IMPROVING ACCESSIBILITY MEASUREMENT COMBINING TRANSPORT MODELLING AND GIS ANALYIS: TWO EXAMPLES FROM FRANCE AND GERMANY

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ABSTRACT

Dealing with two case studies, the first in the German RheinMain region and the second in the Lyon Metropolitan area, two methodologies are presented to measure accessibility. Both approaches combine classical transport modelling techniques with GIS based data and network analysis. With a focus on supporting local and regional decision makers, different indicators are used in order to derive and pre-evaluate planning measures as well as to demonstrate location qualities depending on the quality of transport supply and traffic flow.

Keywords: accessibility, geographic information system, transport model

INTRODUCTION

A general and simple definition presents accessibility as the ease with which activities may be reached from specific locations and using a particular transportation system (Morris and al., 1978). In the literature many specific definitions of accessibility have been developed according to different points of view (see Geurs and Wee, 2004 for a detailed review), focusing for instance on transport infrastructures and on a supply point of view or emphasizing individual perception of accessibility (Ben Akiva and Lerman, 1979; Miller, 1999; Dong and al., 2006; Small and Rosen, 1981; Kwan, 1998). In spite of the various specifications of this concept and its different perceptions, accessibility measures often relate to land-use and transportation components under temporal and individual schedule constraints. In this context, accessibility is widely used in many research fields to understand transport and land-use interactions and to foreshadow travel behavior. More than ambiguous and complex definitions, one of the important current problems regarding accessibility refer to its measurement, operability, and political transferability. While conceptual and methodological frameworks have evolved for thirty years, accessibility measures can still be improved to reflect transport and urban policy impacts on individual choices more precisely. As stated by Litman (2008), current transportation evaluation methods often fail to incorporate factors like “door-to-door” measures, comfort and convenience or actual network conditions. Accessibility indices should not stay a concept only measuring a “theoretical” mobility level, but it has to account for the influence of space, time, and cost regarding the potential of individual activity participation. In a general comment, Gutiérrez and al. (2010) highlight accessibility as an overall indicator related to mobility, economic development, social welfare and environmental impacts.

By means of accessibility it is therefore possible to analyze the potential spatial interaction. The paradigm shift in transportation planning, observed by Litman (2008) from a mobility-oriented analysis to an accessibility-based analysis can be explained by the need of a more efficient and operational tool to perform transport policy assessment. While time component often has been considered as a central element of cost-benefit analysis, it needs to be coupled to a land-use component. As underlined by Straatemeier (2008), this is not the transport system itself that is important but the fact that the transport system provides access to spatially and temporally dispersed opportunities. The contribution of accessibility for public decision-makers is all the more important since this indicator can focus both on the whole population and on specific groups, for instance according to income, gender, age, specific transport means, or rural/urban inhabitants. Accessibility is such a flexible indicator that can be used for an individual group either at urban or regional scale considering a more or less detailed spatial division according to the study objectives and transport/urban policies analyzed.

Referring to these challenges, the paper explores two different methodologies combining classical transport modeling techniques with GIS based data and network analysis to improve accessibility measurement. Two case studies are analyzed, the first in the German RheinMain region and the second in the French Lyon Metropolitan area. Though both approaches refer to different scales and different (urban and political) context, they present common issues and objectives. Interactions between land-use and transportation systems represent an increasing interest regarding congestion and pollution problems. In order to take into account lasting development constraints, transport networks need to be reviewed with regard to both the need for a “green” mobility, limiting congestion and urban sprawl, and land-use patterns that prevent from wasteful commuting. Both the French and the German case study deal with accessibility as an important evaluation criterion considering land use pattern and transport system performance in a sustainable development view.

The paper is divided into three sections. As a first step, the two case studies mentioned above are described separately with their specific interest and objectives. The second section discusses in detail the underlying methodological framework combining GIS and transport modeling techniques as well as individual specifications of each study regarding chosen indicators and methods. Finally, access-results are analyzed with selected cartographic representations and specific as well as common conclusions are drawn in relation to the objectives stated.

CASE STUDY PRESENTATIONS

The choice of a geographical area and of a spatial division is particularly important for the implementation of accessibility indices and their analysis in a transport-land use perspective. Kwan and Weber (2008) highlight that scale and zoning effects can be observed. The scale effect refers to the variation of results obtained from the same statistical analysis at different levels of spatial resolution. The zoning effect refers to different results arising from the regrouping of zones at a given scale.

The German case study: Region Frankfurt RheinMain

The German case study on accessibility has been performed in the context of a German-French cooperation project called Bahn.Ville 2, which realizes railway based urban development in two exemplarily chosen corridors by improving transport supply of the railway ("Bahn"), the orientation of the urban structure towards the transport corridor ("Ville"), and finally the intermodal integration of different modes as well as location development at the stations (".") (for further general information on a former phase of this project, see Wulfhorst and al., 2002; Bahn.Ville Konsortium, 2005). This paper is based on the analysis in the regional railway corridor 'Taunusbahn', located within the catchment area of the agglomeration Frankfurt/Main, Germany, with 2.2 million inhabitants in total. Around 70,000 people live in the municipalities around the corridor with an increasing trend and accordingly high dynamics on the housing market, whereas the overall population of the region Frankfurt RheinMain is currently shrinking. In the Taunusbahn corridor from Bad Homburg v.d.H. to Brandoberndorf, high occupational mobility to the regional centre Frankfurt due to relatively low job availability in the corridor can be observed. Figure 1 gives a first overview of the geographic situation in the case study area.

The transport axis in question is of regional importance with a strong orientation towards the high-level centre Frankfurt/Main on weekdays. At the weekends, the corridor offers access to the highly attractive recreation area 'Taunus' with traffic flows in the opposite direction. Furthermore, there are relevant relationships between the municipalities along the railway line. The rail link mostly operates parallely to a country road that is highly affected from congestion during peak hours, which leads to an advantageous competitive situation of public transport.

In order to support rail based urban development along the Taunusbahn axis (coordination of processes, conception of planning measures, location marketing), detailed knowledge about locations, utilizations, and the quality of transport connections is necessary. The basic objective is to develop an accessibility measurement tool that is easily understandable, applicable and transferable to local and regional practitioners as well as decision makers. It should be able to identify accessibility deficits along the railway corridor on different scales, assess possible options of urban and transport measures, and help improving the sustainability of short-term and long-term mobility decisions. The tool is applied on different levels:

- An important issue of accessibility planning in this context is neighbourhood mobility, since a very high share of railway customers is approaching or leaving the station by foot or by bike. Origins and destinations nearby should be preferred and reached quickly, comfortably and safely. However, planning concepts usually neither consider non-motorized transport appropriately nor do they refer to existing local knowledge or involve citizens.

- An application that to some extent contradicts the necessity of fostering neighbourhood mobility is the improvement of area-wide accessibility of railway stations. A high interchange quality to public and motorized individual transport competes with attractive re-densified utilizations in the direct railway station surroundings, provoking considerable land use conflicts. Therefore different types of stations according to current and future functions and to accessibility potentials are identified in order to weigh up between both legitimate station development alternatives.

- Commuting data shows that some municipalities along the railway corridor in question are not only the origin of trips to the metropolitan core area of Frankfurt/Main, but still offer a remarkable amount of workplaces despite of an overall low job availability. The accessibility analysis contributes to finding suitable companies for the implementation of mobility management strategies and to identifying locations for future business sites development with appropriate public transport catchment areas of possible employees.

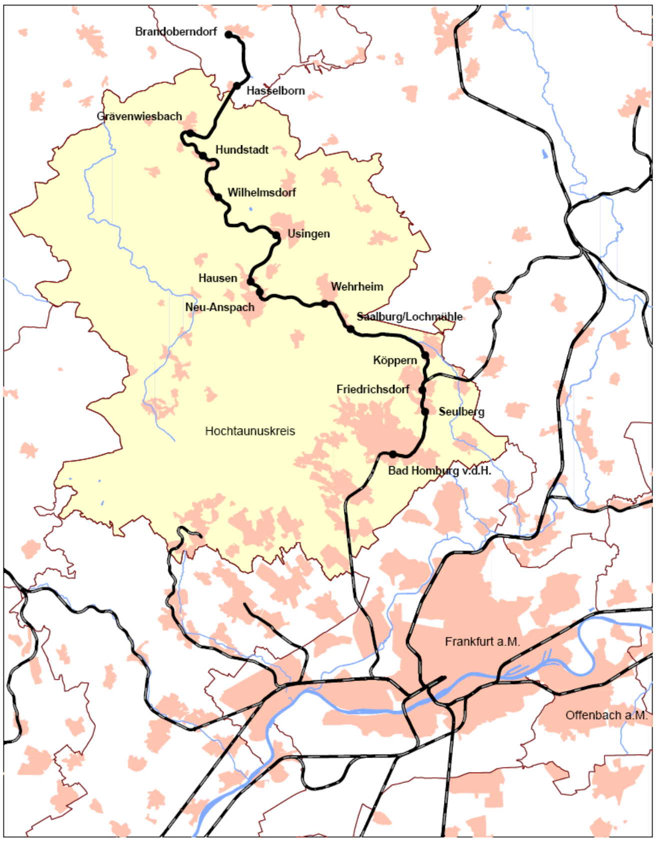


Figure 1 – Study area in the Frankfurt RheinMain area and rail infrastructure

The French case study: the Lyon Metropolitan area

Considering land–use methodological principles the French case study was conducted in the Lyon Metropolitan area depicted in Figure 2**Erreur ! Source du renvoi introuvable.**. The second largest Metropolitan area in France (behind Paris) covers more than 3,356 km² and contains 296 "communes" (the smallest administrative subdivision in France). A briefly division is as follows: the "communes" of Lyon and Villeurbanne form the center of the area comprising the Central Business District. In the Lyon and Villeurbane surroundings, the study area covers further suburban "communes". The overall metropolitan area has a population of 1.7 million people (INSEE RGP, 1999), and a population density of 508 inhabitants per km². Population growth is important (0.8% per year) and higher than in any other French Metropolitan region (Paris, Marseille, Lille). Population tends to be concentrated in the central zones (Lyon and Villeurbanne) and their outlying "communes" with densities higher than 900 inhabitants per km². The Lyon Metropolitan Area offers more than 800,000 jobs (in 1999) for 765,000 workers living in the area. In Lyon as well as in most European cities, the spatial pattern of population and jobs is almost similar: employment density is the highest in the city centre, with more than 10,000 jobs per km² in some CBD divisions.

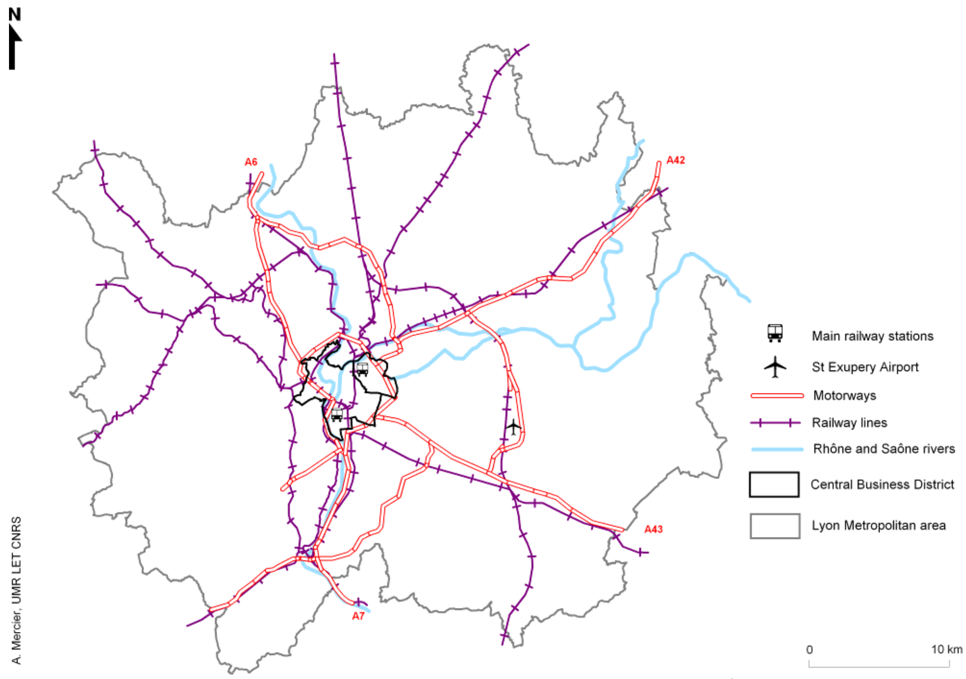


Figure 2 – Lyon metropolitan area, with main transport infrastructures

The Lyon Metropolitan Area is the connecting point of various transport networks linking the North with the South of France. The four main motorways connect Chambery and Grenoble (A43), Genève (A42), Saint-Etienne and Marseille (A7) and Paris (A6) from Lyon. A ring road has been implemented to bypass the CBD. The regional rail network (public interurban network) is well developed (for 10 years, various measures have been taken in order to modernize local trains and improve rail connection) as well as the urban public transport network, which is the densest in France. It consists of 7 subway lines, 4 tram lines, and 135 bus lines and is constantly extended with new tram and bus lines to improve the service to CBD's outlying areas.

The French case study has been developed within the MOSART project framework described in detail in another joined paper presented in the WCTR 2010 (Mercier and al., 2010) Three main objectives have to be achieved.

- A long-term objective (not achieved in this paper) is to analyze urban and transport policy impacts on residential location choices. Given that job location is one of the household's residential location choice factors (Cho and al., 2008), policy impacts on commuting have to be integrated. Increases in job mobility, the prevalence of two-worker households, and the decentralization of urban areas suggest that accessibility to potential employment or activity centres may be a dominant determinant in explaining location choices.

- To apply existing accessibility indices and to be in accordance with reality, specific factors affecting urban accessibility have to be integrated in the computations. Travel time doesn't come down to "in-vehicle time" but also reflects the quality of connection between different public modes (waiting time at stops) and stop locations (travel time between stops and final destination). "In-vehicle" car time depends both on road section characteristics (number of lanes) and private transport demand resulting in daily congestion. This demand is not fixed but varies according to the costs of different transport alternatives or periods of day (peak versus off-peak hour).

- Transport policy impacts have to be analyzed at a very detailed spatial level to fit both to planners' and policy makers' interest (Holl, 2007). Without computing access for every point of the study area, the objective of a detailed spatial approach is achieved by implementing a micro-level based analysis. Accessibility is affected by the spatial partition in units of analysis. Distances and travel time computations strongly depend on zone centroid locations. The more the metropolitan area is divided in detail, the more precise access results can be expected. However, the units of the analysis need to be reasonable and their size can vary according to the density of opportunities: while in CBD spatial partition has to be very detailed, an increasing size of the analysis units to the urban and suburban outskirts usually is more appropriate.

METHODOLOGY

Although the German and the French case studies use different types of accessibility indicators, they have a common methodological basis combining the flexibility of Geographic Information Systems (GIS) regarding spatial analysis with the powerful possibilities of classical transport modeling techniques like calculation of transport demand and analysis of travel times (capacity restrained in motorized individual transport and timetable based in public transport). Both approaches don't analyze accessibility from the viewpoint of individual schedules but rather from a viewpoint of a land-planner, accordingly they use the following elements within their accessibility model:

- A regional intermodal transport demand model that supplies timetables for public transport and therefore allows respective travel time computations. Furthermore, congested travel times for public transport as well as transport zones with underlying spatial attribute data are provided. Whereas for the Lyon Metropolitan Area a classical 4 step demand model has been developed specifically for the analysis presented in this paper, a similar model was provided from the regional administration of the Frankfurt RheinMain region.

- A disaggregation model that transforms spatial socioeconomic data from zonal level either to a raster grid (French approach) or to vector geometries on detailed building block level (German approach).
- A GIS based transport network model in order to perform best route algorithms in different transport modes.
- A GIS based accessibility measurement model that uses centroids of a raster grid as basis for the travel time / general cost analysis. Due to different indicators applied in both studies, the Lyon model uses different raster layers and underlying resistance matrices in order to compute the respective accessibility formula for each raster cell, whereas the German model mostly uses GIS based network analysis techniques in combination with spatial intersections of vector data.

In the following subsections, the different methodological specifications of each approach with respect to the diverging objectives shown abough are described in detail.

German case study specificities

Within the project Bahn.Ville 2, an easily handable accessibility measurement tool has been developed, which surveys the implementation of transport and land use measures to increase public transport mode share in the regional railway corridor of the Taunusbahn. According to the classification of Van Wee and al. (2001), the tool uses a cumulative opportunity measure in the category of activity based accessibility indicators as follows (Vickerman, 1974):

$$A_i = \sum_{j=1}^{n} E_j f(c_{ij})$$

where E_j are opportunities in zone j and $f(c_{ij})$ a binary value equals to 1 if zone j is within the predetermined threshold and 0 otherwise and n reflects the number of zones.
This isochrone based approach shows the number/proportion of destinations accessible within a specified resistance budget (Handy / Niemaier, 1997, Vandenbulcke and al, 2009). This indicator can easily be interpreted and therefore is appropriate for a transfer to local and regional planning practice.

Data sources

- Structural data for the whole Frankfurt RheinMain region is provided by the 940 vector based transport zones of the regional transport model. In the research area, the corridor along the Taunusbahn, that level of detail gives around one zone per municipality in areas with rural structure and up to 10 zones per municipality in centrally located places. The underlying data contains number of inhabitants, number of kindergarten / nursery / school places, number of jobs, and size of shopping area regarding basic and high-level demand.

- GIS land use vector data for the whole region Frankfurt RheinMain contains information on land utilization (residential, commercial, mixed usage) as well as building topology (closed versus open coverage type). With around 13,000 zones, a spatial accuracy comparable to building block level is achieved.

- Regarding the different modes of transport considered in the study, the transport model provides the location of railway stations and other public transport stops, furthermore the respective networks for public transport with timetables and motorized individual transport with congested travel times. Due to its regional purpose the model is less accurate as the GIS model explained below and is therefore only used for computations in the motorized transport means.

- Additionally to the transport model, the official German cartographic products also provide a very detailed network model that contains around 200,000 links for the Frankfurt RheinMain area. As a consequence, this network is very appropriate to analyze neighborhood mobility consisting of the modes walking and cycling.

Data disaggregation

In order to estimate the activity potentials appropriately, a disaggregation approach has been developed, since the spatial resolution of the structural data based on transport zones is not detailed enough, especially for neighborhood mobility assessment. Data on inhabitants and workplaces are distributed from transport zones to the level of GIS land use data, using estimation values (see Table I) derived from FGSV (2007) as weights for different utilizations and building topologies.

Table I – Estimation of structural data based on GIS land use data

Type of utilization	Building type	Number of inhabitants per ha	Number of employees per ha
Residential	Open	70	0
	Closed	150	0
Business		0	50
Mixed	Open	90	80
	Closed	60	300

Accessibility computation

The following sections explain in detail, in what way the accessibility tool developed as an extension of the software ArcGIS 9 performs the accessibility analysis. The method is shown

exemplarily for the combination of the modes walking and public transport. The whole analysis runs automatically after the user has specified the different parameters required, for instance specifications on the analysis area and different trip parameters.
As a first step, depending on the user-defined analysis area and spatial solution, a raster dataset is created. Its centroids serve both as trip origins and as basis for the accessibility measurement. From one centroid, the tool identifies various public transport stops within a certain search radius, identifies the closest network element and performs best route algorithms to the selected stops with an assumed walking speed of 4 km/h. With the remaining resistance budget, a query to a timetable based public transport matrix is triggered that gives back all accessible stops for the specified peak or off-peak hour together with the remaining budget. In case of errors during the matrix query, the ArcGIS extension can automatically access VISUM via its .com-interface and recreate the data for specific departure and arrival times. The remaining budget is used to draw either buffers or network based isochrones around each destination stop in order to consider the walking times to the final activity opportunity. These isochrones are unified and intersected with the layer containing the spatial attribute data that is proportionally counted and cumulated for each accessed land use zone. This procedure is repeated for all centroids within the analysis area.
Exactly the same methodology is applied for the combination of the modes motorized individual transport and public transport (P+R trips). In case of trips that are not composed of different modes, i.e. walking, cycling or motorized individual transport only, the respective network has to be chosen and the analysis is reduced to identifying the closest network element and assessing the final isochrones around this trip origin.

Density assessment

From the disaggregation model, density information of the raster centroids that serve as trip origins is available. That allows weighing the accessibility potential at a given location (i.e. access to workplaces) up with the respective target group density (i.e. population or employees). For this assessment, an indicator similar to LUPTAI index (Pitot and al, 2005) has been developed. It is derived from a matrix shown in Figure 3 with classified values on both axes.

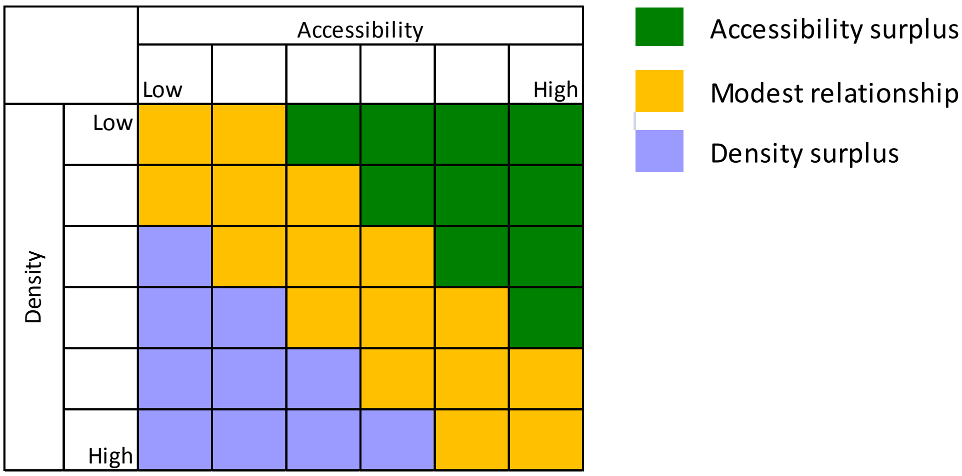


Figure 3 – Relationship between local density and accessibility (based on Pitot and al., 2005)

The outcome is directly used to develop recommendations for planning measures, since a mismatch between level of accessibility and density generally can be seen as a structural urban deficit. In case a location provides a high land use potential due to a high public transport accessibility but is linked to a low density level (accessibility surplus), modest redensification measures should be considered. Correspondingly, low public transport accessibility compared to high urban densities (density surplus) is a good opportunity to widen public transport supply or to invest in accompanying infrastructure improvements.

French case study specificities

The choice of an access-based measure depends on the case study's objectives. Location-based measures reflect urban planning objectives including inhabitants and activity distributions in relation with transport infrastructure networks. Moreover they present a relative ease of calculation, mainly when associating to a Geographical Information System. Among different location-based measures, a gravity indicator is used with the following expression:

$$A_i = \sum_{j=1}^{n} E_j \exp^{(-\beta C_{ij})}$$

where E_j represents opportunities in zone j, C_{ij} denotes the travel cost (or generalized cost) between zones i and j (C_{ij} is the algebraic sum of monetary costs and travel time cost) β represents cost sensitivity parameter and n the number of zones.
Gravity indices, introduced by Hansen in 1959, present a measure of the intensity of the possibility of interaction. They measure the number of opportunities at a location j discounted by a measure of impedance. Gravity-based accessibility is defined by Hansen "as the potential of opportunities for interaction" and not only a "measure of the intensity of the possibility of interaction". In his definition, Hansen also underlines "the ability and the desire of people and firms to overcome spatial separation". Gravity-based indicators highlight the relation between opportunities available to consumers, considered as the trip's "push" factor and the travel cost (or generalized cost) seen as the trips "pull" factor (Wilson, 1970). A transport network is seen as a vector of opportunities. Several difficulties and limitations are identified when gravity indicators are calculated (Pirie, 1979; Geurs and Ritsema Van Eck, 2001). Among them, sensitivity to zone size and spatial disaggregation are mentioned. Considering a large spatial division, self-potential can distort the total accessibility (Gutiérrez and al., 2010). Internal opportunity's weight would be overestimated regarding total number of opportunities. Frost and Spence in 1995 propose a more detailed spatial disaggregation to limit internal zones' impacts on opportunities. Furthermore, travel times are sensitive to levels of road congestion and route choice. Comfort and perceived travel time impacts can also be decisive. A GIS-T and transport model combination should solve these problems.

Spatial data

The Lyon metropolitan area has been divided into 4,344 zones in the form of a raster grid with respective centroids. Zone size varies according to location within the Lyon Metropolitan

area owing to technical and license limits (number of zones should be inferior to 5,000 to use VISUM software) and easy reading. The Central Business District is divided into 1,272 squares of 250 meters edges. Suburbs are divided into 2,291 squares of 500 meters diameter and the suburban model area is divided into 781 squares of 2 kilometers each.
The number of jobs was estimated using the French national statistics for 2006 at the district level. Job-data was disaggregated to zone level considering the number of zones per district and an equal job distribution over all zones within a district.

Transport networks

The GIS-T is composed of three different transport networks:

- The road network was generated from digital maps and databases by NAVTEQ. Each road section is characterised by length, capacity, speed without traffic load and driving direction or one-way streets. In a first step, before integrating a four-step model, different speed levels have been considered according to these characteristics.

- The urban public transport network is composed of 4 subway-lines, 4 tram-lines, 2 trolley-bus lines, 2 funicular lines and 133 bus lines. More than 2,300 stops have been generated. The bus network has been created using existing road links while subway and tram lines have been created by a screen digitalization of a network map. Public transport timetables have been integrated according to frequencies and different periods of the day: peak-hour periods from 6 to 9 AM and from 4 to 7PM off-peak hour periods from 9 to 12 AM and from 7 to 10 PM. Note that both car and public transport networks are composed of 222,000 links and 90,000 nodes.

- The interurban public transport network is a regional rail network with 10 railway lines. For each line, timetables have been integrated considering a typical weekday schedule.

Travel time computations

Travel times have been computed using the VISUM software. Being more than an “in-vehicle time”, travel time by car is composed by an access-time to the road network and a “final-time” to reach the destination (parking search time is not yet integrated in our computations):
“In-vehicle time” refers to travel time between each 4,344 origin and destination centroids. Travel time is computed using a shortest path algorithm. It includes congestion charges determined by a 4-step model. The access-time refers to a distance “as the crow flies” between each centroid and the closest road network node. The time spent by an individual to reach his car is estimated on the basis of a 4 km/hour walking speed. The final time is computed according to the access-time methodology. Travel times by public transport are estimated using a timetable-based assignment procedure associated to a shortest path search. Public transport travel times are more complex to analyze than private ones. They can be divided into several times:

- "In-vehicle time" depends on network structure, frequencies and speeds. These elements are integrated in timetables available for each line. Internal travel times are not computed.

- Access-time or final-time refers respectively to the walking transfer between origin centroid and a public transport station or a public transport station to destination centroid. A distance "as the crow flies" covered at 4 km/hour is considered.

- Origin waiting time is assumed to be equal to zero as if individuals knew public transport timetables exactly and a caution time was not necessary.

- Nevertheless a transfer waiting time is integrated and coupled with a 10 seconds walking time in the transfer station to link two different stops.

While perceived travel time by car is assumed to be equal to the "real" travel time, comfort perception parameters are integrated in travel time by public transport. Following French Transport Ministry recommendations (Commissariat Général du Plan, 2001), travel times by walking (access and final times, walking time in transfers) and waiting times on transfer have been doubled. However no penalties are applied to weight the number of transfers.
Travel time is weighted by a "value of time". This value refers to the amount that a traveller would be willing to pay in order to save time. In economic assessment it is used to give a money value on time spent in transport system. In France value of time for home-based work trips usually is calculated with € 11.4 per hour, independently from the mode of transport.
The lack of data on car speeds for each road section necessitates implementing a four-step model, for which the software VISUM has been applied. In our study, such a model has been developed for determining retroactively congestion charge and real speeds for each section considering socio-economic data and the road network. This model has been implemented not referring to the 4,344 zones division but according to a 749 zones division. The four steps are the following:

1. Trip generation defines productions and attractions for each zone and various trip purposes. Five trip purposes are defined: home-based work trips, home-based non-work trips, work-based (or other-based) home trips, work-based (or other-based) work trips, work-based (or other-based) other trips. The estimation is made with a linear model considering socio-economic data like number of working people, students, and households. The data comes from different French surveys.

2. Trip distribution generates, for each trip purpose, a trip matrix comprising all zonal pairs. This step uses trip generation results and a destination choice model like a gravity model with a combined function (exponential and power):

$$f(U) = aU^{b}e^{cU}$$

   with a, b, and c as parameters and U as transport time by car in the uncongested network. The calibration process has been run considering trip distribution from a French mobility survey.

3. Mode choice produces trip distribution for each mode. Four transport modes have been defined: car (passenger and driver), public transports (urban and non-urban), walking, and two-wheeled transport. Mode choice is estimated using a logit model. Trips made by car represent more than 50% of all trips. The remaining trips are made on public transport (18%), two-wheeled transports (16%), and walking (12%).

4. Route choice distributes traffic on each modal network and section using a Wardrop equilibrium (Wardrop, 1952). Wardrop's principles state that "the journey times in all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route" and "at equilibrium the average journey time is minimum". This equilibrium between various trips has been preferred to a stochastic equilibrium wherein perceived and real costs are equilibrated. Wardrop's equilibrium focuses mainly on supply point of view (network structure and congestion charge) than on demand.

After the first iteration, a feedback mechanism is introduced. As explained by McNally (2008) "with congestion effects explicitly captured at the route choice level, the feedback is to mode and destination choice where congested link travel times are used to determine congested paths for subsequent re-distribution of trips".
Introducing a level of congestion charge for each road section, gravity-based measures of accessibility can be implemented taking into account "real conditions on mobility" and not only theoretical ones.

Monetary cost computations

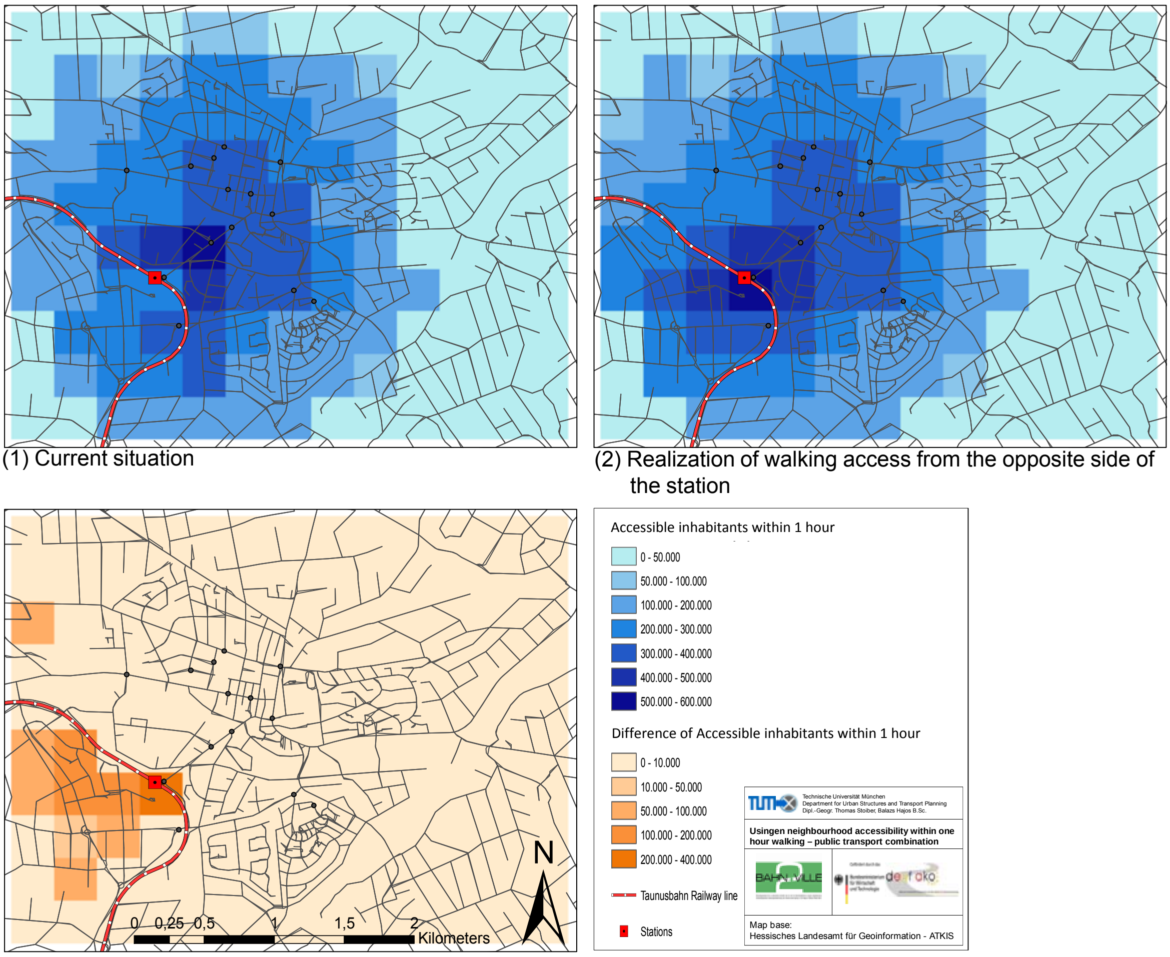
The cost of a car trip is calculated as the sum of fixed (buy and parking costs) and variable costs (fuel and maintenance costs), depending on distance. Public transport cost varies according to the mode used. For urban public transport, monetary cost is computed according to the season-ticket holder share and price as well as single ticket price. It is assumed that each interurban public transport user is season-ticket holder.

RESULTS

German case study results

In the following section, two exemplarily chosen analysis results from the accessibility measurement tool in the RheinMain region, Germany, are shown, the first on the neighbourhood mobility scale, the latter on the regional level considering the whole Taunusbahn corridor.
Figure 4 deals with the accessibility situation around the railway station of Usingen (compare figure 1). The city centre can be accessed via a direct street link to the northeast of the station, whereas an activity zone with high employment potential directly in the south of the railway link has no direct walking access. Map (1) shows the current walking infrastructure situation and visualizes the disparities of location quality between the quarters located on

both sides of the railway line regarding accessed population in the whole RheinMain area within 60 minutes walking-public transport combination. For Map (2), a new network dataset has been created which contains a walking link directly from the railway station to the southern commercial zone in order to recalculate the analysis for the new situation. At first view, local practitioners can realize that the disparities shown in map (1) are removed almost completely. Map (3) shows the number of population that is additionally accessed due to the infrastructure investment, which is between 100,000 and 400,000 inhabitants from the core area of the business zone. This example shows that small measures on the very local level can significantly improve public transport accessibility. Applying this kind of analysis separately for different planning measures, an ex-ante evaluation is possible regarding the improvements to activity participation, and priority lists of investments can either be set up on the local or on the regional level.



(1) Current situation

(2) Realization of walking access from the opposite side of the station

(3) Difference between map (1) and map (2)

Figure 4 – Neighbourhood accessibility in Usingen

Figure 5 visualizes the outcome of a respective accessibility analysis performed for almost the whole Taunusbahn corridor regarding the accessibility to workplaces. The activity potential has been classified into six categories and related to the local population density. According to the map, there are only a few locations with a density surplus, which are concentrated in the core area of the region, Frankfurt / Main (southeast corner of the map).

There, a relatively high density level is linked to a comparably low accessibility value, which could be an indication for improving public transport quality, i.e. timetable frequencies. This core area is surrounded by a belt with an opposite relationship between accessibility and density. This area also is well developed with high-level public transport infrastructure like railway and subway lines, but the population densities partially are on a rural level. As a consequence, modest redensification measures should be examined by municipal and regional authorities for the respective areas. The remaining rural areas in the northern and western parts of the map and along the Taunusbahn corridor generally show a modest relationship between accessibility and density. Except for a few locations with redensification potential directly in the surroundings of Taunusbahn stations and regional bus lines, there are no planning measures to be derived since the analysis is orientated towards a regional level. Furthermore, inaccuracy occurs from the disaggregation of population data: The land use classification in the model only differentiates between residential, mixed, and commercial utilization; therefore, density differences within one land use type can only be estimated vaguely. With the level of detail of the underlying spatial attribute data, the additional benefit for local and regional practitioners would increase significantly. However, workshops held with local politicians and planners point out that accessibility planning necessitates this type of easy-to-interpret indicators, (both for public and practitioners), to increase the approach's chances to be implemented in local planning.

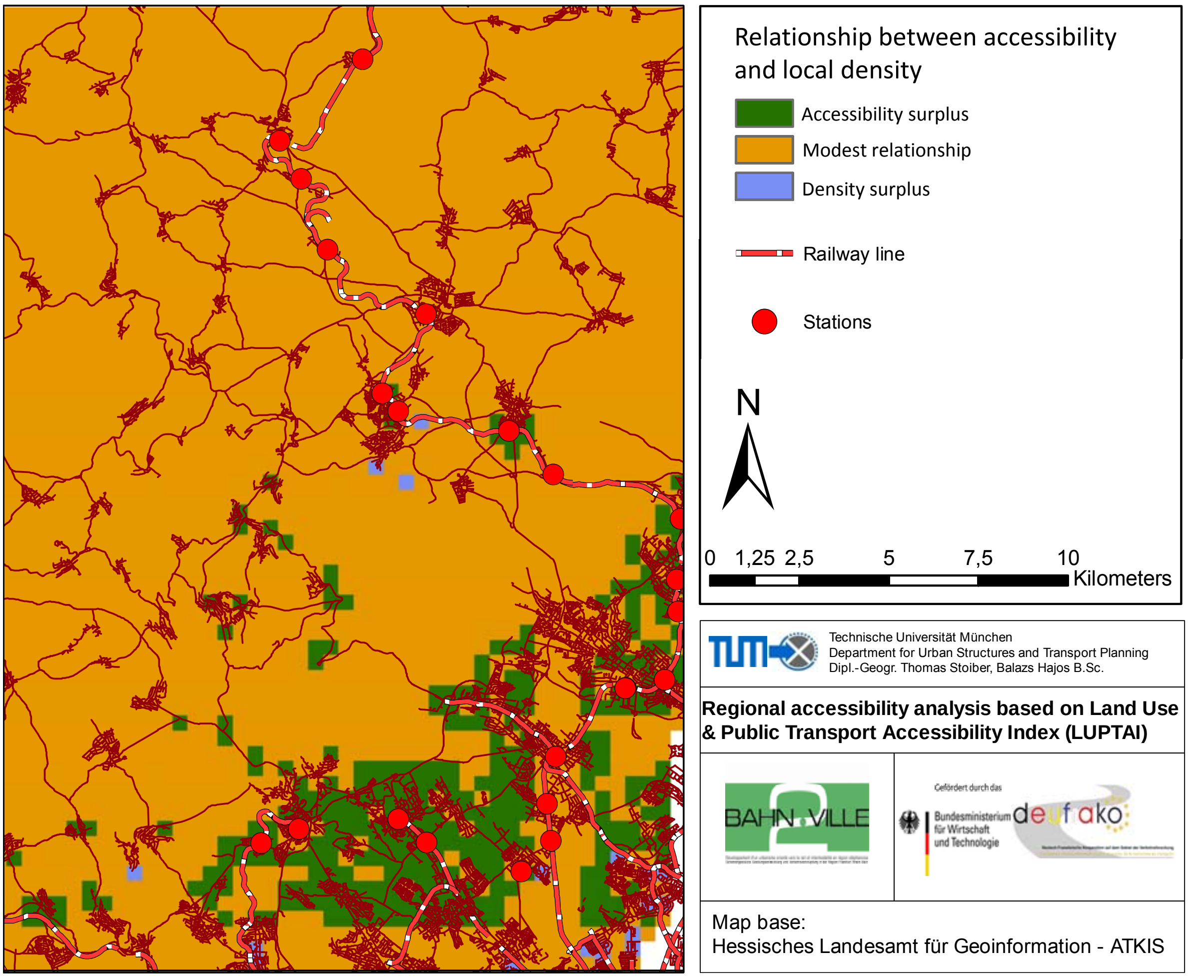


Figure 5 – Regional accessibility analysis

French case study results

In the following section, results are presented referring to the French case study objectives. Based on a detailed spatial approach, transport policy impacts on modal competition are analysed considering congestion in peak periods. Then, sensitivity tests of the access-results to congestion levels and comfort parameters are implemented to perform gravity-based access measures. More detailed transport policy simulations based on the French case study are examined in another paper presented at the WCTR 2010 conference (Crozet and al., 2010).

Transport policy and modal competition

In most parts of the Lyon Metropolitan Area, job-access is higher by car than by public transport (more than 400%). A very dense road network structure and a looser public transport network are the two main explanations. Areas where car-access level is very high (higher than 200%) are either located in the CBD or in the suburbs. What is surprising is that job-access is higher by car than by public transport in the CBD area served by a very efficient urban public transport network. In spite of a congestion rate estimated to 122%, road speeds are higher than public transport ones (maximal urban public transport speed amounts 22 km/h in subway line). The highest car access-results in suburbs are more understandable because of both a motorway network less-congested than in the CBD and the lack of a dense public transport network. Nevertheless, as depicted in figure 6, job-access level is higher by public transport in 5% of the Lyon Metropolitan Area. These zones are located within a 10 km perimeter around railway stations. Generalized transport costs to link CBD jobs from suburban areas are therefore lower by train than by car.

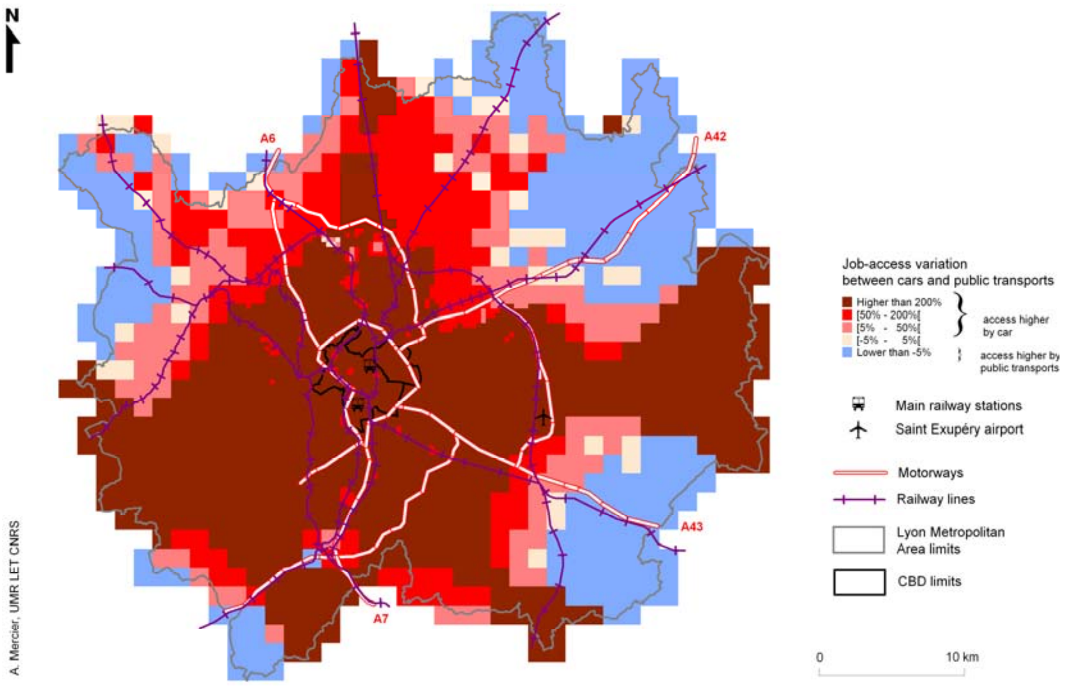


Figure 6 – Job-access variation between cars and public transport

Sensitivity of car access results to congestion level

Congestion levels are integrated in the second iteration stage of the four step model. The initial pass through the model used travel impedance based on free-flow automobile travel time. Traffic assignment and congestion levels therefore reflect a modal choice based on over-estimated travel speeds. When feedback is implemented, travel time depends on real travel congestion level. Comparing the first and second iteration two main phenomenons are observed:

- Intrazonal trip number increases with the expense of interzonal ones. While 19% of total trips were intrazonal in the first iteration, the number amounts to 43% when feedback is taken into account. Including congestion level, travel time is higher with feedback. Individuals prefer limiting their trip length.

- Modal transfer from private motorised modes to others is encouraged by a car travel time increase. Cars trips decrease by 28% while those by foot, two-wheel modes and public transport respectively increase by 103%, 61% and 91%. As presented in table II, in spite of a road congestion increase, most of trips are made by car. The remaining trips are made for the same parts by public transport (18%), two-wheeled transport (16%), as well as walking (12%).

Table II – Modal shares

	Iteration 1	Iteration 2
Car	0.74	0.53
Public Transport	0.09	0.16
Walking	0.06	0.12
Two-wheeled modes	0.11	0.18

After the feedback traffic distribution on road network, it appears that congestion affects mainly high speed sections crossing or skirting Lyon with a saturation rate higher than 70%. In case road sections appear in green in figure 7, road traffic is moving freely (saturation rate ≤ 60). The traffic flow is dense (60 ≤ saturation rate ≤ 80), if road sections are visualized in orange. Road sections are shown in red or in dark red, if they either become saturated (80 ≤ saturation rate ≤ 100) or are totally saturated (saturation rate > 100). As stressed by figure 7, 30% of road sections with a free flow car speed higher than 110 km/h are saturated and 70% of them have a dense traffic. Under the "Tunnel de Fourvière", saturation is estimated to 90% as on the motorway A43. To a less extent, the main urban roads present a congestion rate higher than 50%. These high congestion levels impact travel time to reach Lyon from external zones and therefore influence car-access results.

Figure 7 – Example of saturation rates on various road sections

Integration of congestion levels increases travel time by 23% in the whole area. As depicted in figure 8, zones with rising travel times (more than 20%) are located near high-speed road infrastructures (like motorways) and/or in the CBD. When saturation rate is higher than 60%, travel time can increase by more than 30%. Such travel time variations impact job-access levels, but with a disproportionately small effect. In the entire area, job-access decrease is estimated to 5% with the introduction of congestion levels. As previously, job-access variation depends on locations: the highest access falls are observed close to motorways. Nevertheless, the introduction of monetary costs and opportunities (jobs) in gravity-based accessibility computations allow to offset congestion-based travel time increase. The job-access variation result in the CBD is striking. While travel times increase by more than 30%, accessibility variation is lower than 10% because of the high density of jobs.

This simulation highlights the need for the integration of congestion levels within accessibility computations. Two main conclusions emerge from this analysis. Firstly, considering road traffic access-results is more realistic and can be used by transport and land-use policies. Secondly, if access results are not very sensitive to congestion at the entire area level, they highlight access disparities between zones located near congested road infrastructures and others.

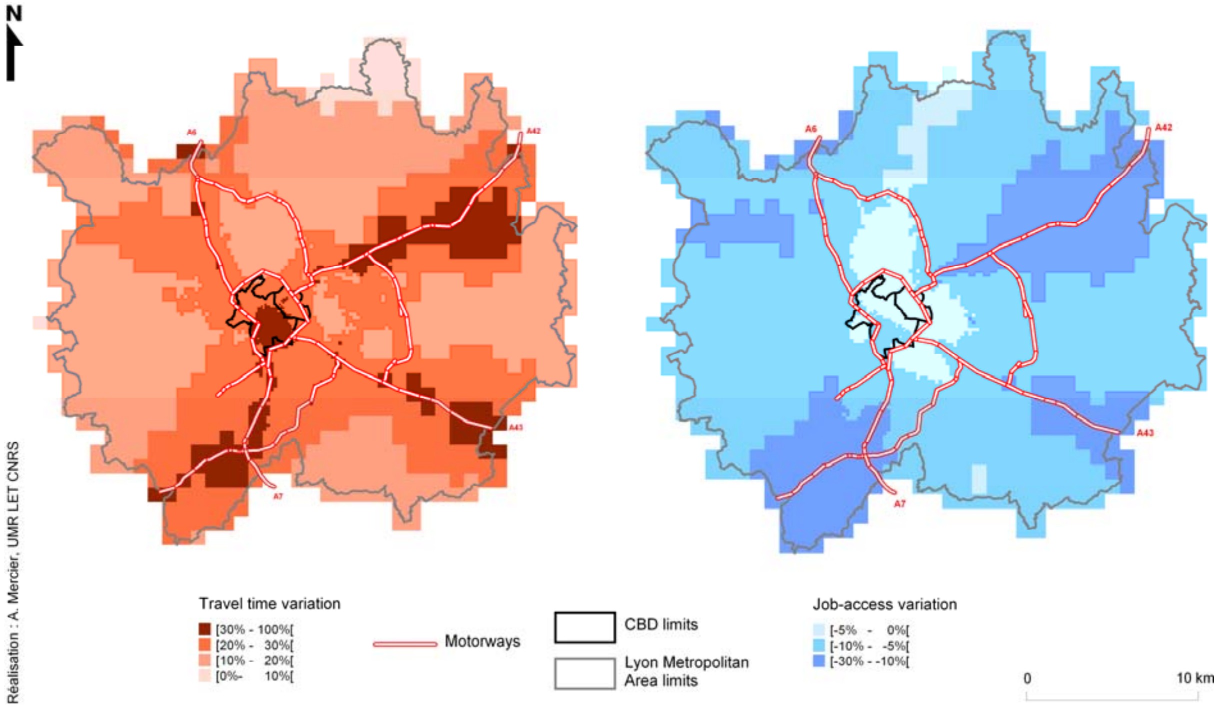


Figure 8 – Road congestion impacts on travel time and job-access variation

Sensitivity of public transports access-results to comfort parameters

The section tests sensitivity of access-results by public transport to comfort and hardness parameters introduced within travel time. The base situation and three simulations are implemented:

- Base situation integrates comfort and hardness parameters as explained previously in the French methodology section.
- Simulation 1 doesn't value comfort and hardness in public transport.
- Simulation 2 only values waiting time: waiting times on transfer have been doubled.
- Simulation 3 only values walking time: travel times by walking are doubled.

Table III – Sensitivity test results (index 100 for the base situation)

	Job-access levels
Base situation	100
Simulation 1	126
Simulation 2	119
Simulation 3	105

Sensitivity test results are presented in Table III. Comfort and hardness parameter values widely impact job-access levels. A non-integration of comfort and hardness penalties (simulation 1) increases job-access level by 26 percent (from base situation). Weighing up between waiting time and walking time (access and destination times, walking time in transfers), the latter parameter has more impact on access results. Considering only waiting time (simulation 2), job-access is estimated to 119 compared to 105 points with a walking time value. On the one hand, waiting time generally is estimated low, since waiting times are not considered at the origin of the trips and public transport in the Lyon Metropolitan Area offers high-quality timetable frequencies. Therefore, only penalizing waiting time has no real impact on the access-level: the access index is estimated to 119 points with only waiting time value while it is estimated to 126 without any penalties. On the other hand, integration of a doubled walking-time (simulation 3) reduces access-level to 105 points. The distance between centroids and public transport nodes (mainly in suburban areas) can explain such a result.

CONCLUSION

This paper has investigated the concept of accessibility and considered how accessibility measures can be improved using two different methodologies combining classical transport modelling with GIS based analysis. The German case study in the region Frankfurt RheinMain as well as the French one in the Lyon Metropolitan Area highlight that a coupling between the time and the land-use component in the concept of accessibility provides a value-added for public decision makers. From a common methodology based on a land-planner's approach, different methodological specifications have been introduced corresponding to diverging objectives. The project Bahn.Ville 2 aims to identify accessibility deficits and to guide transport system and land-use development. In this context of policy guidance, an isochronal-based approach is implemented to allow both an easy interpretation and a transfer to local and regional planning practice. The Lyon Metropolitan Area project reflects a micro-level based analysis and interconnects land-use and transportation systems in a land-use transport model environment. Hence, gravity-based accessibility indicators are used considering a detailed spatial division to avoid zoning effects.

Both approaches provide accessibility computations improvements considering high transport cost sensitivity. Associating a transport model and a GIS allows combining a detailed spatial analysis and an accurate travel time computation. Transport costs are therefore depending on transport mode, route choice but also period of the day (according to road congestion or to public transport timetables). At the same time, socioeconomic data are disaggregated to a detailed spatial level (considering a raster grid or a detailed building block level) for accessibility assessments on different spatial levels.

German case study results have shown in what way planning measures can be developed and derived from accessibility indicators both on the regional and on the neighbourhood level. Based on the relationship between local density and activity potential, the necessity to implement either modest redensification measures or improvements of transport infrastructure has been examined. For a neighbourhood analysis, the investment into a walking infrastructure directly connecting a commercial zone to a regional railway station has proven significant accessibility results.

French case study results reveal high access-results sensitivity to congestion levels and comfort parameters. With a congestion rates estimated higher than 50% on the main urban roads, travel times increase by already 23% compared to the base situation. Its impact on car-access levels highlights disparities between regions: when areas are located near congested road infrastructures and far from jobs, access decreases more than 30%. On the opposite, in the CBD a 30% increase of travel demand generates only a 10% job-access decrease because of closely located high-density job centres. Comfort and hardness parameters have a higher impact on access results than waiting and walking time.

These conclusions underscore the interest for public decision makers to use not only mobility indicators but accessibility indicators based on accurate travel time computations and detailed information on urban structures. Land-use and transport characteristics have to be examined considering congestion and associated effects instead of theoretical mobility conditions in order to measure levels of activity participation appropriately. Furthermore, comfort and convenience improvements, especially in existing public transport, should be considered as equally important as the investment into new infrastructure, since the individual impression of resistances is relevant for the actually perceived accessibility.

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