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ReMuNet

Pioneering resilient and adaptive multimodal transport networks

D2.3
ReMuNet machine processable objective functions

PTV Group

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ABBREVIATIONS

API	Application Programming Interface
FGD	Focus group discussions
RCA	Root-cause analysis
TITR	Trans-Caspian International Transport Route
TEN-T	Trans European Transport Network
GUI	Graphical User Interface
MNFP	Multicommodity Network Flow Problem
MCFP	Minimum Cost Flow Problem
XIMR	PTV xIntermodal Route Server
LP	Linear optimization problems
MIQCP	Mixed-integer optimization problems with quadratic constraints
QP	Quadratic programming
MIQP	Mixed-integer linear programming

Executive Summary

The Horizon Europe project Resilient Multimodal Transport Networks (ReMuNet) aims to improve the resilience of the freight transport network in the EU in the face of disruptive events and to enhance sustainability. This is proposed to be achieved by offering network users alternate routing options and identifying disruptions and ways to mitigate their impacts.

The work package two of the project builds the backbone of the IT system functions for the use cases of the project. Task 2.3 focuses on the optimization of network flows. In this deliverable we explore and develop different options to optimize network flow problems using mathematical solver approaches.

The outcome of the methods will support the project by solving various aspects of planning and optimization tasks in the case of unplanned and unforeseen events. The methods have been implemented into a test system by PTV to enable users to interact with the novel services provided. These services will be subsequently used by different implementations to be done within the project and the connected pilots.

1 Introduction

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

Deliverable 2.3 comprises objective functions of users within the door-to-door transport chain, which are coded in a machine processable way. These objective functions comprise a complexity of variables resulting from a broad spectrum of assets, e.g., intermodal loading unit, pallet, modular loading unit, etc. and industry facilities. The objective functions are subsequently aligned with the developed framework of task 1.2/D1.2 (physical assets) and the classification of task 1.3/D1.3 (disruptive events). The objective functions and the performed implementations build upon existing knowledge basis and implementations of PTV by Alexander Stupp, Simon Prinz, Alex Kleff, Florian Krietsch and Jürgen Stolz.

Within the deliverable we discuss different approaches and methods to solve the problem of logistics network optimization. We provide insights into the implementation of a system which is to be used for testing purposes of work package 2. The deliverable concludes with an outlook on the interplay of services and components in an application scenario within task 2.4.

2 Development of Optimization Models

The fundamental objective of task 2.3 is to develop graph-based optimization models for intermodal freight transport planning.

The modelling is intended to be a formal, quasi machine-readable and solvable model, primarily in the form of a linear program. The optimization should thus be quantitative, based on numbers, data, and costs, and act in a quasi-normative manner for planners, with the aim of producing as accurately calculated decision variables as possible. To make the problem more tangible and reduce the complexity and uncertainty of the real world to some extent, a setting with deterministic travel times, orders, costs, etc., is generally assumed. Furthermore, it is assumed that in every optimization instance there is always at least one—at least theoretically for a transported unit—more favourable transport route than the classic, uncapped direct truck transport. If this were not the case, the problems could still be solved with the presented models; however, the additional optimization step would be pointless due to irrelevant capacity considerations.

Overall, the models should possess a certain degree of generalizability and ideally serve as foundation for various planners from diverse backgrounds and intentions within the context of freight transport planning.

2.1 Planning Task Definition

The application case for ReMuNet is as follows: There are companies that wish to transport several containers, which belong to specific orders and can vary in size, as cost-effectively as possible from their origins to their destinations within a flexibly selectable but fixed planning period. The start and end locations of the orders are at least partially in the same regions or countries, so that -when considered in isolation- the same routes or segments could be optimal for multiple orders. However, since factors like border traffic, customs processing, and different driving and resting times for drivers are outside the scope of consideration, it does not matter whether the specific optimization takes place within a regional, national, or international context.

The companies themselves, or their contracted logistics service providers, now have access to various capacity-limited or unlimited transport options along the different segments of possible transport routes. These transport options, hereinafter referred to as resources, also have prices per container of a certain size, as well as potential time restrictions. The goal is to find an optimal allocation of all containers to be transported to resources while considering all constraints.

At PTV, there is already an intermodal router (XIMR) in place. This router can provide several meaningful route suggestions for each source-destination pair of an order, but it does not consider the dependencies of multiple jointly planned orders, which primarily result from limited resource capacities. However, the time windows and the earliest pick-up and latest delivery times are considered by the router, as long as needed information is available. The possible solutions generated by the router should be optimal concerning a specific objective criterion. This objective criterion may include monetary costs, transport duration, and CO_2 emissions. In cases where more alternatives are desired as input for further optimization, the next best routes should be provided. Additionally, for each order, at least one incapacitated direct truck transport option is stipulated to ensure that a feasible solution can always be found, even with high transport volumes or few intermodal alternatives.

To find an optimal overall solution for all orders to be planned, which particularly takes capacity constraints into account, a model based on the intermodal router is to be developed.

2.2 Formulation and application of mathematical models

It turns out that for the first application case based on the intermodal router, two specific, and slightly different mathematical approaches are relevant. If we limit ourselves to a maximum of one capacitated main run per order, a comparatively simple modelling approach, closely aligned with the classic Minimum Cost Flow Problem (MCFP), is possible. This offers the advantage of significantly faster runtime, at least theoretically, due to its low complexity compared to the Multicommodity Network Flow Problem (MNFP).

Given the greater realism and the significantly constrained data set provided by the preceding XIMR, the MNFP seems more sensible. Nevertheless, both approaches will initially be considered separately.

In summary, the application cases and the derived modelling variants are as follows:

1) Current, concrete case: Goods transport planning based on the intermodal router (XIMR) with a focus on capacities and

a) maximum of one main run, or

b) an arbitrary number of main runs.

2) Abstract case: Independently operating, integrated goods transport planning with extended functionalities and an arbitrary number of main runs.

The focus of the modelling should be on the first application case due to its relevance, the existing database, the presumably relatively simple implementation, and high performance. The solution approaches for the second case should serve as modular proposal for a comprehensive, future optimization model, based on the model of case 1b). This proposal should also ensure the future viability and integrated solvability of the time-, cost-, and capacity-dependent sub-problems in relation to the ReMuNet project. Furthermore, optimizations based on other objective criteria, particularly the increasingly important reduction of CO_2 emissions, or the inclusion of price-reducing consolidation effects, for which the database is often still lacking, should be made possible within a single, flexibly adjustable model.

The reason for the decision to base the second, modular solution proposal largely on variant 1b) is as follows:

Different problem statements generally require different, ideally tailored solution approaches. However, this can lead to the necessity for a complete rebuild if new information or application cases arise later that were not initially considered and may no longer be integrable into the existing procedure. To avoid such problems and the resulting additional costs for research, modelling, and development as much as possible, all variants should use and interpret as many of the involved elements, objects, and information in a consistent manner—or at least offer the possibility to do so without requiring significant changes to the model to be made.

Specifically, this means that all models are based on a directed graph (digraph). In the simplest variant, the nodes and edges of the digraph are interpreted differently due to the specific network structure with a maximum of one capacitated main run. This somewhat inflexible, yet algorithmically simple variant is intended to reflect the reality that, in practice, many routes do not interchange between scheduled transport modes like ship, train, and airplane, but rather, besides the mandatory truck transports, only one of these main runs occurs per route. Moreover, the performance of this approach may later serve as a comparison to the much more general, but at least theoretically more complex solution for problem 1b). Based on these results, a reasoned decision can then be made as to whether the higher development effort and the handling of different models are worth the potential runtime savings.

Common to all the modelling approaches is the concept of resources, inspired by the services used by Ayar and Yaman (2012). This approach allows the problem of spatially identical but temporally or financially different transport options to be solved intuitively without node duplication. Briefly stated, a resource is a unique tuple consisting of the start and end locations, costs, capacities, departure times, and possibly other characteristics. This tuple precisely describes one specific option for transporting goods from a source to a destination without changing the mode of transport.

As soon as a transport option becomes available with at least one of these attributes differing from all previously known resources, a new, distinct resource must be created. In modelling variants 1b) and 2), a new, unique ID corresponds exactly to a new edge between two nodes, resulting in a so-called multigraph, which is a graph with multiple edges between two identical nodes.

2.1 Central Modelling as a Multicommodity Network Flow Problem (MNFP)

2.1.1 *Assumptions and Objectives*

The possible routes output by the XIMR between the source and destination locations of the orders can be reached by either none, one, or any number of main runs. No main run here refers to transport via direct transport; the other options pertain to one- or multi-stage intermodal transport. This provides a significantly better representation of reality, especially for multi-leg transport. The objective remains the purely monetary minimization of total transport costs while considering all constraints, with particular attention to capacities.

Transportation options between two locations in the network

- Unique tuple consisting of source location, destination location, prices, capacity, and departure time

- Capacity-restricted, scheduled, both (typical scheduled services), or neither/flexible (truck transport)

Consideration of different container classes

- Differentiation based on various sizes and prices
- Multiple orders are planned together
- Unique tuples of source location, destination location, and number of containers per container class

Routing objective

- Multiple possible routes per order are provided by XIMR:
  - Direct transport (must always be offered as an alternative to ensure solvability) or
  - (possibly linked) scheduled services with pre- and post-haulage
- The objective is to minimize total monetary costs while considering all constraints.

2.1.2 *Optimization Process in Practice*

The entire optimization process occurs internally in two sub-tasks, with the MNFP being preceded by the XIMR. Without the intermodal router, the current model would also not be functional. However, at the application layer, the sub-steps should not necessarily be explicitly visible.

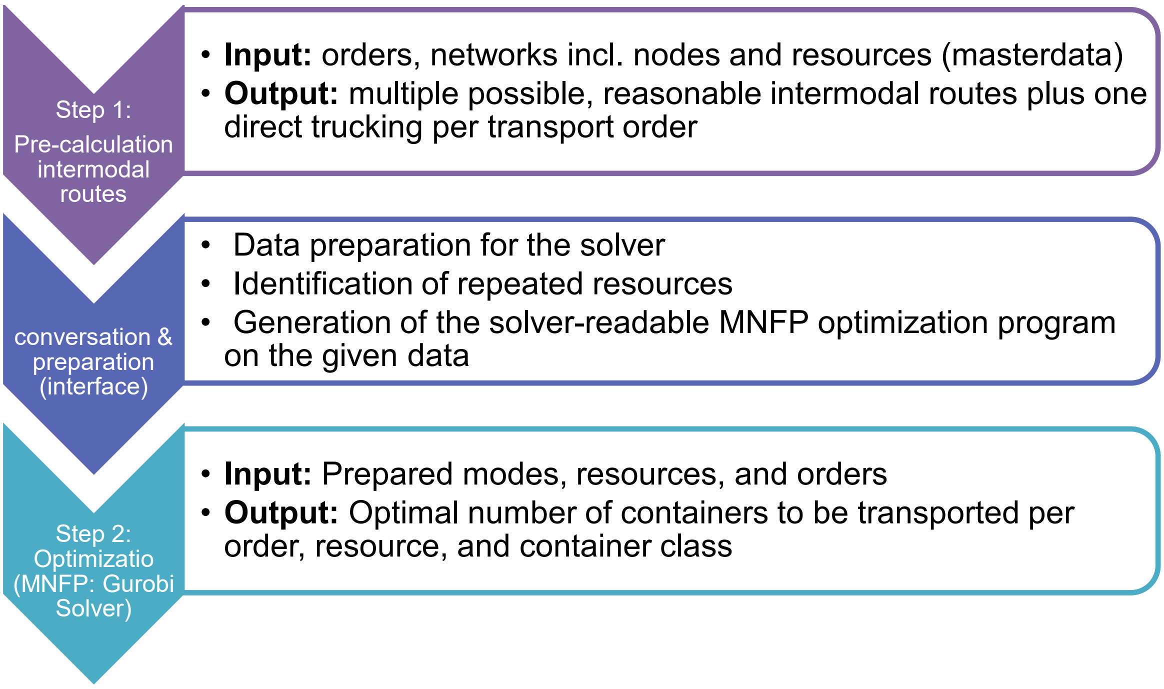


Figure 1: Optimization Process

2.1.3 *The central Model (MFFP)*

Building the central Model MFFP requires to initially determine the intermodal transport options. For two transport orders, a and *b*, routing options from *q* to *z* are calculated.

The visualization of the output from the preceding intermodal router could look as follows in a simple example for two orders to be optimized together later:

- Order *a* with the pickup at q^a and delivery to z^a depicted in Fig. 2, and
- Order *b* with the pickup at q^b and delivery to z^b shown in Fig. 3

within a certain timeframe. The following graph structures of the orders a and b visualize the conversion and preparation process of the input for the solver.

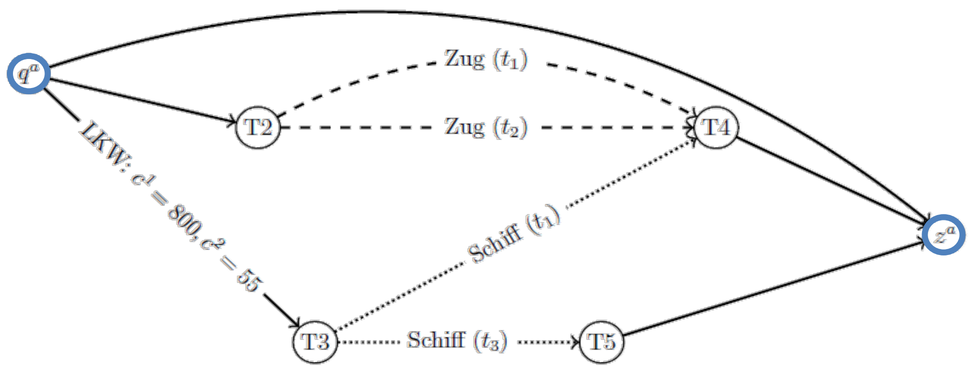


Figure 2: Intermodal Router for Source-Destination Pair (q^a; z^a) of Order *a*.

In Fig. 2 c^1 and c^2 represent the costs per resource for a container of class 1 and class 2, respectively. However, for better readability, these attributes are only exemplarily written on a single edge in the diagram.

Different modes of transport are represented by different line styles for clarity. The timestamps $t_1; t_2; \ldots; t_n$ in parentheses per resource indicate different departure times. These are not explicitly known to the optimization model, but they are intended to illustrate the need for creating parallel resources in the MNFP when segments from the router with the same source and destination nodes differ in at least one other attribute—such as the departure time. Resources without fixed schedules must be declared as undermined by the XIMR and will therefore not be differentiated based on their departure times. For this reason, the typically undermined pre- and post-runs are recognized as identical here, despite their multiple occurrences at the same transport prices, and are included in the model only once as a resource.

For order *a*, five routes are obviously conceivable: the direct transport from q^a to z^a by truck, the two paths via T2 and T4 using two trains running at different times, and the route with shipping via T3 and T4 or via T3 and T5.

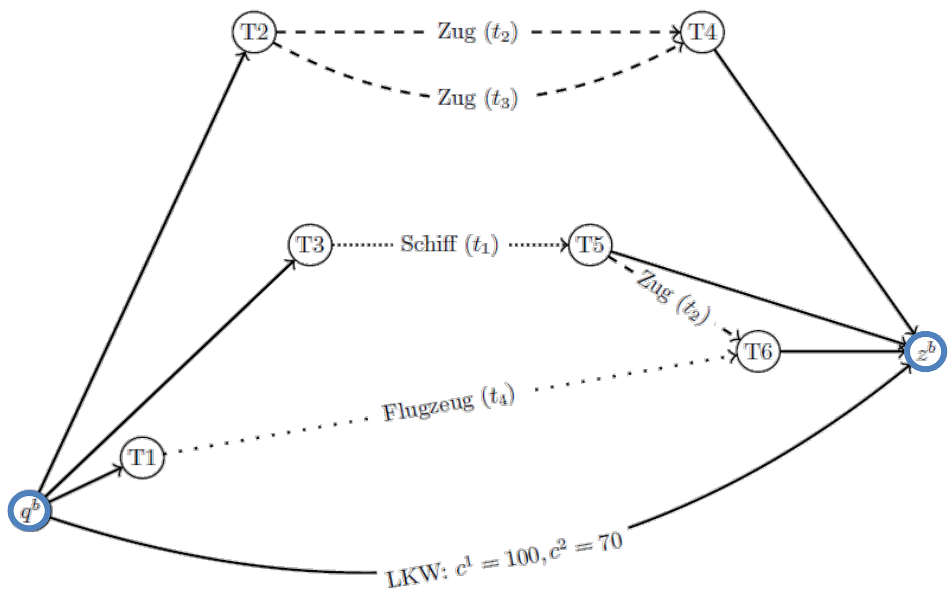


Figure 3: Intermodal Router for Source-Destination Pair (q^b; z^b) of Order *b*.

In the case of order *b* (see Fig. 3), there are six different paths possible, based on one direct transport and five capacitated, scheduled resources along with their pre- and post-runs. All represented scheduled transports are to be understood as temporally, financially, and capacity-related unique resources. An edge between two nodes does not correspond to the theoretical physical connection between two terminals, but rather to a specific actual transport option at a certain time, at certain costs, with a certain capacity, etc.

It is important to note that the solutions proposed by the router each represent different complete paths from q^i to z^i. Potentially reused resources - not only the frequently similar pre- and post-run options but also popular scheduled transports - must be recognized during the conversion to an MNFP-compliant model based on their attribute tuple or a unique ID and should be treated as identical resources going forward.

The data from both orders *a* and *b* serve as input for the general intermodal goods transport planning and are enriched with the desired delivery quantities and capacities *P* per resource to form a total network, which is visualized in a simplified way in Fig. 4 (see below).

The potential bottleneck resources, meaning the scheduled transports relevant for both orders, are highlighted in red. However, even favourable, low-capacity resources that may only be used by one order can already present a bottleneck during optimization.

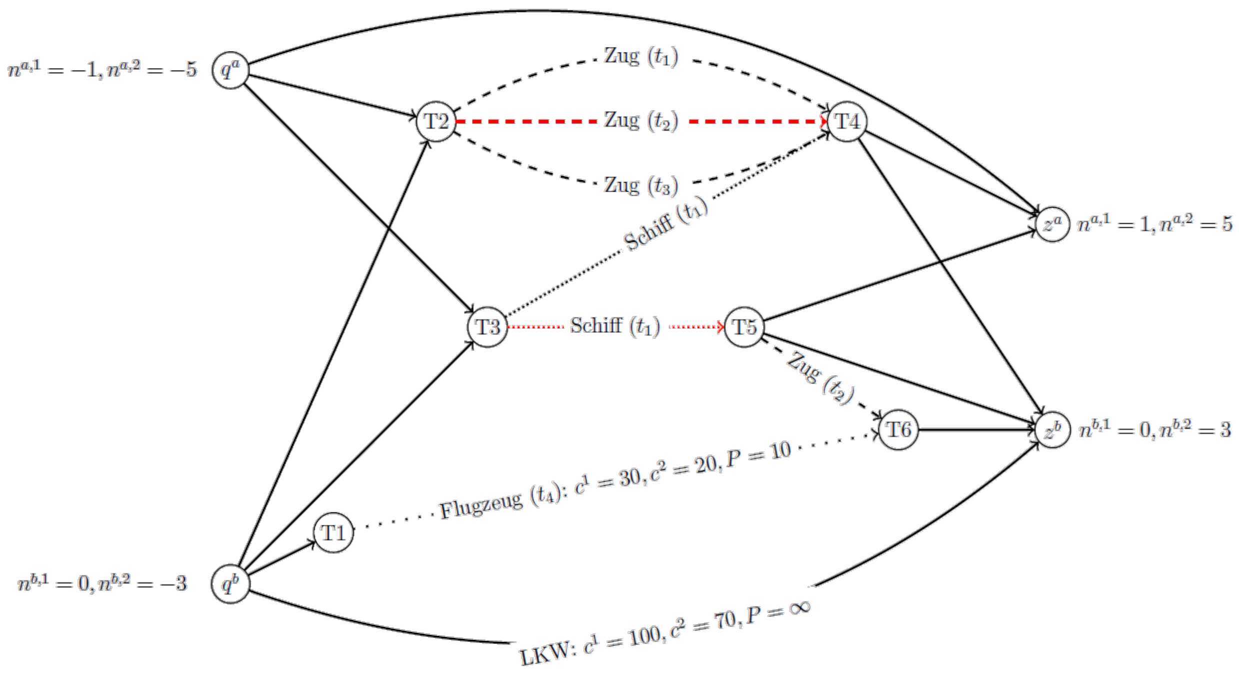


Figure 4: Intermodal router for orders *a* and *b* as input for central MNFP model

The graph in the example is acyclic, as it assumes that the source and destination nodes are located close to each other. However, this does not necessarily have to be the case in practice, depending on the order configuration. Nevertheless, the validity of the model and the optimality of the solution are not affected by this.

Overall, the meaningful and correct conversion or preparation of the data from the intermodal router for subsequent solver optimization is an important step. For this reason, in addition to the already described or obvious concepts, **two central pre-calculations** will be briefly outlined here:

For the **first pre-calculation** during the optimization process, a distinction is explicitly made between certain subsets of the resources used: Initially, there is the total set of resources, which encompasses all resources, regardless of type. This set will later be used, for example, to calculate the total transport costs. In addition to this group, there are also subsets of the capacitated resources R^P and those of the scheduled resources R^T. This allows specific constraints to be applied only to the resources relevant to them. Generally, the explicit distinction between R^P and R^T is not necessary, as they usually correspond to the main runs or scheduled transports. However, to allow for greater flexibility, a possible differentiation will be left open for later.

The **second pre-calculation** is necessary as for the correct temporal representation of the route derived from the XIMR, it is relevant for each resource to know its direct predecessor resource(s). The IDs of these predecessor resources are stored in an attribute H^r for each resource *r*. This way, the time component, which would otherwise be cumbersome to integrate and has already been calculated by the XIMR, can be elegantly and resource-efficiently represented, keeping the model as lean as possible.

All the described information is known to the intermodal router and must be provided or appropriately prepared when passing it to the subsequent optimization step.

2.1.4 *Formulation as an Integer Linear Program*

The Linear Program (as Solution via Gurobi Solver) can be defined as follows:

Multicommodity Network Flow Problem (MNFP - Modell 1b)

min

$$g_c(x) = \sum_{r \in R} \sum_{k \in K} \sum_{l \in L} c_r^l \, x_r^{k,l} \tag{3.5}$$

u.d.N.

$$\sum_{r \in R:\, z_r = i} x_r^{k,l} - \sum_{r \in R:\, q_r = i} x_r^{k,l} = \begin{cases} -n^{k,l} & \text{wenn } i = q^k \\ n^{k,l} & \text{wenn } i = z^k \\ 0 & \text{sonst} \end{cases} \qquad \forall\, i \in V, k \in K, l \in L \tag{3.6}$$

$$\sum_k \sum_l \frac{1}{l} x_r^{k,l} \le p_r \qquad \forall\, r \in R^P \tag{3.7}$$

$$x_r^{k,l} \le \sum_{r' \in H^r} x_{r'}^{k,l} \qquad \forall\, r \in R^T, k \in K, l \in L \tag{3.8}$$

$$x_r^{k,l} \in \mathbb{N}_0 \qquad \forall\, r \in R^k, k \in K, l \in L \tag{3.9}$$

$$x_r^{k,l} = 0 \qquad \forall\, r \in R \backslash R^k, k \in K, l \in L \tag{3.10}$$

Interpretation of the model

The present model is an integer linear program. The objective function describes the minimization of total costs in (3.5). Specifically, the transportation costs *c* per resource *r* and container class *l*, multiplied by the number of containers of this size class utilizing that resource, summed over all orders. This slightly modified approach is necessary since multiple edges (which must differ in at least one property) can now exist between any two specific nodes.

The constraints express the flow conservation required for all network flow problems at each node (3.6). Explicitly, for a node *iii*, this means that the sum of all outgoing containers per order and container class, subtracted from the sum of all incoming containers per order and container class, is exactly zero if this node is neither the start nor the destination node of the order *k* in question. However, if the node is the start node/supplier (destination node/customer) of the order, the difference must correspond exactly to the negative (positive) number of containers $n_{k;l} \in N_0$ for that order-container class combination.

As mentioned above, adherence to capacity limits is ensured by the constraint which must apply to all capacitated resources $a \in R_P$, usually corresponding to the scheduled services (3.7). For each of these resources, a capacity $Pa \in N_0$ in slots is defined. Here, a slot corresponds to a maximum of $l \in N$ containers of class *l*. This clever labelling allows the capacity constraints to be expressed very simply and precisely through the sum of all transported containers per edge, each multiplied by the normalization factor $\frac{1}{l}$.

Finally, several lines define the values that the decision variables $x_{k,l}^{r}$can take: If a resource *r* is in the set R_k, meaning it has been pre-identified by the intermodal router as an acceptable (favorable) transport option for order *k*, then a non-negative integer number of containers can be transported on it (3.9). However, if a resource is not in this set for a particular order and container class - something that should generally be the case in the modelling with XIMR - then all corresponding variables $x_{k,l}^{r}$c = 0 must hold, and no containers for this order may be transported on it (3.10).

Regarding the temporal dependencies in the case of **multiple linked main runs**, there is a special consideration to be made:

It may occur that two terminals are connected by several identical but temporally staggered scheduled services. If, at the end node of these services, multiple scheduled resources for an order-container class combination are allowed, it must be ensured that all partial shipments are planned only on temporally feasible resources. Therefore, constraint (3.8) specifies that on each scheduled resource $r \in R_T$, a maximum quantity of containers for a specific order and container class can only be transported if they have been delivered on their assigned direct predecessor resources $r' \in H_r$ in time.

By considering these predecessors stored in H_r for each scheduled resource, adherence to the overall paths permitted by the XIMR through the network is ensured. Thus, both an edge-node perspective and a path-oriented perspective are combined in this formulation. If this were not done, it could happen in an unfortunate solution configuration for a delivery that individual scheduled services (namely the edges between two adjacent nodes considered in network flow problems) could be linked, which in practice are not combinable due to their temporal conditions. For this reason, such a case must be excluded from the outset through the described modification of the problem. However, to address this difficulty, an alternative modelling approach could also utilize duplicated nodes. These temporally or attribute-expanded nodes would inherently ensure compliance with the temporal dependencies of multiple resources. On the other hand, the effort required to create a meaningful, internally consistent graph with correct node-edge relationships would increase and translating a real location into a network node and vice versa would no longer be straightforward. Modelling using an additional time component per resource could also be feasible, similar to the holistic problem described in the section. However, the significantly increased data and runtime complexity should be consciously avoided here. For this reason, a balance must be struck for the concrete implementation among all variants, and the decision should be made based on empirical runtime comparison tests if necessary.

3 Test implementation of objective functions for ReMuNet WP2

PTV has implemented the MNFP introduced in chapter 2 to a server. The model can be prepared by inputs of the PTV intermodal routing service. The model creation is triggered by an API, which basically fledges the model with the input of possible candidate route and provided capacities and then sends it to a solver. In the PTV implementation, we use the state-of-the-art solver by Gurobi.

Gurobi is a solver for calculating optimization problems. It supports linear optimization problems (LP) as well as quadratic programming (QP), mixed-integer linear programming (MILP), mixed-integer quadratic programming (MIQP), and mixed-integer optimization problems with quadratic constraints (MIQCP).

There are object-oriented interfaces for C++, Java, the .NET Framework, MATLAB, Python, and Julia (via JuMP), as well as a matrix-oriented interface for Python, R, MATLAB, C, and Julia. Modelling languages such as AIMMS, AMPL, GAMS, and MPL can be integrated as well.

PTV also implemented a GUI to visualize the workflow to interact with the services as well as to deliver the results in a presentation mode for further adaptation by the planners.

3.1 Main task and interplay of planning service component intermodal router in ReMuNet

The **intermodal routing service** calculates alternatives for multimodal transport chains at a door-to-door level. It takes different transport modes and possible combinations of transport legs and transport services into account. The service is based upon provided transport service data (TSD), transport network data and consignments.

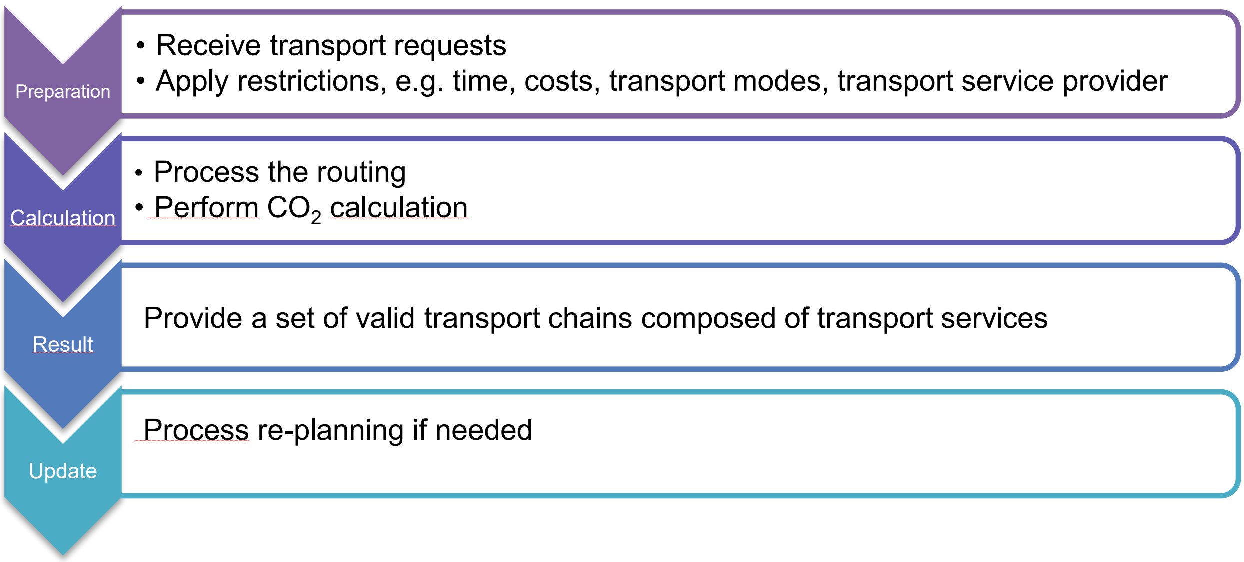


Figure 5: Process sequence of intermodal router component

3.2 Related screen shots of the PTV implementation

The following screen shots provide a visual of the PTV test implementation for ReMuNet WP2. The following screenshots document the workflow of planning and optimizing transport orders following the outlined workflow.

The configuration of routing properties includes load unit, cost-time ratio, cost limit, freight rates, allowed transport modes, and allowed transport operators (see Fig. 6).

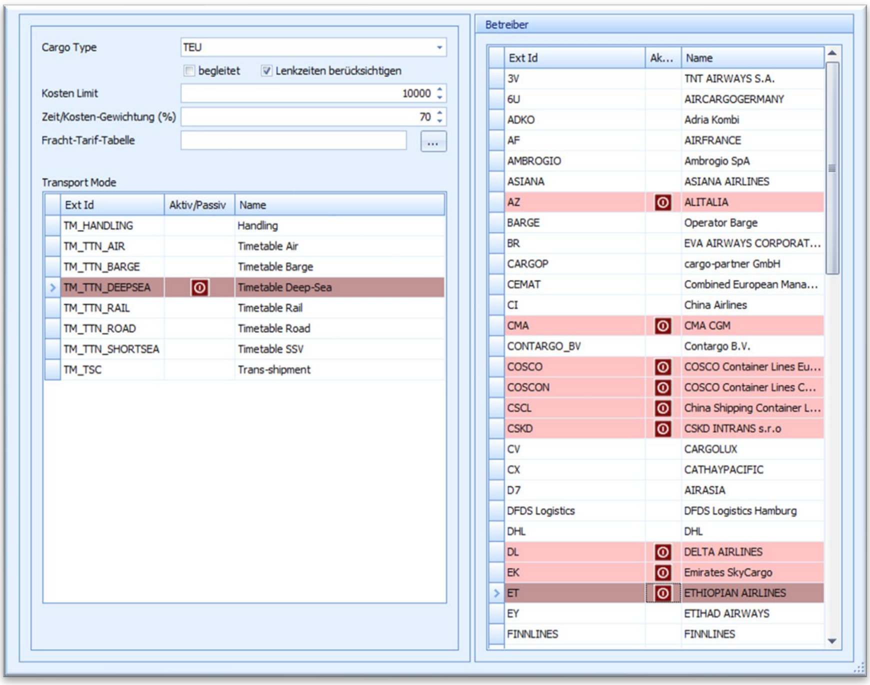


Figure 6: Configuration of intermodal routing properties

The graphical presentation of calculated intermodal transport chains and KPIs for fictive transport order within the test environment is depicted in Fig. 7. Additionally, the routing of transport chain alternatives at an order level including cost factors such as transport time, monetary costs, and environmental costs (CO_{2eq}) can be assessed as well.

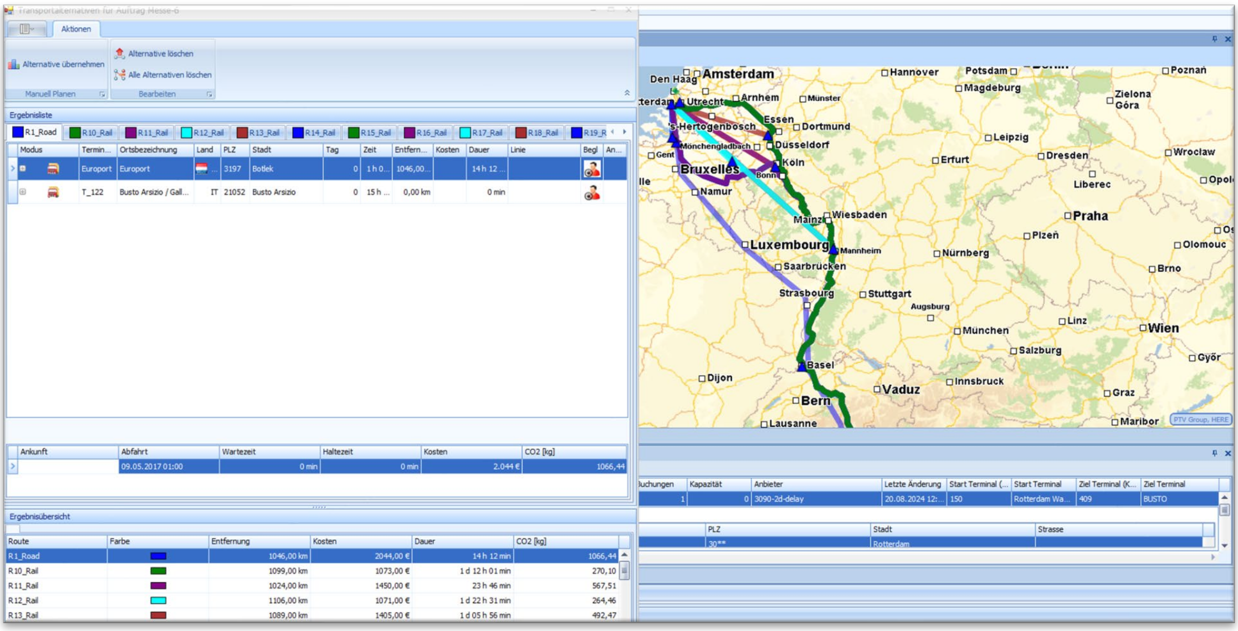


Figure 7: Transport chain alternatives at order level

An example for optimized Hinterland transport chains includes an allocation of transport orders to transport services under additional consideration of limited transport capacities. Fig. 8 shows the corresponding GUI in the test environment.

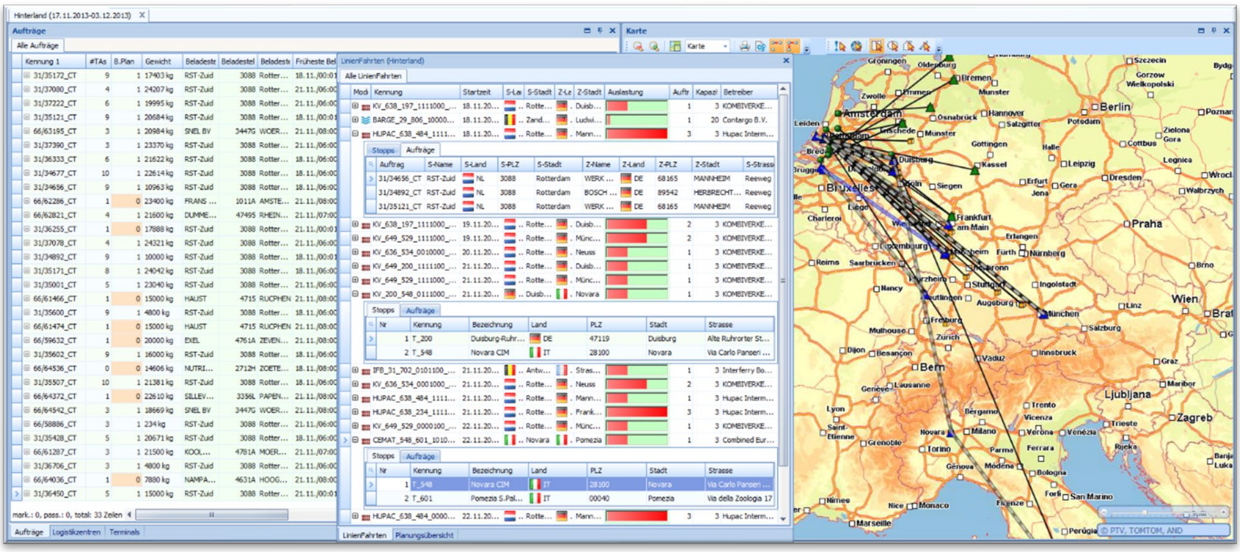
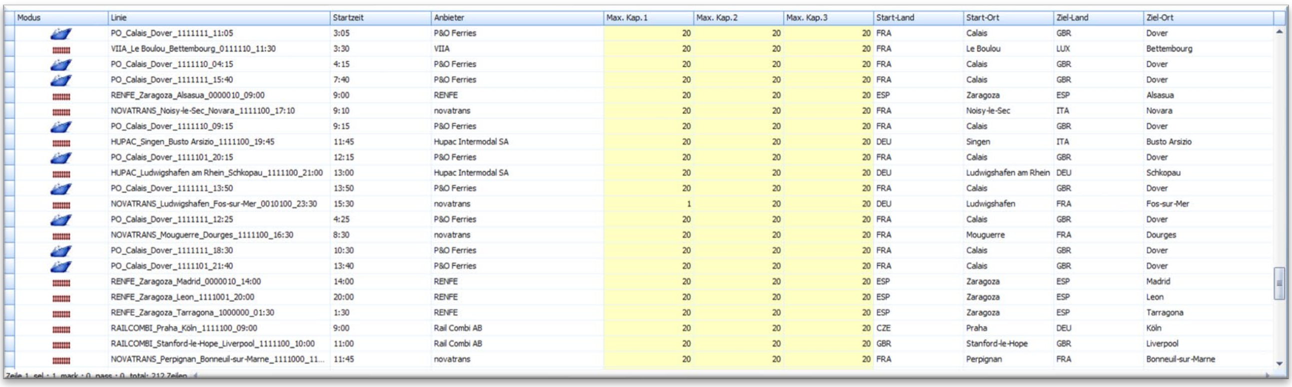


Figure 8: Optimization example Hinterland

Using the PTV test implementation, users can manipulate capacities of specific, discrete lines for testing purposes. This enables the user to test against fictive scenarios, e. g. next Monday, 9h00 not 20 capacity 1 (TEU) slots are available but only 5 on the rail service between Duisburg and Milano by operator X (see Fig. 9).



Modus	Linie	Startzeit	Anbieter	Max. Kap.1	Max. Kap.2	Max. Kap.3	Start-Land	Start-Ort	Ziel-Land	Ziel-Ort
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	VIIA_Le Boulou_Bettembourg_0111110_11:30	3:30	VIIA	20	20	20	FRA	Le Boulou	LUX	Bettembourg
	PO_Calais_Dover_1111110_04:15	4:15	P&O Ferries	20	20	20	FRA	Calais	GBR	Dover
	PO_Calais_Dover_1111111_15:40	7:40	P&O Ferries	20	20	20	FRA	Calais	GBR	Dover
	RENFE_Zaragoza_Alsasua_0000010_09:00	9:00	RENFE	20	20	20	ESP	Zaragoza	ESP	Alsasua
	NOVATRANS_Noisy-le-Sec_Novara_1111100_17:10	9:10	novatrans	20	20	20	FRA	Noisy-le-Sec	ITA	Novara
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	HUPAC_Ludwigshafen am Rhein_Schkopau_1111100_21:00	13:00	Hupac Intermodal SA	20	20	20	DEU	Ludwigshafen am Rhein	DEU	Schkopau
	PO_Calais_Dover_1111111_13:50	13:50	P&O Ferries	20	20	20	FRA	Calais	GBR	Dover
	NOVATRANS_Ludwigshafen_Fos-sur-Mer_0010100_23:30	15:30	novatrans	1	20	20	DEU	Ludwigshafen	FRA	Fos-sur-Mer
	PO_Calais_Dover_1111111_12:25	4:25	P&O Ferries	20	20	20	FRA	Calais	GBR	Dover
	NOVATRANS_Mouguerre_Dourges_1111100_16:30	8:30	novatrans	20	20	20	FRA	Mouguerre	FRA	Dourges
	PO_Calais_Dover_1111111_18:30	10:30	P&O Ferries	20	20	20	FRA	Calais	GBR	Dover
	PO_Calais_Dover_1111101_21:40	13:40	P&O Ferries	20	20	20	FRA	Calais	GBR	Dover
	RENFE_Zaragoza_Madrid_0000010_14:00	14:00	RENFE	20	20	20	ESP	Zaragoza	ESP	Madrid
	RENFE_Zaragoza_Leon_1111001_20:00	20:00	RENFE	20	20	20	ESP	Zaragoza	ESP	Leon
	RENFE_Zaragoza_Tarragona_1000000_01:30	1:30	RENFE	20	20	20	ESP	Zaragoza	ESP	Tarragona
	RAILCOMBI_Praha_Köln_1111100_09:00	9:00	Rail Combi AB	20	20	20	CZE	Praha	DEU	Köln
	RAILCOMBI_Stanford-le-Hope_Liverpool_1111100_10:00	11:00	Rail Combi AB	20	20	20	GBR	Stanford-le-Hope	GBR	Liverpool
	NOVATRANS_Perpignan_Bonneuil-sur-Marne_1111000_11...	11:45	novatrans	20	20	20	FRA	Perpignan	FRA	Bonneuil-sur-Marne

Zeile 1, sel.: 1, mark.: 0, pass.: 0, total: 212 Zeilen

Figure 9: Line capacities editor

Fig. 10 provides a selected screen shot from the online documentation of the software implementation for the allocation planning function. The complete software documentation is available to project partners as online version.

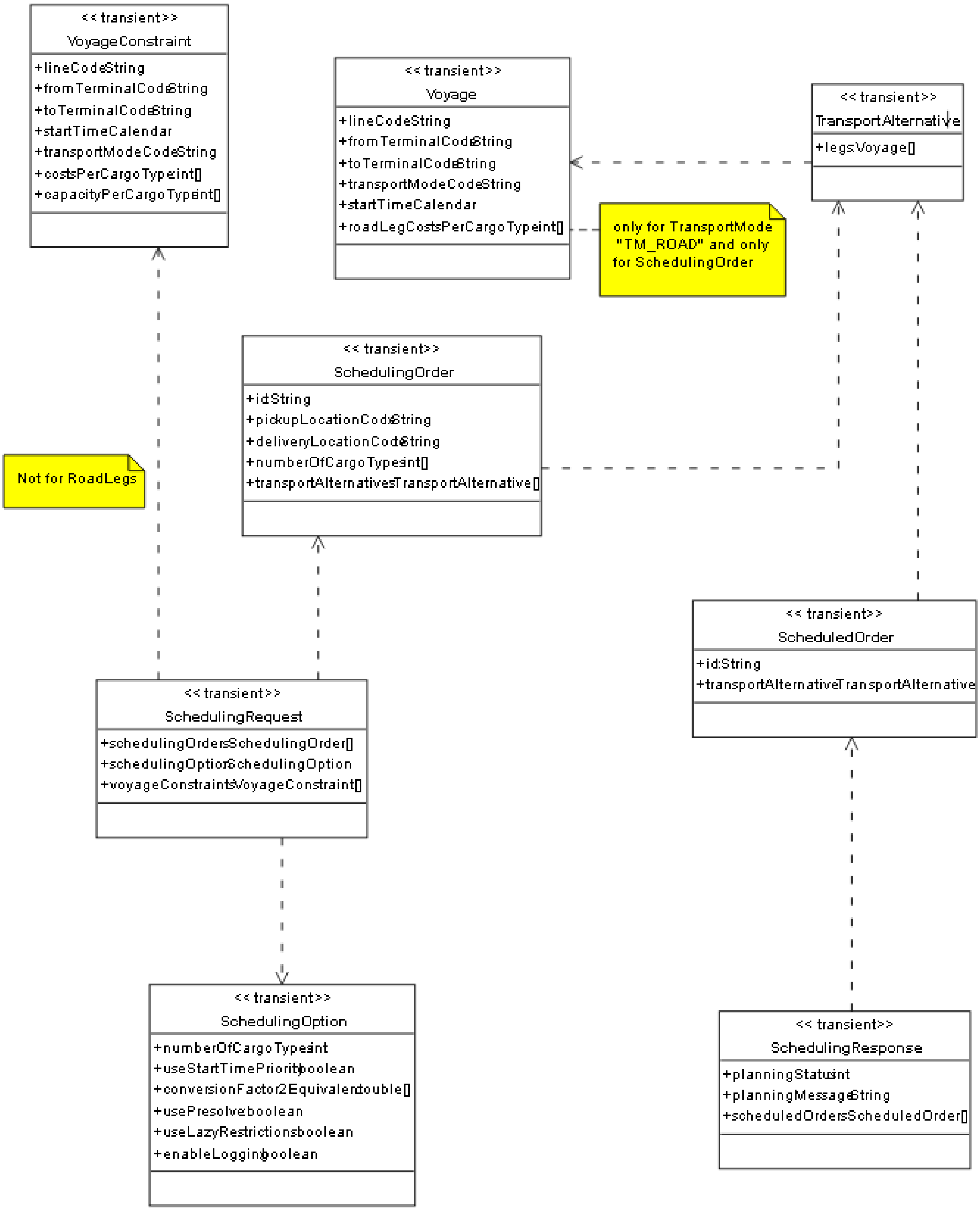

Figure 10: API documentation for scheduling implementation

4 Testing and Outlook

The system has been tested along with test data provided by PTV on intermodal services for rail barge and sea. Different transport orders have been simulated and planned in realistic test scenarios. The system has also been tested with test data in real world simulation cases were over the day different additional orders have been injected as well as deviations have been simulated. The system could cover all cases in an appropriate way and delivered the optimum solution regarding costs. Although these results look promising there is still the need to calibrate and to test in real world scenarios. Both aspects will be taken up by task 2.4 and by the pilots when the system will be used to test with real world data. In both cases experts will review the data, planning quality, and potential process optimizations for the existing systems.

5 Conclusions

We want to highlight **two main conclusions**:

Conclusion 1 is geared towards the support of it for planning and optimization. Planning is a stiff task which requires a lot of attention by the planner at daily level. Over the day he must take care of multiple changes in the transport network, he must adapt the affected transport order plans accordingly if needed. The planner needs to receive planning and decision-making support by an IT system to perform his workload in an efficient fashion. To provide IT support for this task, we developed services to optimize existing transport chains and to support the decision-making at a semiautomatic level. We provide IT support tools to target the question "which transport chain for a specific transport order" shall be selected. We provide an optimized solution respecting given constraints towards time-windows, capacity, costs and efficiency. Hence, this process can be run constantly, meaning the system will always include effects by occurred events and provide a system optimum solution.

We expect this to be a significant improvement towards the support of the planners' daily operations. However, we consider this support only a first level support to the planner but not the replacement of the planner. The planner in our view remains as the ultimate decision-maker. He has knowledge about circumstances which are eventually not known to the system yet (or can`t be modelled) but which could have significant impact to the overall transport network. Therefore, the planner will remain in the control position.

Conclusion 2 is focusing on the implementation and the usability of the system. We delivered an API-based solution which flexibly allows scaling of the system. We can use the provided implementation or specific services in the project context for the platform but also in connected platforms in collaboration scenarios. In future scenarios, different shippers and logistics providers can collaboratively work together and optimize at large pool of transport orders and transport services. Ultimately, this effect leads to a global system optimum which is desirable for the ecological and also for the commercial aspects of the logistics systems stakeholders.

6 References

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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.

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PTV GROUP	PTV PLANUNG TRANSPORT VERKEHR GmbH	PTV
4PL Intermodal	4PL INTERMODAL GMBH	INT
MANSIO truck meets truck	MANSIO GMBH	MAN
Fraunhofer AUSTRIA	FRAUNHOFER AUSTRIA RESEARCH GMBH	FHA
HAFEN WIEN	HAFEN WIEN GMBH	HWI
WHITE	WHITE RESEARCH SRL	WRE
UIRR	UNION INTERNATIONALE DES SOCIETES DE TRANSPORT COMBINE RAIL-ROUTE SCRL	UIR
CONTARGO trimodal network	CONTARGO GMBH & CO KG	CON
vedia	VEDIAFI OY	VED

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