Designing Intermodal Transportation Systems in Rural Areas

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In rural areas, providing sufficient accessibility in terms of transport mobility requires high effort due to low population density and long travel distances. The resulting disproportionate costs lead to insufficient public transport systems with long waiting and travel times. Therefore, rural inhabitants avoid using public transport systems and often depend on private cars to reach workplaces and social facilities mainly located in urban areas (cf. Pucher and Renne, 2005). In addition to insufficient accessibility for rural inhabitants without access to a car, insufficient public transport systems and the resulting dependence on cars lead to congested roads towards urban centers and high emissions.

To tackle these challenges, public decision makers intent to improve overall public mobility in rural areas by a controlled and efficient integration of alternative mobility offers. The integration of alternative mobility offers into public transport systems may offer additional and faster connections, especially if these allow for transfers between modes (intermodality) by an intelligent link with the public transport system. Designing intermodal transportation systems requires complex planning tasks. The planning tasks include deciding on where and what kind of additional modes of transport will be offered depending on the current demand and supply. At the same time, multiple modes of transport, transfers between available modes as well as routing decisions result in a high variety of different travel itineraries even for a single connection. The high variety of travel itineraries in intermodal transportation systems requires a suitable modeling approach.

Against this background, the objective of this presentation is to develop a decision support tool for public decision makers aiming at the design of multimodal as well as intermodal transportation systems. Herein, the target is to improve overall accessibility of rural inhabitants by strengthening the current public transport system. For this purpose, we locate alternative mobility offers within an existing public transport system. In addition, we allow for intermodal connections by enabling transfers between different mobility offers. Our approach reflects an appropriate degree of complexity for both stakeholders and shareholders and thus serves as a transparent decision support tool for direct real world applications.

As part of our research, we provide a comprehensive literature review of two research streams related to our planning model. First, we review geographic approaches that improve accessibility in terms of transport mobility. Second, we review public transport planning models either approaching intermodality or siting public transport hubs.

Research on improving accessibility is usually based on descriptive models which focus on measuring total travel costs, times or distances between locations as well as the quantity or quality of points-of-interest within reach. Herein, these measurements often rely on strong inherent simplifications using population centers or population weighted centroids as well as point-based indicators for accessibility (cf. Páez et al., 2012).

Research on public transport planning is extensive, e.g., it comprises public transport design, timetabling, frequency setting, scheduling and passenger routing (cf. Guihaire and Hao, 2008; Daraio et al., 2016). Related approaches are usually based on mathematical optimization models which optimize demand coverage as well as travel times including transfers. In contrast to freight transport (cf. Guastaroba et al., 2016), in which planning intermodal routes as well as hubs has a long history, most public transport planning models still neglect intermodality or are limited to transfers between selected public transport modes, such as feeder-in-network models. Due to a high inherent complexity, most approaches include heuristic or metaheuristic algorithms. By additionally taking into account alternative mobility offers, the complexity of the shortest-path search in public transport planning models even increases (cf. Zhang et al., 2014).

We conclude that existing literature is not suitable for our objectives. On the one hand, approaches with strong simplifying assumptions exist in the area of accessibility in terms of transport mobility. On the other hand, several solution methods have been developed to solve complex multi- and intermodal mobility systems. However, neither research stream serves as an appropriate and transparent decision support tool for public decision makers in rural areas.

Our model includes the following interdependent decisions. On the one hand, the model determines the fastest feasible travel itinerary with public mobility offers including existing public transport and alternative mobility offers. On the other hand, it locates specific alternative mobility offers at terminal and potential transfer locations. We assume the intermodal transportation system to offer bikesharing and carsharing in addition to existing public transport offers.

Our mixed integer programming model is defined on a complete graph with a set of vertices representing terminal and potential transfer locations. Further, we set all potential travel itineraries as input. Any potential travel itinerary is characterized by specific requirements with respect to available mobility offers at terminal and transfer locations. Consequently, selecting a potential travel itinerary is only feasible if all terminal and transfer location requirements are met. Besides these requirements, we consider travel volumes of any connection as well as travel times of any potential travel itinerary including transfers as input. Further, we model an upper bound for the number of locations for a specific alternative mobility offer. In order to look at the planning problem from an edge-based perspective, our objective function minimizes total travel time weighted with travel volumes of connections. It is subjected to certain constraints such as travel itinerary selection, meeting of terminal and transfer location requirements, determination of travel times as well as upper bounds.

The variety of potential travel itineraries for one connection includes any combination of vertices as transfer locations as well as any combination of mobility offers along these transfer locations. Since creating all potential travel itineraries affects both complexity and quality of the model, we eliminate inferior travel itineraries. First of all, we only identify travel itineraries that are faster than initial public transport connections. Further, we eliminate travel itineraries with redundant transfers between the same mobility offer as well as travel itineraries that are dominated by others in terms of both location requirements and travel times. Since a traveler only wants to make a limited number of transfers, we enable only a customized number of transfers within a travel itinerary.

For our case study, we examine a typical rural area, the district Heinsberg, Germany. The district Heinsberg has $250,000$ inhabitants, a population density of 400 inhabitants per km^2 and a high proportion of private cars of 67 % (Kreis Heinsberg, 2018). The current public transport system within the district is designed to connect surrounding medium and larger sized cities for commuters rather than providing connections within the district. An agile development process in close cooperation with responsible transport planners in Heinsberg makes our model the ideal solution for public decision makers in rural areas. In our case study, we validate our model, get results for public decision makers and gain general managerial insights.

The population structure in Heinsberg is given in clusters of about 1,000 inhabitants. These clusters serve as demand centers as well as terminal and potential transfer locations within our model. In order to estimate the travel volumes of any connection, we apply a customized radiation model (Kang et al., 2015; Simini et al., 2012). We customize the radiation model with real vertex-based data for commuters (IT.NRW, 2017). In order to assess the current public transport system as well as alternative mobility offers, we determine travel times of any potential travel itinerary, i.e., travel times of any connection with any mode of transport. For this purpose, we make requests on public available routing machines (OSRM, 2019; Google, 2019).

Our results provide several insights. A priori, an analysis of travel volumes and the current public transport system highlights weaknesses within the current public transport system. Further, we decrease the overall travel time and thus improve accessibility. First results promise enormous potential to reduce travel times for inhabitants within the district Heinsberg. Besides, we obtain optimal locations for alternative mobility offers as well as a decision support tool tailored to the needs of Heinsberg's transport planners.

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