

Advances in the Measurement of Transport Impedance in Accessibility Modelling

Karst T. Geurs¹

Centre for Transport Studies, Faculty of Engineering Technology, University of Twente, The Netherlands.

John Östh²

Department of Social and Economic geography, Uppsala University, Sweden.

Accessibility is a key concept in both transport and urban planning. The key aims of transport policies, not only at the urban level but also at the supra-national (for example, European Union), national and regional level, are to improve accessibility. Accessibility is also a key concept that has become central to physical planning and in spatial modelling for more than fifty years. As measure of the relative nearness or proximity of one place and persons to all other places or persons, conceptually linked to Newton's law of gravity, its origins can be traced back to the 1920s when it was used in location theory and regional economic planning (Batty, 2009). In his classic paper 'How Accessibility Shapes Land Use', Hansen (1959) was the first to define accessibility as a potential of opportunities for interaction and applied the concept to forecast employment developments in Washington D.C.. Accessibility is thus a key concept in planning and research but often a confusing one. Many different accessibility definitions and operationalisations in accessibility models and instruments have in the past decades been developed and applied by researchers from several academic fields (e.g., urban geography, rural geography, health geography, time geography, spatial economics, transport engineering) and transport and urban planners (e.g., see for reviews Geurs and van Wee, 2004; Páez et al., 2012; Papa et al., 2016).

Many different applications have been developed in these fields and can be categorized in several ways. Here, we use the categorization of accessibility measures from the review paper from Geurs and Van Wee (2004). They provide an overview of components of accessibility and perspectives on accessibility, which we will use as a categorization of accessibility measures. Geurs and Van Wee distinguish four basic perspectives on accessibility. Firstly, infrastructure-based (or mobility-based) measures analyse the performance or service level of transport infrastructure. These measures vary from simple travel time or congestion level measures to more complex network connectivity/centrality measures based on graph theory and are typical the domain of civil engineers, transport engineers and planners. Secondly, location- or place-based accessibility measures, analysing access to spatially distributed activities, typically estimated on an aggregate level. This perspective is the typical domain of urban planners and geographers, using a wide range of measures but threshold-based measures (e.g., number of jobs within 30 minutes travelling) and Hansen's potential accessibility measure as most popular ones. Thirdly, person-based accessibility measures used to analyse accessibility at individual level, taking individual limitations regarding freedom of action in the environment, into account. This perspective is founded in Hägerstrand's time-space geography (Hägerstrand, 1970), and has become a growing research field within geography (e.g., see Farber et al., 2013; Neutens et al., 2011). Finally, utility-based accessibility measures, analysing the welfare benefits that people

¹ A: P.O. Box 217 ,7500AE, Enschede, the Netherlands. T: +31 534891056; E: k.t.geurs@utwente.nl

² A: P.O.Box 513, SE-751 20 Uppsala, Sweden.; T: +46 471 73 88; E: john.osth@kultgeog.uu.se

derive from levels of access to the spatially distributed activities. This economic perspective on accessibility is founded in welfare economics and discrete choice theory (e.g., see for applications Chorus and de Jong, 2011; de Jong et al., 2007; Geurs et al., 2010).

These perspectives typically focus on one or more of the four components of accessibility distinguished by Geurs and Van Wee: (i) the land-use component reflecting the amount, quality and spatial distribution of opportunities, (ii) the transportation component describing the disutility of travel in terms of time, cost and effort, (iii) the temporal component reflecting the temporal constraints and variability, and (iv) the individual component reflecting the needs and abilities of individuals. In both research and planning, the academic discipline of researchers and planners, together with the uses for which the accessibility metrics are designed, strongly determine the perspective on accessibility and focus on the component(s) of accessibility. In transport engineering and planning typical focus is on the transport component of accessibility, typically using transport demand models and distinguishing between various time and cost impedance factors (e.g. travel and waiting time, reliability, comfort, fuel costs) in the analysis, but ignoring the land-use and individual components of accessibility. Urban planners and human geographers typically focus on the land use component and less on the transport component of accessibility (e.g., using on crow-fly distance or travel time isochrones) and differences between population segments. Time geography provides a comprehensive approach to accessibility, including the land-use, temporal and individual components, but typically does not measure the transport component in detail (i.e. total travel time as a proxy for the transport component).

It seems with advances in geospatial technology, internet technology, and growing abundance of detailed spatial data and real-time transport datasets, the field of accessibility modelling is thriving. As a result, the disciplinary foci and boundaries between transport planning, urban planning, geography and spatial economics in measuring accessibility could diminish. New generation of interdisciplinary accessibility models will benefit from advances in geospatial technology and growing abundance of transport and spatial data, which allows a comprehensive treatment of the transport and land-use components of accessibility in the different disciplines. Already, location-based measures have evolved from simple calculations to more complex and detailed methods that use algorithms within a Geographic Information Systems (GIS) framework to estimate for example block-level accessibility (e.g., Chen et al., 2011). Furthermore, an upcoming research stream focuses on web-based mapping and applications that use internet technologies to retrieve detailed information about local amenities. Paez et al. (2013), for example, developed a web-based accessibility instrument employing Google Maps API to retrieve information about local amenities (e.g. groceries, restaurants, fitness, banks, etc.) and estimate accessibility by car, walking and cycling.

Mainstream accessibility models are static measures of access, since the score for a particular location does not vary temporally, which as a result may not suitably represent the actual levels of access for different population groups and activity purposes. However, a recent trend in the literature is also to examine continuous accessibility patterns, examining time-of-day variations in accessibility are using realtime driving speeds, open source web-based mapping and public availability transit supply data. Nowadays, time-of-day variations in road network accessibility can be examined using realtime driving speeds on road networks based on GPS measurements from mobile phones and navigation systems such as TomTom or NavTeq (Moya-Gómez and Garcia-Palomares, 2015). Recent advances in geospatial technology open source web-based mapping such as OpenStreetMap and public availability of Transit Feed Specification (GTFS) data from transit authorities gives room for a growing field of research on time-of-day variations in public transit accessibility (e.g., Lei et al., 2012; Owen and Levinson, 2014).

In this era of growing data abundance, reflections on the role of accessibility modelling are more than ever important in the search for sound and interdisciplinary accessibility theories and tools.

This is the rationale which characterizes the articles included in this Special Issue. The papers in the special issue use a range of advanced methodologies and new data sources to improve the treatment of the transport component in accessibility modelling. Some of the contributions in this special issue have been inspired by concepts and ideas discussed in the papers presented at the NECTAR International Conference at St. Miguel, Azores Islands (Portugal), 16-18 June 2013.

In operationalising location accessibility, analysts have to deal with intra-zonal or internal impedances which affect the weight of the intra-regional interactions. The contribution of the internal accessibility of each zone to its overall accessibility is known in the literature as self-potential. Several studies demonstrate its importance in accessibility analyses, especially in the most urbanized regions. It is precisely in urban regions where internal travel distances (measured as travel length, time or cost) are more difficult to estimate due to congestion, which in turn may be influenced by factors such as urban density, urban morphology, network infrastructure, etc. The first paper in this special issue, authored by Condeço Melhorado, Demirel, Kompil, Navajas and Christidis addresses this issue (Condeço Melhorado et al., 2016). Their paper explores different forms of estimating internal travel distances in accessibility analysis in the EU level, at the level of NUTS-3 regions. The availability of data from navigation systems allows for a detailed analysis of internal travel impedances. The authors use speed profiles data from TeleAtlas/TomTom to calculate internal travel distances for European NUTS-3 regions. The authors test the sensitivity of potential accessibility indicators to the combined effect of different internal distance metrics and distance decay factors. The paper confirms that changing the internal distance measure does not only impact on accessibility values but also affect the spatial distribution of accessibility. The availability of data on traffic speeds and volumes thus makes a substantial contribution to a more accurate measurement of location-based accessibility measures at the European level.

The interest in disentangling the role of national borders in international trade is growing even within virtually borderless areas like the European Union. While there are a variety of research studies measuring how borders affect trade, there is little insight into the impact of borders on the potential accessibility to markets. The second paper in this special issue, authored by Salas-Olmedo, García-Alonso and Gutiérrez (Salas-Olmedo et al., 2016) addresses this issue. The authors first provide a coherent calibration of the impedance parameters affecting trade (border effect based on best official data available and with a sound estimation of distance and the distance decay parameter with the use of network-based measurements). Secondly, the authors examine to what extent the market potential of different countries is hampered by border effects. The analysis reveals that calibrating distance decay and considering border effects provides more realistic results. Moreover, peripheral areas are more sensitive to the estimation of the distance decay parameter, whilst the main metropolitan regions are less affected by both distance decay and border effects.

In the accessibility literature various impedance functions are used to mimic observed travel behaviour in modelling works, with implications for the results of the accessibility analysis. The third paper in this special issue, authored by Östh, Lyhagen and Reggiani (Östh et al., 2016), explores and compares various techniques for the calculation of spatial impedance functions and decay parameters for Sweden which are estimated using statistical methods and different levels of data disaggregation. The authors show that the choice of the impedance function depends on the availability of data. Using highly detailed and disaggregate datasets, half-life derived parameters are shown to be more accurate than more conventional distance decay functions used in unconstrained and doubly-constrained spatial interaction models. The authors explain that the increase of accuracy half-life models with increasing degrees of disaggregation is likely related to a reduction of systematic error between observed individual level commuting distance and modelled distances between origins and destinations. The growing availability in spatial and transport data thus has implications for the estimation and choice of impedance functions.

The last three papers in the special issue focus on advances in the measurement of transport impedances in public transport accessibility, and address the complexity in estimating public transport accessibility. Firstly, as not only accessibility to locations via public transport but also access to public transport has to be dealt with. Secondly, measuring transport impedances is challenging as it is well known in transportation research and modelling that travellers perceive different parts of a public transport journey stages differently, such as the time spent in feeder modes, waiting and transfer times at public transport stops and in-vehicle travel time (e.g., see Schakenbos et al., 2016; Vande Walle and Steenberghen, 2006). Thirdly, public transport accessibility will differ substantially between population segments (by age, gender, etc.) because of differences in preferences and needs and abilities to travel (e.g. resulting in differences in walking speed), and resulting perceived levels of accessibility. However, a few studies have so far examined the diversity of accessibility needs to train stations for different groups of people and between travel modes.

In this special issue, Martínez, Moyano, Coronado and Garmendia (Martínez et al., 2016) examine the spatial influences of HSR (high-speed rail) stations, based on the notion of catchment area. The authors take a high resolution spatial approach to analyse a range of factors that may affect the size and shape of the catchment areas according to the relationship between distance and ridership, such as station type, train service levels, and socio-economic characteristics of catchment areas. This study employs data from on-board user ridership surveys of six stations of the Spanish HSR system to apply the model and demonstrates that the context is crucial for regional use. The empirical analysis also demonstrates that the structure and shape of catchment areas may be significantly affected by network effects, such as overlapping catchment areas of HSR stations and the presence of regional train networks.

The inclusion of unobserved (latent) variables to measure individuals' values and attitudes in travel demand models has been an emerging research field in the choice modelling literature (e.g., see Bhat and Dubey, 2014; Paulssen et al., 2014). The paper from La Paix and Geurs (2016) in this issue is probably the first attempt in the literature to include unobserved impedance factors in an accessibility model. The paper examines the role of perceptions and attitudes in railway station accessibility. The authors add unobserved (latent) variables to traditional time and cost factors in a Generalised Transport Access Cost index of cycling to railway stations in the Netherlands. Two latent variables which were obtained through factor analysis: perception of station environment (including factors such as the users' judgement of the station, assessment of travel information, presence of high speed trains) and perceived connectivity (including factor such as the evaluation of punctuality and the frequency of the train and quality of bicycle infrastructure). The results show, first, that perceptions of station accessibility and connectivity in the wider The Hague - Rotterdam metropolitan area affect accessibility levels and omitting unobserved effect in utility-based measures tends to lead to overestimations of the accessibility levels. This highlights the need for more interdisciplinary research in accessibility analysis and modelling.

In the final paper of this special issue, Ryan, Lin, Xia and Robinson (Ryan et al., 2016) compare perceived and measured accessibility to train stations among three age groups: young adults (18-24), middle aged adults (25-59) and elderly adults (60+) and three travel modes, Park and Ride, Bus and Ride and Walk and Ride. The study focuses on the Greenwood railway station, Perth, Australia. The paper shows that measured accessibility is lower than perceived accessibility for all three age groups. Both perceived and measured accessibility to train stations were lower for the elderly than the other groups. The catchment area of Park and Ride users was the smallest for elderly adults and highest for and young adults. Moreover, the paper identified inadequate accessibility to Greenwood Station for different age groups and by different travel modes, which can be used as a decision-making aid by practitioners and station managers for improving accessibility for these cohorts.

In summary, the papers in the special issue illustrate the importance of more comprehensive and interdisciplinary approaches to measuring accessibility, using advanced modelling and making use of detailed spatial and transport data sources. In the coming years, the growing abundance of detailed spatial and real-time transport data will continue to fuel the thriving research field of accessibility analysis and modelling, and contribute to more interdisciplinary accessibility theories and models.

References

- Batty, M. (2009). Accessibility: in search of a unified theory. *Environment and Planning B: Planning and Design*, 36, 191-194.
- Bhat, C.R., S.K. Dubey (2014). A new estimation approach to integrate latent psychological constructs in choice modeling. *Transportation Research Part B: Methodological*, 67(0), 68-85.
- Chen, Y., S. Ravulaparthi, K. Deutsch, P. Dalal, S. Y. Yoon, T. Lei, K. G. Goulias, R. M. Pendyala, C. R. Bhat, H. H. Hu (2011). *Development of indicators of opportunity-based accessibility*. Transportation Research Record, 58-68.
- Chorus, C. G., G. C. de Jong (2011). Modeling experienced accessibility for utility-maximizers and regret-minimizers. *Journal of Transport Geography*, 19(6), 1155-1162.
- Condeço Melhorado, A.M., H. Demirel, M. Kompil, E. Navajas, P. Christidis (2016). The impact of measuring internal travel distances on self-potentials and accessibility. *European Journal of Transport and Infrastructure Research* (this issue).
- de Jong, G., A. Daly, M. Pieters, T. van der Hoorn (2007). The logsum as an evaluation measure: Review of the literature and new results. *Transportation Research Part A: Policy and Practice*, 41(9), 874-889.
- Farber, S., T. Neutens, H. J. Miller, X. Li (2013). The Social Interaction Potential of Metropolitan Regions: A Time-Geographic Measurement Approach Using Joint Accessibility. *Annals of the Association of American Geographers*, 103(3), 483-504.
- Geurs, K. T., B. van Wee (2004). Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport Geography*, 12(2), 127-140.
- Geurs, K., B. Zondag, G. De Jong, M. de Bok (2010). Accessibility appraisal of integrated land-use/transport policy strategies: more than just adding up travel time savings. *Transportation Research Part D*, 15, 382-393.
- Hägerstrand, T. (1970). What about people in regional science? *Papers of the Regional Science Association*, 24, 7-21.
- Hansen, W.G. (1959). How accessibility shapes land use. *Journal of American Institute of Planners*, 25(1), 73-76.
- La Paix Puello, L., K.T. Geurs. (2016). Integration of unobserved effects to improve transport impedances of cycling to railway stations *European Journal of Transport Infrastructure Research* (this issue).
- Lei, T., Y. Chen, K. Goulias (2012). *Opportunity-based dynamic transit accessibility in Southern California*. Transportation Research Record, 26-37.
- Martínez, H.S., A. Moyano, J.M. Coronado, M. Garmendia (2016). Catchment areas of high-speed rail stations: a model based on spatial analysis using ridership surveys. *European Journal of Transport Infrastructure Research* (this issue).
- Moya-Gómez, B., J.C. Garcia-Palomares (2015). Working with the daily variation in infrastructure performance. How can this be included in territorial accessibility measurements? *European Transport Research Review*, 7(1-13).

- Neutens, T., T. Schwanen, F. Witlox (2011). The Prism of Everyday Life: Towards a New Research Agenda for Time Geography. *Transport Reviews: A Transnational Transdisciplinary Journal*, 31(1), 25 - 47.
- Östh, J., A. Reggiani, G. Galiazzo (2016). Half-life and Spatial Interaction Models: Job Accessibility Analysis in Sweden. *European Journal of Transport and Infrastructure Research* (this issue).
- Owen, A., D. Levinson (2014). *Access Across America. Transit 2014*. University of Minnesota, Minneapolis.
- Páez, A., Md. Moniruzzaman, P. Bourbonnais, C. Morency (2013). Developing a web-based accessibility calculator prototype for the Greater Montreal Area. *Transportation Research Part A: Policy and Practice*, 58(0), 103-115.
- Páez, A., D.M. Scott, C. Morency (2012). Measuring accessibility: positive and normative implementations of various accessibility indicators. *Journal of Transport Geography*, 25(0), 141-153.
- Papa, E., C. Cilva, M. te Brommelstroet, A. Hull (2016). Accessibility instruments for planning practice: A review of European experiences. *Journal of Transport and Land Use*, 9(3), 1-20.
- Paulssen, M., D. Temme, A. Vij, J. L. Walker (2014). Values, attitudes and travel behavior: A hierarchical latent variable mixed logit model of travel mode choice. *Transportation*, 41(4), 873-888.
- Ryan, M., T. Lin, J. Xia, T. Robinson (2016). Comparison of Perceived and Measured Accessibility between Different Age Groups and Travel Modes at Greenwood Station, Perth, Australia. *European Journal of Transport Infrastructure Research* (this issue).
- Salas-Olmedo, M.H., P. García-Alonso, J. Gutiérrez (2016). Distance deterrence, trade barriers and accessibility. An analysis of market potential in the European Union. *European Journal of Transport and Infrastructure Research* (this issue).
- Schakenbos, R., L. La Paix, S. Nijenstein, K.T. Geurs (2016). Valuation of a transfer in a multimodal public transport trip. *Transport Policy*, 46, 72-81.
- Vande Walle, S., T. Steenberghen (2006). Space and time related determinants of public transport use in trip chains. *Transportation Research Part A: Policy and Practice*, 40(151-162).