MEASURING LOCAL ACCESSIBILITY BY PUBLIC TRANSPORT

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Abstract: Due to the fact that transport projects always draw the public's attention, planning processes have to comply with high standards. In this paper, which is based on a diploma thesis, an enhanced GIS-based method for measuring local accessibility by public transport is presented. In order to generate valuable information for planning it is proposed to use a disaggregated travel time budget indicator that considers both changes of spatial structures and travel behaviour.

Introductorily the background of public transport planning in Germany is outlined. Then, a brief categorisation of existing accessibility indicators is given, and weaknesses of accessibility indicators used in today's German planning practice are discussed. Next, the proposed travel time budget indicator is derived and the approach of measuring local accessibility by public transport with a geographic information system (GIS) is explained. Finally, the potentials of the developed method are practically demonstrated, and further possible developments are outlined.

Keywords: Accessibility indicators, GIS, public transport, assessment method

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1 Background of Public Transport Planning in Germany

With the objective to improve and optimise public transport services the German legislator adopted a fundamental railway structural reform consisting of a package of new statutes and amendments in the early nineties. An essential part of this reform was the federal law on the regionalisation of local passenger traffic. Under the 'Regionalisation Act' (RegG) the responsibility for public transport services was relinquished to the federal states, the *Bundesländer*. The *Bundesländer* were required to accomplish the necessary detailed arrangements by the beginning of 1996 (cf. Löw, 2000). In North Rhine-Westphalia where the new measuring method is applied, the government assigned the responsibility for the planning, organization, and implementation of regional and local public transport services to the counties and major cities which are not part of a county.

In the same year by the amendment of the 'Passenger Transport Act' (PBefG) the local transport plan was established as a new instrument for planning and designing regional and local public transportation services. The public transport plan mainly serves the purpose of managing, coordinating and improving the attractiveness of public transport services in its effectual area.

In Germany local public transport is considered to be an important element of providing basic public welfare services. The objective of public transport planning is to supply a powerful and efficient public transport that guarantees social and economic interactions for all citizens and population strata. Authorities are legally obligated to work out or readjust the public transport plan at least every five years.

In the plan they define ideas and concepts for establishing and ensuring adequate public transport services. In particular, the plan

- records and analyses existing transport systems,
- expresses goals and defines specific standards for the further development of public transportation services, and
- develops plans for an efficient design of public transport by taking into consideration the existing and planned settlement areas (cf. Barth, 2000).

2 Use of Accessibility Indicators in Practice

Public transport plans primarily comprise medium-term strategies to expand and improve the attractiveness of the public transport system in its area. From a customers point of view the attractiveness of public transport supplies is mainly perceived by the quality of access to the public transport system, the level of service and the quality of connectivity. Therefore, public transport planning has to ensure and improve the accessibility by public transport. Considering accessibility indicators the purpose of a public transport system is not mobility per se, but rather the access to activities by public transport (O'Sullivan *et al*., 2000). However, the original goal of public transport planning is to ease as much as possible the reachability of locations where passengers are able to perform certain activities such as working, living, shopping, doing leisure-time activities, visiting friends etc.. On the one hand this is achievable by land-use planning, which can settle activity opportunities near major axes of mass transit and on the other hand by public transport planning, which can improve the quality of development as well as the quality of connectivity.

To include accessibility as a criteria for planning obviously accessibility indicators are needed which can measure accessibility by public transport. In general terms, two different concepts of measuring accessibility with indicators can be identified (cf. Schürmann *et al*., 1997; Wegener *et al*., 2000). These two concepts can be named as simple and integrated accessibility.

In the *concept of simple accessibility* only parameters of the transport system in the area itself are applied:

- Equipment indicators consider only transport infrastructure or services itself, expressed by measures such as the number of public transport stops, the number of departures, or the total net length.
- Graph theoretical indicators abstract a transport net with regard to its topology, expressed by measures such as the distance between public transport stops, or the index π (total net length divided by its diameter) that describes the level of development.
- Connectivity indicators determine the qualities of connections within transport nets, expressed by measures such as the number of interchange facilities, interchanging times, or the number of public lines that can be used to get from origin to destination.

While simple accessibility indicators can contain a lot of valuable information about the transport system itself, they fail to answer the question what activities can be reached at the destinations. In contrast, *integrated accessibility* “is determined by the spatial distribution of potential destinations, the ease of reaching each destination, and the magnitude, quality and character of the activities found there“ (Handy and Niemeier, 1997).

Both, land-use planning and transport planning have influence on accessibility. Accessibility is a “construct of two functions, one representing the activities or opportunities to be reached and one representing the effort, time, distance, or cost needed to reach them:

$$A_i = \sum_j g(W_j) \cdot f(c_{ij}) \qquad (1)$$

where $\boldsymbol{A_i}$ is the accessibility of area i, $\boldsymbol{W_j}$ is the activity W to be reached in area j, and $\boldsymbol{c_{ij}}$ is the generalised cost of reaching area j from area i. The functions $g(W_j)$ and $f(c_{ij})$ are called activity functions and impedance function, respectively“ (Wegener *et al*., 2000). Accordingly, for planners the use of these complex indicators can support to take into consideration the interdependence between land use changes and public transport supply on accessibility. Three generic types of integrated accessibility indicators can be differed (Wegener *et al*., 2000):

- Travel cost indicators are based on the assumption that only a specified set of destinations is relevant for the accessibility, expressed by measures such as the mean travel time to e.g. municipal authorities, or the travel costs to swimming baths.
- Travel budget indicators are based on Zahavi’s theory of fixed budgets for traveling (cf. Zahavi, 1974; 1979; Zahavi *et al*., 1981), generally in terms of

maxi-mum time intervals in which a destination has to be reached to be of interest. They can be described as cumulative-opportunity indices (cf. Makri and Folkeson, 1999; Halden *et al*., 2000), expressed by measures such as the number of e.g. work places that can be reached by public transport within 30 minutes, or the number of supermarkets that can be reached by car within one hour.

- Potential accessibility indicators are based on the notion that the attraction of a destination increases with size but declines with travel effort. Potential accessibility indicators are frequently expressed by relative measure units such as the percentage of average accessibility of all areas.

To find out which accessibility indicators were actually used by public transport planners in practice the first generation of North Rhine-Westphalia's public transport plans (1997-2001) were evaluated (cf. Schwarze, 2002). However, a very wide range of different accessibility indicators was applied. Table 1 gives a first impression of it.

Table 1: Accessibility indicators used in North Rhine-Westphalia's public transport plans

Authorities (selection)	Used Accessibility Indicators																
	Simple Indicators													Integrated Indicators			
	Number of public transport stops	Total length of public transport net	Number of used vehicles	Kilometrage performance	Catchment area of public transport stops	Potential demand at public transport stops	Extent of area served by public transport	Service time frequency	Service period	Travel time to main station	Travel time ratio car/Public transport	Necessity of interchange	Interchanging times	List of locations tied to public transport net	Travel time to city centre	Travel speed to city centre	Weighted average travel time to city centre
City of Bielefeld	X		X	X	X		X	X	X			X	X		X		
City of Cologne	X	X		X	X	X	X	X	X		X	X		X	X	X	
District of Düren	X				X		X	X	X	X				X	X		
City of Duisburg		X			X	X	X	X	X	X		X			X	X	
City of Hagen	X	X		X	X			X	X	X		X	X	X	X		
City of Krefeld		X			X	X	X	X			X			X	X	X	
City of Mönchengladbach					X		X	X	X	X	X	X			X	X	X
City of Mülheim a.d. Ruhr	X			X	X			X	X					X		X	
District of Neuss	X		X		X			X				X			X	X	
City of Oberhausen				X	X			X	X		X	X		X	X	X	
District of Viersen	X			X	X	X	X	X		X	X	X					
District of Wesel	X	X	X	X	X		X	X	X		X	X	X	X	X	X	
(..)																	

In the investigated public transport plans accessibility indicators were used in two ways, to analyse the status-quo and to forecast and assess the effects of planned measures and projects. Public transport planners did not apply just one single indicator. For the assessment of public transport systems and planned measures and projects a multiplicity of different simple and integrated accessibility indicators was used.

Simple accessibility indicators are suitable for identifying strengths and weaknesses of public transport systems by measuring either its quality of development or its quality of connectivity. Accessibility indicators such as equipment indicators or connectivity indicators are usually easy to calculate and easy to understand. But simple accessibility indicators can be counteracted and contradictory. For instance, a high density of public transport stops is required to get an easy access to the public transport system, while a fast connection contrarily requires a lower density of stops. Therefore, simple accessibility indicators are never suitable for assessing public transport systems as a whole.

The assessment of measures and projects should always be done with integrated accessibility indicators. The complex interrelationship of changes in the allocation of activities and adjustments of public transportation services can only be illustrated by these indicators. Therefore, only integrated accessibility indicators are able to adequately represent the complex system of accessibility of activities, which eventually is the original goal of public transport planning. To identify which areas benefit or loose as an impact of a measure, and to determine the overall result, integrated accessibility indicators have to be used by public transport planners.

As the evaluation of public transport plans has shown, the most commonly used integrated accessibility indicator in practice is the travel cost indicator *travel time to city centre*. Results of this approach of measuring the accessibility are usually

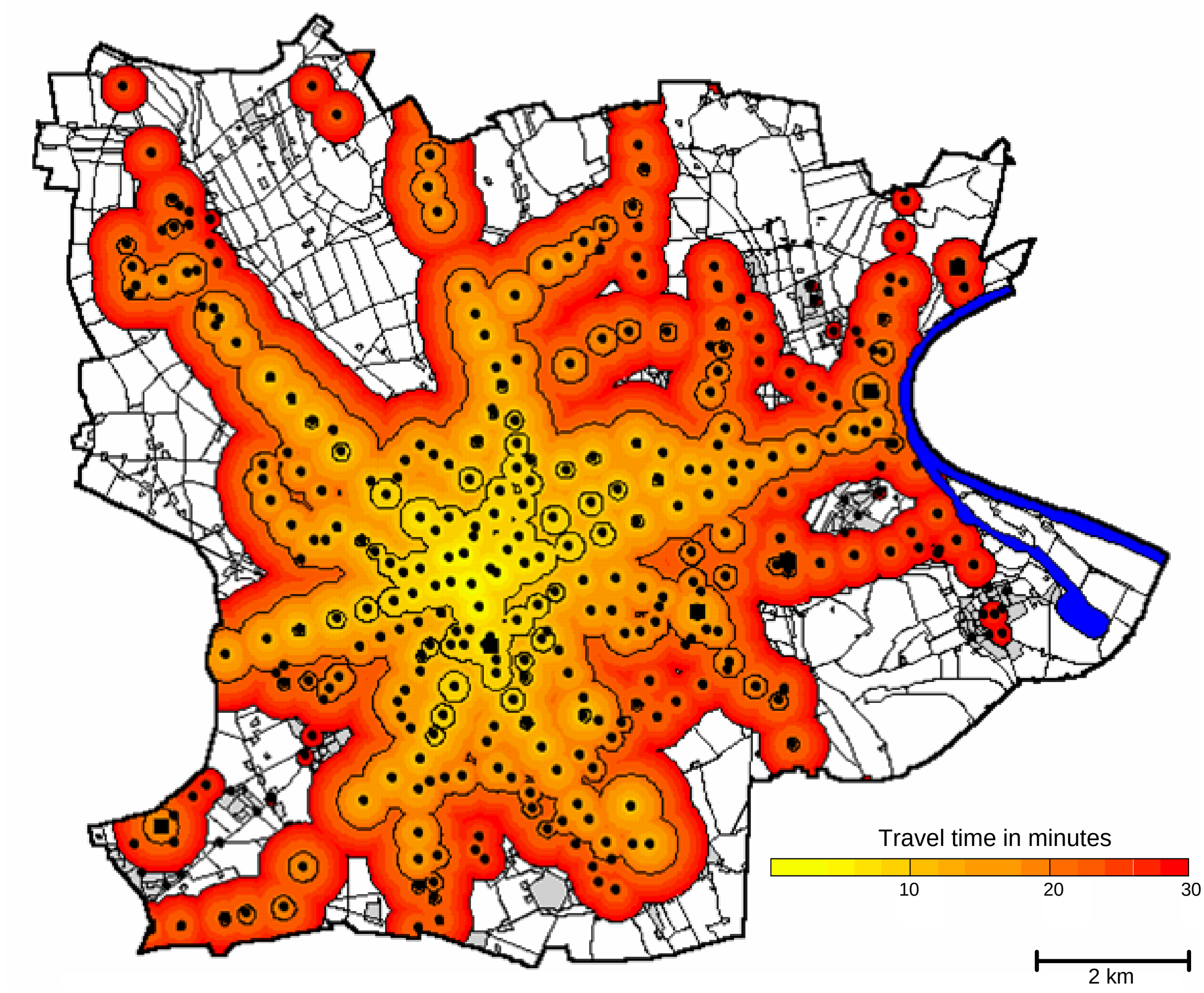

Figure 1 Trave time to city centre by public transport in Krefeld, Germany

displayed in maps which show isochrones as lines of equal travel time. Figure 1 exemplarily illustrates this for the city of Krefeld, Germany.

3 Travel Time Budget Indicator

The travel time indicator usually used in practice is based on the assumption that all relevant opportunities are accumulated at one destination, in this case the city centre. This generalised idea of the distribution of activities in space is mostly inappropriate nowadays. Spatial structures have changed profoundly during the last decades. Since the nineteen sixties the spatial separation of working and living has significantly increased in Germany. This separation is the result of a continuous remigration of the population from densely built-up quarters of the inner city into the urban peripheries, which was followed by a suburbanization of companies and public facilities. A tremendous sprawl of the urban agglomerations was the result. The suburban space has become a patchwork of small mono-functional central places. For this phenomenon of spatial development Sieverts (2003) uses the terms the ‘city without city’ and the 'in-between-city' (see Figure 2).

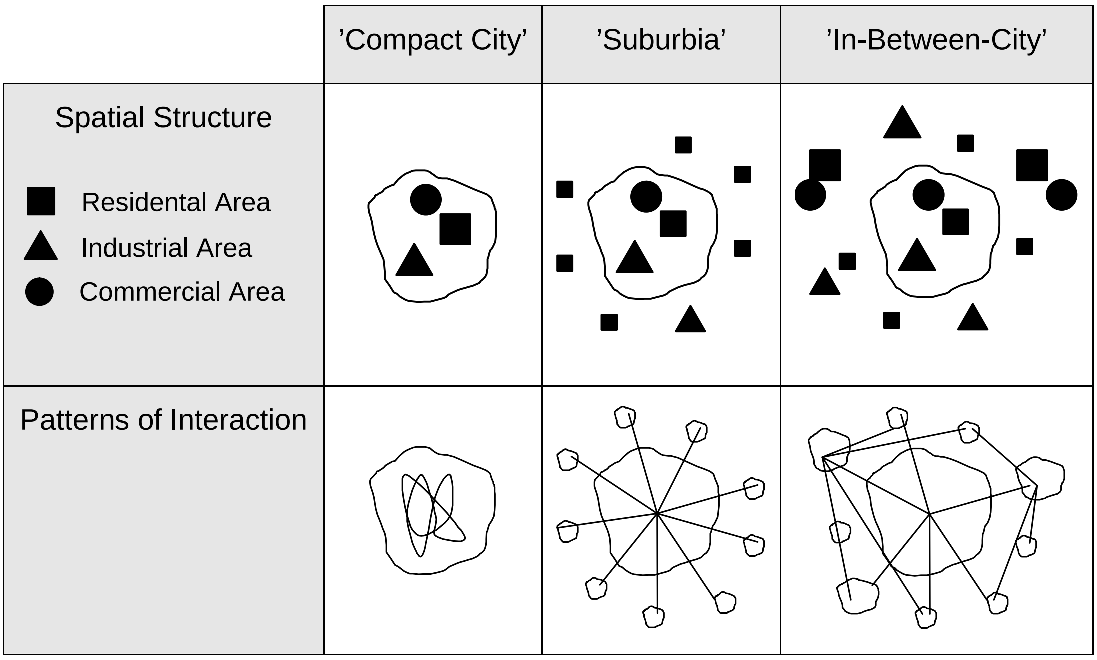

Figure 2 Development of spatial structures and patterns of interaction
(Source: based on Hesse and Schmitz, 1998)

As a logical consequence of these spatial transformation processes travel patterns also have changed. The vast majority of traffic volume is still geared to the city centres, but it is obvious that tangential orientated traffic rapidly gains in importance.

Thus, future analyses of local accessibility need to be calculated on a disaggregated level as well as they have to take into account different trip purposes. A suitable and alternative proposal is to use a travel time budget indicator, which is very easy to understand and to communicate to others. The travel time budget indicator is a cumulative-opportunity index that answers the question: *How many opportunities of type X can be reached by public transport within Y minutes*?

It goes without saying that the accessibility indicator travel time to only one destination is less informative than a travel time budget indicator considering a large number of destinations and different trip purposes. Calculations can be done with geographic information systems (GIS).

4 Using a Geographic Information System

A GIS application based on ArcInfo 9 was developed to measure local accessibility by public transport using the travel time budget indicator. Figure 3 gives an overview of the application flow. The application integrates a graphical user interface including

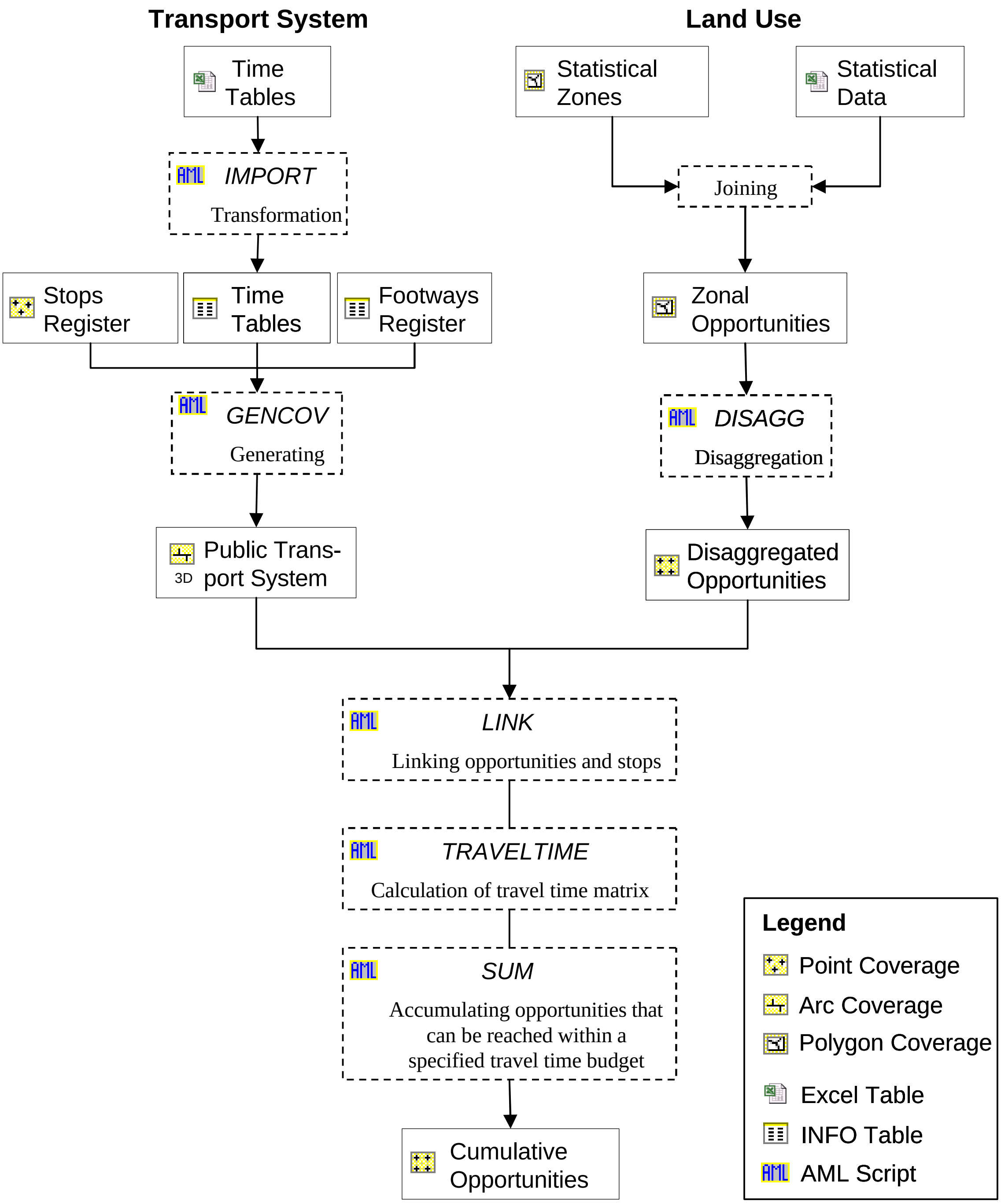

Figure 3 GIS application flow

dialog windows for a user-friendly handling, even for non-GIS experts.

Table 2 shows the input data that are needed to run the accessibility analysis. Programmed import tools allow to load the input data into the GIS database.

Table 2: Input Data

	Transport Information	Land-Use Information
Obligatory	- Time tables (INFO table, dbf, xls, txt) - Coordinates of stops (coverage, shape file)	- Statistical data, e.g. population, work places, schools etc. (coverage, shape file)
Optional	- Interchanging footways (coverage, shape file) - Road network (coverage, shape file)	- Land use (coverage, shape file) - Covered areas (coverage, shape file)

Before the local accessibility analysis can be started the transport system and land-use data have to be prepared.

From the public transport stops coordinates and the official time-table data a three-dimensional GIS vector data model representing the public transport system in space and time is automatically generated, where time is represented by the third dimension (see Figure 4). Thus, real interchanging times are taken into consideration when calculating travel times. The three-dimensional data model is the basis for the calculation of a travel time matrix using the pathfinding algorithm of Dijkstra involved in ArcInfo. Interchanging footways between two nearby stops can be optionally added.

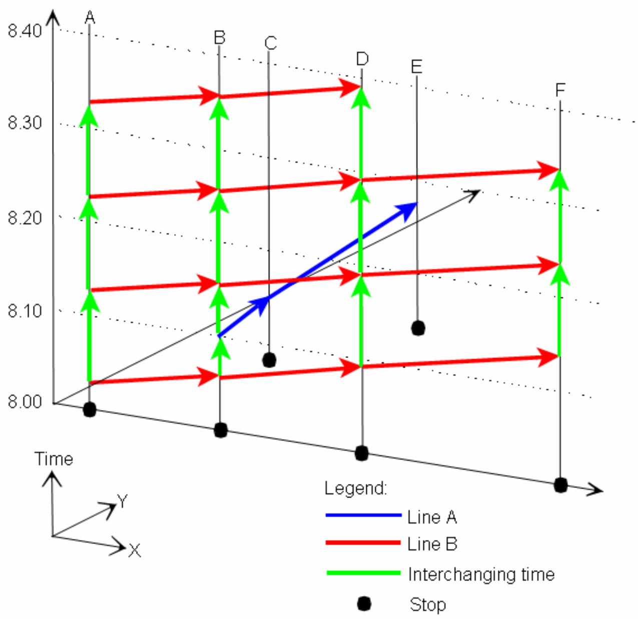

Figure 4 Three-dimensional GIS vector data model of public transport system

Measuring local accessibility by public transport requires very disaggregated data of the locations of activities. Ideally all statistical data are available with adress coordinates. More realistically seen, statistical data are provided for zones representing municipalities, urban districts, block groups or single building blocks. A way of disaggregating the data is to decrease the area of zones and to increase the number of zones, repectively.

However, the area of zones can easily be clipped with GIS intersection functionalities using optional land cover data. As statistical data such as opportunities normally are located in built-up areas, open space can be erased from the area of the statistical zones to allocate the statistical data on the remained area. Figure 5 demonstrates this principle.

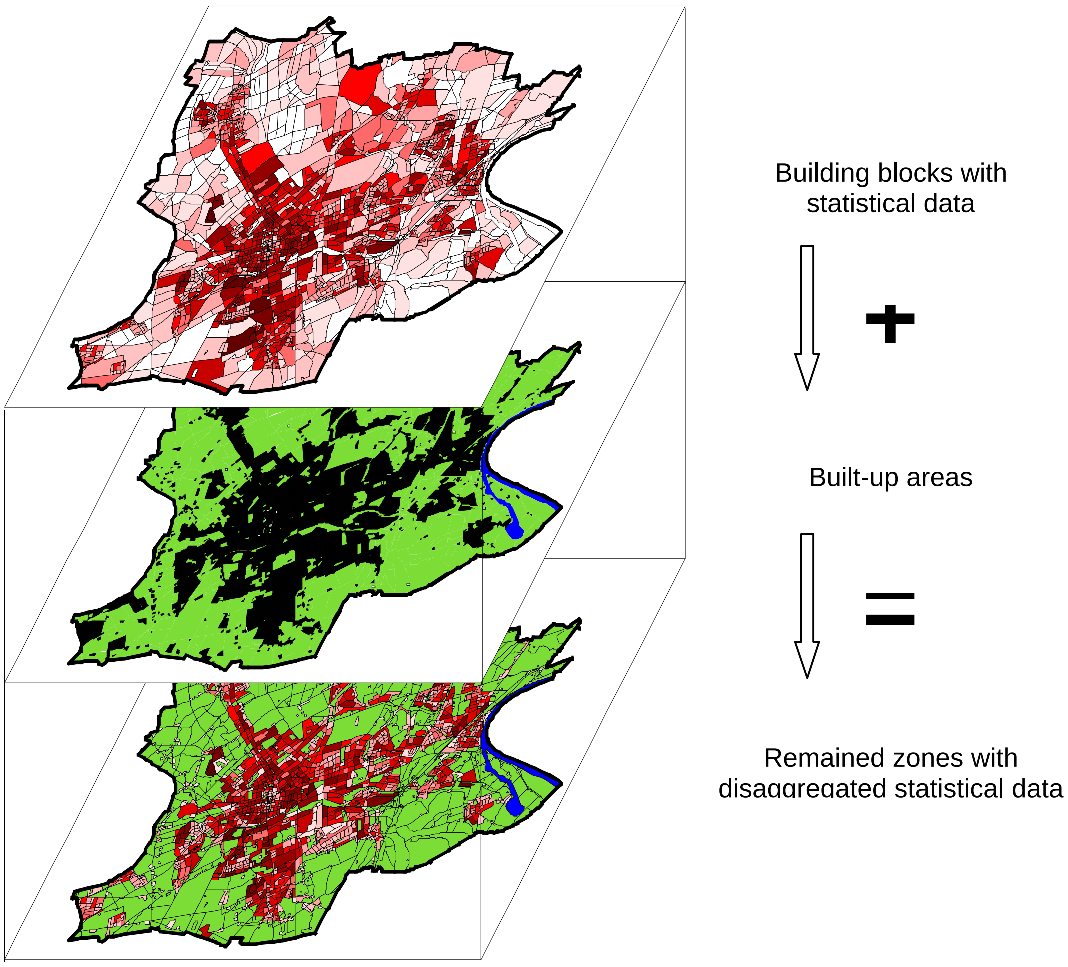

Figure 5 Simple disaggregation method using GIS intersection functionalities

Another more comprehensive way to calculate spatially disaggregated accessibility indicators is to allocate the statistical data from zones to much smaller uniform raster cells or pixels using probabilistically optional land-use information. Such a method was developed, for instance, by Spiekermann and Wegener (1999; 2000; Spiekermann, 2003).

Journeys may include an initial walk to a public transport stop, several interchanges, and a final walk to the destination where an activity will be realised. Before starting the accessibility analysis several parameters have to be determined such as estimated walking speed, and estimated waiting times at initial public transport stops specified as an interval function of departure frequencies. In addition the travel time budget has to be defined as well as the service period for which the analysis shall be applied.

5 Results for the City of Krefeld

The developed GIS-based method for measuring local accessibility by public transport using a travel time budget indicator was applied to real projects. Study area was the city of Krefeld where planned measures and projects as well as changes of accessibility in time were analysed. In the following some results are pointed out.

The city of Krefeld is an important administrative centre in North Rhine-Westphalia, Germany, with a population of 240,000. It is located southwest of the Ruhr area and north of the cities of Düsseldorf and Cologne, situated at the river Rhine. As it is shown in Figure 6 its public transport system is quite well developed.

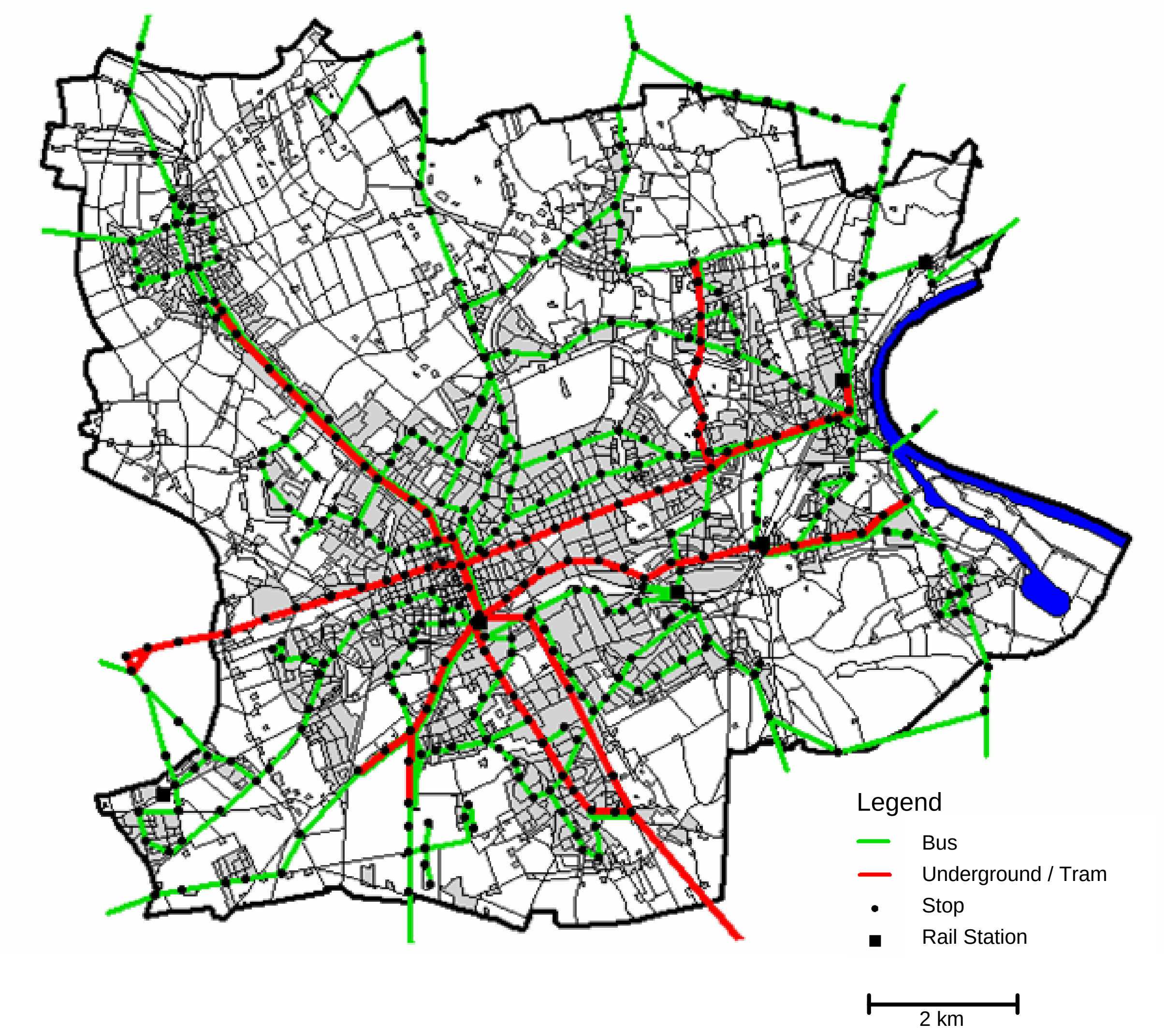

Figure 6 Public transport system in the case study city Krefeld, Germany

Accessibility analyses were done for the four main trip purposes ‘going to work’, ‘going to school’, ‘shopping’, and ‘visiting friends’, which were chosen on the basis of the traffic volume. The travel time budget was fixed to 30 minutes. Figure 7 shows a typical result of the analyses: the current local accessibility of work places by public transport in the case study city Krefeld for the peak period. In the map the absolute number of working places that can be reached by public transport within 30 minutes is displayed in equal intervals.

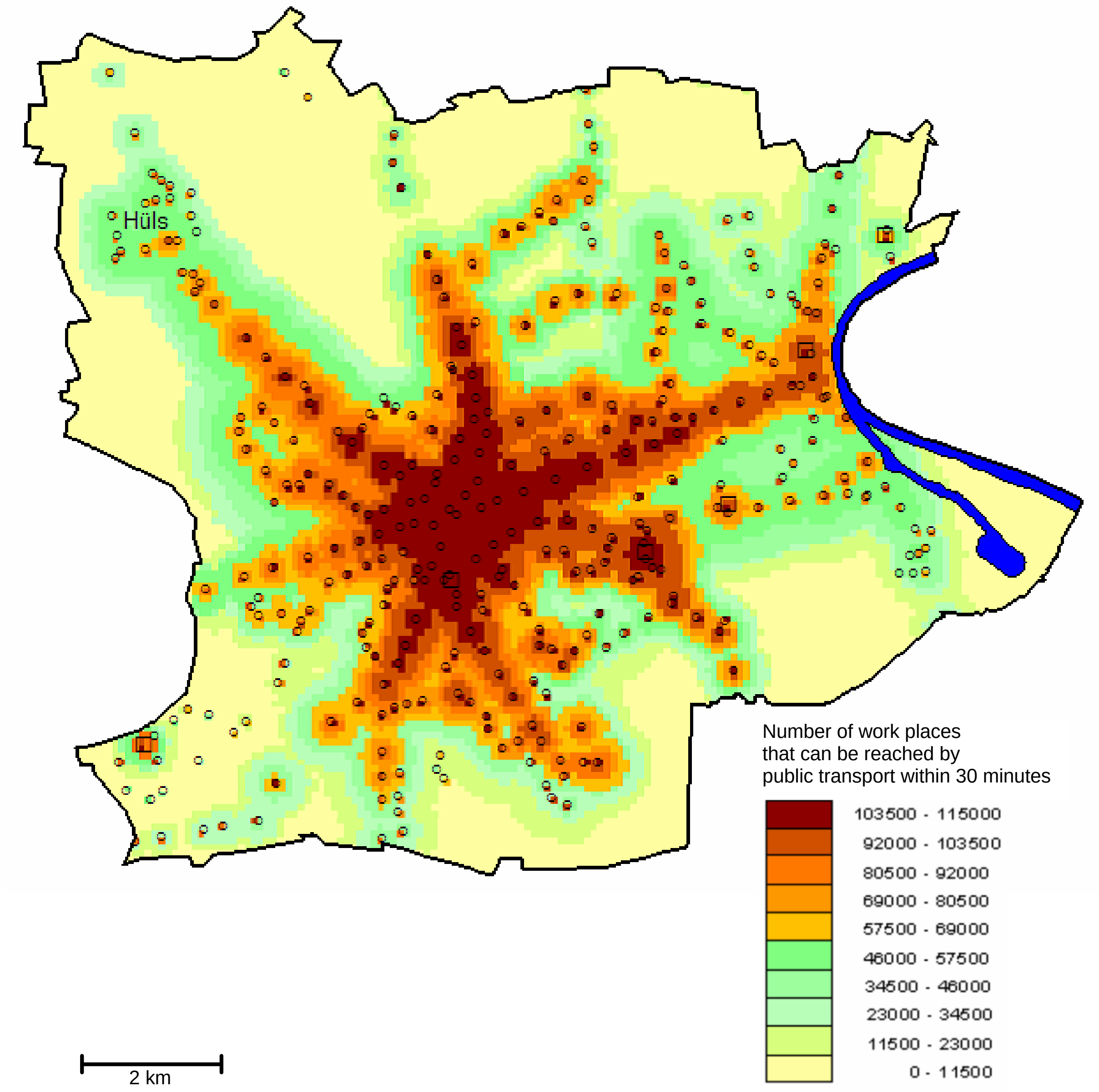

Figure 7 Accessibility of work places by public transport in Krefeld, Germany

It is clearly discernible that the city centre has the best accessibility of work places, but also a couple of south-eastern urban districts are characterised by a high accessibility, which can be explained by a well-developed underground line connecting these districts to the metropolitan centre of North Rhine-Westphalia’s capital Düsseldorf.

Another advantage of the accessibility analysis using a travel time budget indicator is that accessibility of different trip purposes is distinguished. Locations having a good accessibility of work places have not necessarily, for instance, a good accessibility of shopping facilities as well. Figure 8 illustrates how accessibilities vary in the case study city Krefeld.

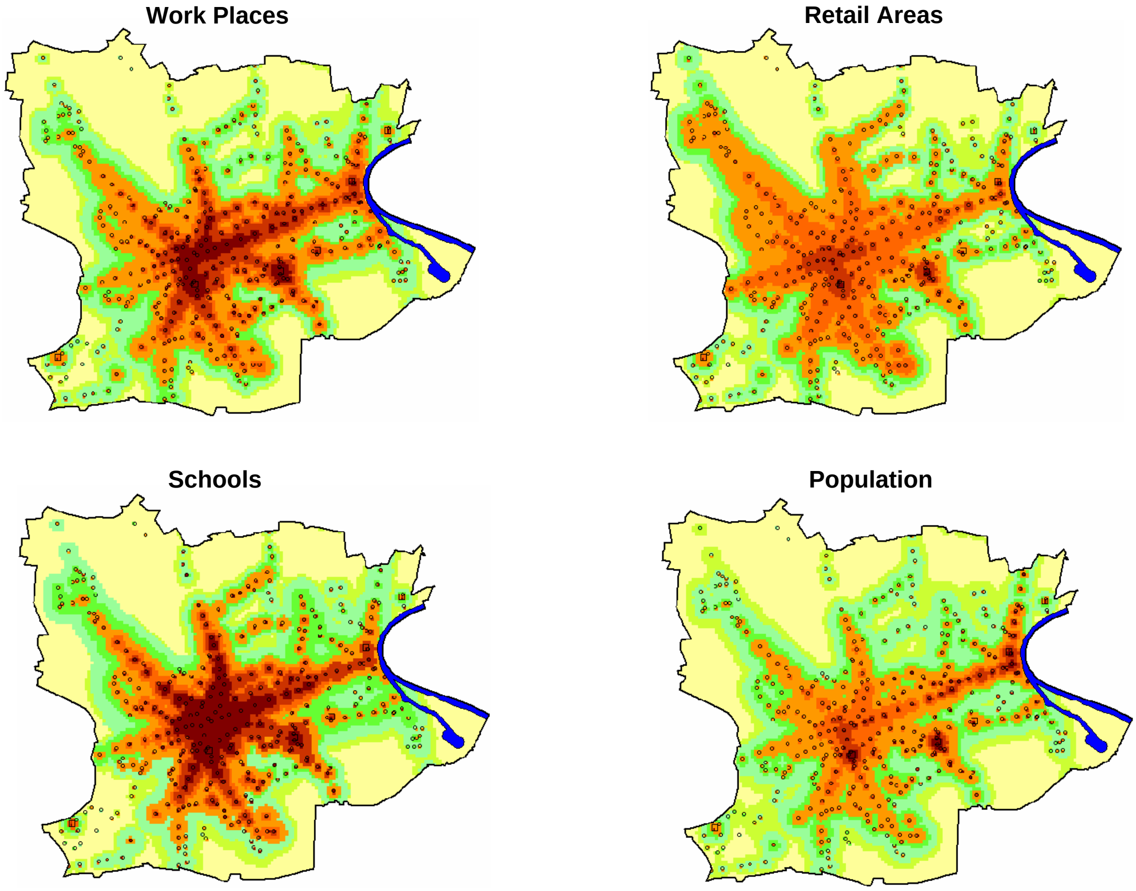

Figure 8 Varying accessibility of different travel purposes in Krefeld, Germany

The full potential of this developed approach can be achieved if it is used for analysing and comparing the probable effects on accessibility of planned projects or different scenarios. For the case study city Krefeld several planned projects were assessed and compared by this method against each other and with the present state. On the base of the travel time budget indicator absolute and relative changes of accessibility by public transport were calculated and visualised.

The Fischeln-Project comprises an adjustment of the public transport system in the context of enlarging a residential area in the south of Krefeld. In Figure 9 the effects on accessibility of work places by public transport are shown in comparison with the do-nothing scenario. It can be clearly seen which areas would benefit and which areas would loose as a consequence of the planned changes of public transport supplies. The decrease of accessibility in some areas is mainly caused by the installation of new public transport stops which probably implicate longer travel times.

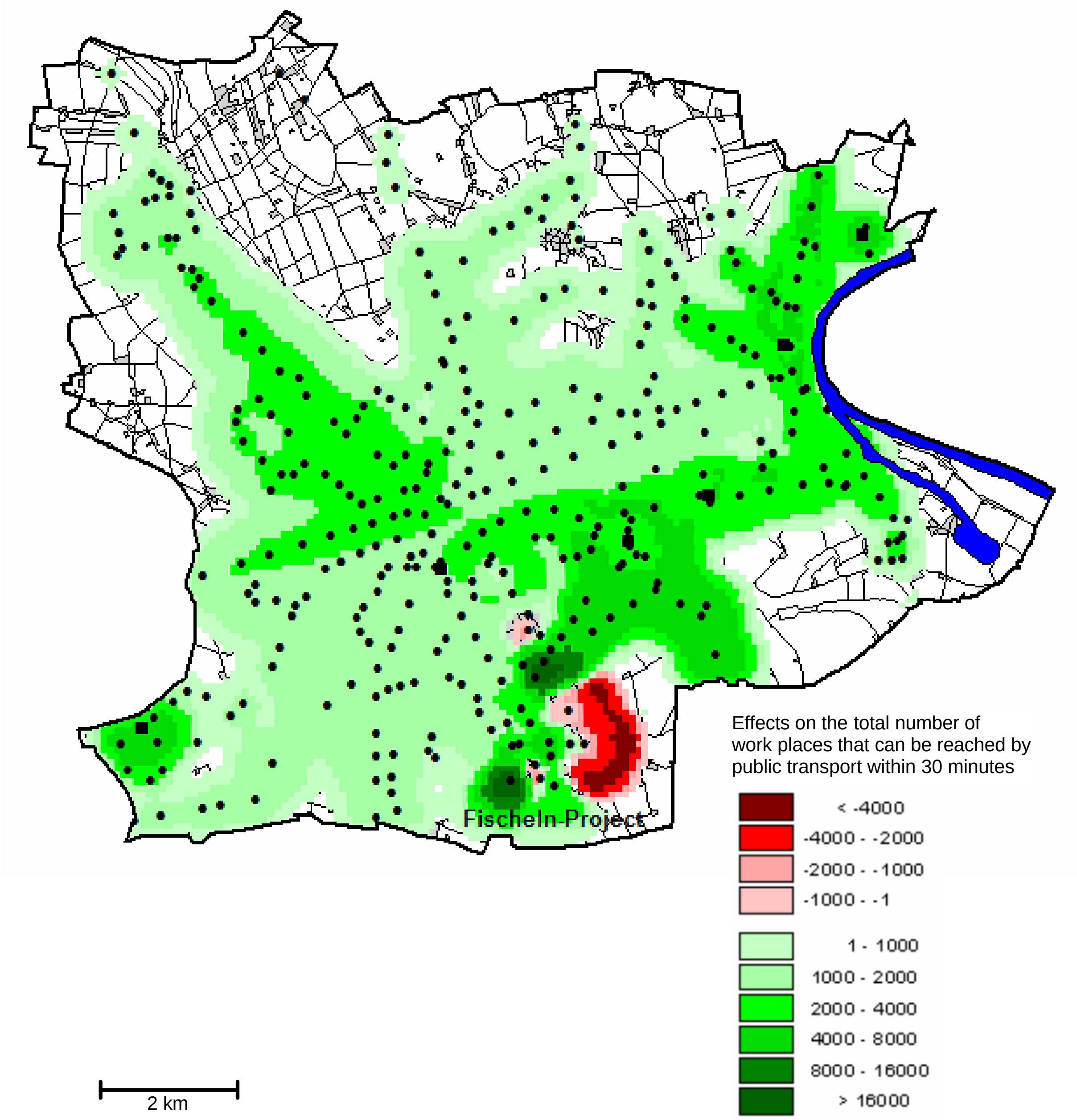

Figure 9 Effects on accessibility of work places by public transport in Krefeld, Germany

Altogether the Fischeln-project were rated positive because the average accessibility by public transport in the case study Krefeld will increase higher than in other planned projects that were analysed.

6 Conclusions

The aim of the work was the enhancement of accessibility indicators to be used in public transport plans. In traditional public transport plans planners mainly examine the transport system itself and its own quality of development and connectivity. This paper presented a proposal to use a travel time budget indicator for analysing local accessibility by public transport. By using the developed GIS application the method was exemplarily demonstrated for a planned project in the case study city Krefeld.

As shown, the method allows to model the accessibility of activities in a comfortable way. It can reveal how many opportunities are reachable by public transport within a given travel time budget. Therefore, the complex interdependence between land-use changes and public transport supply is taken into account. The results of this integrated accessibility analysis can be represented with tables and maps in an easy-to-understand way.

Even small and cost-efficient measures such as timetable changes can be investegated by this approach. Another advantage is its ability to demonstrate that local measures often cause region-wide effects.

The investigated planned projects were analysed and compared in the context of changes of accessibility by public transport. A further enhancement of the assessment may include the additional consideration of individual transport modes. Multimodal accessibility indices and measures such as the ratio between accessibility by public transport and accessibility by car can provide new valuable information.

In this project a cumulative-opportunity index was used to get traceable results that can be easily communicated to others. However, potential accessibility indicators model travel behaviour more realisticly. The next step to improve local accessibility analysis could be to find out how potential accessibility indicators can be used regarding the specific demands of transport planning in terms of communication processes and transparency.

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