International Transport Forum

Accessibility and Transport Appraisal

Approaches and Limitations

182 Roundtable

Discussion Paper

Karst Guers

University of Twente,
Enschede

Accessibility and Transport Appraisal
Approaches and Limitations

182

Roundtable

Discussion Paper

Karst Guers
University of Twente,
Enschede

The International Transport Forum

The International Transport Forum is an intergovernmental organisation with 62 member countries. It acts as a think tank for transport policy and organises the Annual Summit of transport ministers. ITF is the only global body that covers all transport modes. The ITF is politically autonomous and administratively integrated with the OECD.

The ITF works for transport policies that improve peoples' lives. Our mission is to foster a deeper understanding of the role of transport in economic growth, environmental sustainability and social inclusion and to raise the public profile of transport policy.

The ITF organises global dialogue for better transport. We act as a platform for discussion and pre-negotiation of policy issues across all transport modes. We analyse trends, share knowledge and promote exchange among transport decision-makers and civil society. The ITF's Annual Summit is the world's largest gathering of transport ministers and the leading global platform for dialogue on transport policy.

The Members of the Forum are: Albania, Armenia, Argentina, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Canada, Chile, China (People's Republic of), Croatia, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Kazakhstan, Korea, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Mexico, Republic of Moldova, Mongolia, Montenegro, Morocco, the Netherlands, New Zealand, North Macedonia, Norway, Poland, Portugal, Romania, Russian Federation, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Tunisia, Turkey, Ukraine, the United Arab Emirates, the United Kingdom, the United States and Uzbekistan.

International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
contact@itf-oecd.org
www.itf-oecd.org

ITF Discussion Papers

Cite this work as: Guers, K. (2020), "Accessibility and Transport Appraisal: Approaches and Limitations", *International Transport Forum Discussion Papers*, No. 2020/22, OECD Publishing, Paris.

Table of contents

Introduction 4
Measuring and valuating accessibility: a brief overview 4
- Infrastructure-based accessibility measures 5
- Location-based accessibility measures 6
- Utility-based accessibility measures 9
- Person-based accessibility measures 10
- Conclusions 11

Accessibility and transport appraisal - limitations of current practices 12
- The land-use component of accessibility 12
- The transport component of accessibility 15
- The temporal component of accessibility 16
- The individual component of accessibility 17
- Accessibility, digitalisation and appraisal 18
- Equity and distributive justice 19
- Accessibility measures in appraisal frameworks 21
- Current transport appraisal practices: conclusions 21

Conclusions 22
References 24

Introduction

Accessibility has been central to physical planning and spatial modelling for more than fifty years. The concept of accessibility, as it accounts for both the pattern of activities and for the links between activities, provides a basis for making trade-offs between land use and transport policies. As a measure of the potential for interaction of one place and persons to all other places or persons, conceptually linked to Newton's law of gravity, the origins of accessibility 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 development in Washington, D.C. A multitude of accessibility definitions and operationalisations of accessibility measures have been developed and applied in several academic fields such as urban geography, rural geography, health geography, time geography, spatial economics and transport engineering.

From the 1970s, economists have developed utility-based accessibility measures from different transport modelling frameworks. If utility is transformed into monetary terms, with some assumptions, accessibility benefits can be estimated, which can directly be used in the economic appraisal of transport investments. A number of approaches have been developed which allow an integration of transport demand models, valuation of accessibility and economic appraisal (i.e. Social Cost Benefit Analysis).

Over the past decade accessibility research has flourished due to a growing abundance of spatial and transport data. However, it seems the application and development of accessibility measures in transport appraisal has not received an increasing amount of attention. The aim of this discussion paper is to describe the current practice of assessing and valuating accessibility impacts in transport appraisal and the limitations of the different approaches taken.

This discussion paper firstly describes the different approaches to measuring accessibility benefits then considers the limitations in the current practice of measuring accessibility benefits. It looks at the role of accessibility when examining economic efficiency and equity impacts in transport appraisal and finishes with a section presenting the conclusions.

Measuring and evaluating accessibility

There are many different possible categorisations of accessibility measures. Here, the categorisation is based on the well-known review paper from Geurs and Van Wee (2004), which identified four basic perspectives on accessibility: infrastructure-based, location-based, person-based and utility-based accessibility measures. In the literature, various methods have been developed to estimate accessibility benefits within each of these four different perspectives on accessibility. Utility-based accessibility measures have been developed to assess the value that people derive from having access to spatially distributed opportunities, based on the random utility framework. If transformed to monetary terms, the utility-based measures can directly be integrated into an economic appraisal of transport investments (i.e. cost-benefit analysis [CBA]). However, researchers have also developed methods to measure user benefits within the other three perspectives, using alternative travel demand modelling frameworks. The different approaches are described in the sections below.

Infrastructure-based accessibility measures

The infrastructure-based perspective on accessibility is the typical domain of civil engineers, transport engineers and planners. These range from simple to link-based travel speed and congestion indexes to more complex network-based measures analysing the relative performance of a node or an area in the transport network. A typical example of this type is the access cost indicator, i.e. the summation of all travel impedances (time and/or costs) of area i to all areas j, divided by the number of locations. The lower its value, the more accessible a location is. Variations involve the weighted by actual or modelled origin-destination trip pattern or the probabilities of trips taking place between i and j (Linneker and Spence, 1992).

The infrastructure-based approach to measuring accessibility, used as input for the standard practice approach to measuring the accessibility benefits of transport strategies, is to use the "rule of a half" measure, originating from Tressider et al. (1968), as an approximation of Marshallian consumer surplus. The rule of a half formula computes the total change in user benefits as the sum of the full benefit obtained by original travellers and half that benefit obtained by new travellers or generated traffic. This can be calculated by multiplying the average number of trips T_{ij} between a base scenario (0) and a scenario with a project (1) by the difference in (generalised) travel costs between i and j (c_{ij}):

$$\Delta CS_{roh} = \frac{1}{2}\sum_{i}\sum_{j}\left(T_{ij}^{0}+T_{ij}^{1}\right)\left(c_{ij}^{0}-c_{ij}^{1}\right) \tag{1}$$

The main advantage of the rule of a half approach is that it is a transparent (in simple situations), fairly intuitive measure and, therefore, relatively easy to explain to non-experts. Rule of a half calculations can, however, get complicated when taking into account all the possible changes in travel behaviour resulting from a transport project, for instance, changes in route choice, time of day, destination and/or modes of transport.

The rule of a half is typically applied in CBA of transport investments, based on outputs (trip and generalised cost matrices) of four-step transport demand models or discrete choice models. These models allow both the distribution of the existing and generated (induced and/or attracted) demand between OD relations and, considering the relative generalised costs that determined the choices, the calculation of user paths. The use of (specific) multimodal transport demand models is mandatory in some countries in Europe, such as the Netherlands (Rijkswaterstaat, 2018) and Italy (Beria, Bertolin and Grimaldi, 2018). In some countries and regions, CBA guidelines define the standard rule of a half to measure consumer surplus. This is for example the case for projects which are (co)funded by the Dutch national government (Romijn and Renes, 2013) and Lombardy Region (Beria, Bertolin and Grimaldi, 2018). In the United Kingdom, the rule of a half formula forms the basis of the user benefit calculations performed by the Department of Transport's appraisal software, TUBA (DfT, 2019).

The difficulties with the rule of a half measure in the economic evaluation of transport and land-use policies been extensively described in the academic literature. The issues relevant for the purpose of this paper are briefly described below. To use the rule of a half measure as a practical approximation of consumer surplus, a number of assumptions are made that do not generally hold but are accepted in transport policy appraisal. Neuburger (1971), for example, criticised the rule of a half for the two reasons mentioned below. See also Bates (2006) for an extensive discussion.

Firstly, the rule of a half does not start from a specific functional form, but effectively assumes a linear demand function. This is satisfactory for the levels of change normally brought about by new infrastructure projects. The rule of a half can be shown to give a good approximation of consumer surplus when the change in (generalised) cost can be regarded as marginal. However, for measures which can result in large changes in demand, the rule of a half can lead to significant errors (SACTRA, 1999). Kohli and Daly (2006) for example estimate that the rule of a half benefits of an extended traffic management scheme (estimated from a mode/destination transport model) are 9% underestimated compared to exact user benefit measures (i.e. the logsum method, discussed more fully in the "Utility-based accessibility measures"section). Geurs, de Bok and Zondag (2012) find that the rule of a half underestimates user benefits of a railway investment by 20 - 30% when compared to more exact user benefit measures directly derived from the disaggregate mode/destination choice model (i.e. the logsum method).

Secondly, the rule of a half assumes that all accessibility benefits accruing to economic agents are attributable to generalised cost changes within the transport system. This is a convenient argument with a practical outcome, since it is easier to identify and estimate the benefits/disbenefits accruing directly to travellers rather than to search for their more elusive manifestations further along the chains of reaction in other markets (SACTRA, 1999). This assumption becomes problematic, however, when land-use changes are to be taken into account (Geurs, de Bok and Zondag, 2012; Geurs et al., 2010b).

Location-based accessibility measures

Location-based measures can be used from the perspective of the origin, e.g. the location of the dwelling of a person, or from the perspective of the destination, e.g. a location of a shop, expressing, for example, the potential number of clients. There are many different operationalisations used in the literature. Most of accessibility instruments used in urban planning practice in Europe are based on location-based accessibility indicators (e.g. Hull, Silva and Bertolini, 2012). The two most popular location-based measures are cumulative opportunity (threshold) measures and potential accessibility. The cumulative accessibility measure is a simple indicator expressing the absolute number of opportunities within a specified cut-off travel impedance (e.g. 30 minutes). The cumulative accessibility indicator is however not consistent with travel behaviour and cannot be used in economic valuations as it assumes an arbitrary cut-off point (to be determined by the researcher) and does not allow for variations in demand at the supply points (Morris, Dumble and Wigan, 1979). This approach is inconsistent with microeconomic theory. The classic Marshallian demand curve gives the change in demand for a commodity as a result of a price change for that commodity, assuming other prices remain fixed. Hence, consumer surplus can also not be measured as the area under the (inverse) demand curve and above the current market price.

The potential accessibility measure, or gravity-based measure, estimates the accessibility of opportunities in zone i to all other zones (n) in which smaller and/or more distant opportunities provide diminishing influences, and is based on the notion of potential, which dates back to the social physics school of the 19th century. The literature gives a wide range of distance decay form. The power form was used by Hansen (1959) but the negative exponential form appears to be the most popular, given also their theoretical roots in the entropy maximising approach (Reggiani, Bucci and Russo, 2011). A potential accessibility measure A_i, using a negative exponential cost function, has the following form:

$$A_i = \sum_{j=1}^{n} D_j e^{-\beta c_{ij}} \qquad (2)$$

A_i is a measure of accessibility in zone i to all opportunities (mass) D in zone j, c_{ij} the (generalised) costs of travel between i and j, and β the cost sensitivity parameter.

It is well known in the literature that there are strong links between potential accessibility, spatial interaction models and discrete choice models. Spatial Interaction Models (SIMs) provide an explicit link between accessibility modelling and economic, demographic and transport flows. SIMs have a long history and have been used in a wide variety of contexts. Wilson (1970) gave SIMs theoretical strength by deriving them using the entropy maximisation approach, and the doubly-constrained version formed the basis for transport flow modelling. Wilson's production-attraction constrained model, embedding a negative exponential cost function, leads to the well-known specification of a transport model (Wilson, 1970) and potential accessibility embedding a negative exponential cost function (equation 2) emerges as the inverse of the calibration factor in origin-constrained spatial interaction model (Reggiani, 1998).

$$\mathrm{T}_{ij} = A_i O_i B_j \mathrm{D}_j \exp(-\beta c_{ij}) \qquad (3)$$

subject to $\sum_j T_{ij} = O_i$ and $\sum_i T_{ij} = D_j$ and with

$$A_i = \frac{1}{\sum_j B_j D_j \exp(-\beta c_{ij})} \qquad (4)$$

$$B_j = \frac{1}{\sum_i A_i O_i \exp(-\beta c_{ij})} \qquad (5)$$

This model is more or less the same as the traditional (Newtonian) gravity model but with one difference: the power law for the cost function has been replaced by an exponential function (Wilson, 2010). The core model essentially assumes that people perceive their travel costs as increasing linearly.

Anas (1983) observed that entropy-maximising spatial interaction models (SIM) and multinomial logit models are analytically compatible. It is not surprising therefore that it can be shown that the potential accessibility and logsum measure have several features in common. The differences to some extent refer to differences in conventions adopted in the various domains for using a default specification. Regarding valuation of accessibility, there are several approaches followed in the literature. These approaches arise in the context of deriving the gravity model from microeconomic theory. Here, we will illustrate a few as it is beyond the scope of this paper to explore all of them. Neuburger (1971) provided an intuitive measure of consumer surplus, assuming trip distribution is correctly described by an (unconstrained) gravity model with a negative exponential distribution function as:

$$S = \frac{1}{\beta} O_i \ln \sum_{j=1}^{n} D_j e^{-\beta c_{ij}} \qquad (6)$$

This result is later extended by Williams (1976), in accordance with Neuburger but more precise, giving it a basis for economic valuation. Koenig (1980) already wondered why this result had attracted so little attention, at least among practitioners, since it was published. There seems to be little applications of this measure of accessibility benefits. One exception is from Raux, Mercier and Ovtracht (2008) who applied the measure to estimate the economic benefits of public transport investments in Strasbourg, France.

Balancing factors

Cumulative and potential accessibility measures implicitly assume that the demand for available opportunities are uniformly distributed in space, and do not account for capacity limitations of available opportunities (whereas jobs can only be for one worker at any moment in time). In other words: they do not handle competition effects. This may lead to inaccurate or even misleading results (Shen, 1998). To incorporate these competition effects, several authors developed alternative accessibility measures based on the potential accessibility model specification. Several authors (e.g. Joseph and Bantock, 1982; Shen, 1998) tried to incorporate the effects of competition on opportunities in accessibility measures by evaluating both the opportunities within reach from origin zone *i* (the "supply" potential) and the relevant population within reach from the same origin zone *i* (the "demand" potential) and dividing the two. This approach in health geography is called the two-step floating catchment area method (2SFCA). For a recent overview, see Chen and Jia (2019).

A more advanced approach involves interpreting the balancing factors A_i and B_j of the doubly-constrained spatial interaction model (equations 4 and 5) as accessibility measures (Williams and Senior, 1978; Wilson, 1971). In the interaction model, the balancing factors serve to ensure that the magnitude of flow (e.g. trips) to and from each zone equals the correct number for that zone (e.g. inhabitants or jobs). Since they are mutually dependent, they have to be estimated iteratively. The first step is computing the demand potential for all zones and the second is equivalent to computing Shen's measure of accessibility. In the third step, demand in all zones is divided by this measure and then used to compute a modified demand potential. Next, supply in all zones is divided by this modified demand potential and used to compute a modified supply potential and so on, until convergence is reached. In this way, the mutual dependence between the competition on supplied opportunities and the competition on demand is reflected in the inverse balancing factors. The balancing factors have for example been applied to examining job accessibility by car and public transport in the Netherlands (Geurs and Ritsema van Eck, 2003).

Martínez (1995) and Martínez and Araya (2000b) have derived transport user benefit measures from the doubly-constrained spatial interaction model. This approach has also been applied by Geurs, Van Wee and Rietveld (2006). Martínez (1995) obtained the following accessibility measures from:

$$A_i = \frac{-1}{\beta}\ln(a_i) \quad \text{and} \quad A_j = \frac{-1}{\beta}\ln(b_j) \qquad (7,8)$$

where A_i represents the relative accessibility benefit travellers derive at each origin zone i (or the expected benefits per trip generated), and A_j, the relative attractiveness of destination zone j (or the expected benefit per trip attracted) for a given transport situation and subject to trips complying with total trip origins and destinations from the entropy model. The terms a_i and b_j have already been defined in Equation 3. The advantage of Equation 5 compared to the logsum measure is that it allows the additional interpretation of the balancing factors as utility-based accessibility measures, including competition effects. The measures can be used to compute Marshallian consumer surplus in economic (cost-benefit) analysis of both land-use and infrastructure policies. Using Martínez and Araya's framework (2000b), an elemental trip-user benefit *Tub* for mode *m* is defined as:

$$Tub_{ijm} = \frac{-1}{\beta}\ln(a_{im} b_{jm}) \qquad (9)$$

representing a unit of absolute benefit, perceived by a user travelling between zones, and j for a given transport situation. This will also be subject to trips complying with total trip origins and destinations from the entropy model. Martínez and Araya (2000b) derived Marshallian consumer surplus by using ΔTub_{ijm} as the difference in user benefits between a situation without (tub_{ijm}^0) and with a project (tub_{ijm}^1):

$$\Delta CS_{ab} = \sum_i \sum_j \sum_m \left(T^*_{ijm} \Delta Tub_{ijm} - \frac{1}{\beta} \Delta T_{ijm} \right) \qquad (10)$$

where T^*_{ij} denotes the average number of trips between situations 0 and 1. The user benefits in Equation 9 are composed of the benefits of trip distribution, measured by a pseudo-rule of a half, and a macro-level correction to account for the benefits of an aggregated trip generation effect. The latter relaxes the overall constraint in the entropy framework, where total trips, trip origin and destinations are exogenously defined in each situation, and where these are relevant in the long term, when the total number of activities (O_i or D_j) changes in a study area as the result of a project.

Furthermore, by using ΔTub_{ij} instead of the difference in generalised costs, CS_{ab} avoids the linear approximation of benefits embedded in the standard rule of a half measure (Martínez and Araya, 2000b). Martínez and Araya (2000a) show that CS_{ab} correctly measures total user benefits accruing from accessibility changes when used within a land-use/transport interaction framework. The authors state that the use of an integrated land-use/transport interaction model that properly forecasts land-use transport feedback mechanisms is an important condition. See "The land-use component of accessibility" section for a more detailed discussion of this issue.

Utility-based accessibility measures

This (random) utility perspective on accessibility is founded on the economic utility theory of choice behaviour (e.g. Burns and Golob, 1976; de Jong et al., 2007; Geurs et al., 2010b). The focus is on analysing the welfare benefits that people derive from levels of access to the spatially distributed activities. Probably the most well-known random utility measure is the logsum measure derived from the multinomial logit model. Publications on the logsum as a measure of consumer surplus (the difference between the market value of a good or service and the value for the user) date back to the early 1970s.

The term "logsum" refers to the log of the denominator of this logit choice probability, i.e. the sum of exponentially transformed utilities of the alternatives in a choice set. It gives the expected maximum utility associated with a traveller's choice set. This is simply the outcome of the mathematical form of the extreme value distribution associated to the logit model. Logsum accessibility can be expressed in monetary terms, defined as the utility in money terms, that a person receives in the choice situation (also taking account of the disutility of travel time and costs). Person n chooses the alternative that provides the highest utility, so that, provided that utility is linear in income, the accessibility benefit can be calculated in money terms, multiplying the logsum by the inverse of the marginal utility of income. Usually, a price or cost variable enters the representative utility and, in case that happens in a linear additive fashion, the negative of its coefficient is αn by definition.

$$A_n = (1/\alpha_n)\ \ln \sum_{j=1}^{J^1} e^{V_{nj}} \qquad (11)$$

The change in consumer surplus for decision maker n is calculated as the difference between $E(CS_n)$ under the conditions before the change and after the change (e.g. introduction of policy):

$$\Delta E(CS_n) = (1/\alpha_n)\ [\ \ln (\sum_{j=1}^{J^1} e^{V^1{}_{nj}}) - \ln (\sum_{j=1}^{J0} e^{V0_{nj}})] \qquad (12)$$

The (1/α) factor is the trade-off between accessibility and money. When α is low, so that (1/α) is high, the weight of the price in the underlying utility function is low which implies a high willingness to pay for accessibility improvements, implying a high economic value of a given accessibility increase. Note, that there is also a clear link between the gravity-based formulation (Equation 6) and the logsum formulation

(Equation 11), i.e. the logsum measure is similar to the natural logarithm of the potential accessibility measure.

The logsum has several advantages as an accessibility measure. Firstly, it provides a closed form expression for accessibility well founded in discrete choice theory (Ben-Akiva and Lerman, 1985) and consumer surplus theory (McFadden, 1981). This gives the logsum a robust theoretical underpinning. Secondly, it directly measures the expected utility derived from accessibility which allows integration into a Cost-Benefit Analysis (CBA) framework. The logsum provides an elegant and convenient means of measuring the full direct accessibility benefits from land-use and/or transport policies (Geurs et al., 2010a). Secondly, the strength of the logsum lies in the variety of attributes of the alternatives that it can encapsulate within a single term. The logsum is derived from the MNL specification and the specification of the discrete choice models is flexible. This flexibility allows accessibility models to be extended to include perceptions of transport attributes, if these are to be incorporated in the utility definition. Thirdly, logsums are first calculated for each individual decision maker in the sample, and then aggregated over groups of decision makers. This has the advantage that various population segmentations can be used. In most cases, segmentation depends on the segmentation used for the time or cost coefficients used later on to convert from the utility scale to money or time. A common segmentation for the logsum calculations and outputs is by travel purpose (de Jong et al., 2007).

However, the number of applications remains limited. The logsum measure is not often used in practical applications (de Jong et al., 2007). One example is found in Niemeier (1997), who analysed mode-destination accessibility for home-to-work trips in Washington State. Niemeier uses the logsum to evaluate "compensating variation'; the amount an individual would have to be compensated to be as well off as he or she was before a policy change. Another example is Geurs, de Bok and Zondag (2010a; 2012) who analysed the accessibility benefits of integrated spatial planning and public transport investments in the Netherlands within a land-use/transport interaction framework. Although the logsum allows a direct integration with economic appraisal (CBA), there are only a few examples where the logsum has been applied in the cost-benefit analysis of transport projects. Examples of applications using a land-use/transport interaction framework in economic appraisal of rail investments are described by Geurs, de Bok and Zondag (2012) and Zondag et al. (2015). However, in the official CBA report (Zwaneveld et al., 2009), the standard rule of a half measure and a stand-alone regional transport model was used to measure consumer surplus, as these methods are prescribed in Dutch national CBA guidelines. Beria, Bertolin and Grimaldi (2018) provide a recent example of a CBA of transport scenarios with investments in bicycle and public transport infrastructure, speed limits and road pricing in Milan.

Person-based accessibility measures

Person-based accessibility measures involve analysing accessibility at an individual level, i.e. the activities in which an individual can participate at a given time. This type of measure is founded in space-time geography (Hägerstrand, 1970). Person-based measures recognise that activity participation has both spatial and temporal dimensions, that is, activities occur at specific locations for finite temporal durations (Miller, 1999). Person-based measures express personal accessibility in terms of the space-time feasibility of opportunities to an individual using the volume of the (three-dimensional) space-time prism (or potential path space, PPS) or the number of opportunities in its projection on planar space (potential path area, PPA) as indicators. They are person-specific measures that provide a framework for incorporating the spatial configuration of the transport system, spatial distribution of urban opportunities, and individual spatial and temporal constraints into a single measure of accessibility (Kwan, 1998). In the early 1990s, methods were developed to estimate person-based measures using GIS procedures.

Hybrid approaches between utility-based and person-based accessibility have also been developed. Miller (1991) developed a utility-based space-time accessibility measure representing an individual's benefit to perform an activity in space and time. Dong et al. (2006) and Neutens et al. (2010) developed similar approaches rooted in utility-maximisation theory, estimating logsums within a space-time framework, expressing the individual's expected maximum utility over the choices of all available activity patterns. These measures provide a very comprehensive user benefit measures, moving away from the trip-based to activity-based approaches. However, person-based approaches have not found its way into the economic appraisal and transport planning practice. Despite years of development, activity-based models are still in their infancy (Timmermans and Arentze, 2011) and not many activity-based models are used in the transport planning practice, with some exceptions in the United States (Bhat et al., 2013; Bradley, Bowman and Griesenbeck, 2010). However, there is little evidence of applications of activity-based models in transport project appraisal.

The state of play

Many researchers have focused on the improvement of one or more components of accessibility, depending on their disciplinary background. In the literature, various methods have been developed to estimate accessibility benefits within the four different approaches to accessibility: infrastructure-based, location-based, person-based and utility-based accessibility measures.

The first, and most applied, accessibility benefit measure is the rule of a half. The main advantage of the rule of a half approach is that it is a transparent (in simple situations), fairly intuitive measure and, therefore, relatively easy to explain to non-experts. However, the rule of a half only gives a good approximation of Marshallian consumer surplus when the change in (generalised) cost can be regarded as marginal and land-use changes do not occur.

A second group of accessibility benefit measures follows from derivations of spatial interaction models and gravity models from microeconomic theory. Several user benefit measures have been developed in the literature. These measures have underpinnings in economic theory as there are theoretical links between potential accessibility, spatial interaction (entropy) models and discrete choice models. Accessibility benefit measures have been developed based on the gravity model and the balancing factors of the doubly-constrained spatial interaction model. These user benefit measures have overall constraint from the entropy framework that total trips, trip origin and destinations are exogenously defined in each situation, and land use is assumed not to be affected by the transport investments which are examined. However, user benefit measures have also been developed relaxing this overall constraint.

A third group of user benefit measures is rooted in random utility framework. A well-known random utility measure is the logsum measure derived from the multinomial logit (MNL) model. It provides a closed form expression and provides an exact measure of user benefits and assumes a non-linear demand function (in contrast with the standard rule of a half measure). A major strength of the logsum lies in the variety of attributes of the alternatives that it can encapsulate within a single term.

Finally, hybrid approaches between utility-based and person-based accessibility have also been developed. Miller (1991) developed a utility-based space-time accessibility measure representing an individual's benefit in performing an activity in space and time. Dong et al. (2006) and Neutens et al. (2010) developed similar approaches rooted in utility-maximisation theory, estimating a logsum within a space-time framework, expressing the individual's expected maximum utility over the choices of all available activity patterns. These mechanisms provide a very comprehensive user benefit measure, moving away from trip-based to activity-based approaches.

The most simple accessibility benefit measure, the rule of a half measure, based on outputs from stand-alone transport demand models seems to dominate the economic appraisal practice. This can probably be partly explained by the complexity of the transport demand model needed to estimate more comprehensive accessibility benefit measures, and the presence of national or regional CBA guidance's which focus on - or prescribe - the use of the rule of a half method. More comprehensive and theoretically more attractive approaches to measuring accessibility benefits have major difficulties finding their way into the economic appraisal and transport planning practice.

Accessibility and transport appraisal: The limitations of current practice

This section looks at some of the main limitations in the current practice of assessing and valuing accessibility. As a starting point, the four basic components of accessibility distinguished in the paper from Geurs and Van Wee (2004) are used:

1. the land-use component reflecting the amount, quality and spatial distribution of opportunities
2. the transport component describing the disutility of travel in terms of time, cost and effort
3. the temporal component reflecting the temporal constraints and variability
4. the individual component reflecting the preferences, needs and abilities of individuals.

Firstly, some of the limitations of these four components of accessibility are analysed. This is followed by a discussion of two topics which affect multiple components of accessibility: the influence of digitalisation on accessibility, which potentially has an impact on all four components of the concept of accessibility, and research on equity which has revolved around the concepts of accessibility. The final section reviews the role of accessibility in appraisal methods (CBA and MCA).

The land-use component of accessibility

The land-use component reflects the land-use system, consisting of: 1) the amount, quality and spatial distribution of opportunities supplied at each destination (jobs, shops, health, social and recreational facilities, etc.), 2) the demand for these opportunities at origin locations (e.g. where inhabitants live), and 3) the confrontation of supply and demand for opportunities, which may result in competition for activities with restricted capacity such as job and school vacancies and hospital beds. Advances in geospatial technology, internet technology and growing abundance of detailed spatial data allowed accessibility researchers in the past years to develop indicators at a high spatial resolution, and web-based mapping and applications that use internet technologies to retrieve detailed information about local amenities (Páez et al., 2013). However, related to accessibility benefit measurements, there are limitations in the treatment of land use and transport interactions and the treatment of the choice set.

Land use and transport interactions

Despite the higher level of detail in the treatment of the land-use component, there remains a lack of attention for the dynamic relationship between land use and transport in accessibility modelling and transport appraisal. This is despite the fact that the two-way interaction between transport and land use has been one of the central research topics of transport studies (Banister and Berechman, 2001) and many land-use/transport interaction (LUTI) models have been developed around the globe (see for overview Chang, 2006; Waddell, 2011).

Early literature on user benefit measures already pointed out issue of land use and transport interactions. The rule of a half measure of consumer surplus assumes that all accessibility benefits accruing to economic agents can be attributed to generalised cost changes within the transport system. If there is an implied change in the "destination" utility, then a failure to include this to include this will invalidate the approximation. The rule of a half results in incorrectly-measured welfare effects of land-use policy plans (Neuburger, 1971) and of transport strategies that lead to land-use changes (Bates, 2006; Geurs et al., 2010b; Geurs, Van Wee and Rietveld, 2006; Simmonds, 2004). User benefit measures based on the spatial interaction (entropy) framework also have the same problem as trip origin and destinations are exogenously defined in each situation. To capture these benefits, a method is needed that not only values the changes in generalised costs, but also values accessibility benefits due to changes in location and the relative attractiveness of location. Different approaches have been investigated in the literature.

Martínez and Araya (2000a) developed a user benefit measure (Equation 10) composed of the benefits of trip distribution, measured by a pseudo rule of a half, and a macro-level correction to account for the benefits of an aggregated trip generation effect which relaxes the overall constraint in the entropy framework. The authors show the user benefit measure correctly measures total user benefits accruing from accessibility changes when used within a land-use/transport interaction framework. The authors state that the use of an integrated land-use/transport interaction model that properly forecasts land-use/transport feedback mechanisms is an important condition.

Bates (2006) suggests one approach to evaluation of user benefits in land-use/transport planning is therefore to add to the conventional transport benefits an evaluation of changes in attraction, and an evaluation of changes in location, both measured in terms of transport generalised cost and, if necessary, deduced from the otherwise unexplained changes in travel patterns. The attraction and location benefits will be measures of net benefit to users.

Zondag et al. (2015) developed a quasi-dynamic land-use and transport interaction model, in which the Dutch National Model System, the main transport model used in Dutch national transport policy making and evaluation, is fully integrated in the modelling framework. Accessibility modelling and evaluation are disaggregated and fully consistent. Logsum accessibility measures estimated by the transport model are used as explanatory variables for the residential and firm location modules and as indicators in policy evaluations, expressing accessibility benefits in monetary terms. The logsum also captures accessibility benefits due to changes in location and the relative attractiveness of locations. Geurs, de Bok and Zondag (2012) describe an application within the framework of an economic appraisal of railway investments and show that even modest changes in location choices resulting from railway link investments can have significant effects on accessibility benefits for train users.

Option value and motility

The valuation of accessibility in the entropy and random utility frameworks is derived from travel demand. An accessibility measure based on utility will reflect observed behaviour and not the benefit of having increased choices (Morris, Dumble and Wigan, 1979). The logsum is defined as the expected maximum utility associated with a traveller's choice set. The "expected" relates to the imperfect knowledge of the analyst, not the traveller. As such, he or she does not know for sure which alternative will be chosen, and what will be the exact utility associated the chosen alternative. At least implicitly, this definition suggests that the utility a traveller experiences upon executing an alternative from the choice set is measured, which would indeed constitute an intuitive measurement of accessibility (Chorus and De Jong, 2011). This creates an important limitation of the logsum - only the utility of the choices made is counted. The only reason to include more options in the logsum than the alternative with the best utility performance is the stochastic element (reflecting imperfect knowledge of the analyst).

However, literature on the *option value* concept explains that people might value *options* that they have available (in this case: options to reach destinations, use modes or maybe even routes) that they do not use (Geurs, Van Wee and Rietveld, 2006; Laird, Geurs and Nash, 2009). This notion is also reflected in the first definition of accessibility given by Hansen (1959) as "the potential of opportunities for interaction". Van Wee and Geurs (2016) argue that the concept of the option value can be applied to accessibility and that the option value depends on characteristics of both the transport and the land-use system. Although there are a few papers in this area, our understanding of the usefulness of the option value for accessibility evaluations is still limited. Research will be needed to examine the value different groups of people and companies attach to which options to access specific destinations. For example, the added value of having six instead of two supermarkets within ten minutes from one's dwelling hardly adds value, but for jobs the decrease of utility of having more options available probably is much lower (Maat, van Wee and Stead, 2005). Metz (2008) argues that the value of the additional benefit from access to any particular kind of location would tend to decline as choice increases -a case of diminishing marginal utility. This is an area that needs more research. Empirical research can be done to, for example, test perceptions of the choice set desirability and the choice satisfaction.

Furthermore, the concept of *motility* could provide a new perspective to link mobility and accessibility. In sociology, the capacity of humans to be mobile in social and geographic space has been described with the term *motility*. Kaufman (Flamm and Kaufmann, 2006) operationalised the concept of motility in order to deal with the increase in the number of travel opportunities and complexity in travel patterns (e.g. due to household interactions, flexibility in job contracts) among a population and greater variety in individual travel behaviours. Motility is defined as having three elements fundamentally linked to social, cultural, economic and political processes and structures within which mobility is embedded and enacted:

- Access: defined by Kaufman as the range of possible mobilities, constrained by options (transport modes, spatial distribution of services, ICT) and conditions (e.g. cost, socio-economic position).
- Competence: i.e. skills and (physical) abilities that may directly or indirectly relate to access and appropriation.
- Appropriation: refers to how individuals, groups, networks, or institutions interpret and act upon perceived or real access and skills. Appropriation is shaped by needs, plans, aspirations and understandings of agents, and it relates to strategies, motives, values and habits.

Over and above realised travel, a person's motility can affect their wellbeing. Having access to many spatially-distributed opportunities and transport modes can generate feelings of freedom, competence and belonging. The access dimension of motility has been shown to be related to travel satisfaction and wellbeing. Abou-Zeid et al. (2012) examined the impact of free public transport passes on habitual car drivers in Switzerland and concluded that an increase in the possible ways of travelling can increase travel satisfaction. Transport disadvantages and not being able to be mobile have an indirect negative link with wellbeing, through social exclusion (de Vos et al., 2013).

The transport component of accessibility

The transport component describes the transport system, expressed as the disutility for an individual to cover the distance between an origin and a destination using a specific transport mode; included are the amount of time (travel, waiting and parking), costs (fixed and variable) and effort (including reliability, level of comfort, accident risk, etc.). This disutility results from the confrontation between supply and demand. The supply of infrastructure includes its location and characteristics (e.g. maximum travel speed, number of lanes, public transport timetables, travel costs). Several researchers have focused on a detailed treatment of transport impedance factors to improve accessibility estimations. Discrete choice models and accessibility estimations are typically based on travel time and travel cost variables.

Value of time and comfort

At the heart of the economic appraisal of a transport project is an assumption that any travel time saved during the working day represents a conversion of unproductive time to productive time thereby realising an economic value. As such, travel time is considered as a disutility or cost (Lyons, Jain and Holley, 2007). This concept of “value of travel time” originates from the theory of the allocation of time by Becker published in 1965 (Chiappori and Lewbel, 2015). However, the assumptions behind this approach may have been realistic in the 1960s, when the approach was adopted. They are evidently not appropriate to the 21st century.

Firstly, technological advances have for example made mobile working effective and wide spread. Studies in the United Kingdom indicate clearly that accounting for in-train working of business travellers reduces the economic value of time to 65% of the “existing wisdom” value (DfT, 2012). For many railway passengers the goal is to make the best use of their time. For commuting and business trips, a train journey typically has an obligatory character and these passengers tend to be task oriented toward attainment of functional goals during their journey (Van Hagen, Galetzka and Pruyn, 2014). Being able to engage in work-related activities such as reading and emailing during the train journey saves time at the destination, and creates value while travelling. Also for non-commuting trips (leisure, shopping, visiting friends, etc.), travel time is not “wasted” time either. However, little research is available on the degree to which different rail travellers take advantage of the journey to conduct tasks they would otherwise face at home or at the office. Travel time and activity time have been treated as separate notions, albeit with some assumed interdependencies. However, the research literature shows that people accept a significantly higher travel time when travelling by public transport compared to when travelling by car (Schwanen and Dijst, 2002), as part of the travel time can be productive and can create value of comfort (Warffemius et al., 2016).

Secondly, the value of travel time is not only related to actual time and money spent (objective time) but also to the value of the time as experienced by the passenger; the subjective or psychological value of time. Recent experiments showed that in-train travel time perceptions and travel experience can be influenced. Galetzka et al. (2017) examined the appraisal of time in different dimensions (cognitive appraisal, hedonic and utilitarian) using an online survey with video content and experiments with a mock-up compartment of an NS sprinter train. Showing entertaining or informative content on digital screens, hearing slow music in a clean environment or hearing fast music in an unclean environment afforded distraction from time and a more pleasant travel experience among railway passengers. Cascajo et al. (2019) examined user perceptions of transfers in multimodal trips and found that the provision of real-time passenger information helps reduce the perceived waiting time and transfers are also associated with mental effort and activity disruption, as travellers need to be alert when making a transfer and cannot continue in-vehicle activities such as reading, music, sleeping.

Thirdly, railway stations nowadays can perform a range of functions in society beyond the instrumental activity of facilitating the boarding of trains. In the Netherlands, several facilities have been added and improved in major railway stations over recent decades. Stations such as Utrecht CS, Rotterdam CS and Schiphol have transformed from being limited to their primary function as a transport node to also becoming a place for shopping, business meetings, eating, etc. This change implies that parts of train passengers' waiting time can be converted to productive time.

In the literature, there have been few studies measuring "perceived" accessibility attempting to incorporate latent constructs. Cheng and Chen (2015), for example explored the latent traits of urban travellers, including their perception of accessibility, mobility, and connectivity. Furthermore, discrete choice models can be extended to include perceptions of transport attributes, if these are to be incorporated in the utility definition. ''Soft'' latent variables and ''hard'' observed variables can be used together to explain choice in a random utility maximising choice model set-up. Ben-Akiva et al. (1999) proposed a choice modelling framework to include psychological factors in integrated choice and latent variable (ICLV) models, also called a hybrid choice model. This approach has become a rapidly growing field of study that integrates latent psychological constructs such as attitudes and preferences within traditional choice models (Bhat and Dubey, 2014). Applications of hybrid choice models in mode choice studies show that inclusion of latent variables (including satisfaction with travel) result in a superior model fit (Yáñez, Raveau and Ortúzar, 2010). La Paix Puello and Geurs (2016) are probably the first who estimate hybrid choice models to include latent variables in the impedance function of access mode choice of train stations.

It appears, however, that these new developments in the choice modelling domain have not resulted in the development of new accessibility benefit measures and have not found their way into transport project appraisal. To date, logsum measures have been derived from multinomial logit models, and not more complex models with unobserved taste variation (mixed logit) or ICLV models. However, de Jong et al. (2005) state that a "mixed" logsum is theoretically justified, building on work by McFadden and Train (2000) which showed that any random utility model can be approximated by a random mixture of multinomial logit models and that calculations using the model can then be made by drawing from the mixing distribution. If each such draw from the mixing distribution is considered as representing a small fraction of the population, then for that small fraction the logsum can be calculated and by integrating over the mixing distribution it is possible to obtain a population value. Thus if an unobserved taste variation is represented in the model by using mixed logit models, then the "mixed logsum" is a valid construct and is justified on the same basis as the simple logsum.

The temporal component of accessibility

A third and growing field of accessibility modelling is related to temporal dynamics in accessibility. The temporal component reflects the temporal dynamics in transport impedances and temporal constraints of individuals such as the availability of opportunities at different times of day and the time available for individuals to participate in certain activities (e.g. work, recreation). A growing field of accessibility modelling is related to temporal dynamics in accessibility. In the recent past, mainstream accessibility models were 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, nowadays, time-of-day variations in road network accessibility can be examined using real-time 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; Moya-Gómez and Geurs, 2018). Moya-Gómez and Geurs show that dynamic accessibility models are useful instruments to examine the accessibility impacts of dynamic traffic management strategies, which nowadays are an important part of increasing road infrastructure capacity or rescheduling education/job schedules, which is of interest to smooth journey flow values.

Recent advances in geospatial technology, open source web-based mapping (e.g., OpenStreetMap) and public availability of Transit Feed Specification (GTFS) data from transit authorities gives also room for a growing field of research on time-of-day variations in public transit accessibility (Owen and Levinson, 2015; Pritchard, Stępniak and Guers, 2019a; Stępniak et al., 2019)

In particular there is a need for more research on the interactions between the temporal component, transport, individual and land-use components of accessibility. For example, low-skilled workers are in many cases unable to commute by public transport to work sites (industry, distribution centres etc.) early morning, in the evening or at night.

The individual component of accessibility

Assessing and valuing accessibility at the individual level is at the heart of both utility-based and person-based accessibility perspectives, where person-based measures focus on the limitations on an individual's freedom to move around in time and space. As noted, broader psychological and sociological perspectives focus on needs and capabilities rather than wants (which relate to preferences for ways to satisfy needs), which are the main focus of microeconomic theories.

Over the past decade, studies have started analysing the link between travel and (subjective) wellbeing, mainly focusing on the positive utility of travel, possible effects of travel on life satisfaction (e.g. through activity participation) and aspects explaining people's satisfaction levels with travel, such as travel mode choice and trip duration (Chatterjee et al., 2019). In particular, commuters typically experience negative satisfaction level and longer commuting times are associated with lower life satisfaction. Chatterjee et al. conclude from a literature review that mood is lower during the commute than other daily activities and stress can be induced by congestion, crowding and unpredictability. Research in the United Kingdom also indicates that each successive minute of travel decreases the level of life satisfaction. Average mood levels significantly drop after 15 minutes of commuting and life satisfaction after more than 45 minutes. In general, commuting times between 60 and 90 minutes are most detrimental to subjective wellbeing levels. Satisfaction decreases with duration of commute, regardless of mode used, and increases when travelling with company. It is found that longer commute times are associated with lower job and leisure time satisfaction, increased strain and poorer mental health (Clark et al., 2019). Some studies have indicated that the relationship between commuting time and subjective wellbeing is non-linear. In addition, based on a "Happiness indicator" survey in the Netherlands, Lancée, Veenhoven and Burger (2017) find that it is not the commuting time *per se* that depresses the mood, but specific combinations of commuting time and commuting mode. Increasing commuting times can even lead to an uplift of mood when the commute is by bike or foot. Chatterjee et al. state that people who walk or cycle to work are generally more satisfied with their commute than those who travel by car and especially those who use public transport.

However, the role of travel satisfaction in accessibility estimations and valuations has not yet been fully explored. Moreover, people’s experience of travel might also affect interactions between the different components of accessibility, as travel attitudes can influence travel behaviour and residential location choice.

Accessibility, digitalisation and appraisal

Furthermore, digitalisation and technological advances are changing the way people move, communicate, socialise, work, or shop. Access to destinations generally is not a goal in itself, but aims to allow people to carry out activities. Some of those activities have electronic substitutes, examples being e-working, e-shopping and information and communication technology (ICT) supported personal contact such as Skype meetings.

To some extent electronic activities can be substitutes for location-based activities and even if they are not, they can replace other activities. Many people are spending increasing amounts of time on line and in multiple ways (PC, laptop, tablet, smartphone, etc.). ICT-based activities have become a more regular part of life. Consequently accessibility in general and accessibility measures in particular should recognise the importance of ICT. Although there are several studies linking ICT and accessibility, there are hardly any attempts to fully integrate ICT and accessibility. Van Wee, Geurs and Chorus. (2013) give an overview of the literature in this area concluding that ICT potentially has an impact on all four components of accessibility: digitalisation affects activity and location decisions, transport impedance and user preferences, and the impacts differ between digitally skilled and unskilled individuals. Literature does exist on the direct impact of ICT on accessibility, but fails to incorporate the impacts due to the interactions between the accessibility components. Van Wee et al concluded that indicators need to include ICT's impact on accessibility, at least for some applications. But the literature on how this could or even should be done, is still in its infancy.

Furthermore, digitalisation and technological advances are rapidly changing the way people move, communicate, socialise, work, or shop. The ride-sharing market is growing and car makers are already offering mobility services. This trend has encouraged sharing businesses, especially in the transportation sector with shared mobility (Zipcar, Car2go, emov, WiBle, ZITY, Cabify, Blablacar, Uber, or e-cooltra). Moreover, there are hundreds of bike-sharing schemes around the globe and app-based micromobility services (e.g. Lime and Bird) have recently emerged in cities in and beyond Europe. In Paris, for example, 12 electric scooter companies operate across the city with many as 20 000 electric scooters in operation. Today there are more than 60 000 travel apps available at Google Play and these options are growing daily.

This evolving landscape of transport options increases the need for more advanced accessibility models and appraisal methods. The inclusion of new transport options adds complexity to transport and accessibility models. The introduction of “new modes” (or, more generally, new alternatives within a discrete choice framework) remains a difficult area and the problems relate both to demand modelling and evaluation issues (Bates, 2006). For evaluation, the problems occur when an option which is available in the before case is not available in the after case, or vice versa. For example, the rule of a half cannot be used in those instances where large changes in cost take place, which is always the case when the availability of options changes.

Consequently, there is a lack of knowledge on how to include shared modes (car sharing, bike sharing), cycling and modal integrations (Mobility-as-a-Service) in accessibility indicators. Moreover the diffusion of new transport products is inherently a social process. However, these classic choice models assume that individuals are rational and maximise their utility by always making an independent choice. Ajzen’s Theory of Planned Behaviour (TPB), used as a point of departure in many mode choice studies, states that behavioural intentions are shaped by attitudes, subjective norms and perceived behavioural control. The connection between social influence and travel behaviour has been increasingly studied in transport research (e.g. Maness, Cirillo and Dugundji, 2015). Recently, Manca, Sivakumar and Polak (2019) used stated preference (SP) data on shared mobility services (shared taxi and bike sharing) to estimate mixed logit models, including the effects of social norms and social interactions.

Equity and distributive justice

The tension between efficiency and equity has been the focus of major debate since equity aspects started to be considered as part of project evaluation procedures (Thomopoulos, Grant-Muller and Tight, 2009). Accessibility indicators have also already been discussed as equity indicators for decades. For example, Wachs and Kumagai (1973) already proposed a cumulative opportunity index to measure employment accessibility for different population segments (by income and employment class) as a social indicator to measure the quality of urban living. Equity analysis using accessibility indicators is however not straightforward. Firstly, the term is often not well defined and fairness and justice are usually used interchangeably depending on the context. Secondly, accessibility equity analysis can be difficult because there are several types of equity and various ways to define and estimate accessibility and categorise people for equity analysis, numerous impacts to consider, and various ways of measuring these impacts.

To examine inequalities, statistical index indicators that express levels of (in)equity are often used. In recent years, attention to more comprehensive approaches to measuring social equity has been growing, such as the “Capabilities Approach”, focusing on an individual’s opportunities for travel and participation in activities, and “Motility”, focusing on the capacity to engage in travelling and the intrinsic value of travel experiences. Several authors have discussed how to measure accessibility by using social justice principles (Golub and Martens, 2014; Hananel and Berechman, 2016; Lucas, van Wee and Maat, 2016; Martens, Golub and Robinson, 2012; Martens, 2012; Pereira, 2018). However, it goes beyond the scope of this section to provide a comprehensive overview of this aspect.

The Gini index is widely accepted as a statistical measure of inequality, often focusing on distribution of income over the population of a country. The Gini index varies between 0 and 1, with higher coefficients representing higher levels of inequality. A major advantage of the Gini index over other equality indices is that it is scale independent (insensitive to changes in measurement, such as currency or price year in the case of income). The Gini has been widely applied in transport analyses despite the interpretation for accessibility being fundamentally different from that of income due to units being counted more than once (Lucas, van Wee and Maat, 2015). The Palma ratio (Palma, 2011) is less used in transport research but is argued to more accurately reflect the societal picture by focusing on the extremes (Banister, 2018). Originally, the Palma ratio depicted the ratio of income shares between the richest 10% and the poorest 40% of the population, as Palma had found that the middle-income group generally accounts for half of the national income and has a relatively stable share over time (Banister, 2018). In a recent paper, Pritchard et al. (2019b) analysed the impact of different accessibility measures on the interpretation of associated equity analysis using the Gini coefficient and the (pseudo) Palma ratio. Two types of potential accessibility measures (zonal and person-based) and two ratios of potential jobs to potential population (intra-modal and multi-modal) are estimated for car and transit in the Dutch Randstad region, for Greater London and in São Paulo, relying on network data, schedule-based data and speed profiles. The conclusion was that the result of the equity analysis is heavily influenced by the accessibility indicator and the method of assignment.

Van Wee and Geurs (2011) state that there are least three theories on ethics relevant for evaluating the social justice of inequalities in accessibility: utilitarianism, egalitarianism and sufficientarianism. Utilitarianism is strongly related to CBA: a CBA lists all the pros and cons as much as is possible in monetary terms and compares alternatives using indicators such as benefits minus costs, benefit to cost ratio, and return on investments. Choices of travellers are based on their willingness to pay for travel options. As a point of departure this makes sense and is consistent with the utility-based framework of CBA. However, monetising utility-based measures is problematic. Low incomes are often the very reason to be social excluded, and willingness to pay of low-income persons for (additional) travel is inherently low because they need all their income for housing, food, clothing and medical services, leaving very little income for travel. For example, when monetising the logsum measure (Equation 11), the marginal utility of income (α) tends to decrease with income. If α is high for low-income households then the ($1/\alpha$) factor makes the valuation of the accessibility increases for those groups low.

Lucas, van Wee and Maat (2016) state that although utilitarian framing can be useful for many areas of policy delivery, especially where the aim is to maximise the benefits of an investment for all members of society, it is not appropriate when there is a specific aim to achieve greater equity from that investment. They suggest that egalitarian and sufficientarian approaches more adequately justify policies that specifically aim to redistribute transport resources towards currently disadvantaged population groups and deprived areas.

Egalitarian theories focus on interpersonal differences in wellbeing, not on absolute levels of wellbeing. An important theory in this category is Rawls' "Theory of Justice" (1971). Pereira, Schwanen and Banister (2017) give an elaborate description of Rawls' theory and Lucas, van Wee and Maat (2016) conclude that egalitarian theories are particularly useful to legitimate policies that aim for equality of accessibility.

The "Capability Approach" shares both egalitarian and sufficientarian concerns (Pereira, Schwanen and Banister, 2017). The application of the capability approach to transport policy raises challenges. Pereira, Schwanen and Banister (2017) state that understanding accessibility in capability terms couples accessibility needs with the idea of social rights insofar as some minimum level of accessibility is necessary for the satisfaction of an individual's basic needs and a necessary, though not sufficient, condition for people to exercise basic rights such as going to school, receiving health care and voting in elections. It certainly requires the identification of the minimum acceptable thresholds of accessibility to key activities and demands government initiatives to guarantee the accessibility needs of people who fall below those thresholds. The identification of such minimum thresholds remains an unresolved challenge in academic literature. An example of an operational criterion could be that households should have a shop selling food within reach of a certain non-care based travel time interval. If certain minimum levels of accessibility of destination categories are to be included, what are the minimum levels? Should meeting these levels be included as a 0-1 variable, or should a form of distance decay or other weighting be added? How should access to different destination types be compared? Can access to different destination types (work, health, shops etc.) be aggregated, and if so, how? In a recent paper, Lucas et al. (2016) used a Gini index based on a "cluster accessibility index" measuring the shortest distances from home locations to a set of primary services, and a cumulative accessibility indicator as a sufficientarian index.

In a practical way, accessibility measures can be easily used as input for statistical equity indicators (such as Gini coefficients and the Palma ratio) and spatial equity approaches examining modal equity or differences in the spatial distribution of accessibility can easily be included in transport project appraisal. However, more comprehensive approaches to measuring social equity should be explored. Further research is needed to discuss which accessibility measures are conceptually consistent with different ethical frameworks and to discuss the challenges of building more comprehensive accessibility measures that go beyond the limits imposed by data conventionally used in transport surveys (Pereira, Schwanen and Banister, 2017).

Accessibility measures in appraisal frameworks

A final, but important, issue is to link accessibility evaluations to appraisal frameworks, such as Cost-Benefit Analyses (CBA) and Multi-Criteria Analyses (MCA) (van Wee, 2016). If accessibility evaluations are part of a wider evaluation framework the choice of indicators will depend on the choice of the framework. Within the context of a CBA, utility-based measures have a big advantage, both theoretically and practically, because they are consistent with microeconomic theory and can be calculated relatively easily using existing transport models.

However, transport and accessibility appraisal should be broader than CBA and the utilitarian perspective for aggregating costs and benefits. Appraisal should cater for a multidisciplinary perspective on the transport system, based on insights and theories from economics, psychology, sociology and geography. For example, psychological theories study opportunities, abilities and skills and also consider the impact of other people (social norms) on behavioural choices, which are important when studying transitions in the transport system (e.g. digitalisation as discussed earlier). Sociological theories, in particular the motility concept, can be helpful to move beyond the valuation of observed behaviour to the value of opportunities for interaction, i.e. the value of accessibility. Ethical theories (including egalitarianism and sufficientarianism) can be further explored to enrich our understanding of the social justice implications of transport projects and policies. In the literature, accessibility measures can and have been linked to this broad set of theories and perspectives.

An MCA is more flexible than a CBA and can relatively easily incorporate a variety of accessibility measures. In a practical way, accessibility measures (and in particular potential accessibility) can be easily used as input for statistical equity indicators (such as Gini coefficients and the Palma ratio) and spatial equity approaches and can be included in an MCA. An MCA can in some cases also explicitly show implications for different actors or actor categories as in the case of the Multi Actor Multi Criteria Analyses (MAMCA) developed by Macharis (Macharis and Baudry, 2018; Macharis, Turcksin and Lebeau, 2012). Broadening transport appraisal from a CBA to an MCA or a MAMCA will thus provide a practical way forward. However, what is poorly understood are the preferences of decision makers and clients of accessibility analyses in general and of MCA and CBA clients in particular. Researchers could study their preferences for indicators, as well as their inclusion in wider evaluations, particularly MCAs (van Wee, 2016).

The future of transport appraisal practice

This section has described a number of limitations in current transport appraisal practices. To overcome these limitations, theoretical and empirical research is necessary in several areas. In the short term, the current approach to transport appraisal could be improved by adopting a broader perspective on accessibility measurement and valuation, and better utilising existing comprehensive modelling tools.

Current appraisal practices utilising transport demand models focus on measuring the utility related to observed behaviour and not the benefit of having increased choices. There is a need for further development of accessibility benefit measures which consider the benefits of increased choices and opportunities for spatial interaction, linked to the concepts of option value and motility.

There remains a lack of attention to the dynamic relationship between land use and transport in accessibility modelling and transport appraisal. However, to capture the full accessibility benefits, not only changes in generalised costs, but also accessibility benefits due to changes in location and the relative attractiveness of a location need to be taken into account.

There is a need to move beyond travel time and cost savings as the main component of accessibility modelling and appraisal. In the travel behaviour literature, methods have been developed to use both ‘‘soft’’ latent variables and ‘‘hard’’ observed variables together to explain choice in a random utility maximising choice model set-up, but these concepts are hardly used in accessibility studies.

Much research has been done in recent years to incorporate the temporal component into accessibility, utilising real time data, but there is a lack of attention to the interactions between the temporal, transport, individual and land-use components of accessibility.

The role of travel satisfaction and wellbeing can be explored in accessibility studies. Also, research on digitalisation and accessibility is still in its infancy, but the growing landscape of transport options increases the need for more advanced accessibility models and appraisal methods.

Transport and accessibility appraisal should reflect the multidisciplinary nature of transport and be broader than a CBA and the utilitarian perspective to aggregate individual costs and benefits. An MCA is more flexible than a CBA and can relatively easily incorporate a variety of accessibility and equity measures.

Conclusions

In recent decades accessibility research has flourished due to a growing abundance of spatial and transport data. The rich body of literature on this topic is largely application-driven. The development of more comprehensive accessibility measures has not yet found its way into transport appraisal. Moreover, there has been little attention to theoretical and applied research on the measurement of accessibility benefits.

In the literature, several accessibility benefit measures have been derived from spatial interaction models, gravity models, random utility models and activity-based models. However, in practice, the rule of a half measure is used in economic appraisal, based on outputs of stand-alone multimodal transport demand models. The rule of a half approach has strong limitations in transport appraisal, but its appeal is that it is transparent (in simple situations), fairly intuitive and relatively easy to explain to non-experts. Also, several countries provide appraisal guidance which focuses on - or prescribes - the use of rule of a half method.

The current practice of transport appraisal can be improved if a broader perspective on accessibility measurement and valuation is taken and existing comprehensive modelling tools are better utilised, including land-use/transport interaction models. There is a need for more research in several areas to broaden the valuation of accessibility. Firstly, is a need for further development of accessibility benefit measures, which consider the benefits of increased choices and opportunities for spatial interaction, linked to the concepts of option value and motility. Secondly, there is a need to move beyond travel time and cost savings as the main component of accessibility modelling and appraisal. In the travel behaviour literature, methods have been developed to use both ‘‘soft’’ latent variables and ‘‘hard’’ observed variables together to explain choice in a random utility maximising choice model set-up, but these concepts are to date not used in accessibility studies. Thirdly, there is a lack of attention to the interactions between the temporal, transport, individual and land-use components of accessibility. Fourthly, the role of travel satisfaction and wellbeing but also digitalisation on accessibility needs to be further explored. Fifthly, more research is needed to develop approaches to measuring accessibility which are conceptually consistent with different ethical frameworks and then include these in transport appraisal. Finally, Multi-Criteria Analyses (MCA) and multi-actor MCAs seem a practical way forward to improve the inclusion of accessibility measurement and valuation in appraisal frameworks. This can broaden the scope of transport appraisal to cater for a multidisciplinary perspective on the transport system based on insights and theories from, amongst others, economics, psychology, sociology and geography.

References

Abou-Zeid, M. et al. (2012), "Happiness and travel mode switching: Findings from a Swiss public transportation experiment". *Transport Policy*, 19(1), 93-104.

Anas, A. (1983), "Discrete choice theory, information theory and the multinomial logit and gravity models". *Transportation Research Part B: Methodological*, 1983, vol. 17, issue 1, 13-23

Banister, D. and Y. Berechman (2001)," Transport investment and the promotion of economic growth", *Journal of Transport Geography*, 9(3), 209-218.

Banister, D. (2018), "Inequality in transport". Alexandrine Press.

Bates, J. (2006), "Economic evaluation and transport modelling: theory and practice", *Moving through nets. The physical and social dimensions of travel. Selected papers from the 10th International Conference on Travel Behaviour Research*, K. W. Axhausen, ed., Moving Through Nets: The Physical and Social Dimensions of Travel.

Batty, M. (2009), "Accessibility: in search of a unified theory", *Environment and Planning B: Planning and Design*, 36, 191-194.

Ben-Akiva, M and SR. Lerman (1985), Discrete choice analysis: Theory and application to predict travel demand"". MIT Press, Cambridge MA.

Ben-Akiva, M. et al. (1999), "Extended Framework for Modeling Choice Behavior", *Marketing Letters*, 10(3), 187-203.

Beria, P., A. Bertolin and R. Grimaldi (2018), "Integration between Transport Models and Cost-Benefit Analysis to Support Decision-Making Practices: Two Applications in Northern Italy", *Advances in Operations Research*, 2018.

Bhat, C.R. and S. K. Dubey (2014), "A new estimation approach to integrate latent psychological constructs in choice modeling", *Transportation Research Part B: Methodological*, 67, 68-85.

Bhat, C.R. et al. (2013), "A household-level activity pattern generation model with an application for Southern California", *Transportation*, 40(5), 1063-1086.

Bradley, M., J.L. Bowman and B. Griesenbeck (2010), "SACSIM: An applied activity-based model system with fine-level spatial and temporal resolution", *Journal of Choice Modelling*, 3(1), 5-31.

Burns, L D. and T.F. Golob (1976), "The role of accessibility in basic transportation choice behavior", *Transportation*, 5(2), 175-198.

Cascajo, R. et al. (2019), "User perception of transfers in multimodal urban trips: A qualitative study", *International Journal of Sustainable Transportation*, 13(6), 393-406.

Chang, J.S. (2006), "Models of the Relationship between Transport and Land-use: A Review", *Transport Reviews*, Volume 26(Number 3), 325 - 350.

Chatterjee, K. et al. (2019), "Commuting and wellbeing: a critical overview of the literature with implications for policy and future research", *Transport Reviews*.

Chen, X. and P. Jia (2019), "A comparative analysis of accessibility measures by the two-step floating catchment area (2SFCA) method", *International Journal of Geographical Information Science*.

Cheng, Yung-Hsiang and Ssu-Yun Chen (2015), "Perceived accessibility, mobility, and connectivity of public transportation systems", *Transportation Research Part A: Policy and Practice*, 77, 386-403.

Chiappori, P.A. and A. Lewbel (2015), "Gary Becker's A theory of the allocation of time", *Economic Journal*, 125(583), 410-442.

Chorus, C.G. and de Jong, G.C. (2011), "Modeling experienced accessibility for utility-maximizers and regret-minimizers," Journal of Transport Geography, Elsevier, vol. 19(6), pp 1155-1162.

Clark, B. et al. (2019), "How commuting affects subjective wellbeing", *Transportation*.

de Jong, G. et al. (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.

de Jong, G. et al. (2005), *Using the logsum as an evaluation measure: literature and case study*, RAND Europe/SEO, Leiden.

de Vos, J. et al. (2013), "Travel and Subjective Well-Being: A Focus on Findings, Methods and Future Research Needs", *Transport Reviews*, 33(4), 421-442.

DfT (2019), *User and Provider Impacts, TAG Unit A1.3*, Department for Transport, London.

DfT (2012), *Productive use of rail travel time and the valuation of travel time savings for business travellers: final report*, Department for Transport, London.

Dong, X. et al. (2006), "Moving from trip-based to activity-based measures of accessibility", *Transportation Research Part A: Policy and Practice*, 40(2), 163-180.

Flamm, M. and V. Kaufmann (2006), "Operationalising the Concept of Motility: A Qualitative Study", *Mobilities*, 1(2), 167-189.

Galetzka, M. et al. (2017), *The pyschological value of time. Two experiments on the appraisal of time during the train journey*, European Transport Conference, Barcelona.

Geurs, K., M. de Bok and B. Zondag (2012), "Accessibility benefits of integrated land use and public transport policy plans in the Netherlands", *Accessibility Analysis and Transport Planning: Challenges for Europe and North America*, K. T. Geurs, K. Krizek, and A. Reggiani, eds., Edward Elgar, 189-216.

Geurs, K., M. de Bok and B. Zondag (2010a), "Accessibility benefit measurement of integrated land use and public transport investments: searching for synergies", Paper for the 58th North American Annual Meetings of the Regional Science Association International, November 11-13, Denver, USA.

Geurs, K. et al. (2010b), "Accessibility appraisal of integrated land-use/transport policy strategies: more than just adding up travel time savings", *Transportation Research Part D*, 15, 382-393.

Geurs, K.T., B. Van Wee and P. Rietveld (2006), "Accessibility appraisal of integrated land-use/transport strategies: methodology and case study for the Netherlands Randstad area", *Environment and Planning B: Planning and Design*, 33(5), 639-660.

Geurs, K.T. and 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.T. and J.R. Ritsema van Eck (2003), "Evaluation of accessibility impacts of land-use scenarios: the implications of job competition, land-use, and infrastructure developments for the Netherlands", *Environment and Planning B: Planning and design*, 30(1), 69 - 87.

Golub, A. and K. Martens (2014), "Using principles of justice to assess the modal equity of regional transportation plans", *Journal of Transport Geography*, 41, 10-20.

Hägerstrand, T. (1970), "What about people in regional science?", *Papers of the Regional Science Association*, 24, 7-21.

Hananel, R. and J. Berechman (2016), "Justice and transportation decision-making: The capabilities approach", *Transport Policy*, 49, 78-85.

Hansen, W.G. (1959), "How accessibility shapes land use", *Journal of American Institute of Planners*, 25(1), 73-76.

Hull, A., C. Silva and L. Bertolini (2012), *Accessibility Instruments for Planning Practice,* COST Office.

Joseph, A.E. and P.R. Bantock (1982), "Measuring potential physical accessibility to general practitioners in rural areas: A method and case study", *Social Science and Medicine*, 16(1), 85-90.

Koenig, J.G. (1980), "Indicators of Urban Accessibility: Theory and Applications", *Transportation 9*, pp. 145-172.

Kohli, S. and A. Daly (2006), "The use of logsums in welfare estimations: application in PRISM", *European Transport Conference 2006*.

Kwan, MP. (1998), " Space-Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point-based Framework. Geographical Analysis, Vol 30, No. 3, July 1998.

La Paix Puello, L.C. and K.T. Geurs (2016), "Integration of unobserved effects in generalised transport access costs of cycling to railway stations", *European Journal of Transport Infrastructure Research*, 16(2), 385-405.

Laird, J., Geurs, K. and C. Nash (2009), "Option and non-use values and rail project appraisal". Transport Policy. 16(4), 173–182 (2009).

Lancée, S., R. Veenhoven and M. Burger (2017), "Mood during commute in the Netherlands: What way of travel feels best for what kind of people?", *Transportation Research Part A: Policy and Practice*, 104(Supplement C), 195-208.

Linneker, B.J. and N.A. Spence (1992), "Accessibility measures compared in an analysis of the impact of the M25 London Orbital Motorway on Britain", *Environment and Planning A*, 24, 1137-1154.

Lucas, K., B. van Wee and K. Maat (2016), "A method to evaluate equitable accessibility: combining ethical theories and accessibility-based approaches", *Transportation*, 43(3), 473-490.

Lyons, G., J. Jain and D. Holley (2007), "The use of travel time by rail passengers in Great Britain", *Transportation Research Part A: Policy and Practice*, 41(1), 107-120.

Maat, K., B. van Wee and D. Stead (2005), "Land use and travel behaviour: expected effects from the perspective of utility theory and activity-based theories", *Environment and Planning B: Planning and Design*, 32, 33-46.

Macharis, C. and G. Baudry (2018), *Decision-Making for Sustainable Transport and Mobility. Multi Actor Multi Criteria Analysis,* Edward Elgar.

Macharis, C., L. Turcksin and K. Lebeau (2012), "Multi actor multi criteria analysis (MAMCA) as a tool to support sustainable decisions: State of use", *Decision Support Systems*, 54(1), 610-620.

Manca, F., A. Sivakumar and J.W. Polak (2019), "The effect of social influence and social interactions on the adoption of a new technology: The use of bike sharing in a student population", *Transportation Research Part C: Emerging Technologies*, 105, 611-625.

Maness, M., C. Cirillo and E.R. Dugundji (2015), "Generalized behavioral framework for choice models of social influence: Behavioral and data concerns in travel behavior", *Journal of Transport Geography*, 46, 137-150.

Martens, K., A. Golub and G. Robinson (2012), "A justice-theoretic approach to the distribution of transportation benefits: Implications for transportation planning practice in the United States", *Transportation Research Part A: Policy and Practice*, 46(4), 684-695.

Martens, K. (2012), "Justice in transport as justice in accessibility: applying Walzer's 'Spheres of Justice' to the transport sector", *Transportation*, 1-19.

Martínez, F.J. and C. Araya (2000a), "Transport and land-use benefits under location externalities", *Environment and Planning A*, 32(9), 1611-1624.

Martínez, F.J. and C. Araya (2000b), "A note on trip benefits in spatial interaction models", *Journal of Regional Science*, 40(4), 789-796.

Martínez, F.J. (1995), "Access: the transport-land use economic link", *Transportation Research Part B*, 29(6), 457-470.

McFadden, D. (1981), "Econometric models of probabilistic choice". In Manski, C. F. and McFadden, D., (1981), "Structural analysis of discrete data: With econometric applications", Cambridge, Massachusetts: MIT Press (pp 198–272).

McFadden, D. and K. Train (2000), "Mixed MNL models for discrete response". J Appl Econometrics 15: 447-470.

Metz, D. (2008), "The Myth of Travel Time Saving". Transport Reviews 28(3):321-336. https://doi.org/10.1080/01441640701642348.

Miller, H.J. (1991), "Modelling accessibility using space-time prism concepts within geographical information systems". International Journal of Geographical Systems, Vol. 5.

Miller, H.J. (1999), "Measuring Space-Time Accessibility Benefits within Transportation networks: Basic Theory and Computational Procedures", *Geographical analysis*, 31(2), 187-212.

Morris, J.M., P.L. Dumble and M.R. Wigan (1979), "Accessibility indicators for transportation planning", *Transportation Research A*, Vol. 13, pp. 91-109.

Moya-Gómez, B. and K.T. Geurs (2018), "The spatial–temporal dynamics in job accessibility by car in the Netherlands during the crisis", *Regional Studies*, 1-12.

Moya-Gómez, B. and 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).

Neuburger, H. (1971), "User benefits in the evaluation of transport and land-use plans", *Journal of Transport Economics and Policy*, 5(1), 52-75.

Neutens, T. et al. (2010), "Equity of urban service delivery: A comparison of different accessibility measures", *Environment and Planning a*, 42(7), 1613-1635.

Niemeier, D.A. (1997), "Accessibility: an evaluation using consumer welfare", *Transportation* 24, pp. 377-396.

Owen, A. and D.M. Levinson (2015), "Modeling the commute mode share of transit using continuous accessibility to jobs", *Transportation Research Part A: Policy and Practice*, 74, 110-122.

Páez, A. et al. (2013), "Developing a web-based accessibility calculator prototype for the Greater Montreal Area", *Transportation Research Part A: Policy and Practice*, 58(0), 103-115.

Palma, J.G. (2011), 'Homogeneous middles vs. heterogeneous tails, and the end of the 'Inverted-U': The share of the rich is what it's all about', Cambridge Working Papers in Economics 1111, Cambridge: University of Cambridge Department of Economics (later published in Development and Change, 42, 1, 87-153).

Pereira, R.H.M. (2018), *Distributive Justice and Transportation Equity: Inequality in accessibility in Rio de Janeiro,* University of Oxford, Oxford.

Pereira, R.H.M., T. Schwanen and D. Banister (2017), "Distributive justice and equity in transportation", *Transport Reviews*, 37(2), 170-191.

Pritchard, J.P., M. Stępniak and K.T. Geurs (2019a), "Equity analysis of dynamic bike-and-ride accessibility in the Netherlands (Chapter 4)", *Measuring Transport Equity*, K. Lucas, K. Martens, F. D. Ciommo, and A. D. Kieffer, eds., Elsevier, 73-84.

Pritchard, J.P. et al. (2019b), "An international comparison of temporal and spatial inequalities in job accessibility – London, Sao Paulo and the Netherlands Randstad Area", *Transport Findings*.

Raux, C., A. Mercier and N. Ovtracht (2008), "Economic Appraisal of transport policy and indicators of spatial accessibility: the contribution of GIS", (Evaluation économique des politiques de transport et indicateurs d‟accessibilité spatiale), *Cybergeo, Systèmes, Modélisation, Géostatistiques*, 435(11/12/2008).

Rawls, J. (1971), "A Theory of Justice". Belknap Press of Harvard University Press.

Reggiani, A., P. Bucci and G. Russo (2011), "Accessibility and impedance forms: Empirical applications to the German commuting network", *International Regional Science Review*, 34(2), 230-252.

Reggiani, A. (1998), "Accessibility, trade and location behaviour: an introduction", *Accessibility, Trade and Location Behaviour*, A. R. (Ed.), ed., Ashgate, Aldershot.

Rijkswaterstaat (2018), *Werkwijzer MKBA bij MIRT-verkenning (Guidance MKBA)*, Rijkswaterstaat, Ministerie van Infrastructuur en Milieu, Den Haag.

Romijn, G. and G. Renes (2013), *Algemene leidraad voor maatschappelijke kosten-batenanalyse*, CPB/PBL, Den Haag.

SACTRA (1999), *Transport and the Economy. The Standing Advisory Committee on Trunk Road Assessment*, Department of the Environment, Transport and the Regions, London.

Schwanen, T. and M. Dijst (2002), "Travel-time ratios for visits to the workplace: the relationship between commuting time and work duration", *Transportation Research. Part A: Policy and Practice*, 36(7).

Shen, Q. (1998), "Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers", *Environment and Planning B: Planning and design*, 25(3), 345-65.

Simmonds, D.C. (2004), "Assessment of UK land-use and transport strategies using land-use/transport interaction models", *European Journal of Transport and Infrastructure Research*, 4(3), 273-293.

Stępniak, M. et al. (2019),"The impact of temporal resolution on public transport accessibility measurement: Review and case study in Poland", *Journal of Transport Geography*, 75, 8-24.

Thomopoulos, N., S. Grant-Muller and M.R. Tight (2009), "Incorporating equity considerations in transport infrastructure evaluation: Current practice and a proposed methodology", *Evaluation and Program Planning*, 32(4), 351-359.

Timmermans, H. and T.A. Arentze (2011), "Transport Models and Urban Planning Practice: Experiences with Albatross", *Transport Reviews*, 31(2), 199-207.

Tressider, J.O. et al. (1968), "The London Transportation Study: methods and techniques", *Proceedings of the Institute of Civil Engineers*, 39, 433-464.

Van Hagen, M., M. Galetzka and A. Th. Pruyn (2014), "Waiting Experience in Railway Environments", *Journal of Motivation, Emotion, and Personality*, 2(2), pp. 41–55.

van Wee, Bert (2016), "Accessible accessibility research challenges", *Journal of Transport Geography*, 51, 9-16.

van Wee, B. and K.T. Geurs (2011), "Discussing equity and social exclusion in accessibility evaluations", *European Journal of Transport and Infrastructure Research*, 11(4), 350-367.

Van Wee, B., K. Geurs and C. Chorus (2013) "Information, communication, travel behavior and accessibility", *Journal of Transport and Land Use*, 6(3), 1-16.

van Wee, B. and K.T. Geurs (2016), "The role of accessibility in urban and transport planning". In Bliermer, M, Mulley, C and Moutou, CJ (Eds) "Handbook on transport and urban planning in the developed world". Edward Elgar, Northampton.

Wachs, M. and T.G. Kumagai (1973), "Physical accessibility as a social indicator", *Socio-Economic Planning Science*, 6, 357-379.

Waddell, P. (2011), "Integrated Land Use and Transportation Planning and Modelling: Addressing Challenges in Research and Practice", *Transport Reviews: A Transnational Transdisciplinary Journal*, 31(2), 209 - 229.

Warffemius, P. et al. (2016), *The value of comfort in train appraisal*, Paper for the European Transport Conference (ETC), held in Barcelona from 5-7 October 2016.

Williams, H.C.W.L. (1976), "Travel demand models, duality relations and user benefit analysis", *Journal of Regional Science*, 16(2), pp. 147-166.

Williams, HCWL and ML Senior (1978),"Accessibility, spatial interaction and the evaluation of land use transportation plans", in Spatial Interaction Theory and Planning Models Eds Karlqvist, A, Lundqvist, L, Snickars, F, Weibull, J W (North-Holland, Amsterdam) pp. 253-287.

Wilson, A. G. (1970), "Entropy in urban and regional modelling", London: Pion.

Wilson A G (1971) A Family of Spatial Interaction Models, and Associated Developments. Environment and Planning, Vol 3, No 1, pp 1-32.

Wilson, A. (2010), "Entropy in Urban and Regional Modelling: Retrospect and Prospect", *Geographical Analysis*, 42(4), 364-394.

Yáñez, M.F., S. Raveau and J. de D. Ortúzar (2010), "Inclusion of latent variables in Mixed Logit models: Modelling and forecasting", *Transportation Research Part A: Policy and Practice*, 44(9), 744-753.

Zondag, B. et al. (2015), "Accessibility modeling and evaluation: The TIGRIS XL land-use and transport interaction model for the Netherlands", *Computers, Environment and Urban Systems*, 49(1), 115-125.

Zwaneveld, P. et al. (2009), *Maatschappelijke kosten en baten van verstedelijkingsvarianten en openbaarvervoerprojecten voor Almere*, Centraal Planbureau/Planbureau voor de Leefomgeving, Den Haag.

Accessibility and Transport Appraisal

This paper describes the different approaches to measuring accessibility benefits and the limitations of their application in practice. It argues that a broader perspective on accessibility measurement and valuation beyond the current focus on time savings will improve transport appraisal. Notably the better utilisation of land use and transport interaction models will benefit transport investment appraisal.

All resources from the Roundtable on Accessibility and Transport Appraisal are available at:
www.itf-oecd.org/accessibility-and-transport-appraisal-roundtable

International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
+33 (0)1 73 31 25 00
contact@itf-oecd.org
www.itf-oecd.org

Published: 11/2020 | Photo credit: Robert_Chlopas /Shutterstock