D2.1

ReMuNet reference model of the multimodal transport

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ABBREVIATIONS

ABBR.	PHRASE
API	application programming interface
CEMT	Conférence Européenne des Ministres des Transports (European Conference of Ministers of Transport)
CRISP-DM	Cross Industry Standard Process for Data Mining
DB Infra	Deutsche Bahn Infrastruktur (German railway infrastructure)
EPAL	European Pallet
ER	entity-relationship
ERP	enterprise resource planning
et al.	et alia (and others)
ETA	estimated arrival time
etc.	et cetera (and so on)
EU	European Union
FEU	Forty-foot Equivalent Unit
ICT	Information and Communication Technologies
ID	identification
ITC	international transport corridors
ITU	Intermodal transport unit
LxWxH	Length x Width x Height
MS	Microsoft
MTN	multimodal transport network
ÖBB	Österreichische Bundesbahnen (Austrian Federal Railways)
SQL	Structured Query Language

TEN-T	Trans-European Transport Network
TEU	Twenty-Foot Equivalent Unit
UIRR	Union internationale pour le transport combiné Rail-Route (or: International Union for Road-Rail combined transport)
UML	Unified Modelling Language
WP	Work package

1. INTRODUCTION

The availability of transport systems is a fundamental prerequisite for the efficient organization of economic processes in countries and continents. The condition of transport systems, which ensure connections between different areas, is directly linked to the sustainable development of national economies. A reliable and state-of-the-art transport infrastructure forms the basis for the transport of goods and thus for meeting the growing needs of society. At the current stage of development, one such infrastructure is a multimodal transport network (MTN) consisting of a series of international transport corridors (ITCs). ITCs are based on the main directions of freight transport, promote the development of interregional and transcontinental economic relations and contribute to the growth of national economies in the context of globalization and global production integration (Nesterova et al. 2016b).

The main problems of MTN development projects are (Nesterova et al. 2016a; European Commission 2013; European Commission 2024):

- Interaction of different transport infrastructure objects
- The different technical condition of transport infrastructures and a significant discrepancy in the required conditions of their capacity, quality and accessibility
- The incoherence of the transport infrastructure projects of the various modes of transport, which are implemented without an overall strategy
- Lack of funds to eliminate ‘bottlenecks’ or to build new transport infrastructure
- A multitude of owners and management structures pursuing their own interests in the development and operation of transport infrastructure

This confirms the complexity, relevance and appropriateness of the MTN's development projects and the improvement of existing or the creation of new instruments to solve the problems mentioned. (Nesterova et al. 2016b)

Reference models are a good tool for structuring and analyzing such complex systems. They are standardized models that are used in various areas. They serve as an orientation aid and help to define generally valid structures and processes that can be applied to similar situations or problems. The most important reasons for the usefulness of reference models are as follows: (Wirtz 2021; Scheer 1999; Grefen 2010)

- **Standardization and comparability**: Reference models offer a standardized structure that makes it possible to compare different systems, processes or organizations with one another. This facilitates the identification of best practices and their transfer to similar situations.
- **Knowledge management and communication:** They serve as a common language and basis for communication between different stakeholders such as developers, consultants and managers. As everyone involved uses the same concepts and structures, communication is made easier.

- **Increased efficiency:** Time and resources can be saved by using proven models, as basic analysis and design work does not have to be carried out again and again. This is particularly advantageous in IT and business process management, where complex systems can often be built on existing models.
- **Flexibility and adaptability:** Reference models are usually designed in such a way that they can be adapted to the specific requirements of an organization or situation. This allows organizations to adapt the models to their individual needs while benefiting from the general principles.
- **Quality assurance:** As reference models are based on tried and tested methods, they contribute to the quality assurance of processes and systems. They help to avoid common errors and ensure consistent results.

Therefore, the key objective of Task 2.1 is to set up a reference model for multimodal transport networks by including a holistic view of multiple transport modes and their properties. To this aim, attributes required to model multimodal transport networks are defined, described and categorized. Throughout the project, this approach will reduce complexity and provide a common language regarding multimodal transport networks.

This report addresses the following research questions:

- How can a common understanding be accomplished for European multimodal transport networks?
- Which elements must be included in a reference model to describe multimodal transport networks?
- How must these relevant elements and their interrelationships be modeled to be generally valid and transferable?

An important contribution of the developed reference model and to answering the research questions is the collection of **relevant attributes of the logistics infrastructure and their categorization and assignment**. Furthermore, this report contributes to the process of data generation, gathering and preparation. Various data sources are cited and the categories for which they can provide the necessary information are listed.

The report is structured as follows:

- The literature review (section 2) provides an overview of academic research on reference models of multimodal transportation networks, underlying issues such as digitalization and travel time estimation and related projects.
- The methodology section (section 3) outlines the approach to identifying relevant elements and the process for incorporating these elements into a model.
- Next, the Reference Model section (Section 4) presents the developed reference model, including its design, possible data sources, use cases and challenges encountered in relation to the data requirement.
- Finally, a conclusion and a discussion on future work are given in Section 5.

2. LITERATURE REVIEW

A reference model serves as a standardized framework that describes the structure, processes and relationships within multimodal transport systems. It acts as a comprehensive guide for incorporating various transportation modes (such as road, rail, sea, and air) into a unified multimodal network. By implementing a reference model, all parties involved can ensure adherence to shared guidelines, thereby averting potential misunderstandings stemming from inconsistent models. Furthermore, this approach facilitates the seamless exchange of data in a universally accepted format. In the context of transport networks, graphs are often employed to depict the infrastructure, with nodes representing terminals where mode transitions occur, and edges serving as links between distinct nodes. Disruptions may impact nodes, routes, or only partially affect them during specific modes. Furthermore, these disruptions possess a specific duration and can be classified based on their severity.

2.1 Related work

As a result of the scarcity and unpredictable nature of events, transportation models frequently neglect to account for disruptions. Some authors strive to tackle this challenge by incorporating stochastic travel times (Demir et al. 2016), while others concentrate solely on disruptions at specific nodes (Abbasi et al. 2024). Furthermore, the transportation industry, being relatively conservative (Altuntaş Vural et al. 2020), fails to fully acknowledge the benefits of digitization. The majority of existing research on multimodal transport networks is based on simulated data or nationwide transportation networks, with only a few studies, such as (Strelko et al. 2022) encompassing full trans-European transport network (TEN-T) (Richardson 1997) corridors.

In a study by (Harris et al. 2015), the crucial role of ICT in logistics is emphasized as a key enabler. They review various EU framework program projects and present the current state of ICT developments in Europe. They also discuss the barriers that hinder the adoption of technological trends. (Giusti et al. 2019) provide a comprehensive overview of synchromodal logistics. They emphasize the importance of utilizing emerging and existing ICT technologies for success. They also highlight the potential positive synergies that can be achieved by adopting common platforms and standards. (Altuntaş Vural et al. 2020) investigate the potential of various digital tools in addressing barriers to the increased utilization of intermodal transport. Their findings indicate that the transport industry tends to be conservative and resistant to adopting digitalization due to a belief that traditional methods are preferable and a lack of confidence in the benefits of digitalization. (SteadieSeifi et al. 2014) give a broad overview over multimodal freight transportation planning. They discuss various sub-problems that arise in multimodal transportation, as well as various problem data sets on which the solution strategies are evaluated. Recent studies indicate that transnational freight transport continues to rely predominantly on the road network (European Court of Auditors 2023).

(Abbasi et al. 2024) conducted a study on the impact of disruptions in seaport terminals on intermodal freight transport networks. They argue that disruptions in seaport terminals significantly degrade performance due to their pivotal role in connecting landside and sea-side operations. To address this issue, the authors develop a mixed-integer linear programming model aimed at minimizing both cost and CO_2 emissions in freight flow. It is worth noting that while the study acknowledges the existence of disruptions, it solely focuses on disruptions that reduce the available capacity in a specific seaport, without considering disruptions that affect transport links.

(Demir et al. 2016) present a Green Intermodal Service Network Design Problem with Travel Time Uncertainty for combined offline intermodal routing. They employ a stochastic approach to generate transportation plans by sampling average travel times from a set of scenarios. However, their model does not explicitly account for disruptions or their impact on travel times. (Spanninger et al. 2022) provide a comprehensive review of different approaches for predicting train delays. They differentiate between event-driven and data-driven approaches. Event-driven approaches estimate delays by considering the dependency structure between trains and events and make incremental predictions. In contrast, data-driven approaches rely more on historical data and require less knowledge of the dynamics of railway operations. Given our objective of estimating delays for different modalities resulting from unforeseen (catastrophic) events, event-driven approaches appear more suitable. (Balster et al. 2020) employ machine learning techniques to predict the estimated arrival time for intermodal transport networks. They utilize various tree-based algorithms, including random forest, gradient boosting, linear regression trees, and ordinal trees. These algorithms assist in predicting individual time components, such as lead time, transport times for rail and sea sections, as well as the time from the marshalling yard to the destination, which collectively contribute to the estimated time of arrival.

2.2 Related projects

Research on the Trans-European Transport Network (TEN-T) corridors and especially multimodal transport network is vital for enhancing Europe's transport efficiency, connectivity, and sustainability. It helps identify bottlenecks, prioritize investments, and improve cross-border coordination, ultimately supporting economic growth and regional integration across the continent. In Table 1 we list publicly funded research projects/initiatives in Europe addressing challenges of (multi)modal transport networks.

Short Name	Full Name	Funding Call/Agency	Description
MOTUS	Key factors for sustainable and resilient transport	Innovation initiative mFUND - BMDV	The MOTUS project aims to develop a simulation platform that models urban transportation systems to help municipalities prepare for and respond to disruptive events like pandemics, climate change, and structural changes, by analyzing mobility data and evaluating the sustainability and resilience of proposed measures.

SENATOR	Smart Network Operator Platform enabling Shared, Integrated and more Sustainable Urban Freight Logistics	H2020-MG-2019-TwoStages	The SENATOR project aims to create a multi-collaborative framework and a "control tower" system to optimize urban planning policies by coordinating stakeholders in urban freight logistics and improving citizen engagement.
SHIFT2RAIL		H2020	The SHIFT2RAIL initiative is a major European research and innovation program designed to develop rail technologies and integrate them into existing and future rail networks to enhance efficiency, sustainability, and performance. SHIFT2RAIL aims to improve rail transport through collaborative projects, promoting innovations such as smart rail infrastructure, advanced signaling systems, and improved passenger services.

Table 1: Research projects addressing challenges in multimodal transport

3. METHODOLOGY

The process shown in the following Figure 1 was chosen for the development of the reference model. Firstly, relevant key elements of transport networks were identified together with project partners and industry experts and documented clearly in accordance with the requirements of the stakeholders in a multimodal transport network. Based on this, a suitable model type was selected for incorporating the information into a reference model. The individual steps for this procedure are explained in detail in this section. The actual implementation of the reference model is described in section 4.

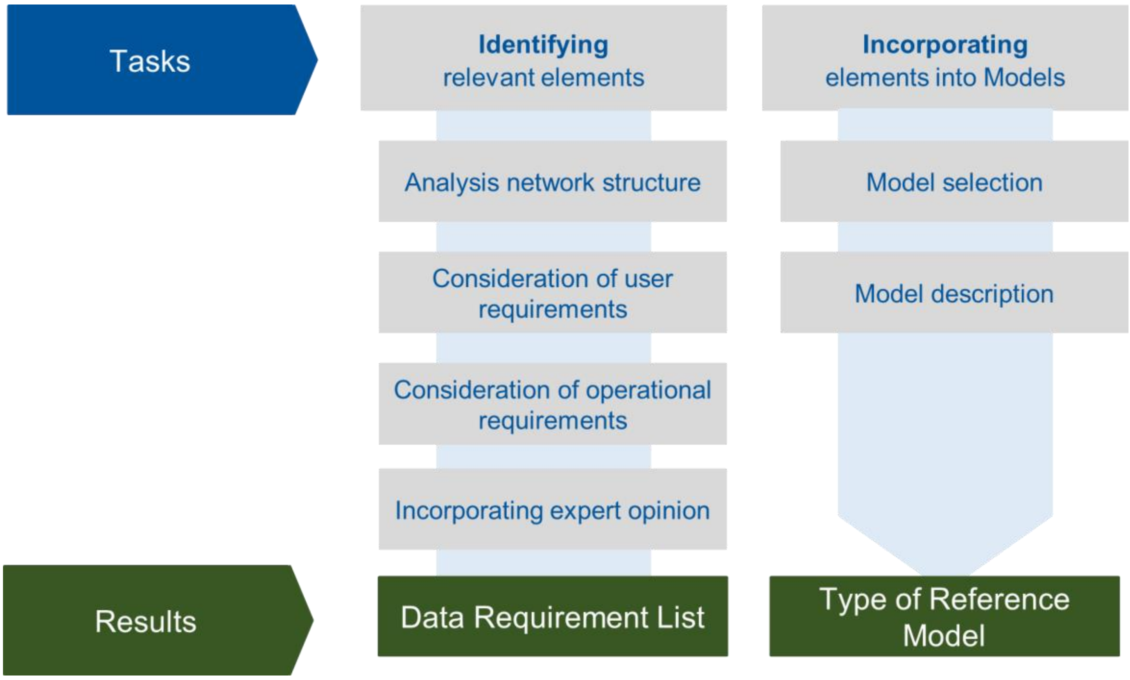


Figure 1: Approach to developing the reference model

3.1 Identifying relevant elements

An essential step in developing the reference model is to identify the key elements of the transport network and its structure. This section outlines the procedure for identifying these elements in a multimodal transport network and categorizing them accordingly. Additionally, the specific attributes that can be used to describe these elements are explained in more detail and assigned to their respective categories.

3.1.1 *Analysis of transport network structures*

A data requirement list was compiled for analyzing the structures of transport networks. This was done due to the numerous attributes that are deemed important by various stakeholders in the multimodal transport network. To document these attributes in a structured manner, it was found more suitable to use a table with different categories of appropriate granularity rather than immediately collecting the information in maps or block diagrams. Transforming the data into such representations can still be done at a later stage.

The procedure for creating this data requirement list is depicted in Figure 2 and is derived from the CRISP-DM cycle (Wirth and Hipp 2000), commonly employed in data science projects.

An iterative approach was adopted, consisting of the following steps:

1. Brainstorming: In this initial step, the consortium partners were asked about the information (i.e., attributes) they require for their day-to-day operations in order to efficiently plan transport orders, transshipments, etc. This information is crucial for the overarching project goal of enhancing the resilience of transport networks, particularly when faced with disruptive events. Various methods were employed for this step, with slight adaptations based on their effectiveness. For instance, the partners were sent MS Forms questionnaires, or an interactive survey method (Mentimeter) was conducted during a physical workshop.
2. Classification: The recorded attributes were classified in a second step to establish a structured overview and to ensure that these attributes later can be utilized and efficiently processed.
3. Discussion: In the final step, the interim results were discussed with the consortium partners of work package 2. Any necessary changes regarding the level of detail of individual attributes or the categorization were deliberated upon, and appropriate adjustments were made.

These steps were repeated until the data requirement list reached the desired quality. This iterative approach allowed for a gradual expansion of the data requirements list for the reference model, while simultaneously ensuring the quality of its creation. As mentioned earlier, this served as the starting point for necessary transformations into alternative forms of representation for illustrating the reference model.

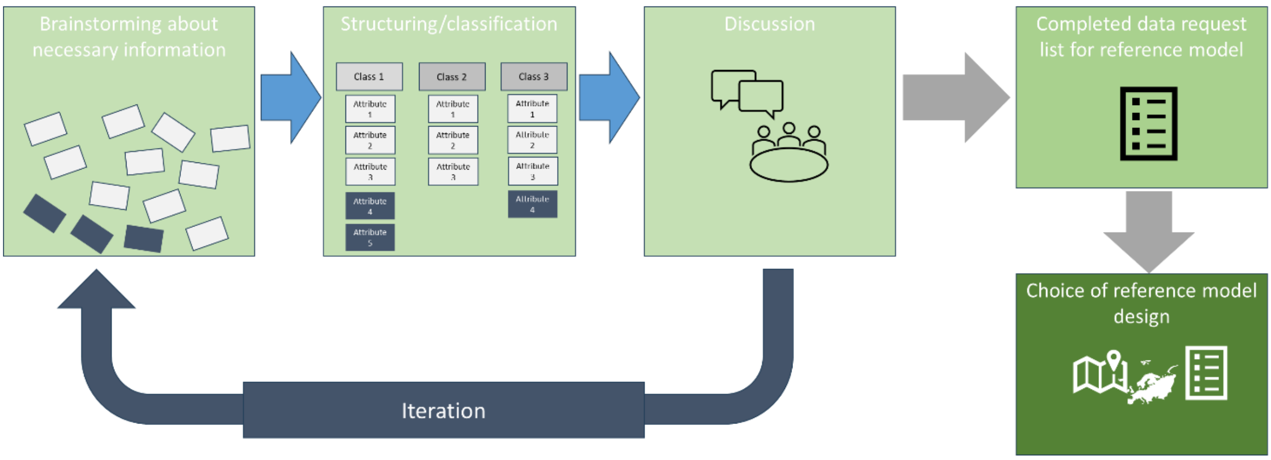


Figure 2: Procedure of creating the data requirement list

At a physical WP2 workshop in Karlsruhe, a possible classification of relevant attributes was presented in advance, the logic of which is based on Figure 3. According to Figure 4 below, this includes four meta levels:

- **Transported goods:** All attributes that are linked to the goods to be transported and do not change during transport along the entire supply chain are collected here.

- **Nodes:** In this categorization, nodes are considered both as transshipment points and as intersections between route sections within the transport network. All attributes that are linked to the node are collected here.

- **Transport route section:** Transport route sections are considered in this categorization as route sections between two nodes within the transport network. All attributes that are linked to the transport route section are collected here.

- **Disruptive Event:** Disruptive events are considered in this categorization as unforeseen events that have an impact on both nodes and transport route sections. All attributes that describe the qualitative and quantitative effects of the disruptive event are collected here.

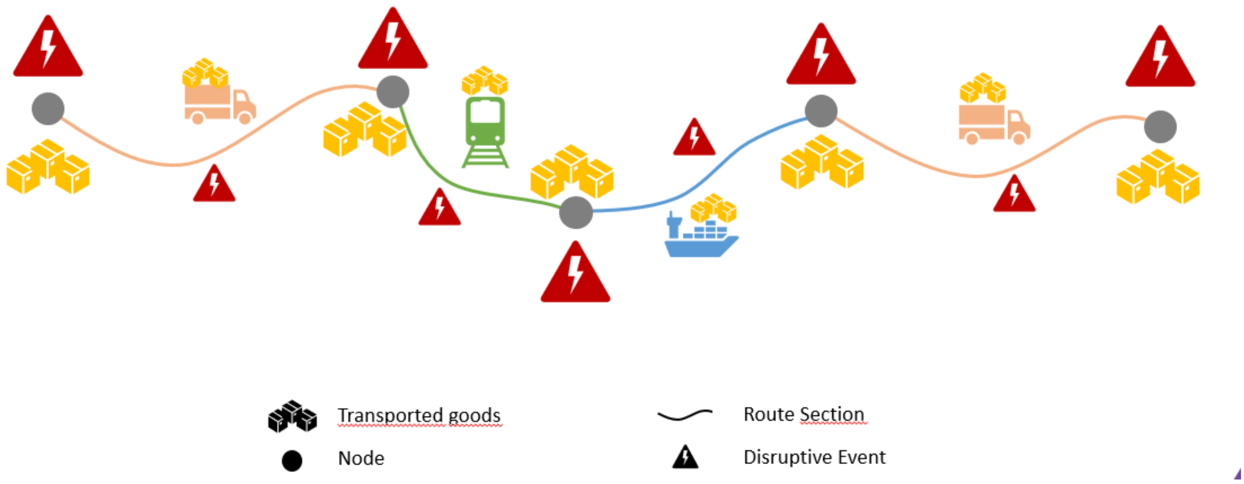


Figure 3: Concept for Classification of the data requirement list

The partners agreed to this categorization at metalevel level. In order to obtain a better overview of the attributes, further block levels were introduced below.

Using the example of transported goods, these are, for example:

- **Identification:** All attributes that uniquely identify the transported goods are collected here:
  - Transport ID
  - Shipment ID
  - Customer Order ID
  - etc.
- **Goods information:** All attributes that describe the properties of the transported goods are collected here:
  - Weight
  - Length
  - Width
  - Load carrier type

    - etc.
- **Start location:** All attributes that describe the starting point of the transported goods are collected here:
    - Pickup location ID
    - Pickup country
    - etc.
- **End location:** All attributes that describe the destination of the transported goods are collected here:
    - Delivery location ID
    - Delivery country
    - etc.

This procedure was carried out in the same way for the meta-level nodes, transport route section and disruptive event to provide initial guidelines for the surveys to the stakeholders. The overview is shown in Figure 4. In this figure, the meta-level is divided into the 4 segmentations, as described above (Transported Goods, Nodes, Transport route Section and Disruptive Events), and the block level is shown in grey.

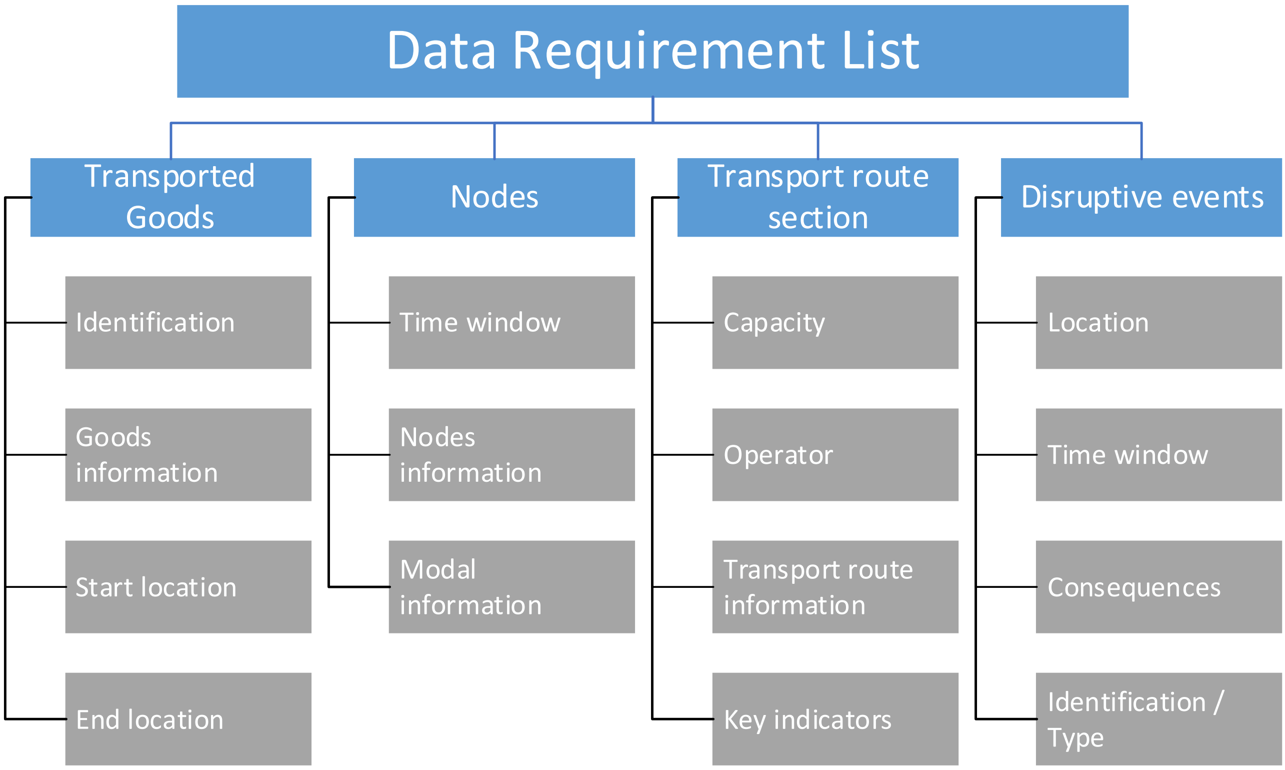


Figure 4: Overview of attribute categorization

The consortium's first enquiry about which attributes they need to know for each meta-level in their day-to-day operations was carried out in a workshop in Karlsruhe. The answers were subsequently analyzed and assigned to the respective meta-levels or block levels. If there was not yet a suitable block level for important attributes, this was added and discussed with the partners in accordance with the procedure from Figure 2.

3.1.2 *Consideration of user requirement and operational requirements*

In this section, the block levels and the associated attributes are described in more detail. The attributes represent the data basis for the reference model and are documented in the required form and granularity in accordance with the user and operational requirements. The attributes and their categorization were developed and validated in workshops with the partners and stakeholders. It should also be noted that the attributes were segmented into static and dynamic attributes. Static attributes are those that do not change over time and dynamic attributes are time dependent. In order to be able to differentiate between these, they are labelled with an "X" in the right-hand column of the following tables.

Transported Goods – Identification

All data relating to the transported goods is collected in the "Transported Goods" area (see Table 2). This includes the identification of the goods. This in turn is necessary to ensure efficient tracking and administration. In addition, attributes are listed here that may originate from a contract or insurance policies.

Attributes for Identification	Description	dynamic
Transport ID	A unique identifier for different transports.	
Shipment ID	It is possible to divide orders according to the unique identification code assigned to each shipment.	
Order ID	The order identification number of the enterprise resource planning (ERP) system may be identical to the transport identification number.	
Customer ID	In the event of a disruptive occurrence, it is imperative that a responsible individual can be identified.	
Order action	The action to be performed is either pickup or delivery.	
Note	Field for additional information that may be relevant.	
Contract	A distinctive identifier for a specific contract data set.	
Insurance Information	Details on the acquired insurance in case of damage, theft, loss, etc.	
Seal (loading carrier)	Information, if there is a lock on the shipping container.	
Operator ID	To facilitate communication during the transport process, it is advantageous to specify an operator identification number.	

Table 2: Attributes for the “Identification” block

Transported Goods – Goods Information

The block for "Goods Information" includes all essential information about the transported goods. This data includes, for example, geometric dimensions, weight and other specific handling information required for the transport. This also applies if the goods are split up during transport. This includes information on how the transport order is divided into several containers and which load carrier type is available. (see Table 3)

Attributes for Goods Information	Description	dynamic
Weight	The total weight of the entire order.	
Volume	The total volume of the entire order.	
Measures	The measures (LxWxH) of the goods concerned.	
Handling Information	The ability to transfer the load to be conveyed, e.g. by crane.	
Assortment	The assortment categories: cooled, fashion, hazardous goods, and food, as well as loose items etc.	
Assortment Group ID	The designation of the assortment group, expressed in a numerical format for the purposes of reference.	
Sequence of Transported Goods	The sequence of goods that can be transported in a specific trailer.	X
Load Carrier ID	It is necessary to determine the type of load carrier and the associated size and weight limits.	
Quantity Load Carrier	The number of carriers (TEU, FEU, EPAL, etc.)	

Table 3: Attributes for the “Goods Information” block

Transported Goods – Start and End Location

Finally, knowledge of the start and end points is essential for carrying out the transport. The data request list includes attributes for the address on the one hand and for the coordinates on the other. This data is essential for planning and the routing process. The time window for collection or delivery is also required for processing. Table 4 lists the attributes for the start location and Table 5 for the end location.

Attributes for Start Location	Description	dynamic
Order start node ID	The identification number of the designated pickup location.	
Pickup Country	Specifies the country where the pickup will occur.	
Pickup Post Code	Specifies the post code where the pickup will occur.	
Pickup City	Specifies the city where the pickup will occur.	
Pickup District	Specifies the district where the pickup will occur.	
Pickup Street	Specifies the street where the pickup will occur.	
Pickup House Number	Specifies the house number where the pickup will occur.	
Pickup Longitude	The geographical position of the pickup location, expressed in degrees of longitude.	
Pickup Latitude	The geographical position of the pickup location, expressed in degrees of latitude.	
Planned Pickup Date Time	The date and time at which the goods are scheduled to be collected.	

Table 4: Attributes for the “Start Location” block

Attributes for End Location	Description	dynamic
Order destination node ID	The identification number of the designated drop-off location.	
Destination Country	Specify the country where the drop-off will occur.	
Destination Post Code	Specify the post code where the drop-off will occur.	
Destination City	Specify the city where the drop-off will occur.	
Destination District	Specify the district where the drop-off will occur.	

Destination Street	Specify the street where the drop-off will occur.	
Destination House Number	Specify the house number where the drop-off will occur.	
Destination Longitude	The geographical position of the drop-off location, expressed in degrees of longitude.	
Destination Latitude	The geographical position of the drop-off location, expressed in degrees of latitude.	
Planned Destination Date Time	The date and time at which the goods are scheduled to be delivered.	

Table 5: Attributes for the "End Location" block

Nodes – Time window

Furthermore, it is essential to consider the time window of each node (displayed in Table 6). The time window defines the specific period of time in which goods can be handled at a particular node. The time window is a key aspect in the planning and coordination of the entire logistics chain and contributes significantly to the efficiency and punctuality of intermodal transport. This ensures the seamless integration of different modes of transport and guarantees a seamless flow of goods.

Attributes for Time window	Description	dynamic
Operating Hours	Details of the operating hours at the nodes.	
Earliest Pickup Time	The earliest possible time for the pickup process.	X
Latest Pickup Time	The latest possible time for the pickup process.	X
Earliest Delivery Time	The earliest possible time for the delivery process.	X
Latest Delivery Time	The latest possible time for the delivery process.	X
Service Time	The duration of the operational phase, or service phase, required to complete the pickup and delivery process.	

Table 6: Attributes for the "Time window" block

Nodes – Nodes information

The geographical information of the individual nodes in the network must be recorded as well as the specific facilities at these nodes. This includes aspects such as the ability to load cranes and the available buffer capacities. Information on intermodality is also of crucial importance. It provides information on the possibility of transshipment from one mode of transport to another, for example from rail to ship (see Table 7).

Attributes for Nodes information	Description	dynamic
Node ID	The identification of the transshipment point/node.	
Name of Node	The name of the transshipment point/node.	
Node Owner	The owner of the transshipment point/node.	
Node Longitude	The geographical position of the node location, expressed in degrees of longitude.	
Node Latitude	The geographical position of the node location, expressed in degrees of latitude.	
Node Country	Specify the country where the node is situated.	
Node Post Code	Specify the post code where the node is situated.	
Node City	Specify the city where the node is situated.	
Node Street	Specify the street where the node is situated.	
Handling Equipment	For example, the availability of a crane at the transshipment node (loading/unloading facility) is a key consideration.	
Means of Transport	The maximum dimensions of a train or ship that can be accommodated. (UIRR Code).	
Handover Information	For example, photos, trailer identification, loading equipment recording, freight document exchange, damage recording.	
In-Storage Requirements	Requirements for transport storage (e.g.: refrigerated storage possible).	
Freight Forwarders per Node	A list of freight forwarders serving this node.	
Value Added Services	Additional services include repair, customs operations, camera detection, weighing options for ITU or charging nodes.	
Maximum Storage Duration	The maximum allowable buffer time at the transshipment node.	X
Capacity of the Intermodal Terminals	The Capacity of the intermodal terminals (slots) (parking spaces for the modes of transport).	X
Storage Capacity	The buffer capacity at the transshipment node.	X
Throughput Rate	Throughput volume per day (throughput).	X
Seasonal Change (Winter conditions)	A description of the characteristics of winter conditions.	

Table 7: Attributes for the “Nodes information” block

Nodes – Modal information

In the context of intermodal transports, intermodal information also becomes highly relevant at the hubs. Furthermore, the specific restrictions at the transshipment node, such as the maximum train length and track gauge, must be considered. From a commercial perspective, a booking system and the handling costs at the node are also relevant (see Table 8).

Attributes for Modal Information	Description	dynamic
Modal Access	Cross-modal access for load carriers.	
Modal Type	Type of mode of transport (road, rail, ship).	
Means of Transport Limits	Maximum train and ship size that can be handled (CEMT requirements, line voltage, train gauge).	
Slot Booking System	Time-based booking system available.	
Transshipment Costs	Handling costs at the Node (per lift).	
Spot Market Price	The price is determined in real time and can fluctuate significantly in response to changes in supply and demand.	X

Table 8: Attributes for the “Time window” block

Transport route section – Capacity

These include a large number of attributes relating to the available capacity on the load carrier used, such as wagons and containers. In addition, data is required on the timetables of the various modes of transport, on the means of transport permitted on the respective route section, on the load carriers permitted there and on the loading gauge in accordance with the UIRR Code (see Table 9).

Attributes for Capacity	Description	dynamic
Timetables	Train / ship / truck timetables.	
Means of Transport	Authorized (capable) means of transport that are permitted to use the specified route.	
Allowed Load Carriers	Allowed load carriers for transported goods (e.g. food transport --> cooled load carriers).	
Allowed Goods	Authorized goods per means of transport (dangerous goods).	
Weight	The load carrier can accommodate a maximum weight load.	X
Height	The load carrier can accommodate a maximum height load.	X
Volume	The load carrier can accommodate a maximum volume load.	X
Load Unit Limits	The maximum usable load carriers (containers, swap bodies, etc.)	
Freight Forwarders per Logistic Section	Transport carriers of the sections.	X
Max. Availability of Carrier	Available means of transportation (wagons, containers, trailers, etc.).	X

Table 9: Attributes for the "Capacity" block

Transport route section – Operator

The "Operator" attribute block contains data relating to the drivers and the means of transport they use. The attributes listed in Table 10 can include, for example, the qualifications and availability of the drivers as well as the technical specifications and capacities of the vehicles. Regarding position tracking, attributes relating to this information are also relevant. These can include information about the current location, speed and estimated time of arrival of the means of transport.

Attributes for Operator	Description	dynamic
Rest areas	Rest areas for drivers, particularly in the context of relay traffic on the road.	
Driver restrictions	Restrictions for drivers (e.g.: driving license).	
Mobile connection	Mobile connection on the route section (2G, 3G).	
GPS position	The Global Positioning System (GPS) is used to determine the location of a vehicle or other object in order to provide real-time data.	
Operator cooperations	It is possible that the operator (system partner) may be restricted in their ability to transmit relay traffic.	X

Table 10: Attributes for the “Operator” block

Transport route section – Transport route information

The information on the transport route is linked to a variety of aspects. In addition to the distance that the goods must cover and the direction of travel, classifications of the routes are also shown in Table 11.

Furthermore, there may be information on the transport route that can influence the transport time. Relevant influencing factors include, for example, traffic jam information, speed restrictions or noise protection regulations.

Attributes for Transport route information	Description	dynamic
Route kilometers	The distance traveled for the purpose of transportation.	
From node	Start node of the transport route section.	
To node	End node of the transport route section.	
Road classification	The percentage of road network sections classified as expressways or highway.	

Rail classification	The classification of railways is dependent on several factors, including the speed at which they operate, the length of the train, the track gauge, the voltage of the line etc.	
Ship classification	In accordance with the requirements set forth by the CEMT, the permissible draught is limited to 2.5 meters. Furthermore, the height of vessels under bridges exceeding 5.25 meters in height is also subject to restrictions.	
Congestion information	Information about traffic delays.	X
Speed limitations	Information on speed restrictions.	X
Noise regulations	Regulations regarding noise.	
seasonal change (Winter conditions)	Accessibility of the transport route in winter.	
Border crossing	In cases where the transportation route crosses an international border (documents required for border crossings).	
Environmental classification	Route classification of the transportation route from an ecological perspective.	
Low emission zones	Low emission zones along the route.	
Energy options	The availability of energy options at petrol stations situated along the designated transport route is to be considered.	

Table 11: Attributes for the “Transport route information” block

Transport route section – Key indicators

The "Key indicators" attribute block contains attributes that enable an evaluation regarding various criteria such as costs, emissions or network resilience (see Table 12).

Attributes for Key indicators	Description	dynamic
Cost / Toll	Charges incurred on the transport route. These include customs duties, tolls and fuel consumption.	
Emissions	The emission profile which is consumed on the route.	
Risk Level	The risk level that this transport route involves in the case of disruptive events.	X

Table 12: Attributes for the “Key indicators” block

Disruptive events – Location

In the event of a disruptive event, location-based data must be accessible. We distinguish between attributes that relate directly to the node and those that relate to the transport route section itself (see Table 13).

Attributes for Location	Description	dynamic
Affected Node ID	The nodes that are impacted by the disruptive event.	X
Affected transport route section ID	The specific transportation routes that are impacted by the disruptive event.	X
Disruptive Location	The geographical position of the disruptive event.	X
Recovery plans/strategy in place	Are recovery plans/strategies in place for the disruptive event.	

Table 13: Attributes for the “Location” block

Disruptive events – Time window

In the event of a disruptive event, the duration of the event must be estimated so that further transports or the rerouting of an existing transport can be carried out (see Table 14).

Attributes for Time window	Description	dynamic
Start	The temporal origin of the disruptive event.	
End	The temporal end of the disruptive event.	

Table 14: Attributes for the "Time window" block

Disruptive events – Consequences

Within intermodal planning, a disruptive event can have certain consequences, which can be both quantitative and qualitative in nature. The quantitative consequences include, for example, an increase in costs, an increase in transport time or a reduction in capacity in the event of a disruptive event (see Table 15).

Attributes for Consequences	Description	dynamic
Quantitative consequences	The quantitative implications of a disruptive event (e.g., additional costs, transportation time, capacity).	X
Qualitative consequences	The qualitative consequences of a disruptive event, for example, the splitting up of a transportation order.	X
Data for insurance (chain of commands)	The objective is to provide data for insurance purposes, specifically regarding the optimal chain of command structure for effective response in the event of a disruptive event.	

Table 15: Attributes for the "Consequences" block

Disruptive events – Identification

The following Table 14 is used to classify disruptive events. The effects on the physical and IT levels are also taken into account. Furthermore, information regarding the chain of command is of crucial importance.

Attributes for Identification	Description	dynamic
Classification of disruptive event	To facilitate analysis, the disruptive event must be classified.	
Predictability	The predictability of the disruptive event.	X
Disruptive layer type	The impact on the physical (workforce strikes, infrastructural damage etc.) or informational level (internet fluctuations, server disruptions etc.).	
Process chain of commands	It is necessary to identify the directly affected instances and determine the appropriate course of action. It is also essential to communicate this information to the relevant parties.	

Table 16: Attributes for the "Identification" block

3.1.3 *Incorporating expert opinions*

The information collected for the reference model was supplemented by input from expert interviews with an Austrian rail transport company and one of the largest operator of a container terminal in a European inland port. During the interviews, both the booking process and disruptive events that had already taken place in the past were discussed.

Booking process rail transport companies

Planning cross-border train transports involves a number of challenges that need to be overcome. In principle, the booking process must be initiated with a certain lead time to ensure that the capacities are available at the relevant time. As part of the planning of cross-border train transports, so-called regular trains with round trips are ordered by the customer for the coming year. The required resources are then booked on the basis of this information. This includes both the locomotives and the wagons for the transport. There is also the option of leasing the wagons from another company. In addition to the means of transport, rail transport also requires the booking of track capacity. In this respect, the ÖBB (Austrian Federal Railways) in Austria and DB Infra (Deutsche Bahn Infrastruktur) in Germany are worth mentioning. In other European countries, bookings are made with the respective national infrastructure managers. Standard concepts are agreed with customers at least three months in advance, resulting in the booking of standard train paths with the required infrastructure.

The remaining parking spaces are considered retrospectively as part of the planning process. However, there are no plans to take this into account during the planning process. The decisive restriction in train transport is the length of the train on the one hand and its weight on the other. With regard to the weight and length of the train, the responsibility for planning lies entirely with the railway company. In this respect, the example of German rail transport can be used. The API provided by Deutsche Bahn (train path finder) enables the maximum weight and maximum train length to be taken into account. It is regrettable that no data platform in Austria offers this kind of information.

An example of this in Austria is the weight restriction due to the gradients on the transport routes. With regard to the Tauern line, it should be noted that a total weight limit of 700 tons applies for trains. As an alternative option, the use of two locomotives, also known as a tandem, with a total weight of 1,150 tons per train can be considered. With three locomotives, also known as leading and trailing locomotives, the permissible total weight of the train is 1,600 tons to overcome the gradient. In this context, it should also be noted that the locomotives are compatible with each other. With regard to the overall length, this depends on the transshipment stations and is regulated at EU level with a maximum of 700 meters. However, it should be noted that this is handled differently in the individual countries. In Slovenia, for example, the maximum train length is only 540 meters.

Within round trip concepts, locomotives and the number of wagons required for transport are taken into account. Slots in the terminals are also coordinated as part of the pre-carriage planning. Coordinating the train path and slots with the customers is essential. This is also necessary in order to take into account any transshipment or personnel exchange processes at the border. Following the preliminary planning, which includes the creation of round-trip concepts, detailed weekly planning is carried out. Knowledge of the infrastructure, for example with regard to the maximum train length, is prepared within the company and communicated internally. There is no systemic storage. This can also be seen in the example data supplied by Contargo.

In the following, individual disruptive events that have already occurred in reality in the rail transport sector are discussed in more detail.

Delays / handling deviations

In the event of delays, the booked train path is rescheduled or a waiting position at the national border is established until the delayed train is able to continue its journey. In the event of serious delays, i.e. delays of more than six hours, a new train path is required. In the event of a difference between the final and loading time, the waiting time must be bridged until the next available slot. In the event of major delays occurring at the terminal, new slots are used. This requires renewed planning of the necessary resources. The decision as to whether a new train path is required in the event of a delay of more than six hours depends on whether the necessary resources along the route are also available with the delay. In addition to the locomotive, this also includes the personnel along the transport route, such as the train driver.

Disruptive event / Terminal Aachen closed

If a transshipment terminal (node) is blocked, the dispatcher coordinates the round trips that are still in the transshipment terminal. Further round trips will be included by the planners in the future and rerouted accordingly. Rescheduling via another terminal only takes place if there is time pressure.

Disruptive event in the form of additional capacity

Due to the detailed weekly planning, the available resources are already utilized. This implies that additional flexible transshipment at a terminal would entail corresponding additional work and the associated time expenditure. As a consequence, the staff at the border station would be forced to wait, as this has already been taken into account in the weekly planning. Various factors have to be taken into account during transshipment at a terminal, including the entry, the turning of the locomotive, the wagon inspector's check and the exit. In this context, the rail network is too rigid for short-term adaptations, as the schedules to be adhered to allow little flexibility.

Container terminal operator on the Danube

As outlined above, a brief description of the disruptive events recorded during the expert interviews is provided here. On the one hand, this serves to develop an understanding and, on the other, to harmonize the reference model accordingly.

History of disruptive events at a trimodal transshipment hub

In the event of a disruption affecting the handling of a transshipment terminal, for example a crane malfunction, a large-scale message is sent to the freight forwarders by e-mail or telephone. The duration of the waiting time depends on the type of disruptive event. Table 17 provides an overview of the recorded disruptive events.

Disruptive event	Description
Crane fault	Experience shows that crane malfunctions usually last a maximum of one day. This is primarily due to the provision of the necessary spare parts, which enables the fault to be rectified quickly.
Train derailment	With regard to the derailment of trains, we are talking about a distance of up to two centimeters from the rail. Such an event can occur, for example, if a container becomes wedged against the wagon. In the event of a derailment, it is necessary to change the terminal at the port of transshipment, which is associated with significant additional costs.
Strikes	So far, there is no information about work stoppages by employees.
Power outage	So far, a power outage lasting five hours has been recorded. The problem lies in the interruption of the connection to the outside world. As a measure, manual processing is carried out on the accompanying documents.
Train delay	If trains are delayed, the trains concerned will be blocked from the last transshipment terminal. The railway undertakings are fully responsible for rerouting trains. In extreme cases, it may be necessary to buffer the affected trains in Germany in order to avoid disrupting the other round trips. Coordination with the train dispatchers regarding permission for a train to enter the port takes place at least 24 hours in advance.

Table 17: Example of disruptive events at the container terminal

3.2 Incorporating elements into Models

Before the attributes collected and categorized in Section 3.1 can be incorporated into a reference model, a suitable model type must be selected. This section explains the procedure for selecting the model type and describes the properties and correct notation of the selected model type.

3.2.1 *Model selection*

The reference model should serve as the basis for further work packages and be usable primarily for routing and transport planning algorithms. This results in the requirement to model large amounts of information in the form of data structures. The selection of models to be evaluated was therefore limited to database models.

Although schematic models in the form of maps, processes etc. could describe a multimodal transport network, they do not allow the necessary data structure to be modelled. A utility analysis was carried out to select the specific database model for a reference model that is to describe multimodal transport networks.

Benefit analysis

A utility analysis helps to act rationally and decouple decisions from subjective preferences. The utility analysis ensures that all aspects of a decision, including those that cannot be counted, measured or weighed, are evaluated and incorporated into a score - the utility value - by means of a transformation process. To this end, the influencing factors on the situation under consideration are first sought, then their relative importance is assessed and finally the alternative courses of action are evaluated in terms of their contribution to solving the problem (goal). The basic concept of

1. searching for descriptive criteria,

2. the weighting of these criteria,

3. the evaluation of the degree of fulfilment and

4. the summation of the evaluations per criterion to an overall score.

This score can then be compared with the scores of other entities. The pair comparison method was used to weight the criteria. The pair comparison method is always useful when not only a ranking of factors, determinants, options etc. is to be formed, but also the distances between the ranking positions play a role. The criteria are therefore not only scaled ordinally, but also cardinally. The process consists of querying the ranking of two criteria in each case: ‘Is A more important for the evaluation of the decision problem at hand or B?’ ‘A or C?’ “B or C?”. And so on. Each criterion is compared with every other criterion. If one criterion is considered more important, it receives 2 points, the other 0 points. If both are equally important, then both receive 1 point. The total number of points for each criterion is added up and the proportion of the total points awarded is calculated. This is the weighting for the subsequent evaluation of the variants in the utility analysis (Kühnapfel 2021).

Requirement criteria

The criteria to be evaluated are listed and described in the following Table 18.

Criteria	Description
High mapping capability of the relationship between attributes	Based on the initial findings from Section 3.1.2, the first dependencies and cardinalities of the attributes can be recognized. This criterion evaluates how well the model is suited to reflecting these structures.
Easy transferability to other corridors	The reference model should also be applicable to other corridors beyond the ReMuNet project. This criterion evaluates how easily the model can be transferred.
Easy to understand semantics	The semantics of the model should also be comprehensible and understandable for people from the field of logistics who do not have an affinity for data. This criterion evaluates how intuitive the semantics of the model are.
High flexibility in detailing	The reference model does not serve as a physical data model, but as a logical one. It should set the direction but leave room for the final detailing so as not to be too rigid with regard to the usual data structures of different users. This criterion evaluates how flexible the model can be designed.

Easy extension of attributes	The reference model should have the ability to be continuously updated and supplemented with new attributes. This criterion evaluates how easily the model can be extended with additional attributes.

Table 18: Requirements criteria for the selection of the data model

Pairwise comparison

The following figure shows the result of the pairwise comparison of the weighting of the requirement criteria. As can be seen in the figure, the weighting is as follows:

- Rank 1: High mapping capability of the relationship between attributes (35%)
- Rank 2: Easy to understand semantics (25%)
- Rank 3: Easy transferability to other corridors (15%)
- Rank 3: Easy extension of attributes (15%)
- Rank 5: High flexibility in detailing (10%)

Pairwise comparison

Pairwise comparison:	
0	Top attribute is more important
1	Both attributes are equally important
2	Left attribute is more important

		High mapping capability of the relationship between attributes	Easy transferability to other corridors	Easy to understand semantics	High flexibility in detailing	Easy extension of attributes	Weighting	Rank
1.	High mapping capability of the relationship between attributes		2	2	1	2	35%	1
2.	Easy transferability to other corridors	0		1	1	1	15%	3
3.	Easy to understand semantics	0	1		2	2	25%	2
4.	High flexibility in detailing	1	1	0		0	10%	5
5.	Easy extension of attributes	0	1	0	2		15%	3

Figure 5: Pairwise comparison of the requirement criteria

Models for the evaluation

The most common data models currently in use were used for the evaluation (Gronwald 2024). These include the following models:

• **Relational model:** All data contained in a database is displayed as tables with a fixed number of columns and a variable number of rows.

• **Dimensional models:** In dimensional models, data is structured in such a way as to optimise the retrieval and analysis of large volumes of data. Dimensional data models capture business questions that relate to a specific business process.

• **Object-orientated model (UML):** The object-oriented model is closely related to object-oriented programming languages. UML (Unifed Modelling Language) has a class model that supports databases. Object-orientated database models map data records and all associated attributes in objects that make all information directly available. Instead of distributing everything in different tables, the data can be called up as a bundle. In addition to attributes, objects also store methods. The objects are also grouped into classes.

• **Fact-based model:** Fact-based modeling languages store raw data as atomic facts in a simple form of natural language. Facts cannot be further subdivided into smaller, more meaningful components. Facts are time-stamped, making them unchangeable and permanently correct. Facts are identifiable so that duplicates can be recognized during queries. The fact-based model provides a simple yet expressive way to store data by preserving the entire time history of all changes to all objects.

• **Time-based model:** Time-based models are used when data is related to specific time values in chronological order.

• **NoSQL:** NoSQL (not only SQL) is the term for a category of databases that are based on non-relational technology. There are four main types of NoSQL databases: Document, Key-value, Column-oriented and Graph databases.

- Document: Instead of splitting a business object into multiple relational structures, document databases often store the business object in a single structure called a document.
- Key-value databases: Allow an application to store its data in just two columns (“key” and “value”), where both simple (e.g. dates, numbers, codes) and complex information (unformatted text, video, music, documents, photos) can be stored in the “value” column.
- Column-oriented: Of the four types of NoSQL databases, column-oriented is most comparable to relational database systems.
- Graph database: Is intended for data whose relationships can be well represented as a set of nodes with an indefinite number of connections between those nodes.

Benefit analysis

A point scale from 1 (very poor) to 5 (very good) was introduced to evaluate the various data models. The result of the utility analysis is shown in the following figure.

Attribute	Weighting	Relational	Dimensional	Object -oriented	Fact-based	Time-based	NoSQL
High mapping capability of the relationship between attributes	35%	5	1	4	1	2	5
Easy transferability to other corridors	15%	5	2	4	1	2	2
Easy to understand semantics	25%	3	5	5	3	3	2
High flexibility in detailing	10%	4	4	4	4	3	5
Easy extension of attributes	15%	5	5	4	1	2	4
1 very bad; 5 very good	Total	4,40	3,05	4,25	1,80	2,35	3,65

Figure 6: Result of the benefit analysis

The data model selected for the reference model is a relational data model based on the result of the utility analysis. The entity-relationship diagram (ER diagram) is used to describe a relational data model.

3.2.2 *Model description*

ER modeling is a technique used in logical design modeling. Once the business requirements and data requirements have been gathered and an understanding of the business rules is reached, the development of the logical data model can commence. The three fundamental components of an ER model include entities, relationships, and attributes.

An entity in the logistics context is a hub, train, good etc. about which the business keeps data. For example, an enterprise keeps track of its products, customers, employees, suppliers, and interactions with partners or other business entities. The enterprise needs all these things, or entities, to operate and manage its business along the multimodal transport network. Relationships show how the entities are related to one another. Relationships are the logical links between the entities that represent the business rules or constraints. For example, a hub's relationship to a transport route section is that she is linked to it. These links have business rules, which are captured in the data model. An attribute is a distinct characteristic of an entity for which data is maintained. For example, if the entity is a good, the attributes may be price, color, and size. These attributes are characteristics the enterprise needs to capture in order to digitally model a multimodal transport network.

There are two types of attributes in an entity: key or non-key. The following figure shows the symbolic representation of an entity with a key attribute (Attribute 1: Primary key; Attribute 2: Foreign key) and the non-key attributes (Attribute 3 to n). A primary key is a field or a group of fields with values that are unique in a table and enable the identification of a record in a table. There is only one primary key per entity. If a primary key occurs in another entity, it is referred to there as a foreign key. Keys are important to join data from different entities. Unlike key attributes, non-key attributes do not uniquely identify an attribute.

	Entity name	
PK	**Attribute 1**	data type
FK	**Attribute 2**	data type
	Attribute 3	data type
	.	
	.	
	Attribute n	data type

Figure 7: Symbolic representation of an entity

Cardinality

Cardinality is defined as the number of instances of an entity in a relationship with another entity. There can be one or many instances. For example, with a parent-child relationship, cardinality defines, on both the parent and child sides, how many occurrences can take place between these entities. There are four main options, described in the following table: 1 Mandatory, 1 Optional, Many Mandatory, Many Optional. (Sherman 2015)

Notation of an ER diagram

The Crow's foot notation was chosen for the notation of the cardinalities of the ER diagram. The possible cardinalities and their symbols are shown in the following Table 19:

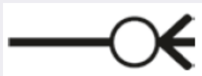
Association type	Number of tuples	Crow's foot
1 Mandatory	Exactly one tuple (1)	
1 Optional	None or exactly one tuple (0/1)	
Many Mandatory	At least one tuple (≥1)	
Many Optional	Any number of tuples (≥0)	

Table 19: Crow's Foot Notation (cf.Gronwald 2024, p.50)

4. REFERENCE MODEL

This section provides a detailed explanation of the specific model design. Additionally, it specifies the data sources that can be utilized to populate the reference model. We present a use case focused on the identification of multi-modal transport routes within two distinct TEN-T corridors. Finally, we discuss the challenges encountered during the development of the reference model and the process of gathering data for the use case.

4.1 Model design

Based on the attributes required for a reference model to describe a multimodal transportation network from section XY and the notation according to section YZ, the ER diagram was created in Figure 8 below.

The main entities in turn correspond to the 4 meta levels:

- **Transported Goods** (Primary key: Order_id)
- **Nodes** (Primary key: Node_id)
- **Transport Route Section** (Primary key: Transport route section_id)
- **Disruptive Events** (Primary key: Disruptive event_id)

The meta levels are shown as entities in the ER diagram. Attributes that can be assigned from a certain pool of values have also been combined into additional entities. This has the advantage that these attributes do not have to be documented individually for each data set from other entities. These are:

- **Locations** – contains all attributes for the localization of nodes
- **Modes -** contains the three different modes of transport (road, rail, ship)
- **Load carriers** – contains all attributes that describe the used or permitted load carrier
- **Freight forwarders** – contains a list of relevant freight forwarders

The eight entities have the following relationships with each other:

- **Transport route section – Nodes:**
    - **departs_at** (Many Mandatory to 1 Mandatory):
      Transport route sections always require exactly one start node. A node can be the start node for several transport route sections.
    - **arrives_at** (Many Mandatory to 1 Mandatory)**:**
      Transport route sections always require exactly one end node. A node can be the end node for several transport route sections.
- **Transport route section – Disruptive Events:**
    - **affects** (1 Optional to Many Optional):
      Transport route sections can be affected by one or more disruptive events.
- **Transport route section – Load carriers:**

  - **allows** (Many Mandatory to Many Mandatory):
    Transport route sections always require at least one load carrier type that can be transported along the route. However, you can also allow several load carrier types.

- **Transport route section – Freight forwarders:**
  - **approached_by** (Many Mandatory to Many Mandatory):
    Transport route sections always require at least one freight forwarder to handle transports along the route. However, several freight forwarders can also serve a route.

- **Transport route section – Modes:**
  - **has_mode** (Many Mandatory to 1 Mandatory):
    Transport route sections use exactly one mode of transport type. A mode of transport category can be relevant for several transport route sections.

- **Nodes – Transported Goods:**
  - **pickup_at** (1 Mandatory to Many Mandatory):
    Transported goods always require exactly one order start node. A node can be an order start node for several transported goods.
  - **delivery_at** (1 Mandatory to Many Mandatory)**:**
    Transported goods always require exactly one order destination node. A node can be an order destination node for several transported goods.

- **Nodes – Disruptive events:**
  - **affects** (1 Optional to Many Optional):
    Nodes can be affected by one or more disruptive events.

- **Nodes – Modes:**
  - **has_mode** (Many Mandatory to Many Mandatory):
    Nodes are connected to at least one mode of transport type. However, a node can also be connected to several modes of transport.

- **Nodes – Locations:**
  - **is_located_at** (1 Mandatory to 1 Mandatory):
    Nodes are assigned to exactly one location.

- **Transported Goods – Load carriers:**
  - **transported_with** (1 Mandatory to 1 Mandatory):
    Transported goods are transported in at least one load carrier. A load carrier can be used for several transported goods.

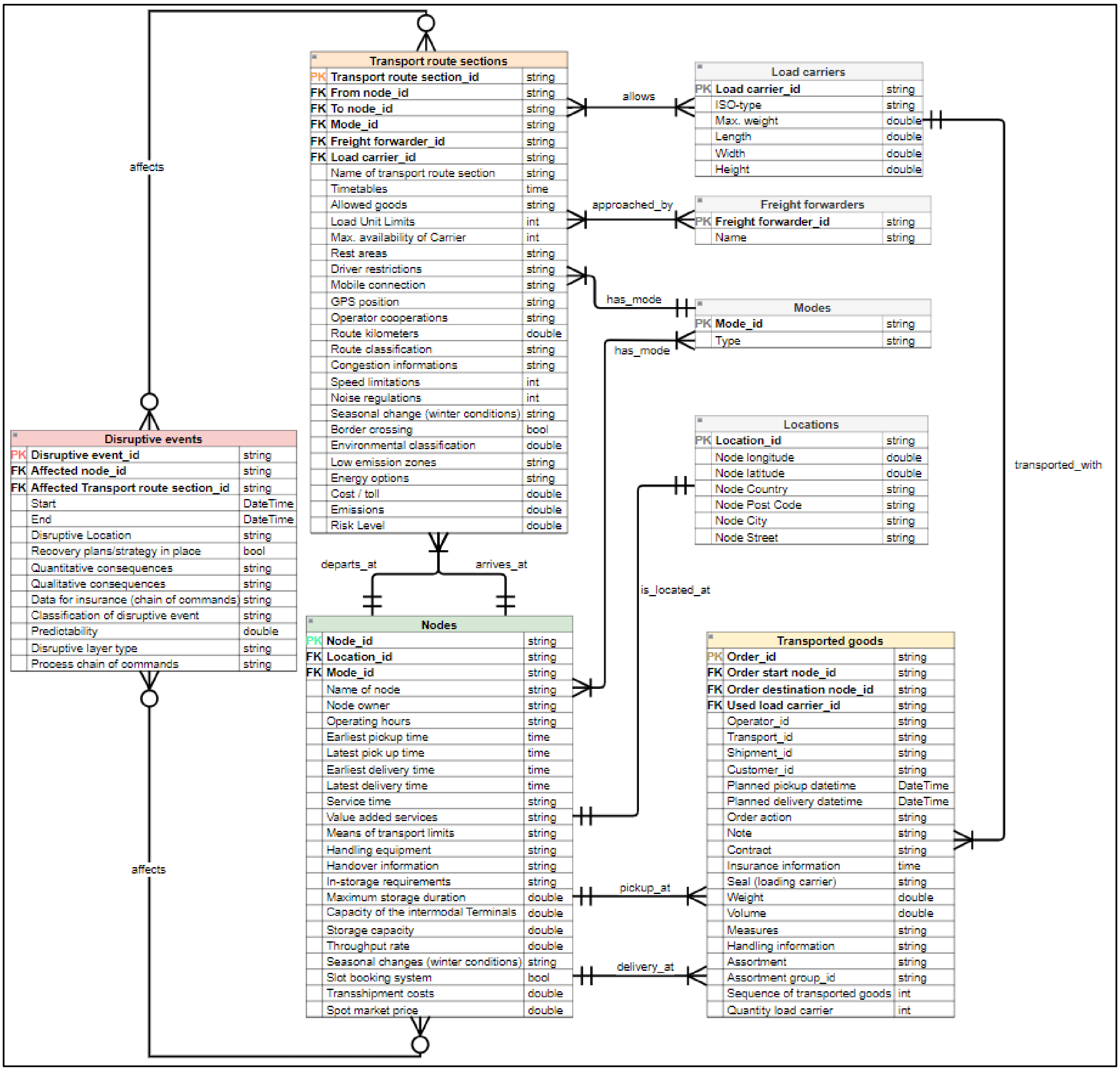


Figure 8: Reference model (ER-Diagram)

4.2 Data sources

The reference model generally specifies which information is required for the four meta-levels and how these must be linked to each other in order to describe a multimodal transport network. The model is therefore independent of the corridor to be described. Nevertheless, sooner or later the reference model will be transformed into a physical data model with specific data sets. For this reason, a joint WP2 workshop was held in Vienna to determine how data can be obtained for the data model. Table 20 below shows platforms, companies, etc. (in Europe) that can serve as data sources for the respective categories (marked in green). It is also indicated whether the information is freely available (open API) or must be obtained for a fee or through memberships (closed API). A further column indicates which modes of transport are covered by this data source. The meta-level “Transported goods” has been omitted from this overview, as these are customer orders and must always be requested from various freight forwarders or transport service providers.

Data Source	Type	Nodes	Transport route section	Disruptive events	Mode of transport
C-roads	Closed API			X	Road
Marine traffic	Open API			X	Ship
Rail Cargo Austria	Closed API			X	Rail
ÖBB	Open API			X	Rail
Qgis	Open API			X	Road, Rail
Ten-T / Ten-Tech	Closed API			X	Road, Rail, Ship
Euris	Open API				Ship
BAW	Closed API				Ship
SGKV	Closed API		X	X	Road, Rail, Ship
TX Logistics	Open API			X	Road, Rail
Mobilithek	Open API			X	Road, Rail, Ship
Asfinag	Open API	X	X		Road
Datex II	Open API	X			Road
Route Scanner	Open API			X	Road, Rail, Ship
Contargo	Open API			X	Road, Rail, Ship
Trassenfinder	Open API				Rail

Table 20: Possible data sources for the reference model

4.3 TEN-T use case

This section demonstrates the application of the reference model in a practical real-world scenario. We specifically examine the problem of identifying multi-modal transport routes, with a focus on the Rhine-Danube corridor and the North Sea-Baltic TEN-T corridors. Our solution enables the generation of multiple transport routes using different modes for a single source-to-destination relationship, allowing for the avoidance of potential disruptions by manually selecting alternative routes.

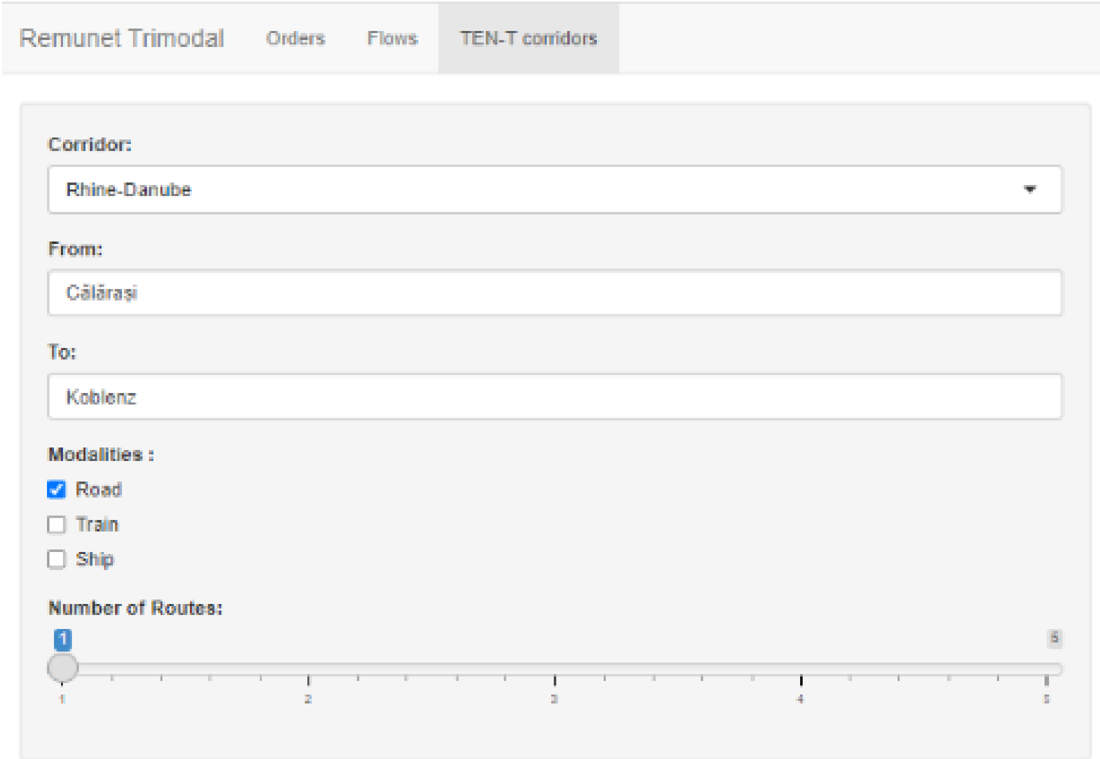


Figure 9: Prototype interface for the use case

To find a feasible transport route, we must specify the relevant corridor, the starting point (source) and the destination (sink) for the transport. Additionally, we need to specify the types of transportation modes to be utilized, as well as the desired number of routes to be identified. We refer to Figure 9 for an illustration of the input interface. Once the route is generated, it is displayed on the map alongside the input interface.

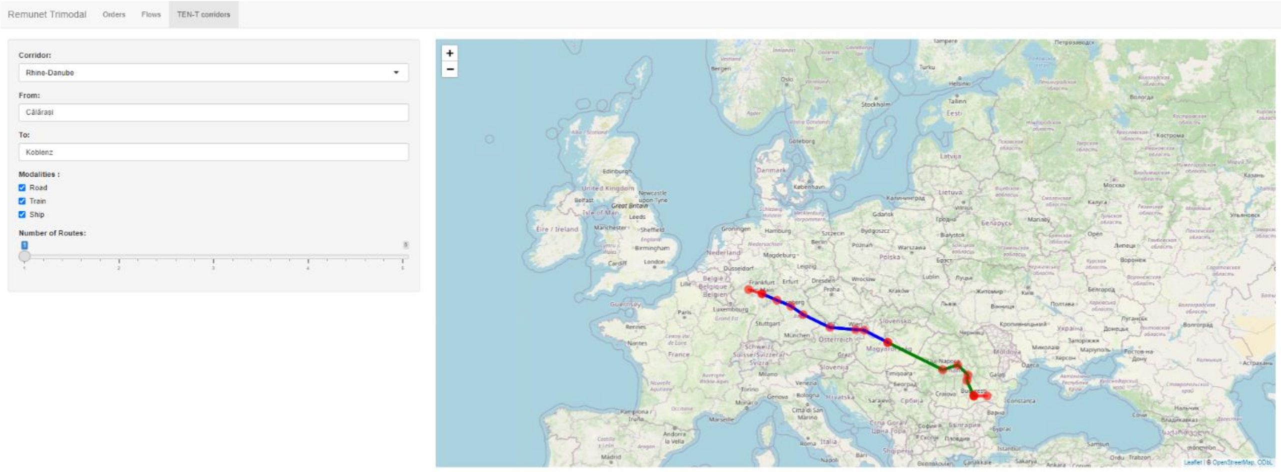


Figure 10: Multi-modal transport route

By considering multiple modes of transportation, it is possible to identify routes that combine different modalities, as shown in Figure 10. Clicking on specific transport nodes provides additional information, such as the estimated time of arrival or departure (see Figure 11). Moreover, details regarding the transport node itself, such as opening hours or the available handling equipment at the terminal, can also be accessed.

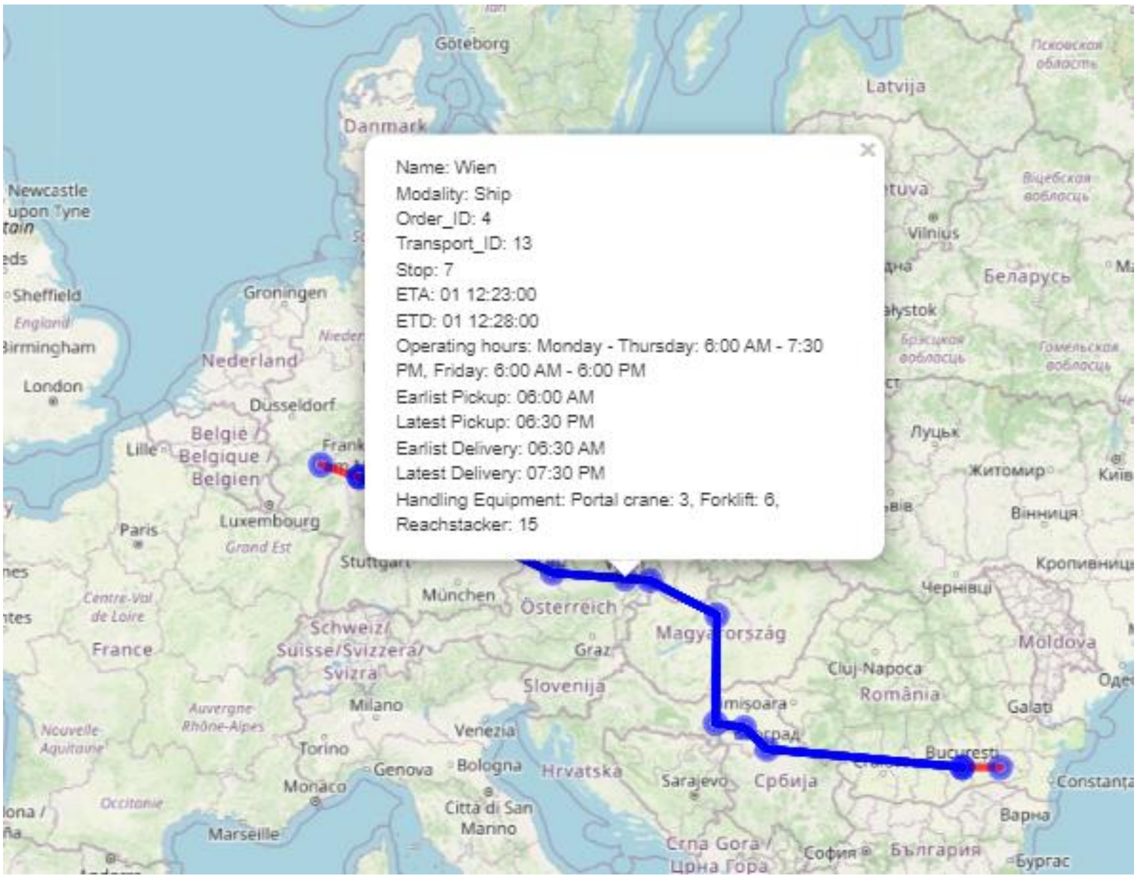


Figure 11: Additional information at transport nodes

As previously mentioned, our prototype also supports the provision of multiple routes for a single connection. This functionality is depicted in Figure 12.

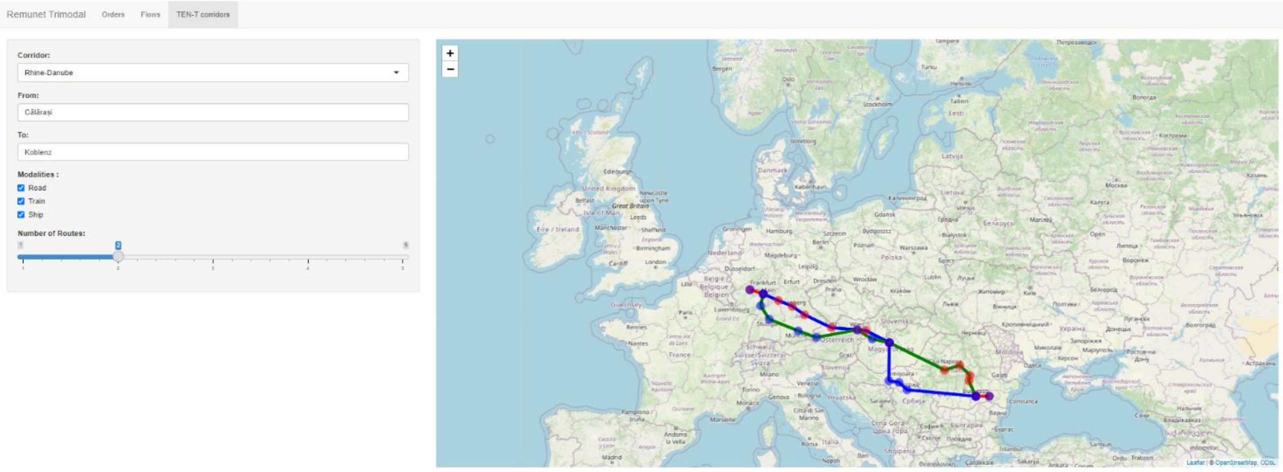


Figure 12: Provision multiple multi-modal transport routes for a single connection

While our focus in this use case primarily lies on the Rhine-Danube corridor due to the data availability from various partners, our prototype can also accommodate the North Sea-Baltic corridor (as shown in Figure 13) provided that the corresponding data is available.

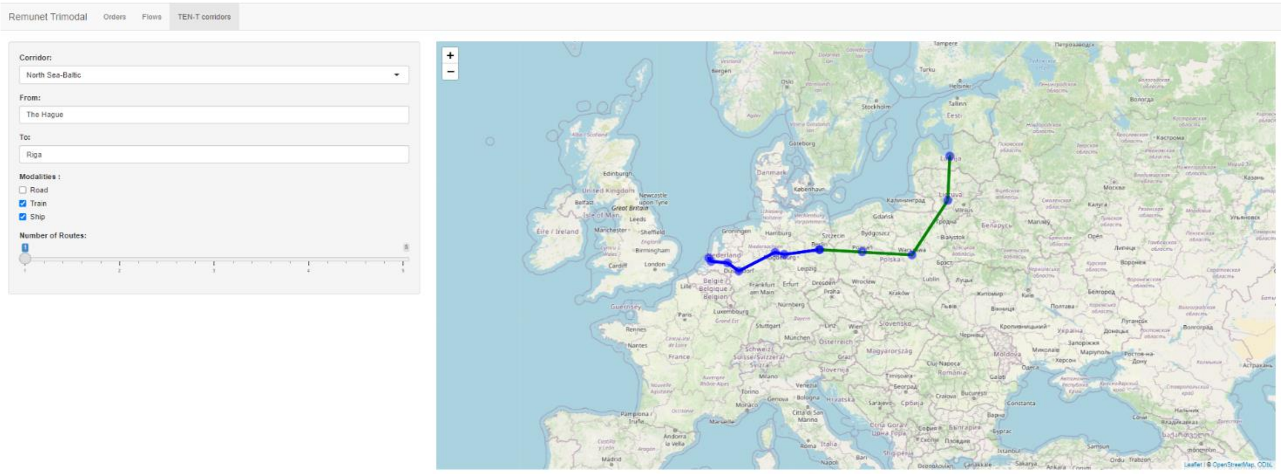


Figure 13: Example of finding a multi-modal transport route from "The Hague" to "Riga"

In the current version of our prototype, we primarily focused on finding multi-modal transport routes regarding data on transport times. However, it could easily be used to optimize transport routes, reduce transport time, or enable sustainable and green transport planning.

4.4 Challenges

The generation and provision of data proves to be a major challenge in the context of a multimodal transportation network that includes a large number of actors. Ensuring efficient and reliable transportation processes requires the seamless integration and exchange of data between the parties involved. The main challenges in data generation for such a network are examined and described below.

Certain methods were used to meet the aforementioned challenges. The methods shown in green in Figure 14 are explained in more detail below. At the beginning of the project, a questionnaire was sent to the stakeholders using MS Forms (Microsoft) to collect the requirements for a reference model. Due to insufficient accuracy, the partner meetings were coordinated and the planning masks of the transportation software were discussed. After the discussion, the process of data collection and data evaluation was initiated. To this end, the consortium partners were asked to submit all available historical data sets containing one or more of the attributes.

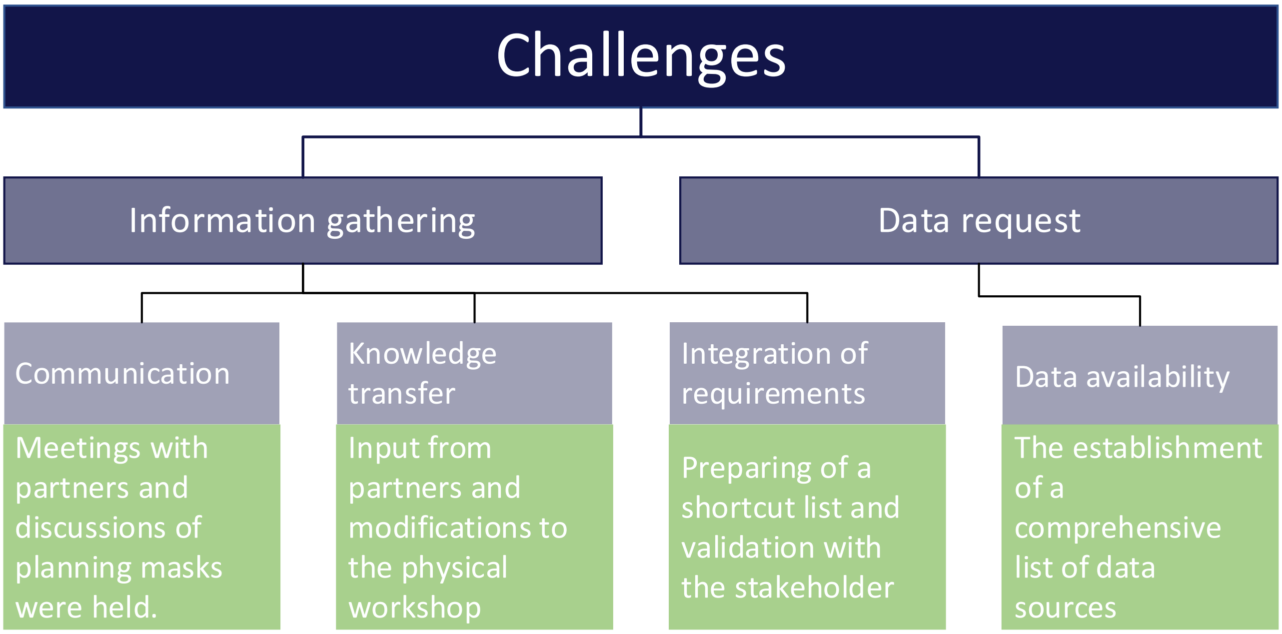


Figure 14: Challenges in the data acquisition process

Subsequently, the knowledge transfer was evaluated by the project partners and feedback was obtained. Joint physical workshops were held due to divergent views, particularly with regard to the terminology of the attributes for the data request list. Due to the different codes and formats contained in the data, such as the labeling for international loading units, standards were introduced to ensure comprehensibility and traceability.

As a result, a list of attributes was created, which was converted into a shortlist. In this context, the structure of the list and the number of attributes were revised once again.

Once the list of data requirements, which included all attributes relevant to the stakeholders, had been finalized, the data collection process began. Another challenge was ensuring the availability of the data. However, the large number of attributes meant that not all of them could be covered with a sufficient number of data sets. For the attributes mentioned, the approach of simulation by artificial intelligence or tapping into an open-source data platform was chosen. As a result, it was possible to generate missing data for certain attributes. An additional challenge in obtaining valid data was data security, which is why some of the data was anonymized to ensure compliance with internal data protection guidelines. It is important to ensure both the security of customer data and the confidentiality of internal company information. This guarantee of data security represents a significant challenge in the provision of data for the reference model.

In summary, the lack of willingness to collaboratively provide data by transportation network stakeholders is one of the main reasons why reference models for multimodal transportation networks did not exist before ReMuNet. In the ReMuNet project, too, a large part of the data sets had to be anonymized or simulated in order to create a useful data model for further use cases.

5. CONCLUSION

In this report, we presented a reference model for multimodal transportation networks and described the methodological procedure for developing the model. Initially, questionnaires and workshops were employed to gather input from both consortium partners and external stakeholders regarding important attributes of a multimodal transportation network. These attributes were identified as pertinent elements for the development of the reference model and were transformed into a list of data requirements.

To enhance the structure of this data request list, categorizations were implemented and the interconnections between them were analyzed. Four overarching categories (meta levels) were established: "Transported Goods," "Nodes," "Transport Route Sections," and "Disruptive Events." To ensure clarity, additional sub-categories (block levels) were introduced to facilitate comprehension of the structure of the data request list by individuals who may not be directly involved in the project.

Expert interviews were conducted to further inform the reference model. These interviews provided a deeper understanding of the relationships between attributes and shed light on relevant processes related to spontaneous adaptations in the event of disruptive events. This allowed us, for instance, to determine the necessary level of granularity and detail required for the reference model.

Based on these findings, a model type was selected that enables all recorded attributes and their links to be represent.

In the concrete implementation of the reference model, all essential elements identified by the actors of multimodal transport networks were incorporated. The relationships and interactions between these elements are illustrated in Figure 8. Furthermore, this report specifies the data sources, such as platforms and companies, necessary to populate the developed reference model with concrete data sets.

The acquisition of particular data sets posed the biggest challenge. The absence of a cooperative inclination among transportation network stakeholders is a primary factor contributing to the nonexistence of reference models for multimodal transportation networks prior to the emergence of ReMuNet. Even within the framework of the ReMuNet project, a substantial portion of the datasets had to undergo anonymization or simulation in order to generate a practical data model for the use case presented in this report, as well as for subsequent use cases.

In summary, it can be said that the development of a Europe-wide database to describe the multimodal transport network in Europe is only possible through the standardized and uniform collection of data from all network players. The reference model developed in the ReMuNet project precisely provides this standardization of the data model, which only needs to be populated with real data records by the user of the model in order to describe any corridor.

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7. APPENDIX

7.1 Data requirement list

Meta-level	Block	Attribute	Description	dynamic
Transported goods	Identification	Transport ID	A distinctive method of identifying transportation.	
		Shipment ID	It is possible to divide orders according to the unique identification code assigned to each shipment.	
		Order ID	The order identification number of the enterprise resource planning (ERP) system may be identical to the transport identification number.	
		Customer ID	In the event of a disruptive occurrence, it is imperative that a clearly responsible individual be identified.	
		Order Action	The action to be performed is either pickup or delivery.	
		Note	Field for descriptions and any additional information that may be relevant.	
		Contract	A distinctive identifier for a specific contract data set.	
		Insurance information	The following section contains information on the insurance in question.	
		Seal (loading carrier)	Information, if there is a lock on the shipping container.	
		Operator ID	To facilitate communication during the transport process, it is advantageous to specify an operator identification number.	
	Goods Information	Weight	The total weight of the entire order.	
		Volume	The total volume of the entire order.	
		Measures	The measures (LxBxH) of the goods concerned.	
		Handling Information	The ability to transfer the load to be conveyed e.g. by crane.	
		Assortment	The assortment categories: cooled, fashion, hazardous goods, and food, as well as loose items etc.	
		Assortment Group ID	The designation of the assortment group, expressed in a numerical format for the purposes of reference.	
		Sequence of Transported Goods	The sequence of goods that can be transported in a specific trailer.	X
		Load Carrier ID	It is necessary to determine the type of load carrier and the associated size and weight limits.	
		Quantity Load carrier	The number of carriers (TEU, FEU, EPAL, etc.)	
	Start Location	Order start node ID	The identification number of the designated pickup location.	
		Pickup Country	Specifies the country where the pickup will occur.	
		Pickup Post Code	Specifies the post code where the pickup will occur.	
		Pickup City	Specifies the city where the pickup will occur.	
		Pickup District	Specifies the district where the pickup will occur.	
		Pickup Street	Specifies the street where the pickup will occur.	
		Pickup House Number	Specifies the house number where the pickup will occur.	
		Pickup Longitude	The geographical position of the pickup location, expressed in degrees of longitude.	
		Pickup Latitude	The geographical position of the pickup location, expressed in degrees of latitude.	
		Planned Pickup Date Time	The date and time at which the goods are scheduled to be collected.	
	End Location	Order destination node ID	The identification number of the designated pickup location.	
		Destination Country	Specify the country where the pickup will occur.	
		Destination Post Code	Specify the post code where the pickup will occur.	
		Destination City	Specify the city where the pickup will occur.	
		Destination District	Specify the district where the pickup will occur.	
		Destination Street	Specify the street where the pickup will occur.	
		Destination House Number	Specify the house number where the pickup will occur.	
		Destination Longitude	The geographical position of the pickup location, expressed in degrees of longitude.	
		Destination Latitude	The geographical position of the pickup location, expressed in degrees of latitude.	
		Planned Destination Date Time	The date and time at which the goods are scheduled to be collected.	

Figure 15: Data requirement list for “Transported goods”

Nodes	Time window	Operating Hours	Details of the operating hours at the nodes.	
		Earliest Pickup Time	The earliest possible time for the pickup process.	X
		Latest Pickup Time	The latest possible time for the pickup process.	X
		Earliest Delivery Time	The earliest possible time for the delivery process.	X
		Latest Delivery Time	The latest possible time for the delivery process.	X
		Service Time	The duration of the operational phase, or service phase, required to complete the pickup and delivery process.	
	Nodes information	Node ID	The identification of the transshipment point/node.	
		Name of Node	The name of the transshipment point/node.	
		Node Owner	The owner of the transshipment point/node.	
		Node Longitude	The geographical position of the node location, expressed in degrees of longitude.	
		Node Latitude	The geographical position of the node location, expressed in degrees of latitude.	
		Node Country	Specify the country where the node is situated.	
		Node Post Code	Specify the post code where the node is situated.	
		Node City	Specify the city where the node is situated.	
		Node Street	Specify the street where the node is situated.	
		Handling Equipment	For example, the craneability at the transshipment node (loading/unloading facility) is a key consideration.	
		Means of Transport	The maximum dimensions of a train or ship that can be accommodated. (UIRR Code).	
		Handover Informations	For example, Photos, trailer identification, loading equipment recording, freight document exchange, damage recording.	
		In-Storage Requirements	Requirements for transport storage (f.e.: refrigerated storage possible).	
		Freight Forwarders per Node	A list of freight forwarders serving this node.	
		Value Added Services	Additional services include repair, customs operations, camera detection, weighing options for ITU or charging nodes.	
		Maximum Storage Duration	The maximum allowable buffer time at the transshipment node.	X
		Capacity of the Intermodal Terminals	The Capacity of the intermodal terminals (slots) (parking spaces for the modes of transport).	X
		Storage Capacity	The buffer capacity at the transshipment node.	X
		Throughput Rate	Throughput volume per day (throughput).	X
		Seasonal Change (Winter conditions)	A description of the characteristics of winter conditions.	
	modal information	Modal Access	Cross-modal access for load carriers.	
		Modal Type	Type of mode of transport (road, rail, ship).	
		Means of Transport Limits	Maximum train and ship size that can be handled (CEMT requirements, line voltage, train gauge).	
		Slot Booking System	Time-based booking system available.	
		Transshipment Costs	Handling costs at the Node (per lift).	
		Spot Market Price	The price is determined in real time and can fluctuate significantly in response to changes in supply and demand.	X

Figure 16: Data requirement list for “Nodes”

Transport route section	Capacity	Timetables	Train / ship / truck timetables.	
		Means of Transport	Authorised (capable) means of transport that are permitted to use the specified route.	
		Allowed Load Carriers	Allowed load carriers for transported goods (f.e. food transport --> cooled load carriers).	
		Allowed Goods	Authorized goods per means of transport (dangerous goods).	
		Weight	The load carrier can accommodate a maximum weight load.	X
		Height	The load carrier can accommodate a maximum height load.	X
		Volume	The load carrier can accommodate a maximum volume load.	X
		Load Unit Limits	The maximum usable load carriers (containers, swap bodies, etc.)	
		Freight Forwarders per Logistic Section	Transport carriers of the sections.	X
		Max. Availability of Carrier	Available means of transportation (wagons, containers, trailers, etc.).	X
	Operator	Rest areas	Rest areas for drivers, particularly in the context of relay traffic on the road.	
		Driver restrictions	Restrictions for drivers (f.e.: driving license).	
		Mobile connection	Mobile connection on the route section (2G, 3G).	
		GPS position	The Global Positioning System (GPS) is used to determine the location of a vehicle or other object in order to provide real-time data.	
		Operator cooperations	It is possible that the operator (system partner) may be restricted in their ability to transmit relay traffic.	X
	Transport route information	Route kilometers	The distance traveled for the purpose of transportation.	
		From node	Start node of the transport route section.	
		To node	End node of the transport route section.	
		Road classification	The percentage of road network sections classified as express or motorway.	
		Rail classification	The classification of railways is dependent on several factors, including the speed at which they operate, the length of the train, the track gauge, the voltage of the line etc.	
		Ship classification	In accordance with the requirements set forth by the CEMT, the permissible draught is limited to 2.5 meters. Furthermore, the height of vessels under bridges exceeding 5.25 meters in height is also subject to restrictions.	
		Congestion informations	Information about traffic delays.	X
		Speed limitations	Information on speed restrictions.	X
		Noise regulations	Regulations regarding noise.	
		seasonal change (Winter conditions)	Passability of the transport route in winter.	
		Border crossing	In cases where the transportation route crosses an international border. (documents required for border crossings).	
		Environmental classification	Route classification of the transportation route from an ecological perspective.	
		Low emission zones	Low emission zones along the route..	
		Energy options	The availability of energy options at petrol stations situated along the designated transport route is to be considered.	
	Key indicators	Cost / Toll	Charges incurred on the transport route. These include customs duties, tolls and fuel consumption.	
		Emissions	The emission profile which is consumed on the route.	
		Risk Level	The risk level that this transport route involves in the case of disruptive events.	X

Figure 17: Data requirement list for “Transport route section”

Disruptive events	Location	Affected Node ID	The nodes that are impacted by the disruptive event.	X
		Affected transport route section ID	The specific transportation routes that are impacted by the disruptive event.	X
		Disruptive Location	The geographical position of the disruptive event.	X
		Recovery plans/strategy in place	Are recovery plans/strategies in place for the disruptive event.	
	Time window	Start	The temporal origin of the disruptive event.	
		End	The probable end of the disruptive event.	
	Consequences	Quantitative consequences	The quantitative implications of a disruptive event (e.g., additional costs, transportation time, capacity).	X
		Qualitative consequences	The qualitative consequences of a disruptive event, for example, the splitting up of a transportation order.	X
		Data for insurance (chain of commands)	The objective is to provide data for insurance purposes, specifically regarding the optimal chain of command structure for effective response in the event of a disruptive event.	
	Identification / Type	Classification of disruptive event	To facilitate analysis, the disruptive event must be classified.	
		Predictability	The predictability of the disruptive event.	X
		Disruptive layer type	The impact on the physical (workforce strikes, infrastructural damage etc.) or informational level (internet fluctuations, server disruptions etc.).	
		Process chain of commands	It is necessary to identify the directly affected instances and determine the appropriate course of action. It is also essential to communicate this information to the relevant parties.	

Figure 18: Data requirement list for “Disruptive events”

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 utilization, suggests transshipment points and optimizes capacity allocation, minimizing 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 incentivize 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)

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	UNION INTERNATIONALE DES SOCIETES DE TRANSPORT COMBINE RAIL-ROUTE SCRL	UIR
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