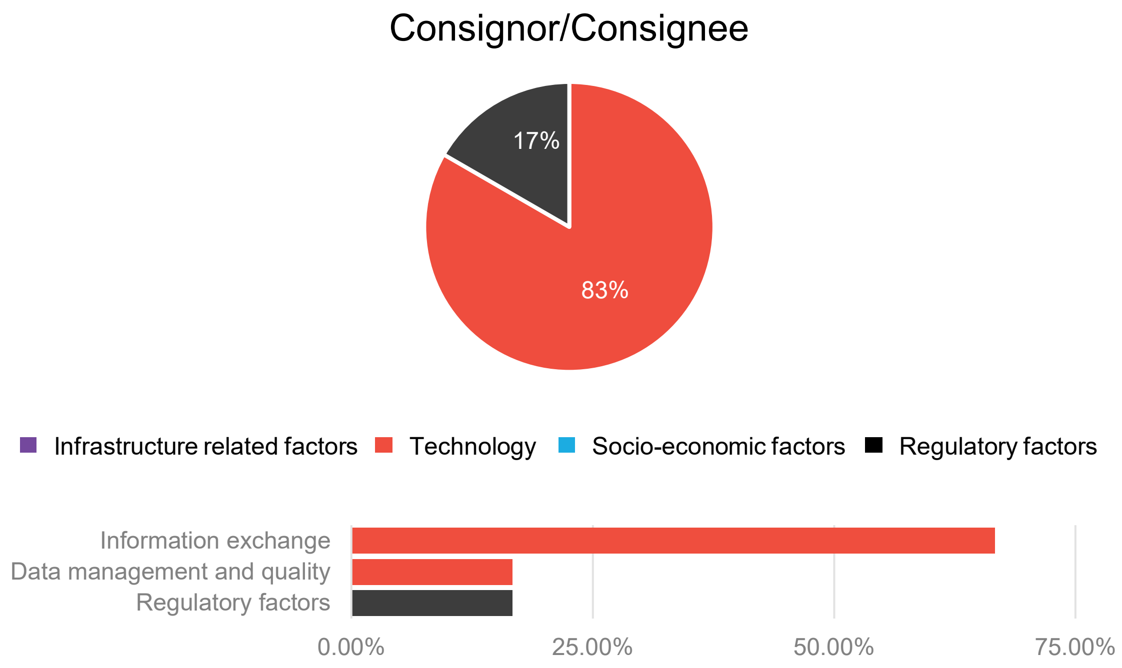


Figure 58: Consignor/Consignee challenges

Due to the position of the consignor at the beginning and the consignee at the end of the supply chain process, both roles only have a small share of the action and are dependent on the information transfer of other stakeholders. This means that both consignors and consignees are primarily affected by technological challenges regarding information exchange. These include, for example, the lack of visibility of transport status, the failure of railway undertakings to pass on information to the Consignee, a general lack of transparency and a general dependence on manual processes for communication between transport partners. Furthermore, there is poor data quality due to insufficient information on delays and their effects, which makes planning more difficult.

As one stakeholder pointed out regarding a large European railway undertaking: “Now to take […] as an example, they have reservations about giving train numbers. For whatever reason. They have reservations about giving exact departure times. So even though, if you make a little effort, you can find out everything without any problems, but they simply don't want to communicate it themselves.” (IP 21, 2024)

Challenges affecting Carriers

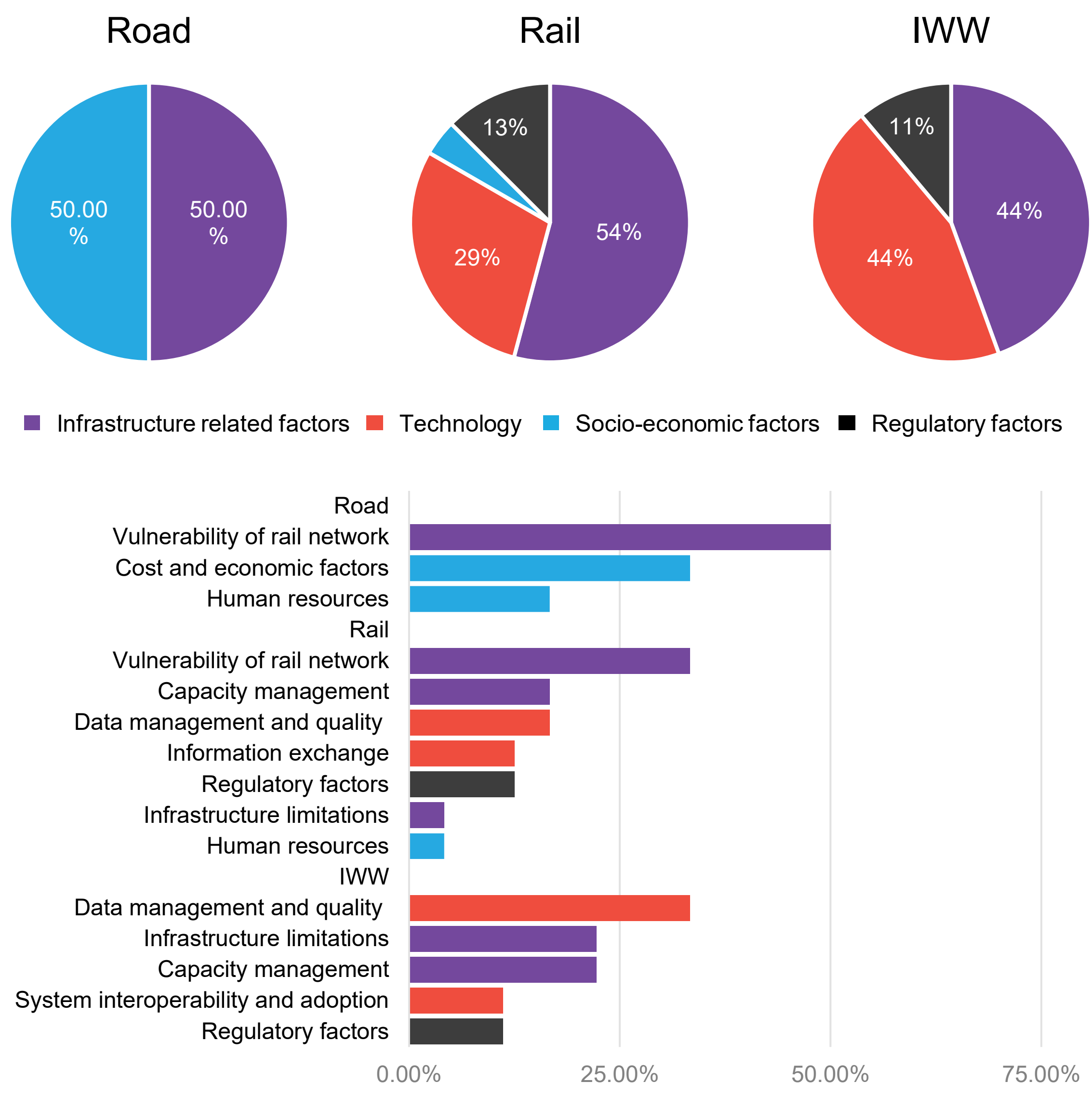


Figure 59: Carrier challenges

The challenges for carriers can be divided into three main modes of transport, as shown in Figure 59: Road, rail, and inland waterways.

Infrastructure-related Factors

At first glance, infrastructure-related challenges play a particularly important role in all three modes of transport. In the case of road transport, it is obvious that there are deficits in the resilience of the network, highlighting the fact that the transport network is highly susceptible to disruption. Added to this are infrastructural constraints such as restrictions on motorways, which hinder heavy and oversized trucks.

In terms of numbers, however, rail transport is by far the most difficult mode of transport (see Figure 59). As far as infrastructure is concerned, the biggest challenge, as with road transport, is the vulnerability of the rail network. "Robustness or non-robustness of the railway network... If something goes wrong, it always has massive consequences because this transport system is a static transport system. You can't just stop or park there. Then you'll never reach your ocean-going vessel again, and then you have a problem" (IP 2, 2023). Moreover, "The problem with the rail network is that [...] diversionary routes are usually those that are not equipped in such a way that the standard trains we run can necessarily pass through them" (IP 13, 2023). This lack of resistance is explained by the closed nature of the systems, which leads to a lack of flexibility. This lack of flexibility subsequently leads to considerable disruption effects and high dependencies, which means that in the event of a disruption, the effects are exacerbated by the lack of resistance leading to inefficiencies such as empty runs that cannot be avoided. Besides the vulnerability of rail networks, capacity management of rail transport is also a challenge. For example, it is mentioned that there are difficulties with efficient access to transport capacity and that residual capacities, which either result from capacities being held "in reserve" far in advance or from short-term rescheduling, cannot be effectively distributed.

Like rail transport, the third mode of transport, inland waterway transport, is quite a static transport system and is therefore also susceptible to infrastructure-related challenges. The further infrastructural challenges mentioned include, for example, the different conditions of the waterways in neighbouring countries or the need to increase storage capacity in inland shipping. These constraints are accompanied by difficulties in capacity management in the form of capacity planning.

Technological Factors

The interviewees pointed at significant challenges in data management, quality, and system interoperability hindering efficiency. Discrepancies from diverse data sources, like manual versus automated tracking, lead to issues such as resource misallocation due to inconsistent cargo information. The vast amount of data generated, especially from real-time tracking, demands advanced analytics for effective decision-making.

Interoperability problems, due to mismatched systems across transport modes, impede smooth data exchange and require manual coordination, exemplified by incompatible freight forwarding and rail scheduling systems. Furthermore, the uneven adoption of digital tools like TMS among stakeholders, due to varying resources and willingness, introduces bottlenecks, particularly affecting smaller entities' ability to monitor and manage cargo effectively.

Regulatory Factors

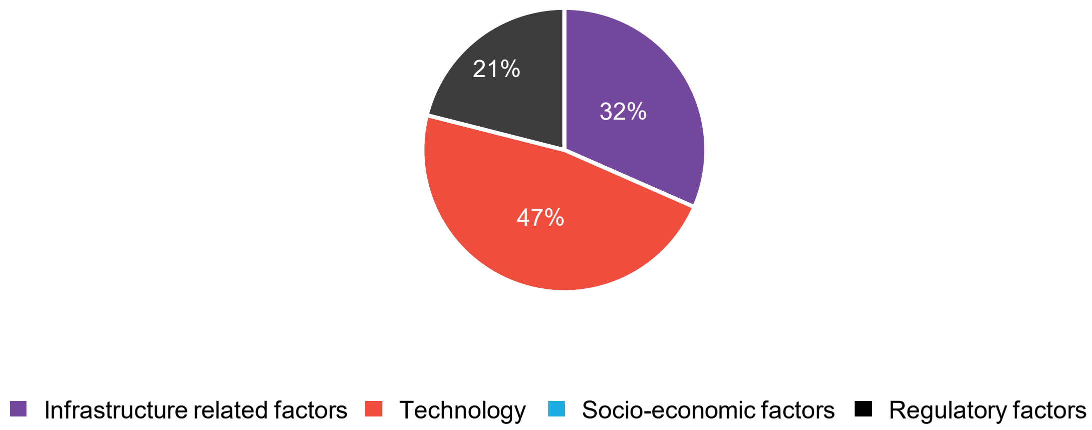
Another challenge faced by both rail transport and inland waterway transport is regulation. Both modes of transport cite the lack of clarity of legal requirements in the event of a disruption as a major challenge. In addition, regulatory barriers within Europe and general railway regulations pose a challenge for rail transport. The lack of regulation and standardisation also leads to problems with the interoperability of locomotives. Examples include the need for country-specific approvals. Also, regulations regarding the protection of personal information – while generally important and useful – can pose a challenge in context of tracking progress in logistics.

As one logistics manager expressed: “Even when we ship a truck across Europe, we don't have full visibility […]. We have tried to put a visibility system in place. But there are a lot of issues. The driver does not want to be tracked. There is personal information. This highlights the complexities and challenges faced in maintaining visibility and compliance across transportation networks." (IP 20, 2024)

Socio-economic Factors

In contrast to rail and inland waterways, socio-economic challenges were also mentioned for road transport in addition to infrastructure-related challenges. These include cost and economic factors such as high-cost pressure, the need for a low carbon footprint and human challenges such as the shortage of truck drivers.

Challenges affecting Freight Forwarders



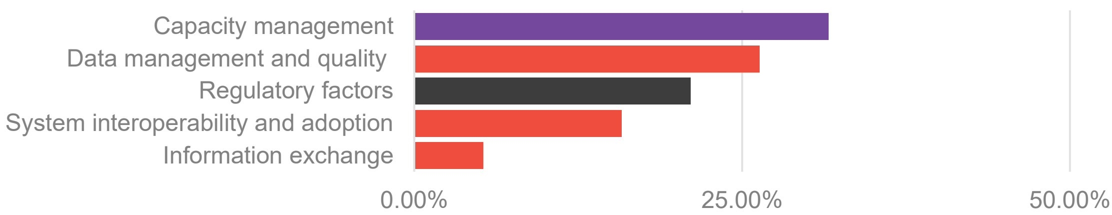


Figure 60: Freight Forwarder challenges

The data collected on the challenges faced by freight forwarders reveal several critical issues in the areas of technology, infrastructure, socio-economic factors, and regulations.

Technological Factors

In the area of technology, there are significant challenges related to data management and quality. Freight Forwarders face data inconsistencies and inaccuracies as well as documentation issues that lead to operational inefficiencies. Maintaining accurate and comprehensive master data is a recurring problem that is exacerbated by incorrect reconciliation of records and information between stakeholders. In addition, shipping information is often insufficient or inaccurate. Interoperability and adoption of systems is also a challenge as non-digital systems are predominantly used, leading to inefficiencies. Compatibility issues make it difficult to introduce and integrate new systems, and shippers' systems need to be adapted to current needs. In addition, the exchange of information, especially the release of freight price information by shippers, is delayed maintaining flexibility.

Infrastructure-related Factors

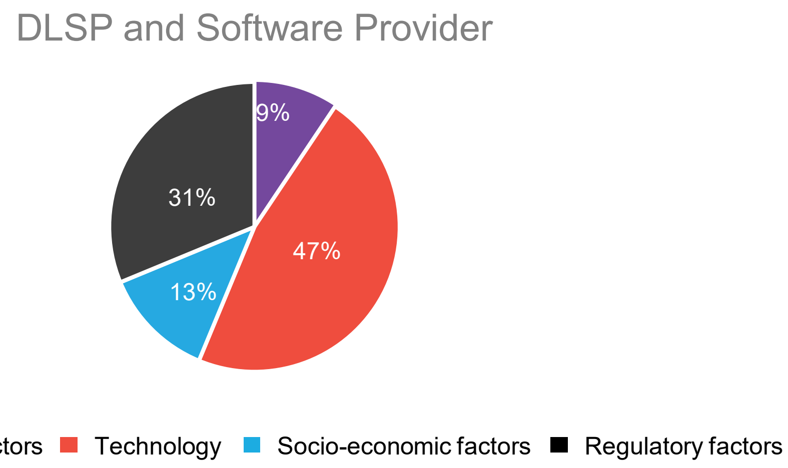
In terms of infrastructure, capacity management is a major issue. Freight Forwarders encounter operational inefficiencies, primarily due to empty runs that result from disruptions and coordination mishaps within the supply chain. The unreliability of estimated time of arrival (ETA) data and scheduling conflicts further complicates operations. Additionally, the logistics planning process is hindered by slot booking systems that necessitate reservations without full information. The challenge of ensuring the availability of necessary transportation modes persists as well.

One stakeholder illustrates the ripple effects of these challenges: "If you produce [...], you need a continuous outflow of goods. But if this flow heads to the harbour continuously without sufficient ship capacity or willingness to take the containers, the entire system eventually clogs up. That's what led to the need for interim storage because the harbours couldn't process the containers anymore. And at some point, this situation spiralled into a vicious cycle" (IP 23, 2024).

Regulatory Challenges

The regulatory framework poses several challenges due to the complexity of regulations and the delays and inefficiencies caused by bureaucratic procedures. The lack of standardised procedures further complicates industry-wide processes and leads to media disruptions, such as the unencrypted transmission of the personal identification number (PIN), which poses a significant security risk.

Challenges affecting DLSP and Software Provider



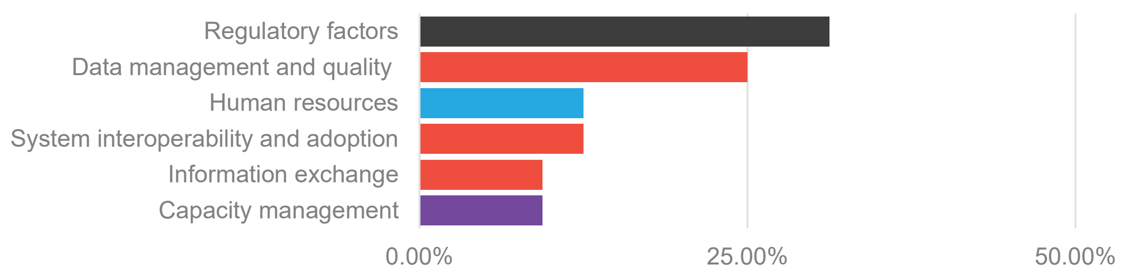


Figure 61: DLSP challenges

Digital logistics service providers (DLSPs) and software providers are currently facing several challenges that hinder their efficiency and business operations in several dimensions. Overall, DLSPs are affected by all four main categories: infrastructure-related, regulatory, technological, and socio-economic factors. Technology-related factors account for the majority, closely followed by socio-economic challenges. DLSPs and software providers are therefore the only roles where socio-economic factors also play a challenge in the information layer.

Infrastructure-related Factors

In terms of infrastructure, a critical issue is capacity management, where DLSPs are constrained by an inadequate planning basis that leads to insufficient consideration of transport capacity. This often leads to a mismatch between the demand for logistics services and the available transport resources, resulting in inefficiencies and potential delays in the supply chain.

Technological Factors

The technological challenges for DLSP and software providers are complex. "Data quality ranges from a minor to a major disaster, depending on what data we look at... Even the bad data we have is planning data. But not at all or to a very small extent data on the actual transport process" (IP 12, 2023). The exchange of information proves to be problematic as the information from the terminals does not arrive in time, although there are interfaces to facilitate this exchange. In addition, there is a recognisable reluctance among the various players to share critical data, which is exacerbated by interoperability issues, especially when data from the rail and intermodal sectors does not reach customers reliably. In addition, DLSPs and software providers face data management and quality issues, which are compounded by the use of outdated technologies and the lack of standardised transport management systems, especially for SMEs. This inconsistent technology landscape hinders the introduction of advanced systems that could enable better integration of logistics services.

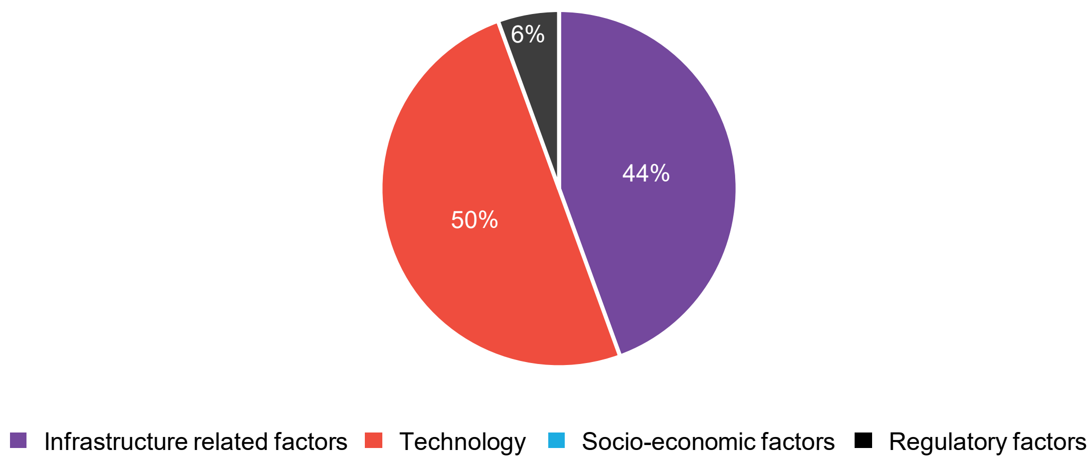
Socio-economic Factors

On the socio-economic front, DLSPs and software providers are struggling with human resource issues. These human factors include cultural differences, language barriers, accessibility issues and administrative hurdles and are significant barriers that can affect service delivery and operational efficiency.

Regulatory Factors

Regulatory factors pose additional challenges for DLSPs and software providers. A striking number of operational issues arise from the individual interpretation of regulations, highlighting a lack of clarity and consistency in the enforcement of regulations. Regulatory requirements can be overly complex, making their effective implementation impossible for some organisations, particularly smaller ones. This complexity is further extended by a lack of standardised terminology and procedures, such as different names for vehicle types, which leads to inefficiency and confusion in the logistics process.

Challenges affecting Terminals



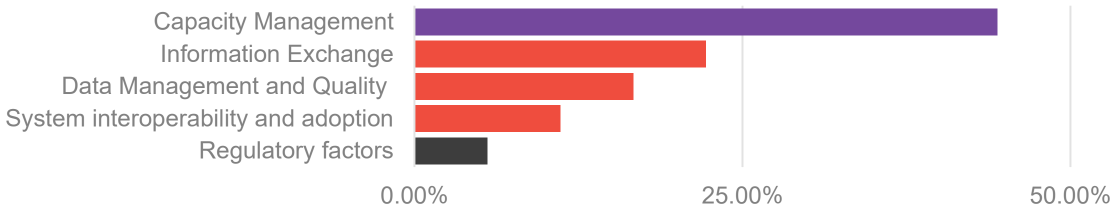


Figure 62: Terminal challenges

Terminals are faced with several challenges that affect their operation. These challenges can be categorised into infrastructure-related factors, technological factors, and regulatory factors. The performance and efficiency of terminal operations is highly influenced by how these challenges are overcome.

Infrastructure-related Factors

A significant portion of the challenges encountered by terminals affect capacity management. Efficiently scheduling terminal slots is fraught with difficulties, resulting in coordination mishaps and missed turnarounds due to road overcapacity. The planning process often faces delays and disorganisation, leading to issues with slot shifting. These problems are aggravated by regular train delays and cancellations, emphasising the necessity of harmonising terminal slots with train paths for improved capacity utilisation.

Highlighting the gravity of these issues, one stakeholder shared, "The clogging of the infrastructure or the overloading of the infrastructure meant that, ultimately, handling became unfeasible, and containers could not be transported in an organised fashion. Consequently, we experienced very slow handling. Trains were underutilised, departing at half capacity, which further strained the terminals. Ultimately, it boiled down to an overutilisation of the available capacities" (IP 23, 2024)

Technological Factors

Technological challenges constitute a significant portion of the difficulties encountered by terminals, representing over half of the identified issues. A critical problem in data management and quality is the absence of automated data exchanges between terminals and railway undertakings (RUs). This deficiency leads to substandard tracking and tracing data quality. The challenge is further compounded by the need for system implementation and interoperability; numerous parallel systems coexist, complicating the maintenance of seamless operations. Highlighting this issue, one stakeholder remarked, "That's the weakness of the terminals. With the RUs, there are still no automated data flows at all. You actually have to change the systems" (IP 4, 2023), underscoring the pressing need for technological upgrades and integration to enhance terminal efficiency.

In addition to these challenges, however, the exchange of information is a critical issue for terminal operations, especially in times of disruption. Communication during disruptions is often inadequate or delayed, which can exacerbate the situation and prolong the impact.

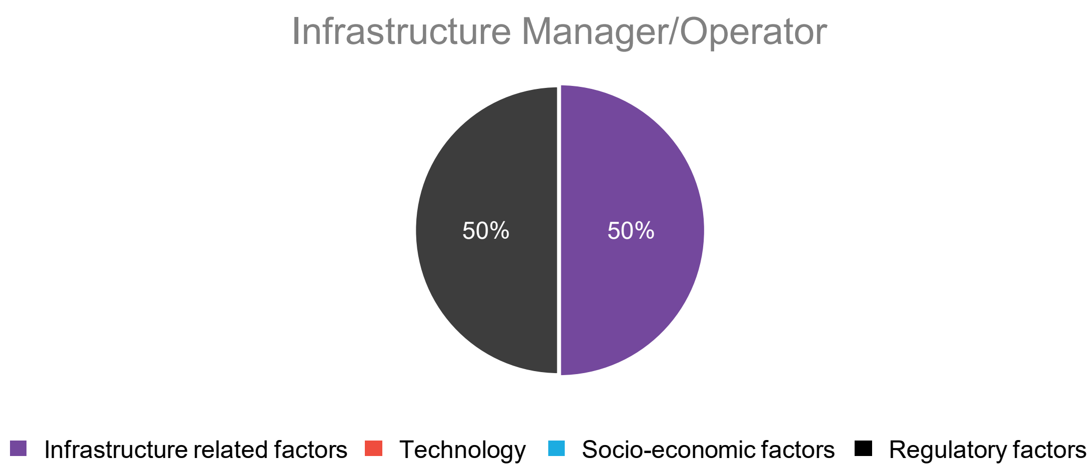
This lack of timely communication does not consider the full extent of the disruption's impact on operations and the logistics chain. In addition, there is a lack of transparency in the information communicated, making it difficult for all parties involved to make informed decisions. One example of this is that freight forwarders tend to announce freight prices late to maintain operational flexibility. This practice can cause problems for other stakeholders who rely on this information for planning and execution.

Regulatory Factors

Regulatory factors further complicate the scenario. The authorities' guidelines are often unclear, especially in the event of disruptions. This lack of clarity can lead to inefficiency and confusion, which impacts all stakeholders involved.

To summarise, terminals face a complex web of challenges. Technological difficulties sit alongside infrastructure-related problems, particularly in capacity management and data processing. Overcoming these challenges requires a coordinated effort that not only addresses the improvement of data and system management, but also requires clear legal guidelines for effective incident management.

Challenges affecting Infrastructure Managers or Operators



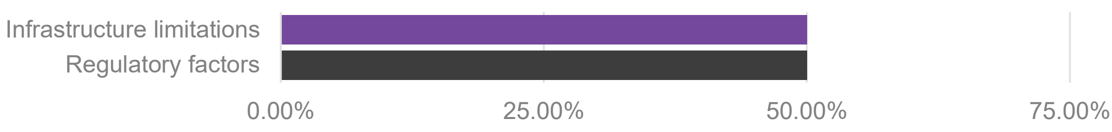


Figure 63: Infrastructure Manager/Operator challenges

The challenges faced by infrastructure managers and are primarily related to infrastructural constraints and regulatory factors.

Infrastructure-related Factors

Infrastructure-related factors include the need for the flow infrastructure to be up to date. This means that for efficient freight transport, the physical framework that facilitates transport, particularly across rivers, must be maintained to a standard that meets current and future logistical requirements. This includes not only the maintenance of existing structures, but also the improvement and modernisation of facilities to meet the changing demands of freight transport.

Regulatory Factors

Regulatory factors include the lack of standards for data formats and quality. This challenge is of great importance in the context of the digitalisation of logistics, where data-driven decisions are of major importance. The lack of standardised data formats can lead to inefficiencies in communication, data processing and information exchange between stakeholders in the freight forwarding industry.

The quality of data, which has a direct impact on operational efficiency, strategic planning, and decision-making, remains an issue that regulators or industry associations need to address through the development and implementation of harmonised standards, according to the stakeholders surveyed.

Challenges affecting NGOs

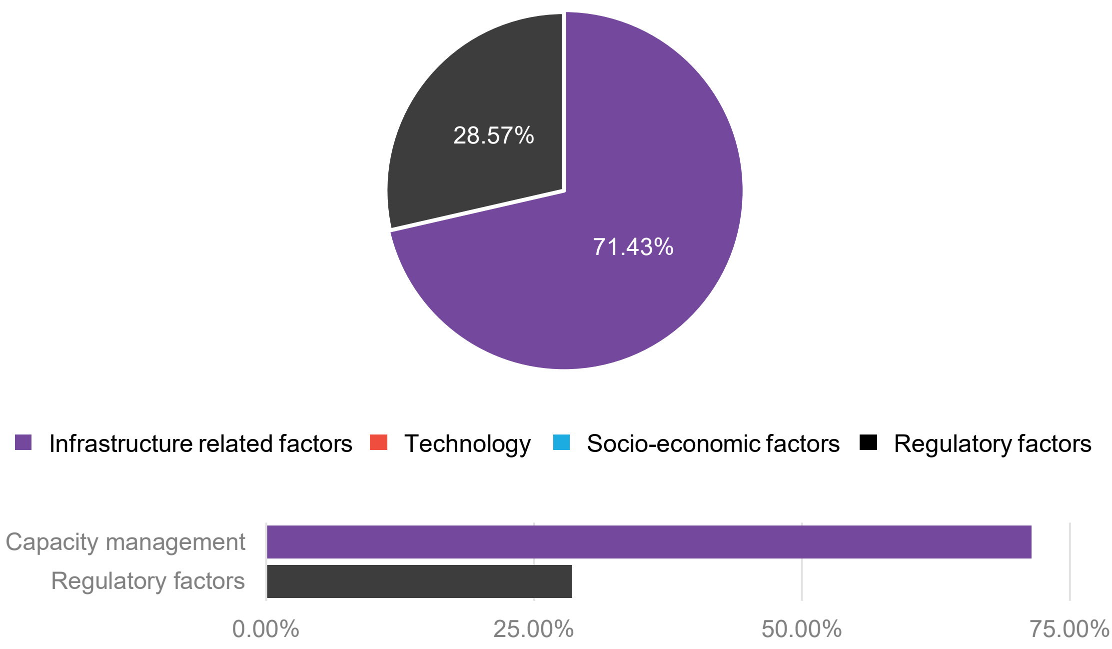


Figure 64: NGO challenges

Non-governmental organisations (NGOs) working in the field of humanitarian logistics face several challenges regarding infrastructure and regulations that affect their operational efficiency and effectiveness.

Infrastructure-related Factors

NGOs need to address the critical issue of capacity management in their logistics activities. This includes the challenges associated with the distribution of capacity, such as ensuring that adequate transport is available where and when it is needed. The sector is facing a shortage of transport, whether due to a lack of vehicles or carriers, which can be exacerbated by fuel shortages. In addition, climate change has led to more frequent and more severe disruptions, that are difficult to manage.

Regulatory Factors

On the regulatory side, NGOs must navigate complex customs clearance procedures. International standardisation and compatibility of fuels and engines pose further complications. These regulatory issues can lead to delays and increase the cost of humanitarian operations, especially in regions with less harmonised regulatory frameworks.

To summarise, the NGO sector, particularly in the field of humanitarian logistics, faces complex challenges that require adaptable and innovative approaches to capacity management and regulatory compliance. However, it becomes evident that NGOs involved in humanitarian logistics need to operate differently from other participants in the supply chain. Although they are not directly involved in the supply chain, they can use networks and tools to solve logistical problems.

Conclusion

The analysis of the stakeholder challenges indicates a noteworthy trend where most challenges predominantly stem from the information layer rather than the physical layer within the transportation and logistics sector. This emphasises the pivotal role of data management, communication protocols, and technological infrastructure in shaping the operational landscape of the industry.

Carriers encounter the most challenges within the transportation network due to their pivotal role in carrying out the transport processes. As the entities directly responsible for physically moving goods from one point to another, carriers contend with several complexities. These challenges encompass various aspects such as data management and quality, the vulnerability of the rail networks, regulatory factors, and capacity management issues.

As a visual summary of the insights gained, the Harvey-Ball-Matrix in Table 8 allows the identification of the most significant challenges. These are used in the following section to determine the central needs of the stakeholders, which are specifically addressed by ReMuNet in order to increase the efficiency and resilience of the multimodal transport network. A challenge is characterised as significant as soon as it is linked to a half-filled

Harvey ball. These challenges represent those that are perceived as significant by the majority of stakeholders through a large number of mentions.

The most prevalent challenges identified encompass regulatory and capacity factors and technology-related issues. Within this domain, challenges related to data management and quality, information exchange protocols, and system interoperability stand out as dominant concerns. „The data quality ranges from a minor to a major disaster, depending on which data we look at“ (IP 12, 2023). Additionally, the availability and willingness to share information is a major concern to many stakeholders. “I think that the unwillingness to share the data is certainly a big obstacle to making our system more efficient” (IP 8, 2023). These challenges highlight the critical need for robust technological solutions and standardised protocols to address the complexities of data exchange and interoperability across various stakeholders and systems within the transport network aiming for real time data availability and a high accuracy of information.

Moreover, regulatory factors and capacity management present another significant challenge for the broader transportation ecosystem. Evolving regulatory frameworks, compliance requirements, and legislative changes introduce additional layers of complexity and uncertainty, necessitating continuous adaptation and proactive engagement with regulatory bodies to ensure compliance and operational continuity.

Although the vulnerability of the rail networks is perceived as a significant challenge, this cannot be considered in the further analysis, as it arises purely from the physical layer and therefore cannot be addressed by a digital solution such as ReMuNet. As the project is not designed to make changes to the physical transport infrastructure, it is investigating how digital technologies can enable improved cross-stakeholder information exchange and how as many stakeholders as possible can be integrated into the solution in order to increase both the performance and resilience of the overall system.

Table 8: Harvey-Ball-Matrix for the identification of central stakeholder challenges

	DATA MANAGEMENT AND QUALITY	SYSTEM INTEROPERABILITY AND ADOPTION	INFORMATION EXCHANGE	REGULATORY FACTORS	VULNERABILITY OF RAIL NETWORK	INFRASTRUCTURE LIMITATIONS	CAPACITY MANAGEMENT	COST AND ECONOMIC FACTORS	HUMAN RESOURCES
Consignor/ Consignee	◕	○	●	◕	○	○	○	○	○
Carrier	◕	○	◔	◑	●	◔	◑	○	○
Freight Forwarder	●	◕	○	●	○	○	●	○	○
DLSP, Software Provider	●	◑	◔	●	○	○	◔	○	◑
Terminal	◕	◑	●	◔	○	○	●	○	○
Infrastructure Manager/ Operator	○	○	○	●	○	●	○	○	○
NGO	○	○	○	●	○	○	●	○	○
TOTAL	◕	◑	◑	●	◑	○	◕	○	◔

○ 0 - 5% ◔ 5 - 10% ◑ 10 - 15% ◕ 15 - 20% ● >20%

7 STAKEHOLDER NEEDS AND IMPLICATIONS FOR REMUNET

The analysis of disruptions and challenges within the transportation and logistics sector provides valuable insights into the complexities and dynamics of the industry. Across both disruptions and challenges, a distinct pattern emerges, underscoring the critical role of carriers and the interplay between physical and information layers. Especially challenges originate predominantly in the information layer being characterised by technology deficits and unwillingness to share data. Although the vulnerability of the rails network is a major concern especially to rail carriers, ReMuNet as a digital solution can only address disruptions and challenges assigned to the information layer, focusing on technology, capacity management and regulatory aspects.

The analysis identified the following challenges at the information level as the most significant to key actors of the multimodal freight transport network:

1. **Information management and quality**
2. **System interoperability and adaption**
3. **Information exchange**
4. **Regulatory factors**
5. **Capacity management**

Reflecting on the main challenges technology emerges as the largest overarching category. Within this domain, three sub-categories stand out: data management and quality, system interoperability, and information exchange.

Issues with data management and quality, such as inaccuracies, incompleteness, and inconsistencies, hinder the reliability and usability of information across the transportation ecosystem. These challenges stem from diverse data sources, which may produce disparate or conflicting data sets. Moreover, ensuring data availability and accessibility remains a challenge, as stakeholders often encounter limitations in accessing relevant data due to isolated systems, proprietary formats, or data ownership issues. Furthermore, the integration of diverse data streams presents additional complexities, as disparate data sources must be harmonised and consolidated to derive meaningful insights. The lack of standardised formats, metadata, and protocols complicates data integration efforts, leading to inefficiencies and errors in analysis and decision-making processes. Additionally, the predominance of non-digital systems and manual data entry further exacerbates these challenges, hindering real-time data exchange and collaboration among stakeholders. Implementing robust data management systems to ensure accuracy, reliability, and integrity of data across the transportation network and the promotion of data standardisation, interoperability, and automation could enhance data quality, availability, and harmonisation within transportation networks.

Another key technological challenge is the system interoperability and adaption. Seamless integration and communication between different systems is essential for efficient operation, but achieving this interoperability is often complex and resource intensive. This is compounded by the problem of data integration, where multiple data sources need to be harmonised and consolidated to provide a single view of operations. Furthermore, the prevalence of parallel systems exacerbates these problems and leads to fragmentation, redundancy, and inefficiency.

Adding to the complexity is the usage of non-digital systems in certain sectors, which further complicates data sharing and integration efforts. In addition, the persistence of outdated technologies is a significant barrier and hinders innovation, scalability, and the adoption of more advanced solutions. Overcoming these challenges requires standardisation, modernisation, and deployment of digital technologies to improve the interoperability, efficiency, and resilience of transport networks. Additionally, the deployment of secure and collaborative communication channels facilitates timely and accurate sharing of information. Solutions such as integrated digital systems can improve system interoperability by adhering to standardised protocols, providing well-documented APIs, and utilising middleware for seamless communication.

Information exchange poses a significant technological challenge for stakeholders within transportation networks, encompassing various hurdles that impede efficient communication and collaboration. One key difficulty lies in data transmission, where stakeholders encounter challenges related to the speed, reliability, and security of transferring data across diverse systems and platforms. Moreover, stakeholders often face a lack of visibility on transportation status, resulting from fragmented data sources and disparate information systems. This lack of visibility makes it challenging to track the movement of goods, monitor transportation assets, and anticipate potential disruptions or delays. Further, the absence of transparency in data sharing practices further complicates information exchange efforts, as stakeholders may be reluctant to share sensitive or proprietary information due to concerns about privacy, competition, or liability.

The reliance on manual processes and the absence of automated data flows exacerbate the challenge of information exchange within transportation networks. Manual data entry, processing, and dissemination are prone to errors, delays, and inefficiencies, leading to inconsistencies and inaccuracies in information exchange. Additionally, insufficient, or delayed communication between stakeholders further aggravates the problem, as critical updates, alerts, or notifications may not reach the relevant parties in a timely manner, impacting decision-making and response times.

Overcoming these challenges requires the adoption of advanced technologies, standardised protocols, and collaborative platforms. Especially collaborative platforms offer a comprehensive solution to address the challenge of information exchange within transportation networks by providing a centralised and efficient mechanism for stakeholders to share data, insights, and resources. These platforms serve as digital hubs that facilitate seamless communication, collaboration, and coordination among diverse stakeholders, overcoming the limitations of fragmented information, interface issues and inefficient communication channels.

Beyond technology-related challenges, regulatory factors present significant challenges for stakeholders within transport networks, encompassing a range of concerns and obstacles that hinder operational efficiency and compliance. One primary challenge arises from concerns over regulatory requirements, as stakeholders must navigate a complex landscape of laws and regulations governing various aspects of transportation operations. These requirements often impose stringent obligations related to several aspects requiring stakeholders to invest substantial resources in compliance efforts. Moreover, uncertainties stemming from unclear guidance from authorities during disruptions exacerbate the challenge of regulatory compliance. In times of crisis or emergencies stakeholders may struggle to interpret and implement regulatory requirements effectively, leading to confusion, delays, and inconsistencies in response efforts. Additionally, regulatory barriers, including bureaucratic processes and administrative hurdles, can impede innovation and hinder the adoption of new technologies and practices within the transportation industry.

Overall, the lack of clear guidance, regulatory barriers, bureaucratic processes, complexity of the regulatory framework, and lack of standards pose significant challenges for stakeholders within transport networks, underscoring the need for streamlined and harmonized regulatory approaches especially regarding adaptability and rapid responses to disruptions to support innovation, efficiency, and sustainability within the transportation industry.

Capacity management presents a multifaceted challenge for transport network stakeholders, stemming from both physical and information layer constraints. Focusing on the information layer, coordination and scheduling issues are a major part of the challenge, as stakeholders across the transportation network must collaborate effectively to allocate resources, manage congestion, and mitigate disruptions enabling an efficient transportation process. Adding to the coordination issues, inadequate data collection methods, insufficient data quality, and limited visibility into transportation status contribute to uncertainties and inefficiencies in capacity management efforts. Addressing capacity management challenges requires the implementation of advanced analytics and forecasting tools to optimise resource allocation, mitigate congestion, and enhance overall capacity orchestration.

Resulting from these challenges, five distinct stakeholder needs assigned to the information layer can be identified:

1. **Data standardisation and automation**
2. **Integrated digital solutions**
3. **Facilitated data exchange and collaboration**
4. **Streamlined transport regulations**
5. **Advanced analytics and forecasting tools**

Addressing these needs, ReMuNet offers multiple solutions to enable and incentivise synchromodal relay-transportation on European rail, road, and inland waterways to increase the holistic network resilience while reducing emissions and boosting freight transport corridor efficiency in case of disruptive events.

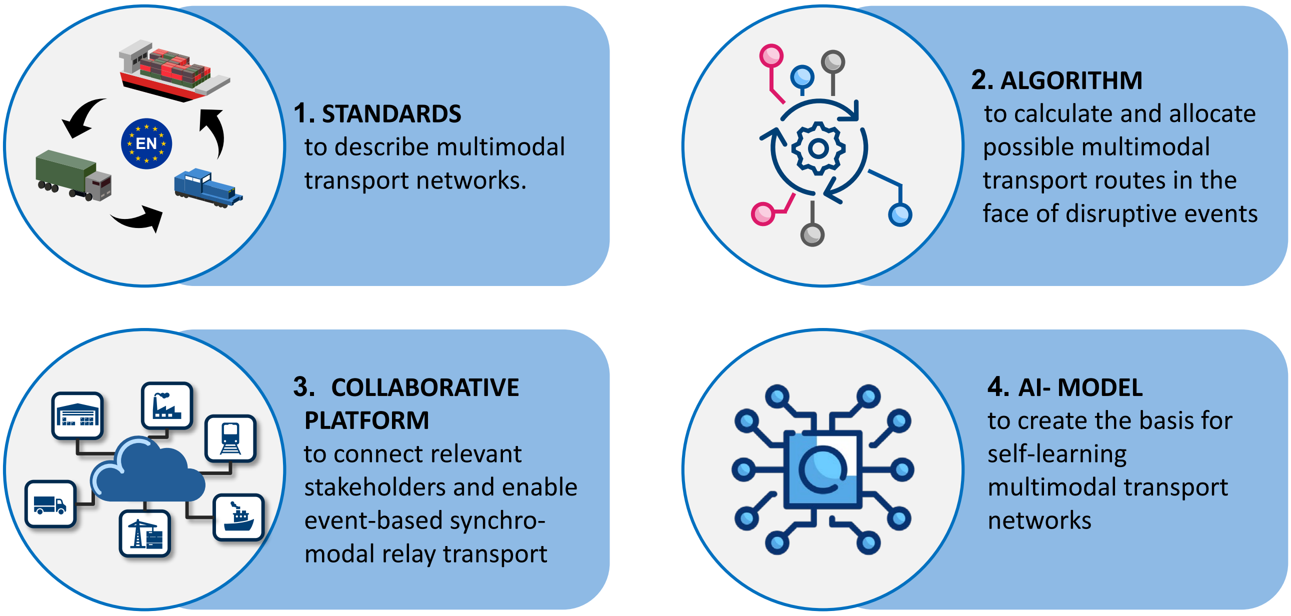


Figure 65: Core functionalities of ReMuNet

1. A **standardised methodology** to describe multimodal transport networks and data standards used within deriving from existing approaches and developed together with critical stakeholders to ensure Europe-wide practicability and acceptance which can be easily transferred into appropriate regulatory frameworks ensuring more efficient communication and operational stakeholder interconnectivity. Creating a unified data pool by integrating all relevant stakeholders via interfaces, a wide variety of anonymous planning data will be refined to create the necessary base for decision making. By establishing uniform formats and automated processes, this methodology streamlines data exchange, enabling real-time decision-making and resource optimisation. Ultimately, this standardised approach enhances operational efficiency, communication, and stakeholder connectivity, contributing to a more resilient and interconnected transportation ecosystem.

2. The development of an **advanced algorithm** capable of calculating multimodal route alternatives and managing capacity utilisation in the face of disruptive events leverages real-time data to dynamically adjust and synchromodally plan alternative routes, ensuring optimal efficiency and resilience. Additionally, the algorithm incorporates capacity management strategies to optimise resource utilisation and mitigate congestion in the transportation network. This involves dynamically allocating available capacity across different modes of transportation based on demand fluctuations and operational constraints. Furthermore, effective data management is critical to the algorithm's success, requiring robust systems for collecting, processing, and disseminating real-time data streams from diverse sources. Overall, the integration of these capabilities

enables the algorithm to enhance flexibility, reliability, and responsiveness in multimodal transportation operations, thereby improving supply chain resilience.

3. The **collaborative platform** represents a solution that fosters connectivity among logistics stakeholders, empowering them to effectively navigate disruptions through digital logistics and network management tools. By seamlessly connecting transport actors, the platform facilitates the exchange of critical information and promotes collaborative efforts to manage disruptions efficiently. Through data-sharing mechanisms, logistics operators can access real-time updates on disruptions and transport statuses and leverage advanced analytics to anticipate and respond proactively to challenges. The platform's integrated digital solutions empower operators to explore alternative route planning information, utilising sophisticated algorithms to optimise transportation routes. Moreover, the platform serves as an orchestrator of event-based synchromodal relay transportation, dynamically coordinating the movement of goods across various modes of transport to minimise delays and maximise efficiency. This integration of digital tools and collaborative capabilities not only enhances operational agility and resilience but also fosters a culture of cooperation and innovation within the logistics ecosystem, ultimately driving value creation and competitive advantage for all stakeholders involved.
4. Utilising **AI**, particularly reinforced learning, to model and evaluate alternative courses of action improves resilience of European trade through a self-learning, adaptive multimodal freight transport and logistics network. By employing AI algorithms, the system can learn from past experiences and continuously adapt its decision-making processes to changing conditions, thereby enhancing its effectiveness in transport orchestration. This adaptive capability enables the network to swiftly respond to disruptions by dynamically adjusting routes, modes of transport, and resource allocations in real-time.

Besides addressing the stakeholders core needs, ReMuNet also fosters to improve ecological sustainability using digital technologies.

Digital solutions in multimodal transportation are pivotal for enhancing sustainability by optimising resource usage, minimising environmental impact, and fostering eco-friendly practices. Through real-time data analytics and optimisation algorithms, these solutions streamline operations, mitigate congestion, and foster the utilisation of greener transportation modes, reducing carbon emissions and enhancing efficiency. Additionally, digital technologies facilitate the implementation of innovative sustainability initiatives such as dynamic pricing models and collaborative platforms, promoting resource sharing and waste reduction. Enhanced visibility and transparency enabled by digitalisation allow stakeholders to track and reduce environmental impact throughout the supply chain, driving consumer demand for sustainably sourced products. Ultimately, the integration of digital solutions within multimodal transportation not only improves operational efficiency and resilience but also aligns with broader sustainability goals, advancing environmental stewardship and driving positive change in the transportation industry. The digital solutions therefore enable a range of improvements (s. Figure 66):

1. **Operational efficiency and emissions reduction:**

   Digital platforms enable dynamic route planning, minimising inefficiencies associated with traditional supply chain operations like empty runs and unnecessary fuel consumption, directly contributing to sustainability.

2. **Collaborative sustainability efforts:**

   The shift towards collaborative approaches between supply chain actors, facilitated by digital platforms, enhances the collective ability to adopt sustainable technologies and practices.

3. **Improved Sustainability Reporting:**

   Freight forwarders and other supply chain participants use digital platforms to provide sustainable value propositions to end customers, including detailed carbon footprint tracking and the use of electric trucks or alternative fuels such as hydrogen. This transparency supports informed decision-making by consumers and businesses and promotes a culture of sustainability.

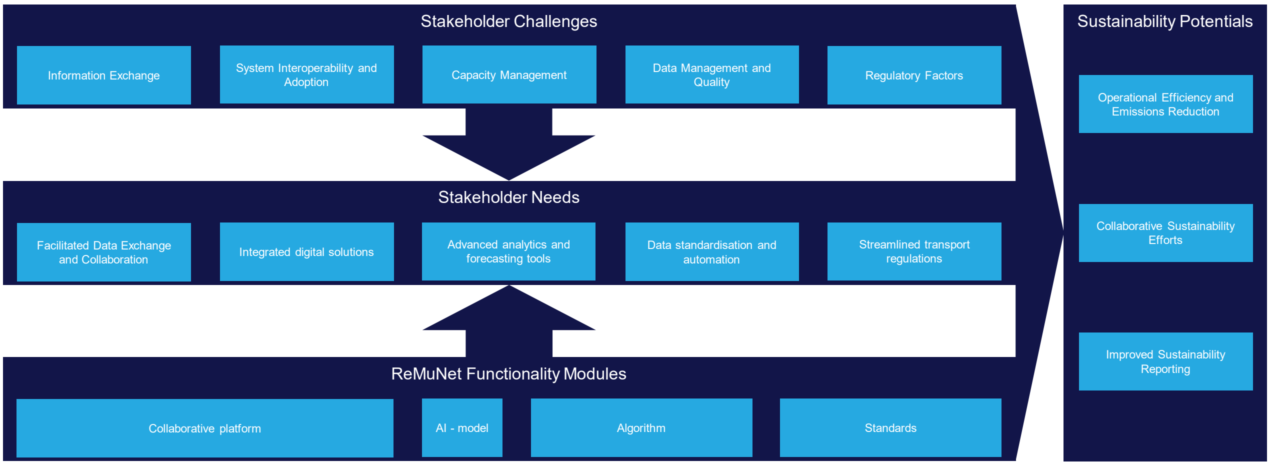


Figure 66: ReMuNet functionality modules addressing stakeholder challenges and needs

To summarise, digital solutions developed within ReMuNet not only address the immediate challenges posed by disruption, but also open opportunities for companies in the supply chain to innovate and create value. This is achieved through improved operational efficiency, collaborative sustainability initiatives and the ability to provide transparent and sustainable value propositions to customers. Through these mechanisms, the ReMuNet platform serves as a bridge between current operational needs and a more sustainable, efficient future for supply chain management.

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ANNEXES

Annex I: Project Glossary

TERM	DEFINITION	REFERENCE	RELATED TERMS/ ELEMENTS IN THE CONCEPTUAL FIELD
Actor	Actors are all individuals, companies or other organisations that are involved in a system and have a common creation of value as their goal.	In accordance with Adner (2017)	Role
Barge	"a long boat with a flat bottom, used for carrying heavy objects"	McIntosh (2013)	
Bimodal terminal	Bimodal terminals are specialised facilities designed for the transshipment of goods between two distinct modes of transportation.	Wisnicki and Bonk (2020)	
Black swan	"First, it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Second, it carries an extreme impact. Third, in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable."	Taleb (2007, p. xvii)	Gray swan, white swan, perfect storm, dragon king
Business model	"A business model describes the rationale of how an organisation creates, delivers, and captures value"	Osterwalder et al. (2010, p. 14)	
Carrier	"Independent logistics service providers to execute […] transport. […] it operates in the so-called hire or reward (HR) mode."	Schönberger (2005, p. 3)	
Combined (freight) transport	"Intermodal transport of goods where the major part of the journey is by rail, inland waterway or sea and any initial and/or final leg carried out by road is as short as possible."	eurostat et al. (2010, p. 157)	

TERM	DEFINITION	REFERENCE	RELATED TERMS/ ELEMENTS IN THE CONCEPTUAL FIELD
Composition	"The process of assembling and consolidating freight at a terminal offering an intermodal interface between a local/regional distribution system and a national/international distribution system. It is commonly referred to as the 'first mile'."	Rodrigue (2020)	
Consignee	The person or company to whom goods or documents are officially sent or delivered.	McIntosh (2013)	Consignor
Consignor	A person or company that sends goods to someone, usually the person who is buying them.	O'Shea (2011)	UN Convention, Consignee
Corridor	A transport infrastructure project that connects different locations, such as urban areas, rural areas, or international gateways, through the construction or upgrade of a transportation system or link. This corridor infrastructure is part of a larger package of interventions that aims to generate wider economic benefits in terms of economic welfare, social inclusion, equity, environmental quality, and economic resilience.	Roberts et al. (2020)	
Decomposition	"Once a load of freight has reached a terminal close to its destination, it must be fragmented and transferred to the local/regional freight distribution system. Commonly referred to as the "last mile" and often represents one of the most difficult segments of distribution."	Rodrigue (2020)	
Disruption, Disruptive event	"A disruptive event can be defined as any interruption or change, planned or unplanned, in the operations of a transport network, creating effects, such as delays, blockages or closures."	(Kulkarni et al., 2023, p. 30)	
Ecosystem	"An ecosystem is a dynamic, at least partially open structure of different interdependent yet autonomous social and economic actors who coordinate their activities towards a shared purpose to co-create value."	Conrad et al. (2022, p. 4)	Value creation system, platform ecosystem, innovation ecosystem, service ecosystem
Fourth party logistics provider (4PL)	"The 4PL is an integrator that assembles its own resources, capabilities and technology and those of other service providers to design and manage complex supply chains."	Badem and Mueller (1999)	Third party logistics provider, lead logistics provider

TERM	DEFINITION	REFERENCE	RELATED TERMS/ ELEMENTS IN THE CONCEPTUAL FIELD
Freight forwarder	"Companies that arrange the dispatch of goods for third parties after concluding a forwarding contract are called freight forwarders [..]. The central task of a freight forwarder is to organise the transport."	Geiger (2013, p. 64)	
Grey swan	"A grey swan is a metaphor for a large-impact and rare event that's somewhat predictable, yet many overlook it. It's the 'known unknown', a rare event that some know is possible, but no one knows when or whether it will occur"	Hole and Netland (2010, p. 21)	Black swan, white swan, perfect storm, dragon king
Hinterland	"The term 'hinterland' [...] was originally associated with the area of a port where materials for export and import are stored and shipped. The use of the word thereafter expanded to include any area under the influence of a particular human settlement."	Caves (2013, p. 229)	
Intermodal Transport Unit (ITU)	"Container, swap body or semi-trailer/goods road motor vehicle suitable for intermodal transport."	eurostat et al. (2010, p. 79)	
Intermodal transportation	"Intermodal transportation is a type of multimodal freight transportation that uses an intermodal transport unit (ITU) (e.g. container) with no handling of the goods themselves between mode changes."	M. A. Ertem et al. (2017, p. 10)	
Intermodalism	Utilisation and thus combination of different modes of transportation along a route,	Nobis (2014)	
Logistics service provider	A company whose main activity is the provision of logistics services for other companies.	Wallenburg (2004, p. 49) quoted after Geiger (2013, p. 61)	
Modal shift	"A modal shift involves the growth in the demand of a transport mode at the expense of another, although a modal shift can involve an absolute growth in both concerned modes."	Rodrigue (2020)	
Modal split	Distribution of transport demand between different modes of transport	Kirchhoff (2002, p. 78)	

TERM	DEFINITION	REFERENCE	RELATED TERMS/ ELEMENTS IN THE CONCEPTUAL FIELD
Mode of transport	“Method of transport used for the carriage of goods and passengers.”	eurostat et al. (2010, p. 158)	
Multimodal transportation	“means the carriage of goods by at least two different modes of transport on the basis of a multimodal transport contract from a place in one country at which the goods are taken in charge by the multimodal transport operator to a place designated for delivery situated in a different country. The operations of pick-up and delivery of goods carried out in the performance of a unimodal transport contract, as defined in such contract, shall not be considered as international multimodal transport.”	United Nations (1981, p. 5)	Intermodal transportation, synchromodal transportation, transmodal transportation
Multimodalism	Use of different modes of transportation within a different time frame	Nobis (2014)	
Multimodal transport operator (MTO), **Combi-operator (CO)**	“The [multimodal transport] process is carried out and coordinated by one operator – the Multimodal Transportation Operator. […] Moreover, the entire process of international multimodal transport is covered by a single contract signed between the MTO and the consigner.”	(Poliak & Salamakhina, 2023)	
NUTS	“The Nomenclature of territorial units for statistics, abbreviated NUTS (from the French version Nomenclature des Unités territoriales statistiques) is a geographical nomenclature subdividing the economic territory of the European Union (EU) into regions at three different levels (NUTS 1, 2 and 3 respectively, moving from larger to smaller territorial units). Above NUTS 1, there is the 'national' level of the Member States.”	eurostat et al. (2010)	
Orchestrator	„[…] a focal firm responsible for the involvement and coordination of the partners, leading them to new opportunities and ensuring fair value sharing and appropriate value creation“	Lingens et al. (2022, p. 560)	
Platform	„A business based on enabling value-creating interactions between external producers and consumers. The platform provides an open, participative infrastructure for these interactions and sets governance conditions for them. The platform’s overarching purpose: to consummate matches among users and facilitate the exchange of goods, services, or social currency, thereby enabling value creation for all participants.“	Parker et al. (2016, p. 177)	

TERM	DEFINITION	REFERENCE	RELATED TERMS/ ELEMENTS IN THE CONCEPTUAL FIELD
Physical Internet	"The Physical Internet is a new paradigm inspired by the Digital Internet. The aim of the Physical Internet is, like the Digital Internet, to interconnect heterogeneous network services."	Ballot (2019, p. 719)	
Port	"A place having facilities for merchant ships to moor and to load or unload cargo or to disembark or embark passengers to or from vessels, usually directly to a pier."	eurostat et al. (2010, p. 107)	
Resilience	"A resilient freight transport network minimises disruption-induced impacts on network performance, in both intensity and duration, along with minimising the system recovery time."	ReMuNet working definition	
Role	"A characteristic set of behaviours or activities undertaken by ecosystem actors"	Dedehayir et al. (2016, p. 1)	
Roll-on-Roll-off (RoRo)	RoRo is a transshipment technology for loading and unloading motor vehicles, railway wagons and intermodal transport units, such as containers, swap bodies/containers and trailers, onto or from a ship.	Studiengesellschaft für den Kombinierten Verkehr e. V. (2020)	Rolling Motorway (RoLa)
Seaport	"Seaports are regarded as concentrations of economic activity related to the arrival and service of ships and cargoes at ports".	Langen (2004, p. 1)	
Semi-trailer	"Goods road vehicle with no front axle designed in such way that part of the vehicle and a substantial part of its loaded weight rests on a road tractor."	eurostat et al. (2010, p. 49)	
Shipper	"A person or company whose job is to organise the sending of goods from one place to another."	McIntosh (2013)	
Shunting	"To move a train or carriage onto a different track in or near a station using a special railway engine designed for this purpose."	McIntosh (2013)	

TERM	DEFINITION	REFERENCE	RELATED TERMS/ ELEMENTS IN THE CONCEPTUAL FIELD
Supply Chain	"a structured manufacturing process wherein raw materials are transformed into finished goods, then delivered to end customers"	(Beamon, 1998, p. 282)	
Supply chain disruption	"Supply chain disruptions are defined as unexpected and unforeseen events or circumstances that disturb the regular flow of goods and materials along the value chain"	Novoszel and Wakolbinger (2022, p. 10)	
Sustainability	"Sustainability can be perceived as an ability to sustain, or a state that can be continued for long at the same level"	(Waseem & Kota, 2017, p. 361)	
Swap body	"A freight-carrying unit optimised to road vehicle dimensions and fitted with handling devices for transfer between modes, usually road/rail."	eurostat et al. (2010, p. 22)	
Synchromodality	The main purpose of synchromodality is reducing costs, emissions, and delivery times while maintaining the quality of supply chain service through smart utilisation of available resources and synchronisation of transport flows.	Giusti et al. (2019, p. 92)	
Terminal	"Place equipped for transhipment and storage of intermodal transport units (ITUs) between modes."	eurostat et al. (2010, p. 159)	
Third party logistics provider (3PL)	"A [3PL] provider is an external provider who manages, controls, and delivers logistics activities on behalf of a shipper."	Hertz and Alfredsson (2003, p. 140)	Fourth party logistics provider, lead logistics provider
Transmodalism	"Transmodalism involves connecting different segments of the same mode between an origin and a destination"	Rodrigue (2020)	
Transport Network	"A transport network may be formally represented as a set of links and a set of nodes. A link connects two nodes, and a node connects two or more links. Links may be either directed, in which case they specify the direction of movement, or undirected."	Bell and Lida (1997, p. 17)	

TERM	DEFINITION	REFERENCE	RELATED TERMS/ ELEMENTS IN THE CONCEPTUAL FIELD
Transport for hire or reward	“The carriage for remuneration of persons or goods.”	eurostat et al. (2010, p. 55)	Transport on own account
Transshipment	“The activity of moving goods from one mode to another”	O'Shea (2011)	
Trimodal terminal	Trimodal terminals can transfer loading units between three modes of transport (Road + Ship + Rail).	SGKV	
Value creating system	„A value creating system (VCS) can be defined as a set of activities creating value for customers; these activities are carried out using sets of human, tangible and intangible resources; they are linked by flows of material, information, financial resources and influence relationships; VCSs also include consumption activities, insofar as the value that final customers enjoy is also a function of the way they use and consume the potential value received; final customers not only receive and consume the value created, but can also participate in value-creating activities; activities may be governed by the market, a hierarchy or intermediate forms of co- ordination (company networks); various economic players may participate in a VCS (companies, families, public bodies, non-profit organisations) by taking responsibility for one or more activities; an economic player may participate in more than one VCS.”	Parolini (1999) quoted after Janello (2010)	Value web, value net, innovation ecosystem, business ecosystem
Value network	“A value network [is defined] as one in which a cluster of actors collaborates to deliver the highest value to the end consumer and where each actor is responsible for the success or failure of the network.”	Bassetti and Romano 2003	Value web, value net value creating system, innovation ecosystem, business ecosystem
Waterway	“River, canal, lake or other stretch of water which by natural or man-made features is suitable for navigation.”	eurostat et al. (2010, p. 73)	
White swan	„A white swan is a highly assured event with three principal qualities: it is certain; its impact can easily be projected; and, after the event, we make a portrayal of the event which can be well recognised, and any mistakes in judgment are related to ambiguity in decision making. “	Devarajan et al. (2023, p. 3230)	Black swan, gray swan, perfect storm, dragon king

Annex II: Semi-structured Interview Guide

Preparing for the Interview

As part of pre-interview exercises, the following aspects of data protection are considered:

1. The interviews will be conducted online using MS Teams and a digital concept board (Mural).
2. The concept boards will be processed and summarized reports will be made publicly available as part of project reports without individual identifiers. Interviewee consent will be sought before beginning the interview. The content developed in the interview is worked out together on a digital whiteboard and prepared in a summarized form and sent to the participants. All records with identifiers will be stored in secure locations at FIR, accessible only to the team. These records will be available for up to 1 year after completion of the project. Results will be published anonymously and consolidated.
3. The terms of confidentiality and the format of the interview will be explained at the start of the interview. The interviewee will be given the opportunity to ask clarifying questions.
4. The meeting will be recorded using MS Teams and written notes on the digital whiteboard. The in-built transcription tool will be used to create first version of the transcriThe interviews will be conducted online using MS Teams and a digital concept board (Mural).pt. This will be revised by the interviewers by listening to the recording.

Interview Content

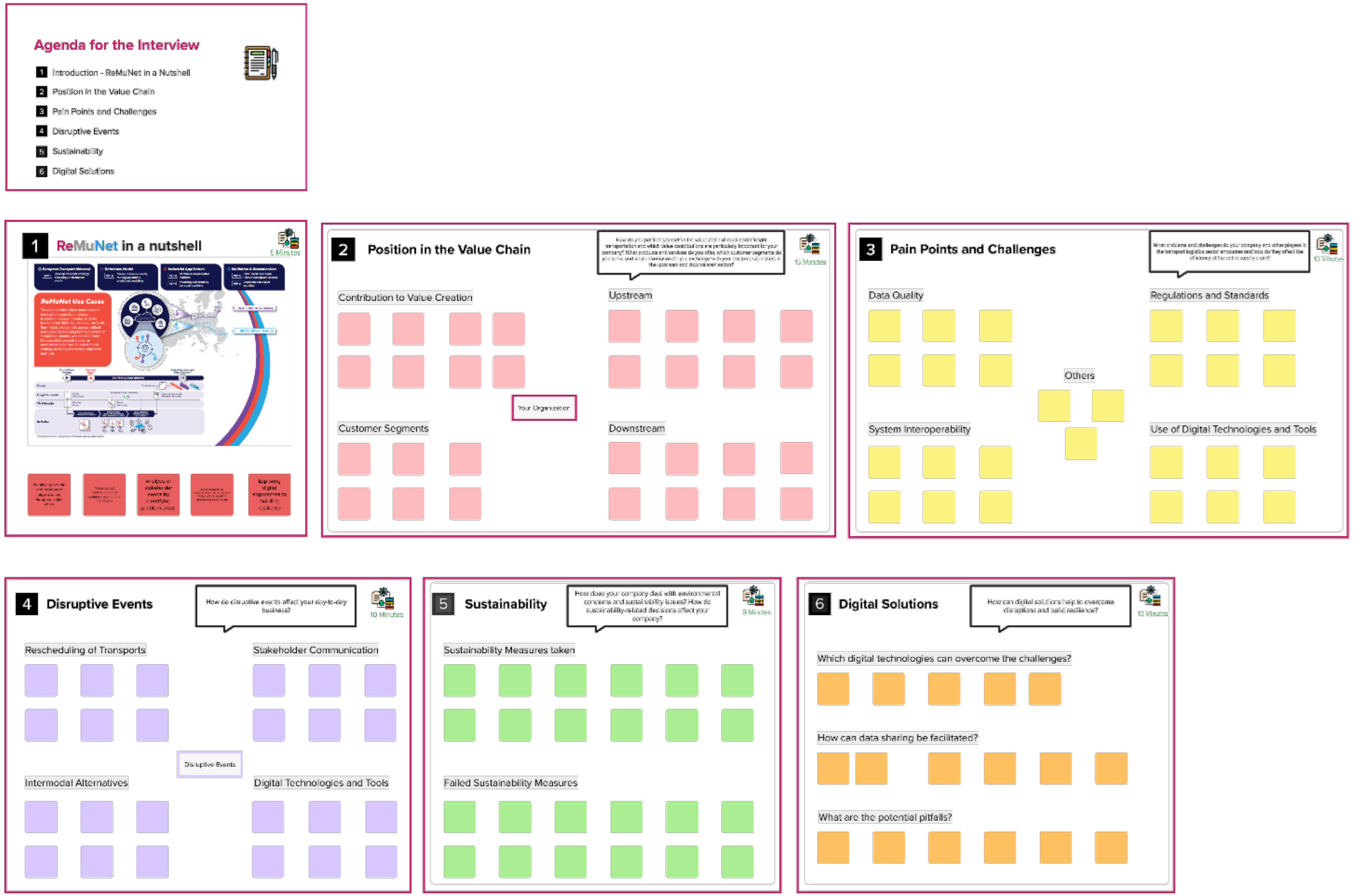
The guiding questions for the interview are identified here. The aim of the interview is to create a common understanding of relevant stakeholder groups involved in European multimodal transport networks. The interview contributes to the following tasks:

1. Identification of the stakeholder's role within the European logistics sector and his position in the value chain.
2. Description of the stakeholder's main value creation contribution and customer segments.
3. Assessing stakeholder needs by pinpointing pain points and challenges in data-sharing and managing disruptions.
4. Investigating the stakeholder's sustainability contributions and the impact of sustainability requirements.
5. Exploring digital approaches for building resilience.

The interview guide presented in this section focuses on these tasks and serves as an orientation and structuring support. The interview format is exploratory. Therefore, certain questions may vary in relevance depending on the interviewee, and we maintain the flexibility to delve deeper into specific aspects that emerge during the interview.

#	Guiding Questions
1	What are the primary needs and requirements of stakeholders involved in the multimodal transport network?
2	How does your organisation position itself in the value chain of the multimodal transport network? • What is your main value contribution? • Which products and services do you offer? • Which customer segments do you serve? • Which type of information is exchanged between your organisation and your clients/partners?
3	Which pain points/challenges does your organisation and other stakeholders of the transport logistics sector encounter and how do they impact the overall supply chain efficiency? Which challenges emerge within the following areas specifically: • Data quality • System interoperability • Regulations and standards • Digital technology and tools
4	How do disruptions affect your daily business? Please elaborate on the following aspects: • Replanning/rescheduling of transports • Intermodal alternatives • Stakeholder communication • Digital technology and tools
5	How does your company deal with environmental concerns and sustainability issues? How do sustainability-related choices impact your business? • Which sustainability measures do you take? • Which sustainability measures have proven (un-)successful?
6	How could digital solutions help to address disruptive events and help build resilience? • How can digital technologies contribute to overcoming current challenges in the multimodal transport network? • How could data-sharing be facilitated? • Which potential pitfalls need to be considered in the design of digital solutions?

Annex III: Digital Whiteboard (Mural)



Annex IV: List of Interviewees

IP	ROLE & NATIONALITY	BUSINESS ACTIVITIES	WHY THE INTERVIEW PARTNER WAS SELECTED
1	DLSP *Germany*	Digital logistics service provider specialising in road freight optimisation and additional services, (with potential for multimodal transportation)	This software-SME is one of Germany's most innovative logistics tech start-ups and has access to an extensive network of freight forwarders and transport companies. Their multi-tenant matching platform enables conducting event-based relay transports to circumvent disrupted infrastructure sections.
2	Carrier Terminals Infrastructure Manager/Operator *Germany*	Trimodal logistics company, specialising in container import/export via inland waterway, rail, and trucking, with a network of terminals across Europe	This company specialises in trimodal transportation connecting seaports with the European hinterland moving an annual freight volume of 2.1 million TEU within its network along the river Rhine. This partner therefore offers crucial industry information along all transport modes.
3	4th Party Logistics Service Provider DLSP *Germany*	Optimisation service provider specialising in road transport, offering solutions to improve customers' transportation, warehousing, and handling processes, with a focus on transparency through their TMS platform	This company is a leading global provider of supply chain consulting, software, and fourth-party logistics (4PL) services. Insights on end-to-end logistics processes and technical requirements are especially relevant for the stakeholder analysis.
4	Terminals *Luxembourg*	Multi-use terminal operator managing train operations, container trading, and employing sustainable practices, including renewable energy and battery-electric vehicles	This operator of a public intermodal terminal in Luxembourg can handle all intermodal transport units on an area of 33 hectares and uses innovative technologies like AI-applications to increase the efficiency of transshipment processes. The company offers valuable insights from the perspective of terminal operators and provides suggestions for the use of digital technologies.
5	NGO (Humanitarian Logistics) *Denmark*	Providing auxiliary support, coordinating logistics operations, and establishing warehousing hubs for efficient disaster response and conflict management	The Danish entity of the largest humanitarian network worldwide provides aid support to people affected by conflicts or disasters. Their extensive expertise in the field of humanitarian logistics contributes fundamentally to understanding the challenges and requirements of aid organisations in freight transport logistics.
6	Terminals Carrier *Netherlands*	Creating a sustainable European network with assets like trucks, trailers, containers, vessels, and rail connections, and operating hub terminals for efficient customer service	The company is one of the larger European transport companies focusing on multimodal transport by operating own terminals, transport vehicles, and loading units. This stakeholder provides crucial information on multimodal transportation and disruption management.
7	Logistic Service Provider	The establishment of an integrated grid network for supply chain partners, facilitating	As a leading Dutch research and consulting organisation this stakeholder holds extensive expert knowledge to facilitate seamlessly connected logistics systems that

IP	ROLE & NATIONALITY	BUSINESS ACTIVITIES	WHY THE INTERVIEW PARTNER WAS SELECTED
	Netherlands	customisable data sharing, multimodal visibility services, and authentication-based link-driven data exchange for the generation of digital product passports	are more efficient, create new business opportunities and reduce emissions. As a leading partner in countless European logistics and digitalisation projects this partner contributes greatly to the design of ReMuNet's digital solution.
8	Industry Association *Belgium*	Raising stakeholder awareness, consulting policy makers, and standardising combined transport operations, while representing intermodal operators as key actors in the integrated freight transport chain	As one of the main industry associations in the European intermodal transport industry this stakeholder actively promotes Combined Transport, primarily towards European decision-makers and supports the daily functioning of this ecologically and economically sustainable mode of long-distance freight transport. The association has in-depth knowledge of existing standards, legal requirements and current challenges in intermodal transport and is familiar with the needs of its members due to its role as an interest representation body
9	Infrastructure Manager/Operator *Austria*	Operating an infrastructure provider, with a primary focus on container handling at a terminal, emphasising various modes of transportation and collaborating on urban logistics initiatives with an academic institution	This stakeholder operates one of the most important inland ports in the Rhine-Danube corridor and handles around 1200 cargo ships per year. The company offers a comprehensive service portfolio and has access to a large network of the most important hinterland logistics companies in Europe. As key stakeholder in one of ReMuNet's focus corridors this partner provides important information on a broad spectrum.
10	Industry Association *Germany*	Promotion and development of sustainable freight transportation using different loading units, conduct research, studies, and consulting activities, and advocate for the adoption of combined transport within the freight transport sector	This partner is one of the most important non-profit membership associations in intermodal logistics. For 80 years this association has connected relevant actors of the Combined Transport sector and created a neutral communication and knowledge platform for research and development. For ReMuNet, this stakeholder provides valuable industry-wide information and an overview of current innovations and relevant research projects
11	Software Provider *Germany*	Providing logistic planning products, including route and tour planning, load optimisation, geo-management/geo-marketing solutions, intermodal component solutions, and customised software-as-a-service options for automated tour planning and delivery time estimation	This stakeholder is a European market leader in traffic and transport route planning. In addition, the company is involved in many innovative projects to further develop its state-of-the-art software solutions and support the logistics industry. As a key stakeholder in planning and optimisation, this partner enhances ReMuNet's knowledge base with its industry expertise, especially in digital service development.
12	DLSP *Germany*	Digital logistics service provider offering a software-as-a-service platform that facilitates stakeholder interaction through a shared monetisation model, acting as a trusted intermediary	This stakeholder operates a leading digital transportation management platform empowering shippers, forwarders, carriers, and retailers to collaboratively move, manage and monitor freight. With more than 150.000 connected carriers and 1400 shippers the platform enables seamless real-time

IP	ROLE & NATIONALITY	BUSINESS ACTIVITIES	WHY THE INTERVIEW PARTNER WAS SELECTED
		for qualified freighters nominated by shippers to engage on the platform	information sharing with a focus on interoperability, automation, and stakeholder collaboration. For ReMuNet this partner provides valuable insights regarding collaboration challenges, information-sharing, and interconnectivity.
13	Carrier, Terminals & Freight Forwarder *Switzerland*	Offering a cost-effective and sustainable transport chain for continental transports, utilising sea, inland waterway, rail, and road modes, optimising efficiency for longer routes, and providing cross-border transport services in Europe with seamless last-mile deliveries	This interview partner is one of the market leading combined transport operators in Europe. As a neutral combined transport operator, this company moves over 1 million road consignments annually and consolidates shipments from transport companies to complete trains utilising 9100 own wagon modules. As a major combined transport operator, this company offers important industry insights and provides significant support in identifying challenges around combined transport.
14	Infrastructure Manager/Operator *Austria*	Owning and managing transportation infrastructure, including parking lots, rest areas, and rest stops, to facilitate smooth and convenient journeys for road users, particularly those engaged in road freight transportation, catering to car and truck drivers, as well as special transports	This infrastructure company is responsible for the planning, construction, operation and tolling of the Austrian motorway and motorway network. As an important road network operator in the Rhine-Danube corridor, this player supplements the stakeholder analysis with important information from the perspective of an infrastructure operator.
15	Software Provider & Logistic Service Provider *France*	Product lifecycle software and collaborative platform provider for multiple industries, with a strong emphasis on mobility, manufacturing, aerospace, and defence	As the second largest software company in Europe, this stakeholder has an extensive software and service portfolio for various industry segments. From the transport logistics perspective especially, the collaborative digital platform holds significant potential to address current business challenges in the transport sector. This partner's experience in the digitalisation of various industries supports ReMuNet in designing a resilience-enhancing digital solution.
16	Software Provider & Logistics Service Provider *Finland*	Software solutions for transparency, optimising parcel routing, acting as middleware between ecommerce stores and warehouses, and providing warehousing services for efficient picking and packing of goods	This logistics service provider helps e-commerce businesses to optimise their supply chain, speed up delivery times, and reduce costs with a modern 3PL service. With extensive experience in e-commerce shipment tracking and other logistics services this innovative SME contributes valuable information on digitalised supply chains.
17	Freight Forwarder *Greece*	Intermodal freight transport, facilitating smooth movement of goods across various modes of transportation, acting as intermediaries between shippers and carriers, and operating primarily in Europe	This SME freight forwarder specialises in road and sea transport organisation and provides – besides specific industry knowledge - detailed insight into the challenges faced by smaller logistics companies when implementing digital solutions.

IP	ROLE & NATIONALITY	BUSINESS ACTIVITIES	WHY THE INTERVIEW PARTNER WAS SELECTED
18	Carrier *Austria*	Rail transportation, including intermodal and wagon loading traffic	This company holds the operating licence for all railway lines in Austria and the EU. This railway undertaking operates freight transport both on its own infrastructure (with its own diesel locomotives) and on third-party infrastructure (with its own diesel and electric locomotives) and provides important information on rail cargo transports in the Rhine-Danube Corridor.
19	Freight Forwarder *Germany*	Managing standardised transport orders, unitising them based on client software systems, handling various container types, good types, commercial types, capacities, departure and provision times, duration of stay, customs clearance, and release processes from terminals	As a maritime, port-neutral operator and specialist in port-to-door logistics, this company organises global supply chains in combined transport and bringing together the system strength of rail with the flexibility of trucking. As an important link between maritime ports and hinterland transportation, this stakeholder contributes significant industry experience to the analysis.
20	Consignor & Consignee *United States, Europe*	Production and distribution of consumer goods	This American multinational consumer goods corporation is one of the largest shippers in Europe and contributes important insights to the ReMuNet stakeholder analysis from a consignor/consignee perspective.
21	Software Provider *Germany*	Digital logistics service provider offering a software for optimising transportation routes and data-driven decision-making	As a leading provider of artificial intelligence and mathematical optimisation systems, this stakeholder's software products support dispatchers and planners in calculating complex and time-critical logistics scenarios.
22	Freight Forwarder *Switzerland*	Offering end-to-end transport solutions, including ocean freight, air freight, European land transport, contract logistics, customs services, and data management, operating as an asset-light company	This large company is the leading sea freight and air freight forwarder worldwide offering specialised transport solutions for major industries as a global logistics partner. Being one of the most important freight forwarding companies this partner provided important insights on freight transportation and the use of digital technologies.
23	Carrier Freight Forwarder *Germany*	Providing rail transport services, including locomotives, and rolling stock, transportation of hazardous goods, customs Clearance, train path orders, local operations, personnel, equipment, and combined transport	As a subcompany of the largest combined transport operator in Europe for road and rail transport, this stakeholder specialises in the transport of high-quality rail products in combined transport between the Netherlands and Germany. This partner contributes to the gain of knowledge with its perspective of a railway undertaking company.
24	DLSP *Germany*	Neutral platform connecting intermodal actors and providing transport chain transparency and intermodal booking options	As a highly innovative SME and neutral platform for intermodal players, this stakeholder makes a decisive contribution to the development of the digital ReMuNet solution.

The project

ReMuNet identifies and signals disruptive events and assesses their impact on multimodal transport corridors. It reacts quickly and seamlessly upon disruptive events in real-time. It supports TMS providers to improve route planning resilience. ReMuNet communicates alternative, pre-defined, multimodal transport routes to logistics operators and subsequently to truck drivers, locomotive drivers and barge captains. Through this, it enables a faster and adaptive multimodal network response. ReMuNet orchestrates route utilisation, suggests transshipment points and optimises capacity allocation, minimising damage and shortening the recovery time. What is ReMuNet's core objective? As trailblazer for the Physical Internet, ReMuNet pursues the vision to enable and incentivise synchro-modal relay transport on European rail, road, and inland waterways to increase the holistic network resilience. It significantly reduces emissions and boosts freight transport corridor efficiency in case of disruptive events. stakeholders to ensure Europe-wide practicability and acceptance.

Coordinator: FORSCHUNGSINSTITUT FUER RATIONALISIERUNG (FIR)

PARTNER		SHORT NAME
	FORSCHUNGSINSTITUT FUER RATIONALISIERUNG	FIR
	SVENSKA HANDELSHOGSKOLAN	HANKEN
	PTV PLANUNG TRANSPORT VERKEHR GmbH	PTV
	4PL INTERMODAL GMBH	INT
	MANSIO GMBH	MAN
	FRAUNHOFER AUSTRIA RESEARCH GMBH	FHA
	HAFEN WIEN GMBH	HWI
	WHITE RESEARCH SRL	WRE
	UNION INTERNATIONALE DES SOCIETES DE TRANSPORT COMBINE RAIL-ROUTE SCRL	UIR
	CONTARGO GMBH & CO KG	CON

	VEDIAFI OY	VED
	DANSK RODE KORS (DANISH RED CROSS)	DRC
	ILMATIETEEN LAITOS	FMI
	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE	ETP-ALICE
	SCHACHINGER IMMOBILIEN UND DIENSTLEISTUNGS GMBH & CO OG	SCH