Towards a Reference Model for Multimodal Transport Networks

Daniel Zöttl[1], Alexander Granig[1], Benjamin Schwendinger[1] and Sebastian Schlund[1,2]
[1]*Fraunhofer Austria Research GmbH, Theresianumgasse 7, Vienna, Austria*
[2]*Institute of Management Science, TU Wien, Theresianumgasse 27, Vienna, Austria*

Keywords: Multimodal Transport Network, Reference Model, Relational Data Model, Transport Planning.

Abstract: A multimodal transport network is a widely used form of transport infrastructure. The ability to describe different modes of transport, taking into account many different attributes, requires a structured model. This paper outlines the requirements for the description of a multimodal transport network in the form of a reference model. To this end, expert interviews were conducted with various expert groups from companies, researchers from the field of transport planning, traffic management system providers and internationally active logistics service providers to ensure that the reference model is suitable for practical applications. Furthermore, an approach to transform the attributes into a relational data model including entities and cardinalities is described and the challenges encountered are highlighted: different data formats, different stakeholders and insufficient data availability. Finally, the application of the reference model as data base in a practical real-world scenario is presented.

1 INTRODUCTION

The availability of efficient transport systems is essential for the organization of economic processes at both national and continental levels. A well-developed transport infrastructure supports the sustainable growth of economies by facilitating the movement of goods and meeting society's increasing demands. One modern approach to transport infrastructure is the multimodal transport network (MTN), which comprises international transport corridors (ITCs). These corridors enhance interregional and transcontinental economic relations, contributing to the integration of global production processes Nesterova et al. (2016a).

However, implementing MTN development projects faces several significant challenges Nesterova et al. (2016a); (European Commission 2024; European Commission 2013):

1. Interaction between Different Infrastructure Objects: Coordination among various transport infrastructures is often inadequate.

2. Technical Disparities: There are considerable differences in technical standards, capacity, and infrastructure quality.

3. Lack of Strategic Coherence: Infrastructure projects are frequently carried out without an overarching strategy.

4. Funding Deficits: Insufficient funds are available to eliminate bottlenecks or build new infrastructure.

5. Diverse Ownership and Interests: The development process is complicated by multiple owners and operators with different objectives.

These challenges highlight the complexity and importance of improving existing tools or developing new solutions to address these issues effectively Nesterova et al. (2016b). Reference models provide a structured approach to analyzing and designing complex systems like MTNs. They are standardized models used across various fields to define general structures and processes applicable to similar problems (Scheer (1999); Grefen (2010); Wirtz (2021). The key benefits of reference models include:

- **Standardization and Comparability:** They offer a standardized framework that allows for the comparison of different systems and facilitates the transfer of best practices.
- **Knowledge Management and Communication:** Reference models establish a common language among stakeholders, such as developers, consultants, and managers, enhancing communication.

Zöttl, D., Granig, A., Schwendinger, B. and Schlund, S.
Towards a Reference Model for Multimodal Transport Networks.
DOI: 10.5220/0013391700003953

In *Proceedings of the 14th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS 2025)*, pages 130-138
ISBN: 978-989-758-751-1; ISSN: 2184-4968

• **Increased Efficiency:** Time and resources can be saved by utilizing proven models, reducing the need for repetitive analysis and design work.
• **Flexibility and Adaptability:** Reference models can be tailored to the specific needs of an organization while maintaining general principles.
• **Quality Assurance:** By relying on tested methodologies, they help avoid common mistakes and ensure consistent outcomes.

The primary objective of this work is to develop a reference model for multimodal transport networks that provides a holistic view of various transport modes and their characteristics. This involves defining, describing, and categorizing the necessary attributes for modeling MTNs. This approach aims to reduce complexity and establish a common language for stakeholders involved in multimodal transport. The paper is structured as follows:

Section 2, the **Literature Review** offers an overview of academic research on reference models of multimodal transportation networks, addressing key issues such as digitalization, travel time estimation and related projects.

Section 3, the **Methodology**, describes how expert interviews were conducted to identify relevant elements and the process of incorporating these elements into a model.

In Section 4, the **Results** present the identified and categorized elements of the developed reference model, including its design and an potential application of the reference model.

Lastly, Section 5 provides a **conclusion** and a discussion on the **next steps**.

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.

Exploring the corridors of the trans-European transport network and in particular the multimodal transport network is crucial for improving transport efficiency, connectivity and sustainability in Europe. The identification of bottlenecks, the definition of investment priorities and the optimization of cross-border coordination are essential elements that ultimately promote economic growth and regional integration across the continent. In this context, reference should be made to publicly funded research projects and initiatives that are already addressing the challenges of multimodal transport networks as well as related work.

Harris et al. (2015) highlight the crucial role of Information and Communication Technology (ICT) as a fundamental aspect of logistics. The transformation to sustainable transport systems can be realized on the basis of forecasts for the transport and logistics sector through the use of ICT. The exploitation of this potential using ICT is contingent upon the introduction of a "common platform without national borders" and uniform standards Giusti et al. (2019). The EU H2020 project SENATOR aims to create a multi-collaborative framework and a ‘control tower’ system in this area.

To facilitate the increased use of intermodal transport, Altuntaş Vural et al. (2020) examine the individual potential of various digital tools to overcome obstacles. The results derived from this indicate a tendency towards conservative and resistant behaviour in the transport industry.

In this context, the SHIFT2RAIL project, funded by the EU as part of the H2020 programme, aims to develop innovative rail technologies and integrate them into existing and future rail networks. The aim is to improve the efficiency, sustainability, performance and resilience of rail transport.

Several methodologies for the planning of intermodal freight transport have already been developed. A variety of approaches to planning intermodal freight transport can be found in the existing literature.

Demir et al. (2016) employ a stochastic approach to describe an optimization problem. In this approach, the objective is to sample the average travel times from a set of scenarios, thereby allowing for partial consideration of unexpected events. Abbasi et al. (2024) investigate the impact of disruptions on seaport terminals, employing a mixed-integer linear programming model. In this intermodal model, the consideration of unexpected events, specifically those occurring at the transshipment port, results in a reduction in the available capacity and performance at the seaport.

At this point, it should be noted that in the transport network, unexpected events have an impact on the transport link in addition to the impact on the transport node. In their work, Hrušovský et al. (2021) also formulate a mixed-integer linear programming model as an optimization model. Balster et al. (2020) introduce machine learning approaches utilizing random forest, gradient boosting, linear regression trees and ordinal trees in the model. Spanninger et al. (2022) also distinguishes between event-driven and data-driven approaches. The MOTOS research initiative is developing a simulation platform in this area that models transport systems on the basis of mobility data.

The majority of existing transport models for MTNs are based on transport networks that use either nationwide transport networks or a small amount of data. Only a small number of studies, such as that by Strelko et al. (2022), include complete corridors of the Trans-European Transport Network (TEN-T) Richardson (1997).

Each of the aforementioned modelling approaches is characterised by a common absence: none employs a standard reference model to describe MTNs. The review of the literature indicates that optimisation models in multimodal transportation have been considered, however, none of the existing models provide a detailed description of the data basis that is employed, or the reference model that is used as a basis for comparison. Furthermore, none address the potential of transferring the model to other transport corridors. The focus of this study is to develop a data model that can be used as a reference in any optimisation models used in the field of multimodal transport planning. To this end, we have developed an approach to a reference model that brings together the different components of an MTN. It is important to emphasise that the reference model serves as a concept. The elements listed, such as the modelling of predictability, serve as placeholders for the individual definition of specific values.

3 METHODOLOGY

The following section presents the methodology of expert interviews as a means of establishing the foundation of the data. Furthermore, it explores the process and visualization of the reference model. Finally, it concludes with a description of the model for MTNs.

3.1 Approach of Expert Interview

Ensuring correct and high-quality data collection requires a strong willingness to communicate on the part of those involved in the model. Furthermore, in addition to the aspects already discussed, special expertise is required to be able to adequately recognize and classify more complex issues. The individual experts were questioned using an open interview technique. This approach allows complex topics to be analyzed using expert knowledge. A further advantage of this method is the identification of new topics that were not apparent at the beginning of the study. (Mayer 2013)

The expert groups consist of companies and researchers in the field of transport planning. The relevant stakeholders therefore include transport management system providers and internationally active logistics service providers.

The interviews conducted are based on four overarching questions for each transport mode (ship, rail and road):

- Which data is required for planning daily transport operations?
- How would you classify the data into static and dynamic categories in the context of disruptive events?
- What classes would you use to categorize the required data?
- Which data is necessary for an optimization model in MTNs?

At the outset, the individual expert groups were presented with the same overarching questions. The sub-questions were developed in an open and individualized approach with the objective of meeting the specific requirements of the respective expert groups.

3.2 Process Model

The procedure and the visualization of the information resulting from the surveys conducted are based on the CRISP-DM process model Wirth and Hipp (2000). As this work involves the development of a reference model in multimodal transport planning, only the first five steps of the process model are applied (Figure 1). These steps include the 'development of a business understanding', 'data understanding', 'data preparation', 'modelling' and 'evaluation'. To create the basis for the reference model, the process model is iterated through.

The categorization of the relevant attributes is based on the approach outlined in the previously described CRISP-DM process model. Furthermore, input is derived from expert interviews, particularly with logistics service providers who require the necessary information for transport planning.

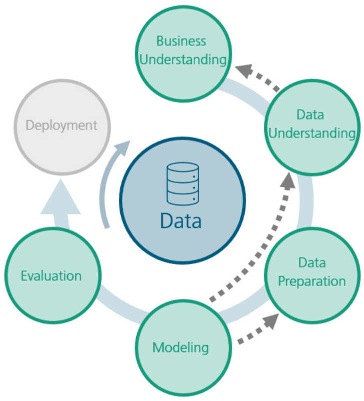

Figure 1: Process model for qualitative data collection (based on Wirth and Hipp (2000)).

3.3 Model Description

The conversion of a significant amount of information into a model is carried out with the aid of database models. Schematic representations, such as maps and processes, can describe a multimodal transport network, but they do not conform to the necessary data structure. Relational data models are often utilized for complex data models. Their straightforward structure, typically represented as flat tables where rows correspond to data objects Kemper and Eickler (2015), supports their application in multimodal data models. Additionally, a relational data model is usually developed using an entity-relationship diagram (ER diagram).

ER modeling is a technique used in logical design modeling, where the development of the logical data model begins after capturing business requirements, data requirements, and understanding of business rules. The three basic components of an ER model are:

- Entities
- Relationships
- Attributes.

Entities in the logistics context can include nodes, trains, commodities, etc., for which the company stores data. Relationships show how entities are related to each other, representing the business rules or constraints. For example, a hub is linked to another hub via a transport route section. Attributes are unique characteristics of entities that are managed in the data model. For example, attributes of a hub can be the location, its storage size or working hours. These attributes are recorded by the company to manage its business along the multimodal transport network.

An entity can have key attributes (such as primary and foreign keys) and non-key attributes. Key attributes uniquely identify data records and link data from different entities. Non-key attributes must not uniquely identify data. Figure provides a symbolic representation of the structure of an entity.

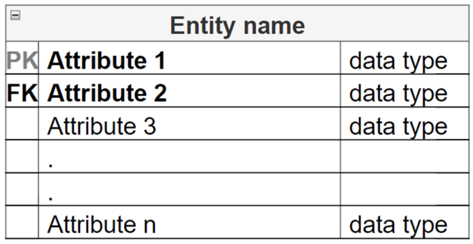

Figure 2: Symbolic representation of an entity (adapted from Sherman 2015).

Cardinality refers to the number of instances of an entity that can be associated with another entity in a relationship. It specifies whether the association involves one or many instances. There are four main cardinality options, as described in Table 1: “Mandatory”, “1 Optional”, “Many Mandatory”, “Many Optional” Sherman (2015).

Table 1: Crow’s Foot Notation. cf.Gronwald (2024)).

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)	

The methodology of entity-relationship models frequently serves as a foundational technique in the conceptualization of data models. The streamlined structure of these relational models represents a pivotal factor in their deployment within the domain of a multimodal data model Kemper and Eickler (2015).

4 RESULTS

This section explains the categorisation of the identified attributes resulting from the CRISP-DM and expert interviews. Furthermore, the specific model design is explained in detail and a use case is presented, focussing on the identification of multimodal transport routes in a TEN-T corridor.

4.1 Categorization of Attributes

To incorporate the attributes into the reference model, the relevant attributes (listed in Figure 4) were categorised based on the input from the expert interviews. This categorisation comprises the four meta-levels 'transported goods', 'node', 'route section' and 'disruptive events' and is shown graphically in Figure 3. Transported goods primarily have attributes that do not change along the supply chain. Nodes can function both as simple intersections and as transshipment points. Transport route sections link the nodes with each other and can be assigned to a specific mode of transport. Disruptive events can occur both at nodes and along the transport route sections.

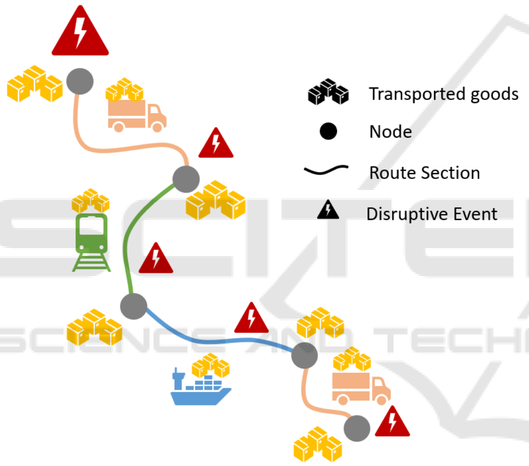

Figure 3: Categorisation of relevant attributes.

4.2 Reference Model

Based on the attributes required for a reference model to describe a multimodal transportation network according to the notation of Section 3.3, the ER diagram shown in Figure 4 was created.
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

These 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, one 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.

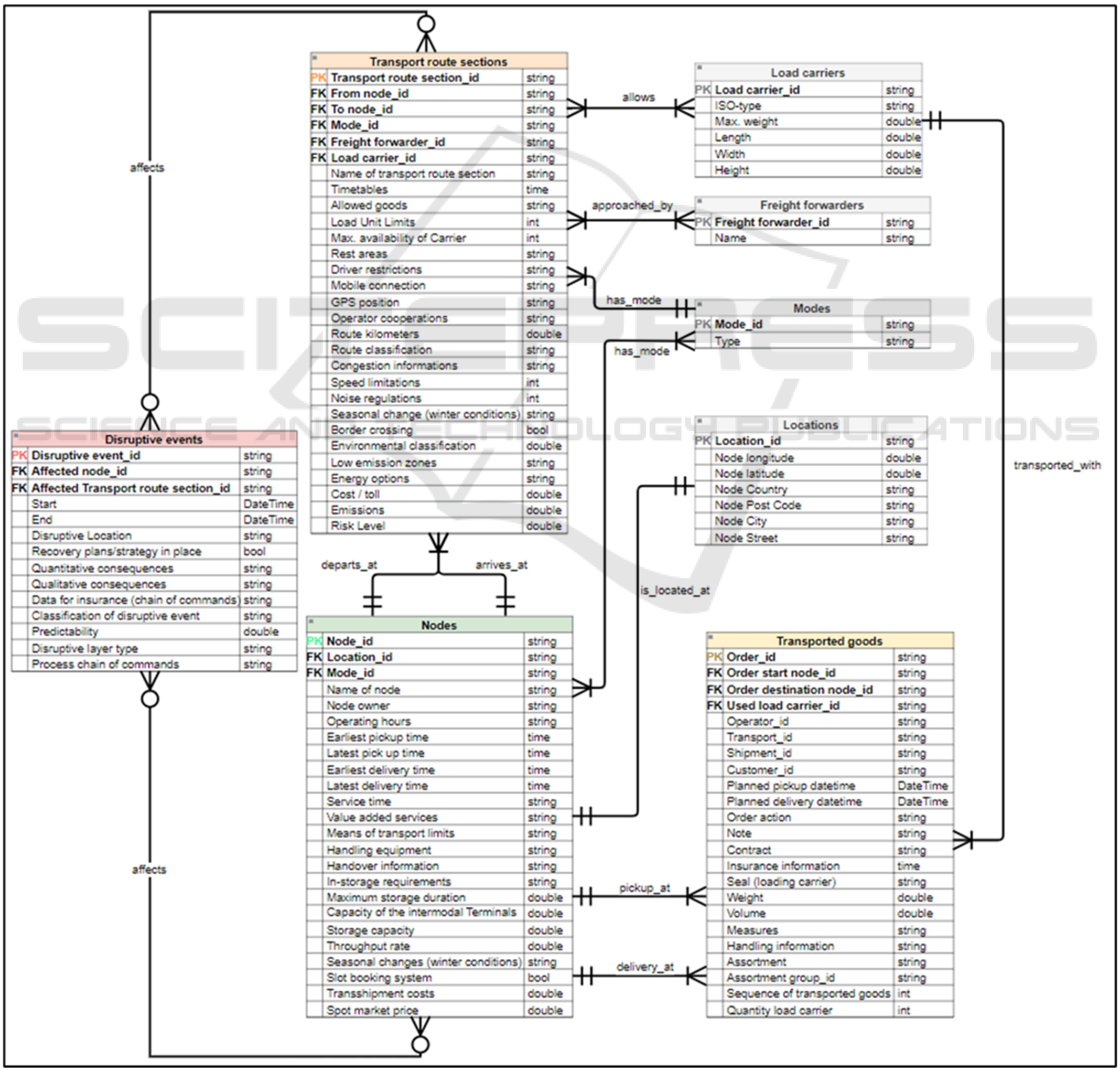

Figure 4: Reference model (ER-Diagram).

4.3 Practical Application: Ten-T Use Case

This section demonstrates the evaluation of the reference model through the application in a practical real-world scenario. For this purpose, an application was created whose underlying data layer was based on the entities, attributes and cardinalities of the developed reference model and fed with specific data records. We specifically examine the problem of identifying multi-modal transport routes, with a focus on the Rhine-Danube TEN-T corridor. 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. 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. Once the route is generated, it is displayed on the map alongside the input interface.

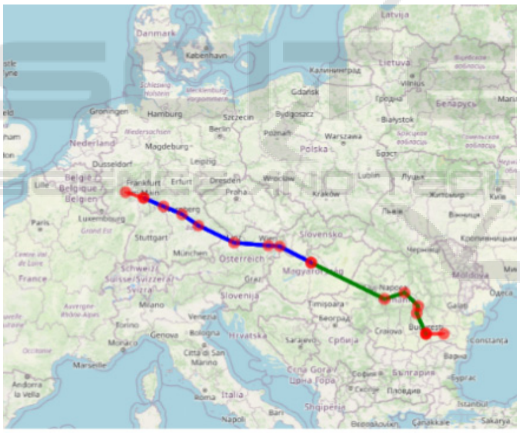

Figure 5: Multi-modal transport route.

By considering multiple modes of transportation, it is possible to identify routes that combine different modalities, as shown in Figure 6. Clicking on specific transport nodes provides additional information, such as the estimated time of arrival or departure (see Figure 6). Moreover, details regarding the transport node itself, such as opening hours or the available handling equipment at the terminal, can also be accessed.

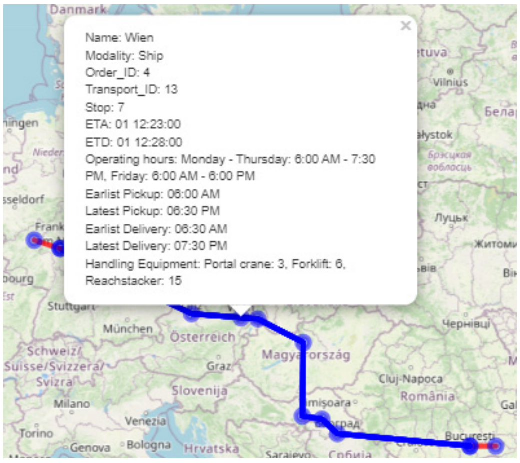

Figure 6: Additional information at transport nodes.

As previously mentioned, our prototype also supports the provision of multiple routes for a single connection. This functionality is depicted in Figure 7.

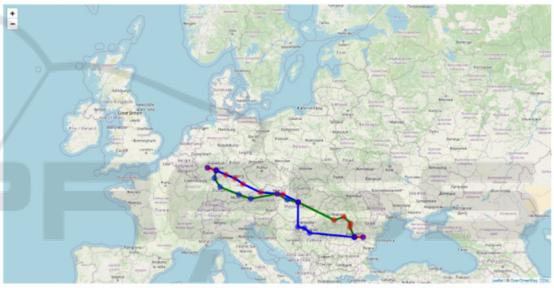

Figure 7: Provision multiple multi-modal transport routes for a single connection.

The use case shows the fulfilment of the key benefits of reference models as follows Scheer (1999); Grefen (2010); Wirtz (2021):

- **Standardization and Comparability:** The use case shows that the reference model reflects the properties of the transport route sections and nodes as well as their relations in a standardised manner. This enables comparability between different transports.
- **Knowledge Management and Communication:** The developed reference model transforms logistical requirements into a relational data base and establishes the basic for solving planning tasks of multimodal transports.
- **Increased Efficiency:** The use of the developed reference model allows the implementation of further use cases without the need for repeated design work for the underlying database.
- **Flexibility and Adaptability:** In the current version of our prototype, we primarily focused on finding multi-modal transport routes in a TEN-T corridor.

However, it could easily be used to describe multimodal transport networks of other corridors.

• **Quality Assurance:** Based on the developed reference model, the use case shows that various transports are reproduced with consistent information content and format.

5 CONCLUSION AND NEXT STEPS

This work presents a reference model for multimodal transportation networks and outlines the methodology used to develop it. First key attributes of MTNs were identified and compiled into a comprehensive data requirements list, categorized under four main meta-levels: "Transported Goods," "Nodes," "Transport Route Sections," and "Disruptive Events." Sub-categories were also added to improve the usability of the list for non-specialists.

Expert interviews provided further insights into the relationships between these attributes and their roles in processes, particularly those involving spontaneous adaptations during disruptions. These interviews helped determine the required level of granularity for the model.

The chosen reference model structure allows for the representation of all identified attributes and their interconnections. Essential elements of MTNs, such as transport routes, nodes, and goods and their relationships were integrated into the model.

In addition, a use case was presented that is based on a data structure in accordance with the developed reference model. This proves that the developed reference model provides comprehensive attributes and relationships for transport planning within the multimodal transport network. Furthermore, the fulfilment of the criteria for a reference model was evaluated with regard to standardisation and comparability, knowledge management and communication, increased efficiency, flexibility and adaptability and quality assurance.

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 this paper. Even within the framework of this work, 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 paper. In conclusion, establishing a Europe-wide database for MTNs depends on standardized data collection from all network participants. The reference model developed, provides a standardized framework, enabling users to populate it with real data and describe any transport corridor effectively.

As part of this study, further use cases for evaluation will be conducted in which a routing algorithm is used to solve transport planning problems based on the developed reference model. After the evaluation, the reference model will be integrated as the basis for an optimisation model using reinforcement learning.

ACKNOWLEDGEMENTS

Supported by Horizon Europe (HORIZON) ReMuNet (GA#101104072)

REFERENCES

Abbasi, Mohammad/Consilvio, Alice/Giglio, Davide (2024). A multi-objective optimization approach for disruption management in an intermodal freight transport network 78.

Altuntaş Vural, Ceren/Roso, Violeta/Halldórsson, Árni/Ståhle, Gabriella/Yaruta, Marina (2020). Can digitalization mitigate barriers to intermodal transport? An exploratory study 37.

Balster, Andreas/Hansen, Ole/Friedrich, Hanno/Ludwig, André (2020). An ETA Prediction Model for Intermodal Transport Networks Based on Machine Learning 62.

Demir, E./Burgholzer, W./Hrušovský, M./Arıkan, E./Jammernegg, W./Woensel, T. V. (2016). A green intermodal service network design problem with travel time uncertainty 93.

European Commission (2013). New EU transport infrastructure policy – background.

European Commission (2024). Infrastructure – TEN-T – Connecting Europe.

Giusti, Riccardo/Manerba, Daniele/Bruno, Giorgio/Tadei, Roberto (2019). Synchromodal logistics: An overview of critical success factors, enabling technologies, and open research issues 129.

Grefen, Paul (2010). Mastering e-business.

Gronwald, Klaus-Dieter (2024). Data Management.

Harris, Irina/Wang, Yingli/Wang, Haiyang (2015). ICT in multimodal transport and technological trends: Unleashing potential for the future 159.

Hrušovský, Martin/Demir, Emrah/Jammernegg, Werner/van Woensel, Tom (2021). Real-time disruption management approach for intermodal freight transportation 280.

Kemper, Alfons/Eickler, André (2015). Datenbanksysteme. Eine Einführung. 10th ed.

Mayer, Horst O. (2013). Interview und schriftliche Befragung. Grundlagen und Methoden empirischer Sozialforschung. 6th ed.
Nesterova, Natalia/Anisimov, Vladimir/Anisimov, Aleksandr (2016a). Balanced scorecard for evaluation of multimodal transportation network development strategies.
Nesterova, Natalia/Goncharuk, Sergey/Anisimov, Vladimir/Anisimov, Aleksandr/Shvartcfel, Viacheslav (2016b). Set-theoretic Model of Strategies of Development for Objects of Multimodal Transport Network 165.
Richardson, Tim (1997). The trans-European transport network: environmental policy integration in the European Union 4 (4), 333–346.
Scheer, August-Wilhelm (1999). ARIS - business process frameworks. 3rd ed.
Sherman, Rick (2015). Foundational Data Modeling. In: Business Intelligence Guidebook, 173–195.
Spanninger, Thomas/Trivella, Alessio/Büchel, Beda/Corman, Francesco (2022). A review of train delay prediction approaches 22.
Strelko, Oleh/Yurchenko, Oksana/Vasilova, Halyna/Gusar, Ievgen/Rudiuk, Maryna (2022). Theoretical Prerequisites for the Development of Multimodal Transport-Logistic Technologies in Cooperation With Ten-T Network.
Wirth, Rüdiger/Hipp, Jochen (2000). CRISP-DM: Towards a standard process model for data mining.
Wirtz, Bernd W. (2021). Business Model Management. Design, Instrumente, Erfolgsfaktoren von Geschäftsmodellen. 5th ed.