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Modelling Intermodal Accessibility Considering Quality Aspects of Transport – a GIS-based Approach for the State of Salzburg

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Abstract

Mobility and access to basic supply, education and working facilities is essential for participation in social, economic, professional and cultural activities. As new transport solutions contribute to an increase in inter- and multimodal mobility, the provision of seamless mobility options has an influence on the accessibility of everyday services for individuals, especially in rural regions. Thus, 'intermodal accessibility' to regional centres (i.e. locations where everyday goods and services are provided) comprises both providing people with basic services in space and the quality of the local transport infrastructure.

This study presents the development of a GIS-based tool that facilitates an area-wide analysis of the population's intermodal accessibility to regional centres. Spatial indicators, which have a substantial influence on intermodal accessibility, are identified and weighted according to their impact. The set of indicators comprises factors reflecting the quality of the public transport service and station as well as comparative factors. Standardized data and interfaces such as GIP or VAO provide detailed spatial information on the multimodal transport infrastructure and support the transferability of the tool. Based on the resulting intermodal accessibility measure, regional disparities and areas with a poor transportation infrastructure can be identified.

As the strategy developed here provides information on intermodal accessibility for the whole State of Salzburg in a transferable and transparent way, it contributes to integrative transport and settlement planning as well as to the assessment of specific locations.

Keywords:

intermodal travel time, spatial indicators, accessibility measure

1 Motivation

Physical access to education and everyday goods and services as well as participation in social and working life strongly depend on the ability to move around (Páez et al., 2012). In order to facilitate equality of participation in social, educational and working life, the provision of public and private transport infrastructures as well as services for accessing potential activities must avoid social exclusion. An unequal distribution of potential activities over space and unequal access to means of transport determine the need for seamless, inter- and multimodal travel options to potential destinations.

Whereas unimodal mobility is the use of just one means of transport, multimodal mobility describes the use of various forms of transport during a certain period of time. In intermodal journeys, more than one means of transport is used during one single seamless journey (VCÖ, 2015).

According to Tomschy et al. (2016), on average 12% of all trips using public transport (PT) within Austria are intermodal journeys. Whereas in cities this share is around 2% (Vienna 3%), in central and rural regions the shares are about 23% and 27% respectively. Thus, in rural regions especially, having to cover the first and last sections of the journey to and from the public transport station by different means (by car or on foot, for example) has an influence on the accessibility to regional centres in terms of seamless mobility. Intermodal mobility solutions involving bike-and-ride (B&R) and park-and-ride (P&R) and alternative mobility solutions such as car-sharing or on-demand concepts have great potential to reduce the daily traffic load on roads, especially in suburban and peripheral areas (VCÖ, 2015).

In the course of integrated settlement and transport planning, nationwide planning objectives and standards for the provision of public transport are developed. Securing basic service provision is a fundamental task in spatial planning (ÖROK, 2011), as well as the support of multi- and intermodal mobility solutions and the reduction of the individual's dependency on a private car (Land Salzburg, 2016). According to previous accessibility studies in Austria (Beier et al, 2007), regional centres must maintain the provision of basic services. Accessibility to regional centres in Austria reflects regional disparities in the course of having access to basic services, as well as regional differences in the quality of the corresponding transport system.

Recent modelling approaches for adequate accessibility using public transport start journeys from a station, and only areas within a certain walking distance of the station are considered. Therefore, accessibility using public transport is not determined for any of the remaining areas (Beier et al, 2007). If other modes for accessing stations, such as cycling or motorized individual transport (MIT) options, are taken into account, a planning tool for analysing intermodal journeys using public transport in combination with P&R and B&R can be developed.

Against this backdrop and in accordance with the increasing importance of inter- and multimodal mobility solutions, the aim of this study was to conceptualize a GIS-based tool for quantifying intermodal accessibility to regional centres, incorporating recent planning objectives, the latest transport and mobility data, GIS technologies, and aspects of the quality of transport services. Moreover, as daily, home-based routes for work or education, and trips to meet daily needs are investigated, the area-wide intermodal accessibility to regional centres, representing potential destinations, is considered. A prototype of the GIS tool was tested for the State of Salzburg, the intermodal accessibility approach of which takes into consideration intermodal journeys that use PT in combination with walking, cycling and/or using a car for journeys to the public transport station. As the seamlessness of a journey is important, intermodal quality aspects like the number of transfers or the waiting times are taken into account.

2 Modelling intermodal mobility and accessibility

Jones et al. (2000) define intermodal transportation as 'the shipment of cargo or the movement of people involving more than one mode of transport during a single, seamless journey' (Jones et al. 2000, p.8). Combining different means of transport facilitates the maximization of benefits. In fact, different modes have different characteristics, such as monetary costs, travel speed and time, environmental and health aspects, temporal and spatial flexibility, physical effort required, availability and infrastructure properties. Health, economic, personal, infrastructural and various other factors determine the access to and choice of these means of transport. Thus, individuals use different modes for similar and dissimilar activities in space and time.

Handy (2005) emphasizes that mobility and accessibility are distinct concepts. Mobility is defined as the 'potential of movement' (Handy, 2005, p. 132) or 'physical movement, measured by trips, distance and speed' (Litman, 2015, p. 9). It focuses on the performance of the transportation system and the ability to move around (Handy, 2005). Because the concepts of mobility and accessibility are distinct, they have different implications for planning practice, not least because accessibility itself is defined in a multiplicity of ways.

Because the concept of accessibility was developed in different disciplines simultaneously, no single definition of accessibility exists. According to Hiess (2008), accessibility describes a potential determined by the transportation system, travel impedances and regional structures. Hence, accessibility concepts characterize the movement from an origin to a specific destination, taking transportation and land-use characteristics into consideration (Handy, 2005). According to Geurs & van Wee (2004), accessibility comprises four main components, namely land-use, transportation, temporal and individual components. As specific research objectives focus on one or more of these specific components, a variety of accessibility concepts exist.

According to Handy & Niemeier (1997), cumulative accessibility measures provide the total number of possible destinations which can be reached within a predefined travel time or distance, whereas gravity-based measures consider the weighting of opportunities and trip distributions based on Newton's law of universal gravitation applied to spatial studies (Wegener et al., 2001). Thus the attraction of a distant location is proportional to its size weighted by a decreasing function of its distance. Handy & Niemeier (1997) state that accessibility is measured by two components – the attractiveness of the opportunities and an impedance function. The impedance function gives more weight to the attractiveness of the opportunities the closer they are to the origin (Handy & Niemeier, 1997). Utility-based measures underlie the theory of random utility (Handy & Clifton, 2001; Baradaran & Ramjerdi, 2001), which states that 'the probability of an individual making a particular choice depends on the utility of that choice relative to the utility of all choices' (Handy & Clifton, 2001, p. 69).

While an extensive scientific literature exists on the subject of accessibility, conceptualizing and measuring intermodal accessibility has scarcely been explored. According to Spiekermann (2005), multimodal accessibility reflects the combined effect of using more than one means of transport, represented by the most cost-effective option or by aggregating all single, mode-specific travel costs, whereas in the context of intermodal accessibility seamless journeys using two or more means of transport are considered. As Bruinsma & Rietveld (1998) noted, introducing a multimodal network is a drastic step when analysing, modelling and measuring accessibility, because the implementation of intermodal journeys entails large, complex travel matrices as well as the need to focus on interconnectivity issues at transfer points.

Whereas accessibility *measures* are used to transform the conceptual approach into quantitative indicators, accessibility *instruments* aim to 'provide explicit knowledge on accessibility to actors in the planning domain', with accessibility instruments having been 'specifically developed to support planning practice by measuring, interpreting and modelling accessibility' (Angiello et al., 2014, p. xvi). Usable planning instruments, however, are still limited due to a misunderstanding of the accessibility concepts behind them. In planning practice, accessibility instruments are often seen as black boxes – inflexible, incomprehensible and too complex (te Brömmelstroet, 2014). In designing planning instruments, the challenge is to harmonize the abstract view of the developer of the instrument and the view of its potential users, e.g. planning practitioners.

3 Conceptualization and design of the GIS Tool 'Intermodal accessibility'

Thanks to recent technologies and developments in data science and data provision, detailed GIS data with high spatial and temporal resolution are available for multi- and intermodal mobility and transport planning. Standardized data and interfaces provide detailed information on the multimodal transportation infrastructures. GIP (the Graph Integration Platform) offers a nationwide transportation graph, including information about average travel speeds, one-way restrictions and mode-specific trafficability. Floating car data (FCD), synchronized with GIP, provide information about the traffic load over a day or week, allowing more realistic travel times to be estimated for MIT. Furthermore, the VAO (Verkehrsauskunft Österreich) provides detailed data on public transport schedules, including the number of transfers, waiting and transfer times, numbers of departures, frequency of service, and the working hours for each specific connection.

Against the backdrop of the increasing importance of inter- and multimodal mobility, the availability of temporally and spatially detailed transportation data, planning objectives and the need for travel, a GIS tool was developed reflecting intermodal accessibility in the State of Salzburg. The intermodal accessibility model is conceptualized to reflect the intermodal accessibility for an inhabitant of the State of Salzburg of the nearest regional centre that provides daily goods, facilities and services based on existing transport services and infrastructures. Quality aspects of the transport services were also taken into account.

The GIS tool is based on a multi-criteria approach, using spatial indicators to describe and quantify intermodal accessibility. Spatial indicators contribute to a quantification and assessment of planning issues and processes, to the transparency of the concept, and consequently to a readily understandable interpretation. Furthermore, spatial indicators support the detection of spatial relationships and patterns, as well as the communication of planning strategies (Prinz, 2007). In Figure 1, the conceptual model of the intermodal accessiblity tool is visualized. In a pre-processing step, a multimodal network dataset based on GIP is created separately, for MIT, cycling and walking. Floating car data are integrated into the MIT network as travel cost attributes in order to take traffic loads into account.

In line with the research objective, the inhabited cells of the 250x250m statistical raster represent all potential origins of travel. The integration of these data into a planning analysis is often worthwhile because of the specific characteristics of regional statistical raster units: they are subject-oriented and of high spatial resolution, presenting standardized metadata and the potential to be related to statistical data. Moreover, the inhabited areas of the State of Salzburg can be identified using the statistical raster data joined with demographical information.

Based on the classification scheme of central places, there is an official Austria-wide list of regional and supra-regional centres, which are appropriate for analyses in respect of public transport as well as of the provision of basic services (Land Salzburg, 2003). Because these regional and supra-regional centres provide essential basic services and facilities, they are most appropriate to use as the potential destinations in the intermodal accessibility analysis for the State of Salzburg.

Based on data and data sources like GIP or VAO, the locations of public transport stations, P&R and B&R sites, floating car data, statistical raster data and regional centres, spatial indicators which have a relevant and decisive impact on intermodal accessiblity are generated using network-based GIS routines and spatial analysis. The set of spatial indicators is based on a literature review. An interim result is the set of all relevant spatial indicators. Based on the impact of each indicator on intermodal accessibility, the standardized spatial indicators are weighted, a procedure which is designed to be user-modifiable. The intermodal accessiblity measure is represented by the aggregation of all spatial indicators according to their weights.

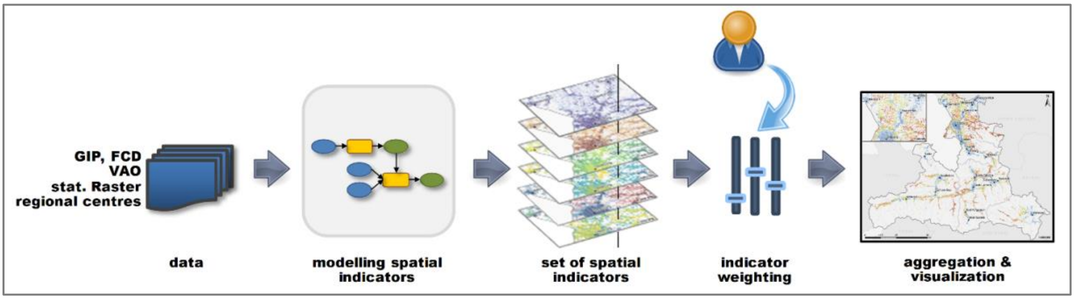

Figure 1: Conceptual model of the GIS Tool

Indicator set

Based on Salonen & Toivonen (2013), Handy & Clifton (2001), Walther (1991), Schwarze (2005), Litman (2015) and deStasio et al. (2011), factors which contribute significantly to the intermodal accessibility to regional centres are identified and generated using network-based GIS routines and spatial analysis. Table 1 lists all identified, relevant spatial indicators. Two groups of indicators are distinguished: (1) spatial indicators which characterize intermodal quality aspects using PT with respect to the quality of the intermodal PT service on the one hand, and the quality of the PT station on the other hand; (2) comparative indicators that reflect the relative competitiveness of the intermodal solution using PT. Therefore, the intermodal route using PT is compared to that using MIT and rated for quality, specifically with regards to differences in travel time.

Indicators for intermodal quality aspects using PT are grouped into indicators that reflect the quality of the public transport service itself, and the quality of the stations. The total intermodal travel time, number of transfers, transfer and waiting times, and frequency of a service characterize the quality of the public transport service in an intermodal context. The quality of the public transport station (Table 1) and its accessibility, integrating the concept of 'ÖV-Güteklassen' (Hiess, 2017), refers to features such as the number of daily departures, the means of transport and the distance to the public transport station. Additionally, the availability of P&R and B&R facilities is taken into account, depending on the distance to the PT station. As the estimation of travel time is based on the door-to-door approach and floating car data provide information about the travel speed in traffic load, travel times using different means of transport can be compared.

Comparative indicators reflect the relative competitiveness of PT and MIT accessibility aspects. The ratio between the intermodal travel times using PT and using a car determines the probability of using public transport (Schwarze, 2005, Salonen & Toivonen, 2013, de Stasio et al., 2011, Boltze et al., 2002). In the case of short travel times, a small difference in travel time can lead to a very uneven ratio. For example, the travel time using a car is 6 min, and using public transport it is 8 min; the ratio is 75%, but the difference is only 2 min. Hence, the absolute difference in travel times is also considered as an indicator. Furthermore, the ratio between the travel time to the nearest public transport station (the access time) and the total travel time using public transport is taken into account. This ratio reflects the attractiveness of public transport. If the access time is a large share of the total travel time, the attractiveness of public transport is reduced (Spillar, 1997). Consequently, the comparative indicators are a measure of the competitiveness of, and equal access to, public and private transport. According to planning objectives, this aspect is relevant in switching away from using a car.

Table 1: Spatial indicators describing the intermodal accessibility to regional centres

intermodal quality aspects using PT		**comparative indicators**
quality of intermodal PT service	***quality of PT station***	
- total intermodal travel time* - number of transfers - transfer & waiting time - frequency **multimodal access to PT station (by foot, by bike, by car); door-to-door approach*	- number of daily departures** - means of transport** - distance to station** - availability of P&R, B&R facilities *** in accordance with ÖV-Güteklassen (Hiess, 2017)*	- ratio total travel time MIT: intermodal travel time using PT - difference total travel time MIT: intermodal travel time using PT - ratio multimodal travel time to PT station: total intermodal travel time using PT

Modelling intermodal travel times using public transport

The conceptual model for quantifying travel times is the key component of an accessibility study and determines its reliability (Salonen & Toivonen, 2013). As intermodal mobility is characterized by the use of more than one means of transport within one journey, the intermodal travel time consists of several components, as visualized in Figure 2. Following a door-to-door approach, the intermodal journey can be quantified by adding together the times for all the components of the journey, including the access time to the public transport station from the origin, the egress time from the station to the destination, the waiting time at the station, the in-vehicle time using public transport, and extra transfer and waiting times in the case of additional transfer(s) within the public transport system. Intermodal journeys using public transport are generally characterized by the use of various mode options for the first and last sections. Depending on the means of transport, the access and corresponding egress times equal the walking times, or, in the case of cycling or driving, the access time to the parking space, the in-vehicle time by bike or car, and the transfer time to and from the public transport station (Figure 2).

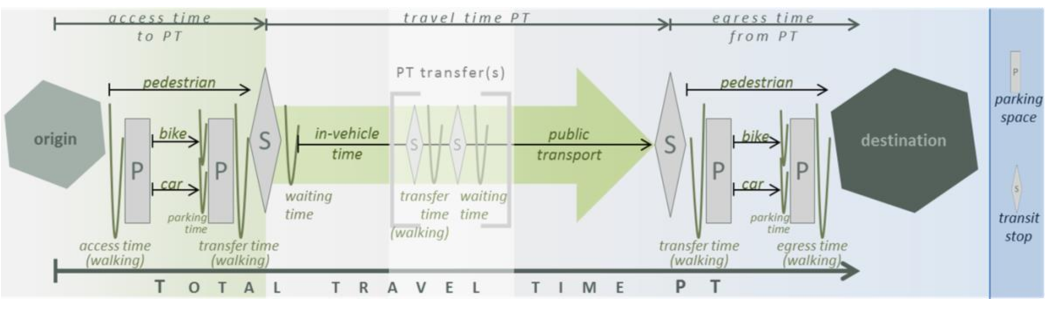

Figure 2: The intermodal journey using public transport according to the door-to-door approach

Within a prototypic modelling approach, a specific routing strategy is developed to identify the intermodal route that requires the least time. For each cell of the statistical raster, the intermodal travel time to the next regional centre is calculated. Access to the public transport station is implemented in a multi-modal manner, considering walking, bike and car as means of transport.

The mode-specific travel times from each inhabited raster cell as origin to the next public transport station are calculated separately. Based on the GIP graph with its specific travel-cost attributes, including floating car data, a shortest-path algorithm, in practice the Dijkstra-algorithm, is applied to the corresponding networks for walking, cycling and using a car. Because the mode choice for the first and last sections of the journey depends strongly on the distance to the public transport station, the average travel time to the station is calculated using mode-specific distance decay functions for walking, cycling and driving by car. Based on discrete modal split statistics by distance, continuous probability functions using a specific mode depending on the distance are estimated prototypically. Based on these estimated mode-specific distance decay functions, an average travel time from each raster cell to the station is calculated, representing the multimodal access time to the station. Therefore, the corresponding travel times for the three mode options (foot, bike and car) are proportionally added up, in line with the probability of using them depending on the distance to the station (formula (1)).

$$t(o,s,G,d) = \sum_{i \in M} f_i(o,s,G,d) * t_i\,(o,s,G) \qquad \text{formula (1)}$$
$$holding\ that \sum_{i \in M} f_i(o,s,G,d) = 1$$

where:
$o \ldots origin$
$s \ldots station$
$G \ldots graph$
$d \ldots distance\ from\ a\ specific\ origin\ to\ a\ specific\ station\ based\ on\ the\ graph\ G$
$(using\ shortest - path\ algorithm)$
$M = \{foot, bike, car\}$
$f_i \ldots probability\ function\ of\ using\ a\ specific\ mode\ i \in M\ dependent\ on\ distance\ d$
$t_i \ldots travel\ time\ from\ origin\ to\ station\ based\ on\ the\ weighted\ graph\ G$
$using\ a\ specific\ mode\ i \in M$

Assuming that some PT stations have less frequent services than others or that express trains do not stop at every station, not only the nearest station is taken into account, but also the nearest five, by default. Hence, potential intermodal travel options are taken into account and calculated. The in-vehicle time using public transport is derived by data of the VAO. The time given by the VAO includes transfer, waiting and egress time by walking. Consequently, the intermodal travel time is composed of the multimodal access time, the in-vehicle time using public transport, the egress time, and the initial waiting time at the station, the last of which is added as a constant. As the intermodal travel time for all five options is modelled and estimated based on network distance, the intermodal route that takes the shortest time is identified. Following this strategy, the minimum intermodal travel time is quantified for each raster cell. Thus, the GIS model considers several intermodal travel options and provides the most time-efficient one.

Multi-criteria assessment for quantifying intermodal accessibility

The intermodal accessibility measure is composed of the sum of all indicators, weighted with respect to their impact on intermodal accessibility. Whereas the initial weighting of the particular factors is determined by the literature, the final weighting is implemented dynamically in the GIS Tool. The aggregation of the indicators is implemented stepwise according to the indicator groups, supporting transparency.

The indicator 'intermodal quality aspects using PT' is composed of the indicators 'quality of intermodal public transport service' and 'quality of public transport station'. All factors that determine the quality of intermodal public transport services are weighted by the potential user of the tool according to their specific research issue. It is recommended to weight the intermodal travel time heavily due to its influence on accessibility (Salonen & Toivonen, 2013; Walther, 1997; de Stasio et al., 2011; Schwarze, 2005). In detail, the shorter the intermodal travel time, the better the intermodal accessibility estimate. Moreover, a small number of transfers, short transfer and waiting times, and a high frequency of the public transport service all have a positive influence on intermodal accessibility. Each factor is standardized and weighted in relation to the others, according to the user-specific weighting. The indicator for quality of public transport station is determined following the scheme of ÖV-Güteklassen (Hiess, 2017), extended by considering P&R and B&R facilities, which within a certain distance between the point of origin and the nearest station have a positive influence.

The influence of the comparative indicators is also determined by the user. Small absolute differences between the intermodal travel time using public transport and the travel time using a car in heavy traffic, modelled by integrating floating car data, have a positive influence on intermodal accessibility. Because travel time using a car is shorter in most cases, high differences between the two indicate poor public transport connections. Moreover, the ratio between the travel time to the station and the total intermodal travel time can influence intermodal accessibility: the lower the access time to the PT station in relation to the overall travel time is, the more attractive the public transport solution is.

The spatial indicators have different data types and value ranges. Consequently, the indicators are standardized prior to creating the weighted overlay for the two main indicators, as determined by the individual user. In addition, the GIS Tool provides each particular indicator and group of indicators as interim results, which can be visualized and analysed to favour the comprehensibility and transparency of the evaluation strategy.

The resulting measure quantifies the intermodal accessibility to regional centres. This measure is visualized relative to the State's average using a quartile classification scheme (see Figure 3). Five categories indicate whether the intermodal accessibility to the next regional centre at a specific raster cell is poor, below-average, average, above-average or excellent in relation to the State's average.

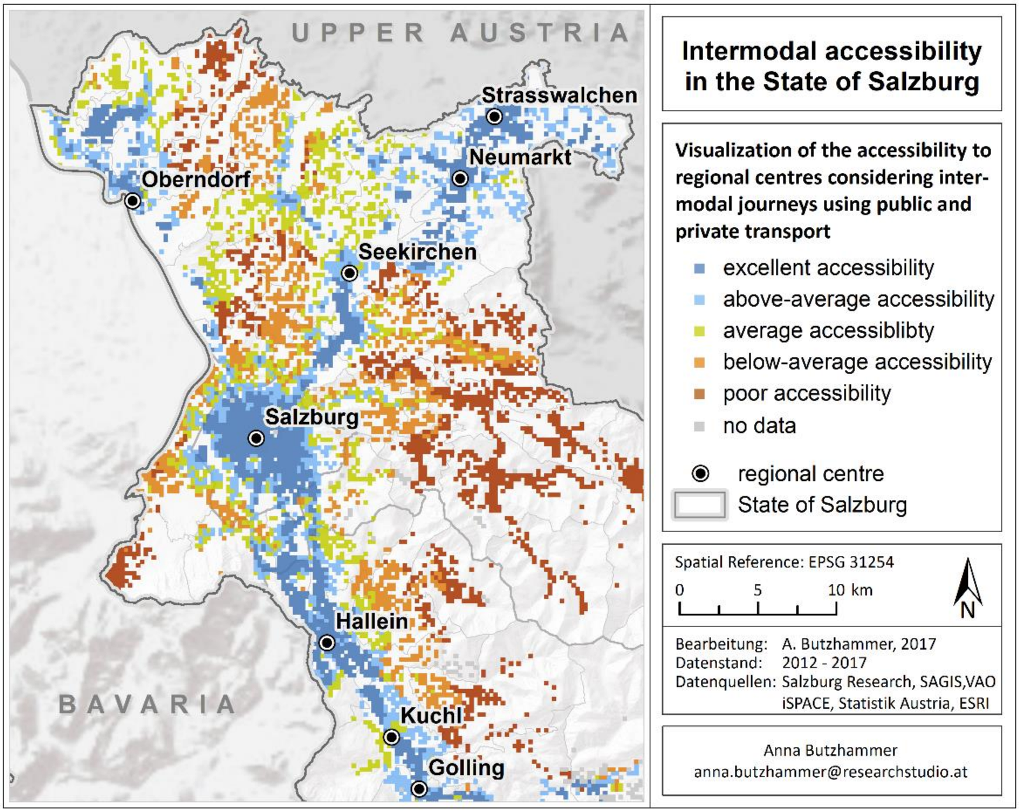

Figure 3: Visualization of intermodal accessibility to regional centres in the State of Salzburg on a raster basis generated by the GIS Tool

4 Discussion and Conclusion

The GIS Tool developed as a prototype for measuring intermodal accessibility meets the requirements of simplicity, transparency, transferability and comprehensibility. Implementing spatial indicators facilitates the understanding of the conceptual framework for potential users without a strong theoretical background, and the examination of particular indicators. In addition, the set of interim results and the modifiable weighting of the indicators enable the application of the tool to specific issues.

The integration of recent data and technologies contributes to a meaningful tool for planning purposes. The GIP, combined with floating car data, contributes to the precise and comparable calculation of travel times according to the door-to-door approach, which are key components of the intermodal accessibility measure. Furthermore, the VAO data provide extensive information on the public transport schedule and service with a high temporal resolution (one hour). Moreover, the VAO data are essential in the course of assessing the quality of public transport services. The data are consistent with each other, are in part open government data, and correspond to the structure of the data used in planning practice. Hence, the resulting information about intermodal accessibility presents an interface for adding further information in the course of integrated spatial planning. Standardized data and interfaces like the GIP or VAO support the transferability of the tool and provide detailed spatial information on the multimodal transport infrastructure. In addition, the integration of planning objectives (e.g. the quality classes of public transport and the concept of regional centres) supports an application of the tool in planning practice.

Based on the area-wide quantification of intermodal accessibility generated by the GIS Tool, regional disparities and areas with a poor transportation infrastructure can be identified. Moreover, the data generated for intermodal accessibility can serve as the basis for further analysis, especially in the context of potential demand for existing or enhanced transport services. As the tool accomplishes the purpose of providing information on intermodal accessibility prototypically for the whole State of Salzburg, in a transferable and comprehensible way, it contributes to integrative transport and settlement planning as well as to location planning. Moreover, combining the intermodal accessibility results with demographic and labour market data represents an enormous potential for use in integrative planning, because they are all based on statistical raster data.

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