Interconnecting Separate Transportation Systems by Introducing Exchange Points

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***Abstract*—To provide seamless information for the travelers, an effective transnational door-to-door journey planner is required, where information from different operators, combined solutions, and value-added parameters appear in a realistic environment. Thus, the aim is to support seamless mobility solutions and create multimodal transport networks connecting separate systems. The elaborated method realizes this by identifying the potential exchange points between separate networks and by filtering the suitable exchange points to run the routing algorithm between the local journey planners. The proposed solution builds on a flexible algorithm, which parameters can be easily updated and extended. In case of any changes, using the formulated theoretical background, an up-to-date and realistic implementation can be derived from the foundations of the framework. In addition, the elaborated method is fully capable to cover wide geographical areas and to provide a transferable solution.**

Keywords—seamless mobility, heuristic algorithm, exchange points, flexible routing

I. INTRODUCTION

Routing is a more and more crucial topic in modern days. Due to urbanization processes, the population of cities and suburban areas are constantly growing putting a pressure on transportation networks. Governments and municipalities are trying to handle the situation by supporting travelers to choose sustainable transport modes. One way to realize this support is to provide information through multimodal routing. An effective door-to-door journey planner is required since the seamless information, combined solutions, and high comfort levels are the most important factors for travelers.

Analytic and heuristic algorithms are often used for the implementation of advanced routing solutions. For example, Idri et al. [1] proposed a goal-oriented single-source single-destination algorithm as a time-dependent shortest path algorithm for multimodal transportation networks. The scholars used the concept of "closeness" to the target node as a heuristic to drive the search toward its destination. In the research, the dynamic form of route planning is described to find the optimal path from an origin to a destination by introducing a constraint-based shortest path algorithm over a time-dependent multimodal graph.

Ayed et al. [2] used a heuristic platform, where they divided a multimodal transport network into smaller graphs as well as introduced an unusual graph structure, which they called transfer graph, determined the exchange points on the surface of the transport network, computed all the "best" paths for all pairs of nodes, stored the "best" paths in a database, processed the request of the user, built the relevant graph, and finally answered the user request.

For the development and testing of a generic multimodal transport network model, an application was developed by Zhang et al. [3] In their research, exclusively time was the main attribute. First of all, the authors modelled multimodal transport networks from an abstract point of view and categorized the networks into private and public modes. Afterward, the scholars applied a generic method to construct a multimodal transport network representation by using transfer links, which are inspired by the so-called super network technique, where different modes are integrated into a single network.

Delling et al. [4] worked on accelerating the multimodal route planning by access-nodes. In their research, the scholars used "Label Constrained Shortest Path Problem". It means that each edge gets a label depicting the type of transportation network it represents. A path between the origin and the destination is valid if certain constraints are fulfilled by the labels along the path. The researchers showed that access-node routing is faster than a label-constrained variant of Dijkstra [5]. Additionally, the scholars assigned a weight parameter for each arc or edge. For the road network, this weight is equal to the average travel time on the specific road segments.

Finding out the best-integrated journey between two points was pursued by Dibbelt et al. [6] The researchers focused on computing exact multimodal journeys, which can be restricted by specifying arbitrary modal sequences at query time. The scholars wanted to compute point-to-point queries on a continental network combined with cars, rail, and flights several orders of magnitude faster than Dijkstra's algorithm.

Zografos et al. [7] presented passenger information and trip planning system provided by both urban and interurban multimodal trip planning services and real-time travel information through a single point of access. They proposed a classification scheme for categorizing passenger information and trip planning systems as well as use the AHP (Analytic Hierarchical Process) method to determine the exchange points of travelers during their trips. They determined the major characteristics of the travelers' trips with their proposed AHP model. The outcome of the evaluation indicated that the users find no difficulty in using or learning to use the system services.

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Based on the literature review, similar approaches appear; however, no comprehensive solution where separate networks would be seamlessly connected has been realized yet. Therefore, the aim of this research is to find a suitable solution for the seamless mobility services, where the separated networks are combined in a distributed routing system. To enhance the efficiency of the process, the definition of the exchange points is automatized.

II. METHODOLOGY

A key point of multimodal networks is the interconnection of the scheduled public and nonscheduled individual transport of a LJP (Local Journey Planner). One possible way is to supplement the scheduled network with the customized traffic that is virtually available all the time and contains the possible routes. During the operation of a routing system, the access to stops around the departure and destination points must be planned.

Subsequently, the possible route options must be mapped from the stops with the help of public transport. A further optimization potential lies in exploring the connections between the stops. In this case, individual transport options can appear, for example, taxis and various sharing systems, or walking if necessary. This solution is particularly important when the task is to plan on a dynamically changing network, where depending on the traffic situation, delays, or early arrivals may occur, which can significantly change the estimated time of arrival.

Managing the whole trip between every origin-destination of huge transport networks by using various transport modes between various countries can be realized based on the following procedure. However, before that, some basic requirements of the routing process need to be identified:

- Information about connections in every network through the LJPs (in case of public transport routes, stops, timetables, in case of individual transport, the road network).
- The list of the potential exchange points (around the network borders) and highlighted exchange points (e.g., main stations).
- The creation and ranking of the most suitable routes based on a utility function.

A. Definition of Exchange Points

Exchange points can be any nodes of the network, which have a connection to other nodes of another network within a predefined distance. These nodes provide the connection between the LJPs. All the stations, stops, modal change nodes between two adjacent countries, where the trip leg (the part of the whole trip, which is realized in the territory of one LJP) of one participating system is connected to the trunk leg (the part of the whole trip, which is realized between LJPs) of another participating system and where the traveler changes the transport mode, can be an exchange point.

There are two types of exchange points. Either the travelers change their transport modes or service providers within the area of a network border (city exchange point), or the travelers change their transport modes or service providers at the border of another network (border exchange point).

In case of city exchange points, the major terminals, the rail stations, and the airports of the cities are the exchange points, which realize long distance trips through the network border (highlighted with red lines in Figure 1). Travelers usually enter the other network without changing the transport mode at the border. The links among the location of these exchange points and the exchange points in the other network should be defined.

To the category of border exchange points those exchange points belong that are near to the border of the countries. In this case, a special walking distance between the nodes should be defined. All nodes of the different service providers within a predefined walking distance can be determined as exchange points (connected with red lines in Figure 2). When arriving at the node of the original LJP, travelers continue their trips from these exchange points and board on a different transport mode or different service provider of the other LJP when crossing the border. It is worth mentioning that all stops along a trunk leg are the potential exchange points.

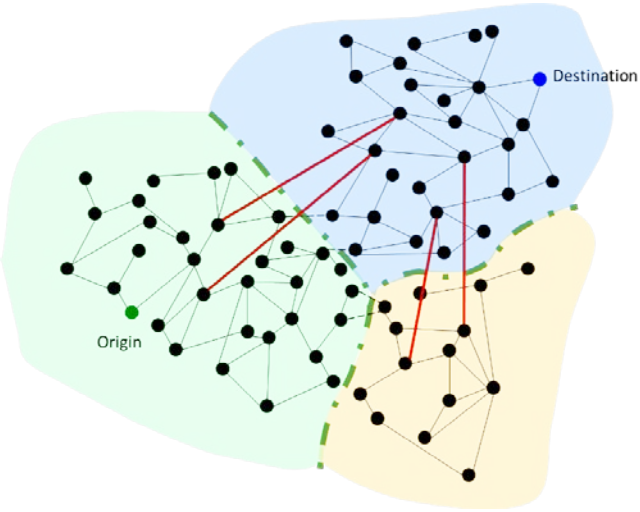

Fig. 1. Distinct networks connected by city exchange points.

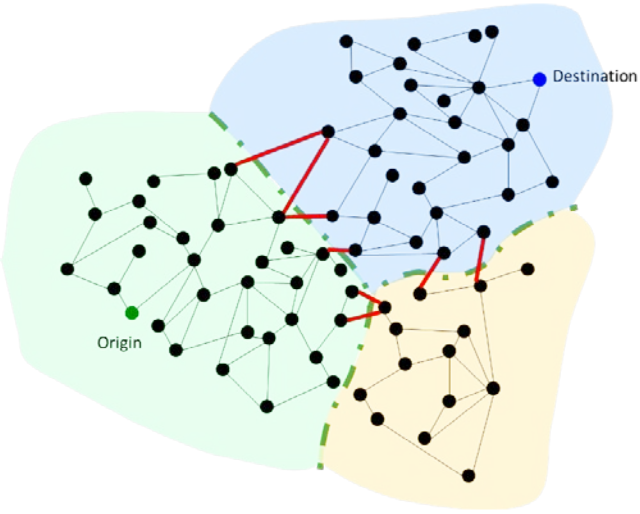

Fig. 2. Distinct networks connected by border exchange points.

B. *Filtering of the Exchange Points*

The main idea of routing is to precompute distances to all relevant exchange points. A mathematical formulation for the route calculation has to be implemented to consider the specific parameters of the traveler as a utility function. This utility function can include travel time, travel cost, emission, health, comfort, and other parameters. The weights of the parameters should be defined by the users.

Before the route calculation, specific exchange points have to be selected, for which the route calculation is realized. This step is required because the number of exchange points may potentially be increased, especially in the case of big international multimodal networks. Furthermore, a threshold for the routing should be considered as a maximum value (e.g., 8-hour trips in case of the travel time parameter). A predefined average weight of the parameters is applied due to calculation purposes, but it is possible to be changed by the user when calculating a trip. Afterward, based on the utilities (e.g., travel times), a rough estimation is calculated between the exchange points. This part is done offline in advance of using the potential exchange points' list and stop information received from the LJPs. This can be considered as a static network because no real-time information is presented. As a method for the calculation, a heuristic optimization algorithm can be considered.

The filtering is realized according to the elaborated utility function, so that the suitable exchange points can be selected from the list of the potential exchange points by applying the threshold. Based on these estimations, if a route request appears, the options above the threshold are not considered. This means that a set of selected exchange points for each "TripRequest" are individually suggested through the algorithm. This list is affected by the defined threshold.

C. *Filtering of the Routes*

The exact routes are calculated based on the real-time information from the LJPs by considering the selected exchange point options. This means that the routing process works based on the trip leg results regarding the exchange points provided by the LJPs, which can be realized in the following way as an example (Figure 3). In this case, a total of eight exchange points (Aa, Ba, Bb, Cc, Eα, Dα, dα, eβ) are selected by applying the predefined threshold value. The LJP in the green network, where the origin is, has three possible routes (A, B, C) through three selected exchange points toward the LJP in the adjacent blue network, where the destination is, by using its routes (a, b, c). The LJP in the green network has two possible routes (D, E) through two selected exchange points toward the LJP in the yellow network by using its routes (α, β). However, in this case, additional selected exchange points need to be used between the LJP in the yellow network and the LJP in the blue network by using its routes (d, e). Using the yellow network to reach from the departure to the destination is a realization of remote use case.

After applying the aforementioned steps, the following simplified network can be acquired (Figure 4). This network serves as the basis for the selected routes provided for the travelers, which is ranked based on the calculations with the utility function.

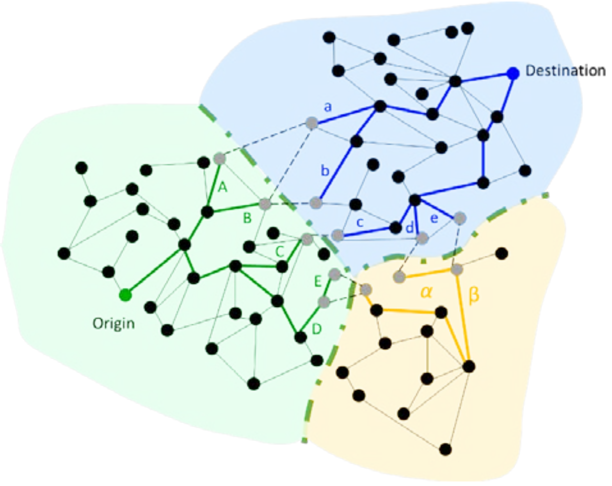

Fig. 3. Routing in the network based on the exchange points.

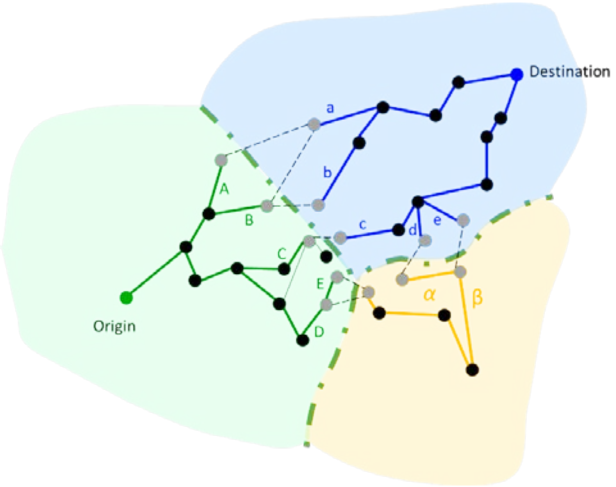

Fig. 4. Routing in the network based on the exchange points with timetable.

III. RESULTS AND DISCUSSION

In the realization of the routing process, six LJPs in Central Europe provide their data. The database contains 126.513 stops, where 6.654.959.900 connections are examined. For the calculations, the algorithm is written in Java (OpenJDK 15.0.2+7-27 and Eclipse 4.18.0.I20201202-1800), and the visualization is realized by using OSM (OpenStreetMap). The exchange points at the border are defined based on the straight-line maximum walking distance calculation. Three scenarios are investigated, where a walking distance of 1, 2, 3 km is applied. As a result, in case of 3 km, almost 7x more exchange points are identified than in case of 1 km in total (Table 1).

TABLE I. THE DEFINED NUMBERS OF EXCHANGE POINTSS

Max. Walking Distance (km)	**Number of Exchange Points**	**SI-AT**	**AT-CZ**	**AT-SK**	**HU-AT**	**CZ-SK**	**SK-HU**	**HU-RO**	**SL-HU**
1	770	38	672	0	0	50	0	10	0
2	2290	812	1356	34	6	68	4	10	0
3	5406	3082	2102	34	50	110	10	12	6

Based on the exchange point identification process, the following areas are highlighted around the border of Central European countries (Figure 5). The most exchange points are found between the Czech Republic and Austria, while between Hungary and Slovakia or Hungary and Romania, solely a few suitable exchange points are detected. This is caused by the received datasets. In case of Slovakia, the regional bus stops are available alone, while in case of Romania, solely the railway connections could be applied for the search.

IV. CONCLUSION

The elaborated algorithm can handle any exchange point regardless of the location. A unique global ID is allocated to each exchange point. With this technique, the names of different stops in the distinct databases can be easily managed. Furthermore, the coverage of the proposed method is not limited to any specific country. Utilizing the relatively low processing times and parallel computing opportunities of the heuristic algorithm, a huge number of requests can be handled at the same time. Thus, the operation in a European environment should not cause technical difficulties. This means that the proposed solution is fully capable to cover wide geographical areas and to provide a transferable solution, which can be applied by any traveler information service provider.

The proposed routing algorithm has to be examined based on the real-world requests of travelers between different origins and destinations. Experiments on multimodal networks with a great number of nodes confirms the feasibility of the proposed approach.

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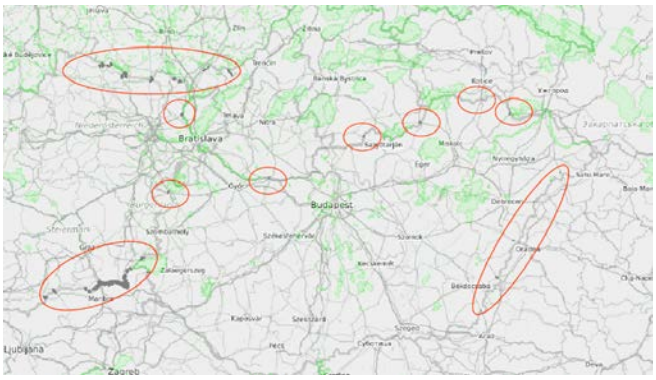

Fig. 5. The identified exchange points in case of 3 km walking distance.

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