9

Accessibility: perspectives, measures and applications

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9.1 Introduction

A principal goal of transport policy is to improve accessibility: the transport system should allow people to travel and participate in activities, and firms to transport goods between locations (from mining, via stages of production, to distribution centres and finally to clients, such as shops or other firms). Several authors have written review articles on accessibility measures, focusing on certain perspectives, such as location accessibility (e.g. Song, 1996; Handy and Niemeier, 1997), individual accessibility (e.g. Pirie, 1979; Kwan, 1998), economic benefits of accessibility (e.g. Koenig, 1980; Niemeier, 1997) or other, different perspectives (Geurs and van Wee, 2004).

However, despite the crucial role of accessibility in transport policy making throughout the world, accessibility is often a misunderstood, poorly defined and poorly measured construct. Accessibility is defined and operationalized in several ways, and thus has taken on a variety of meanings. Gould (1969) noted that one of the problems with accessibility is that 'accessibility is a slippery notion . . . one of those common terms that everyone uses until faced with the problem of defining and measuring it'. Indeed, defining and operationalizing accessibility can be rather complex. This is problematic because the choice and operationalization of an accessibility measure may strongly affect the conclusions on accessibility. For example, Linneker and Spence (1992) illustrated that inner London has the highest access costs (in terms of time and vehicle operation costs) in the UK, but also the highest level of potential accessibility to jobs, despite the high travel cost.

Handy and Niemeier (1997) have stated that 'a distinct gap currently exists between the academic literature and the practical application of accessibility measures. It is important that accessibility measures used in practice are theoretically and behaviourally sound and that innovative approaches to measuring accessibility are made practical.' This statement is still valid today. Land-use and infrastructure policy plans are often evaluated with accessibility measures that are easy to interpret for researchers and policy makers, such as congestion levels or travel speed on the road network, but which have strong methodological disadvantages. Theoretically sound accessibility measures typically involve huge amounts of data or complex transport models, which may restrict analysis to a relatively small region or regions or countries where advanced transport models are available.

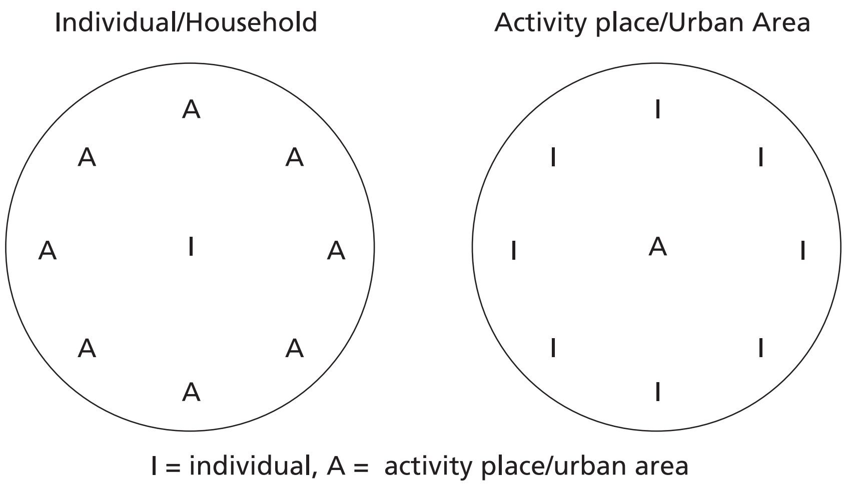
In this chapter we describe the different perspectives on accessibility (section 9.2), the different components of accessibility (section 9.3), the different means by which accessibility can be operationalized (section 9.4) and the different criteria for choosing accessibility measures (section 9.5). Two examples of accessibility measures – potential accessibility and logsum accessibility – are described in section 9.6, and section 9.7 presents the conclusions and future trends in accessibility studies. Chapter 8 has already discussed the relevance of some key technologies for accessibility.

9.2 Perspectives on accessibility

As already noted, accessibility is defined and operationalized in several ways and thereby has taken on a variety of meanings. These include such well-known definitions as 'the potential of opportunities for interaction' (Hansen, 1959), 'the ease with which any land-use activity can be reached from a location using a particular transport system' (Dalvi and Martin, 1976), 'the freedom of individuals to decide whether or not to participate in different activities' (Burns, 1979) and 'the benefits provided by a transportation/land-use system' (Ben-Akiva and Lerman, 1979).

Here, accessibility measures are interpreted as indicators for the impact of land-use and transport developments and policy plans on the functioning of the society in general. This means that accessibility should relate to the role of the land-use and transport systems in society which will give individuals or groups of individuals the opportunity to participate in activities in different locations. Subsequently, we define accessibility as:

> The extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s) at various times of the day (*perspective of persons*), and the extent to which land-use and transport systems enable companies, facilities and other activity



Source: Dijst et al. (2002).

Figure 9.1 Individual and location perspective on accessibility

places to receive people, goods and information at various times of the day (*perspective of locations of activities*).

The terms 'access' and 'accessibility' in the literature are often used indiscriminately. Here, 'access' is used when talking about a person's perspective: the area that a person can reach from his or her origin location to participate in one of more activities at destination locations at certain times. The size of the area depends, for example, on the time, costs and effort that an individual is willing to accept (the transportation component of accessibility; see section 9.3). From the perspective of location, the 'accessibility' is the catchment area where people, goods and information are that can access the destination location from a certain origin location. The size of the catchment area also depends on the time, cost and effort acceptable to bridge the distance from origin to destination (Figure 9.1).

9.3 Components of accessibility

Four components of accessibility can be distinguished: a land-use, transportation, temporal and individual component (Geurs and van Wee, 2004):

1. **The land-use component** reflects the land-use system, consisting of (a) the amount, quality and spatial distribution opportunities supplied at each destination (jobs, shops, health, social and recreational facilities,

etc.), (b) the demand for these opportunities at origin locations (e.g. where inhabitants live), and (c) the confrontation of supply of and demand for opportunities, which may result in competition for activities with restricted capacity such as job and school vacancies and hospital beds (see van Wee et al., 2001). See also Chapter 5.

2. **The transportation 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). The demand relates to both passenger and freight travel. See also Chapter 6.
3. **The temporal component** reflects the temporal constraints, that is, the availability of opportunities at different times of the day and the time available for individuals to participate in certain activities (e.g. work, recreation). See also Chapter 3.
4. **The individual component** reflects the needs (depending on age, income, educational level, household situation, etc.), abilities (depending on people's physical condition, availability of travel modes, etc.) and opportunities (depending on people's income, travel budget, educational level, etc.) of individuals. These characteristics influence a person's level of access to transport modes (e.g. being able to drive and borrow or use a car) and spatially distributed opportunities (e.g. having the skills or education to qualify for jobs near the home residential area) and may strongly influence the total aggregate accessibility result. Several studies (e.g. Cervero et al., 1997; Shen, 1998; Geurs and Ritsema van Eck, 2003) have shown that, in the case of job accessibility, inclusion of occupational matching strongly affects the resulting accessibility indicators. See also Chapter 3.

The different components have a direct influence on accessibility but also indirectly through interactions between the components. For example, the land-use component (distribution of activities) is an important factor determining travel demand (transport component) and may also introduce time restrictions (temporal component) and influence people's opportunities (individual component). The individual component interacts with all other components: a person's needs and abilities that influence the (valuation of) time, cost and effort of movement, types of relevant activities and the times at which one engages in specific activities.

9.4 Operationalization of accessibility measures

Following our definition of accessibility, an accessibility measure should ideally take all components and elements within these components into account. In practice, applied accessibility measures focus on one or more components of accessibility, depending on the perspective taken. There are four basic types of accessibility measures generally used:

1. **Infrastructure-based accessibility measures**, analysing the (observed or simulated) performance or service level of transport infrastructure, such as the length of infrastructure networks, the density of those networks (e.g. kilometre road length per square kilometre), level of congestion, and average travel speed on the road network. This type of accessibility measure is typically used in transport planning. Some of these measures focus only on the supply of infrastructure, while others also use demand factors.
2. **Location-based accessibility measures**, analysing accessibility at locations, typically on a macro-level. The measures describe the level of accessibility to spatially distributed activities, such as 'the number of jobs within 30 minutes' travel time from origin locations'. More complex location-based measures explicitly incorporate capacity restrictions of supplied activity characteristics to include competition effects.
3. **Person-based accessibility measures**, analysing accessibility at the individual level, such as 'the activities in which an individual can participate at a given time'. This type of measure is founded in the space–time geography (Hägerstrand, 1970) that measures limitations on an individual's freedom of action in the environment, that is, the location and duration of mandatory activities, the time budgets for flexible activities and travel speed allowed by the transport system. See also Chapter 3.
4. **Utility-based accessibility measures**, analysing the (economic) benefits that people derive from access to the spatially distributed activities. This type of measure has its origin in economic studies and is increasingly receiving attention in accessibility studies (e.g. de Jong et al., 2007; Geurs et al., 2010).

Table 9.1 presents an overview of different types of accessibility measures, applications and examples, with brief comments on the advantages and disadvantages of the measures used.

The different accessibility perspectives focus on different components of accessibility, often ignoring other relevant elements of accessibility.

Table 9.1 Accessibility indicators, applications and examples

Accessibility type	Applications	Examples	Disadvantages and comments
Infrastructure-based accessibility measures:			
Supply-oriented measures – network level	Description and comparison of characteristics of infrastructure supply in a region or country	Length of motorways, density of rail network	Partial measure of accessibility; does not include land-use and individual components of accessibility, e.g. it does not say anything about the number of opportunities that can be accessed.
Supply-oriented measures – connectivity of locations to transport networks	Analysis of how well locations are connected to transport networks	Distance to nearest railway station, exit point of a motorway	Partial measure of accessibility; measures are not suited for a comparison of transport modes, taking available opportunities into account.
Supply-oriented measures – network connectivity	Describing network connectivity, expressing how well each node in a network is connected to each adjacent node	Connectivity or centrality of a node relative to the rest of the network	Partial measure of accessibility. It also does not provide plausible results in complex networks with many indirect linkages between nodes.
Demand- and supply-oriented measures	Describing actual quality of performance of infrastructure networks	Actual travel times on the road network	Partial measure of accessibility; does not include land-use and individual components of accessibility, e.g. it does not say anything about the number of opportunities that can be accessed.
Location-based accessibility measures:			
Cumulative opportunities	Counts the number of opportunities that can be reached from an original location within a given travel time, distance or cost (fixed costs); or a measure of the (average or total) time or cost required to access a fixed number of opportunities (fixed opportunities)	Number of jobs within 30 minutes' travel time by car; average travel time or cost to reach 1 million jobs	These measures are relatively undemanding of data and are easy to interpret for researchers and policy makers, as no assumptions are made on a person's perception of transport, land use and their interaction. The measure is extremely sensitive to travel time changes and is not suited to describing accessibility developments in time.
Potential or gravity-based accessibility	Estimates the number of opportunities in destination locations that	Index of jobs, population or services which	The measure evaluates the combined effect of land-use and transport elements, and

Table 9.1 (continued)

Accessibility type	Applications	Examples	Disadvantages and comments
Location-based accessibility measures:			
	can be accessed from an original location, weighted by a distance decay function, which describes how more distant opportunities provide diminishing influences	can be accessed from an original location	incorporates assumptions on a person's perceptions of transport by using a distance decay function. The measure has no meaning in absolute terms (index). For plausible results, the form of the function should be carefully chosen and the parameters should be estimated using empirical data on travel behaviour in the study area.
Actual accessibility	Estimates total travel distances, times or costs from an original location to all destinations, weighted by the actual number of trips on an original destination location	Analysis of competition between different transport modes	Detailed information of spatial patterns of travel behaviour is needed.
Person-based accessibility measures:			
Space–time approach	The measures analyse accessibility from the viewpoint of individuals, incorporating spatial and temporal constraints	The number of household activity programmes that can be carried out by individuals, given personal and time constraints	Founded in space–time geography. Measure is theoretically advanced but is very data demanding.
Utility-based accessibility measures:			
Utility of accessibility	The measures estimate the utility or monetary value (when utility is converted into monetary terms)	Logsum accessibility describing the direct economic benefits of having access to spatially distributed activities	Founded in microeconomic theory. More difficult to communicate to non-experts.

Source: Based on van Wee et al. (2001); Geurs and van Wee (2004).

Table 9.2 Types of accessibility measures and components

Measure	Component			
	Transport component	Land-use component	Temporal component	Individual component
Infrastructure-based measures	Travelling speed; vehicle-hours lost in congestion		Peak-hour period; 24-hour period	Trip-based stratification, e.g. home to work, business
Location-based measures	Travel time and/or costs between locations of activities	Amount and spatial distribution of the demand for and/or supply of opportunities	Travel time and costs may differ, e.g. between hours of the day, days of the week, or seasons	Stratification of the population (e.g. by income, educational level)
Person-based measures	Travel time between locations of activities	Amount and spatial distribution of supplied opportunities	Temporal constraints for activities and time available for activities	Accessibility is analysed at individual level
Utility-based measures	Travel costs between locations of activities	Amount and spatial distribution of supplied opportunities	Travel time and costs may differ, e.g. between hours of the day, days of the week, or seasons	Utility is derived at the individual or homogeneous population group level

Note: Dark shading: primary focus of measures; light shading: non-primary focus.

Source: Geurs and van Wee (2004).

Table 9.2 presents a matrix of the different accessibility measures and components. Infrastructure-based measures do not include a land-use component; that is, they are not sensitive to changes in the spatial distribution of activities if service levels (e.g. travel speed, times or costs) remain constant. The temporal component is explicitly treated in person-based measures and is generally not considered in the other perspectives, or is treated only implicitly, for example by computing peak- and off-peak-hour accessibility levels. Person-based and utility-based measures typically focus on the individual component, analysing accessibility on an individual level. Location-based measures typically analyse accessibility on a macro-level but focus more on incorporating spatial constraints in the supply of opportunities, usually excluded in the other approaches (see the dark-shaded cells in Table 9.2).

To operationalize accessibility measures, the most suitable type of accessibility measure needs to be chosen (the columns in Table 9.2), and then the different elements within the different components need to be determined (the rows in Table 9.2). A few examples can illustrate this process:

1. In determining travel times between origin and destination locations, one can choose whether or not to weigh the different time components of a trip, such as access and egress times to and from boarding points, in-vehicle travel times, waiting times and so on. Generally speaking, access and egress and waiting time will incur greater disutility to travellers than in-vehicle time (e.g. see Balcombe et al., 2004).
2. In determining the costs of car trips, one can include only fuel costs, but also total variable costs, including for example parking costs and fixed costs (e.g. depreciation of the car).
3. One can use either objective costs or perceived costs, which may differ greatly (e.g. see van Exel and Rietveld, 2009).
4. In determining the land-use component, one needs to consider whether available opportunities have capacity limitations (such as in the case of school locations and health-care facilities), and where accessibility measures need to account for differences in the spatial distribution of the demand and supply of these opportunities (competition effects).

9.5 Choosing and using accessibility measures

In defining and operationalizing accessibility, there is no one best approach because different situations and purposes demand different approaches (Handy and Niemeier, 1997). However, several criteria can be derived to evaluate the usefulness and limitations of accessibility measures for different study purposes. Such criteria can, for example, be found in Black and Conroy (1977), Jones (1981), Handy and Niemeier (1997) and Geurs and van Wee (2004).

Purpose of the study

This is the starting point of the operationalization process. What is the purpose of the study and, following from that, what is the main reason for analysing accessibility? All other choices essentially follow on from this. The definition and operationalization would, for example, strongly differ when the study purpose is to evaluate accessibility impacts of a transport project, or to analyse social equity effects, or the economic benefits that people derive from having access to opportunities. This means that the analysis of transport policy can be carried out through more aggregate, location-based accessibility measures, whereas the analysis of social equity effects requires a highly spatially differentiated and disaggregated analysis. The analysis of economic benefits would require choosing a utility-based accessibility measure that is directly linked to microeconomic theory.

Scientific quality

An accessibility measure should ideally take all of the components and elements within these components into account (section 9.2). Thus an accessibility measure should firstly be sensitive to the changes in the transport and land-use systems and the temporal constraints of opportunities, and it should take individual needs, abilities and opportunities into account. Geurs and van Wee (2004) derived the following five criteria which an accessibility measure should behave in accordance with, keeping all other conditions constant:

1. If the service level (travel time, costs, effort) of any transport mode in an area increases (decreases), accessibility to any activity in that area or from any point within that area should increase (decrease).
2. If the number of opportunities for an activity increases (decreases) anywhere, accessibility to that activity should increase (decrease) from any place.
3. If the demand for opportunities for an activity with certain capacity restrictions increases (decreases), accessibility to that activity should decrease (increase).
4. An increase in the number of opportunities for an activity at any location should not alter the accessibility to that activity for an individual (or groups of individuals) not able to participate in that activity given the time budget.
5. Improvements in one transport mode or an increase of the number of opportunities for an activity should not alter the accessibility to any individual (or groups of individuals) with insufficient abilities or capacities (e.g. driving licence, educational level) to use that mode or participate in that activity.

These criteria should not be regarded as absolute, but more in the line of what accessibility studies should strive for. Applying the full set of criteria would imply a level of complexity and detail that can probably never be achieved in practice. However, it is important that the implications of violating one or more theoretical criteria should be recognized and described.

Operationalization (cost, ease)

This is the ease with which the measure can be used in practice, for example in ascertaining availability of data, models and techniques, and time and budget. This criterion will usually be in conflict with one or more of the theoretical criteria described above.

Interpretability and communicability

The literature shows a trend towards more complex and disaggregated accessibility measures, partly in response to the recognition that the aggregate measures lack many important details. However, increased complexity increases the effort for calculations and the difficulty of interpretation. Clearly, researchers, planners and policy makers should be able to understand and interpret the measure, and communicate results to clients, as otherwise it is not likely to be used in evaluation studies of land-use and/or transport developments or policies and will thus have no impact on the policy making process.

The interpretations of more complex accessibility measures can firstly be improved by comparing accessibility across place or time, or both place and time, rather than focusing on absolute levels of accessibility. Secondly, the interpretation can be much improved by estimating the separate influence of the different components of accessibility. For example, Geurs and Ritsema van Eck (2003) computed the separate influence of land-use changes, infrastructure investments and congestion on the development of (job) accessibility for the Netherlands. Computation of the different components of accessibility facilitates both the explanation of overall accessibility changes and the relative position of regions. Thirdly, the more complex utility-based accessibility measures can be expressed in monetary values, and this strongly improves the interpretation and communication to planners and policy makers. Fourthly, for measures that are difficult to interpret, such as utility-based measures, the output could be indexed. For example, the base year value or a reference scenario can be indexed at the level of 100. The value of the accessibility indicators could then be indexed and compared to this base level value.

However, there are no guarantees that accessibility measures will be used in public policy even when they are easy to interpret and communicate. Pirie (1981) clearly points out that there is no guaranteed or easy transition from accessibility research to the formulation of public policy and its implementation; public policy on accessibility will only be forthcoming if accessibility is a well-politicized issue.

9.6 Two examples of accessibility measures

Potential accessibility measures

Several types of location-based measures are used in accessibility studies. The distinguishable groups of measures are distance based and contour based, along with potential measures and the balancing factors of spatial interaction models. Potential accessibility measures (also called gravity-based measures) have been widely used in urban and geographical studies since the late 1940s; well-known studies are from Hansen (1959), Ingram (1971) and Vickerman (1974). The potential accessibility 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. The measure has the following form, assuming a negative exponential cost function:

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

where A_i is a measure of accessibility in zone i to all opportunities D in zone j, c_{ij} the costs of travel between i and j, and β the cost sensitivity parameter. The cost sensitivity function used has a significant influence on the results of the accessibility measure. For plausible results, the form of the function should be carefully chosen and the parameters of the function should be estimated using recent empirical data of spatial travel behaviour in the study area. The function (form, parameters) is generally referred to as the impedance function. Impedance functions show a decrease in value if costs increase.

Several studies have used different impedance functions, such as the power, Gaussian or logistic functions. However, the negative exponential function is the most widely used and the most closely tied to travel behaviour theory (Handy and Niemeier, 1997). The potential measure overcomes some of the theoretical shortcomings of the contour measure, as it evaluates the combined effect of land-use and transport elements and incorporates assumptions on a person's perceptions of transport by using a distance decay function. The measures are appropriate as social indicators for analysing the level of access to social and economic opportunities for different socio-economic groups. Potential measures have the practical advantage that they can be easily computed using existing land-use and transport data (and/or models), and they have been traditionally employed as an input for estimating infrastructure-based measures. The disadvantages of potential measures are related to more difficult interpretation and communication. The measure is not easily interpreted and communicated, as it combines land-use and transport elements and weighs opportunities (according to the cost sensitivity function).

Standard potential accessibility measures ignore so-called competition effects. For example, the labour force compete for jobs; firms compete for the labour force. Ignoring such effects could lead to misleading conclusions. For example, locating all jobs at the 'best' location in a country shows the highest value for potential accessibility of the labour force, but if all employers were to locate there they would compete strongly for employees. To incorporate competition effects, several authors have adapted potential accessibility measures. Here, we summarize the different approaches. (See Geurs and Ritsema van Eck, 2003, for a more elaborate description.) Firstly, a number of authors have tried to incorporate the effects of competition on opportunities in accessibility measures by dividing the opportunities within reach from origin zone i (the 'supply' potential) by a demand potential from zone i (see Weibull, 1976; Knox, 1978; van Wee et al., 2001). This approach is useful if the travel distance between origins and destinations is relatively small, such as for elementary schools. A second approach is to use the quotient of opportunities within reach from origin i (supply potential) and potential demand of those opportunities from each destination j (see Breheny, 1978; Joseph and Bantock, 1982). This approach is useful for the analysis of accessibility to destinations where competition effects occur on destination locations (e.g. nature areas) or where available opportunities have capacity limitations (e.g. in the analysis of recreational or health-care facilities). A third approach is based on the balancing factors of Wilson's double constrained spatial interaction model (Wilson, 1971). The balancing factors a_i and b_j ensure that the magnitude of flows (e.g. trips) originating at zone i and destined for zone j equals the number of activities in zones i (e.g. workers) and j (e.g. jobs). The balancing factors of this model can be interpreted as accessibility measures, modified to account for competition effects. The balancing factors are mutually dependent, so they have to be estimated iteratively. As the balancing factors are dependent and estimated in an iterative procedure, they incorporate the competition on supplied opportunities and the competition on demand. The balancing factors are not often applied but are useful in analysing accessibility for opportunities where competition effects occur on both the origin and the destination location, such as job accessibility, where workers compete with each other for jobs and employers compete with each other for employees (Geurs and Ritsema van Eck, 2003).

Logsum accessibility measure

Publications on the logsum as a measure of consumer surplus (the difference between the market value of a product or service and the value for the user – see Chapter 12) date back to the early 1970s. One of the earliest references to the logsum as an accessibility measure is from Ben-Akiva and Lerman (1979). An introduction can be found in the textbooks on discrete choice models (e.g. Train, 2003). Here, we base our description of the logsum on De Jong et al. (2005, 2007), who present a contemporary review on the theoretical and applied literature on the logsum as an evaluation measure.

The utility that decision maker *n* obtains from alternative *j* is decomposed into an observed and an unobserved (random) component:

$$U_{nj} = V_{nj} + \varepsilon_{nj} \tag{2}$$

where U_{nj} is the utility that decision maker *n* obtains from alternative *j* ($n = 1,..N$; $j = 1, \ldots ,J$), V_{nj} = 'representative utility' and ε_{nj} captures the factors that affect utility but are not measured by the researcher. In a standard multinomial logit (MNL) model, the choice probabilities are given by:

$$P_{nj} = \frac{e^{V_{nj}}}{\sum_{j} e^{V_{nj}}} \tag{3}$$

The 'logsum' now is the log of the denominator of this logit choice probability. It gives the expected utility from a choice (from a set of alternatives). It is defined as the integral with respect to the utility of an alternative, and provides an exact measure of transport user benefits, assuming the marginal value of money is constant. In the field of policy analysis, the researcher is mostly interested in measuring a change in consumer surplus that results from a particular policy. By definition, a person's consumer surplus is the utility in money terms that a person receives in the choice situation (also taking account of the disutility of travel time and costs). The decision maker *n* chooses the alternative that provides the greatest utility so that, provided that utility is linear in income, the consumer surplus (CS_n) can be calculated in money terms as:

$$CS_n = (1/\alpha_n)\, U_n = (1/\alpha_n)\, max_j\, (U_{nj}\, \forall\, j) \tag{4}$$

where α_n is the marginal utility of income and equal to dU_{nj}/ dY_n if j is chosen, Y_n is the income of person n, and U_n is the overall utility for the person n. The division by α_n in the consumer surplus formula translates utility into money units (e.g. dollars, euros), since $1/\alpha_n = dY_n/dU_{nj}$. If the model is an MNL model and the income utility is linear (that is, α_n is constant with respect to income), the change in expected consumer surplus for decision maker n can be calculated as the difference between $E(CS_n)$ under the conditions before the change and after the change (e.g. introduction of policy):

$$\Delta E(CS_n) = (1/\alpha_n)\, [ln\, (\sum_{j=1}^{J^1} e^{V^1_{nj}}) - ln\, (\sum_{j=1}^{J0} e^{V0_{nj}})] \tag{5}$$

where superscript 0 and 1 refer to before and after the change. To calculate this change in consumer surplus, the researcher must know (or have estimated) the marginal utility of income α_n. 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 α_n by definition (McFadden, 1981). The above equations for calculating the expected consumer surplus depend critically on the assumption that the marginal utility of income is constant with respect to income. If this is not the case, a far more complex formula is needed. However, for policy analysis, absolute levels are not required; rather only changes in consumer surplus are relevant, and the formula for calculating the expected consumer surplus can be used if the marginal utility of income is constant over the range of implicit changes that are considered by the policy. So, for policy changes that change the consumer surplus by small amounts per person, relative to their income, the formula can be used – even though in reality the marginal utility of income varies with income.

The logsum measure seems to be getting more attention in academic studies but is less popular among practitioners. An explanation for this is that the measure cannot be easily explained without reference to relatively complex theories of which most planners and political decision makers may not have a complete understanding (Koenig, 1980). See de Jong et al. (2007) for an overview of applications, and Dong et al. (2006) and Geurs et al. (2010) for recent examples. Dong et al. presented a novel approach, developing a logsum accessibility measure within a space–time framework, expressing the individual's expected maximum utility over the choices of all available activity patterns. Furthermore, attention has been paid to the behavioural assumptions underlying the logsum approach to measuring accessibility: Chorus and Timmermans (2009) show how logsum-based measures of user benefits associated with changes in the transport system (such as increases in accessibility) can be extended to allow for limited awareness among travellers.

Applying utility-based accessibility measures such as the logsum in policy appraisal may generate different results (and therefore conclusions) from infrastructure-based or location-based accessibility approaches. Suppose the researcher evaluates the accessibility effects of certain candidate policy options related to transport and land use; then there can be at least two important reasons for different results. Firstly, in the case of land-use policies, utility-based accessibility benefits from these policies can be quite large compared to investment programmes for road and public transport infrastructure. This is shown by Geurs et al. (2010), who applied the logsum accessibility benefit measure to examine the accessibility benefits from land-use and transport policy strategies. The accessibility impacts from the land-use scenarios are largely due to changes in trip production and destination utility. Ignoring accessibility benefits from land-use changes resulting from transport investments may lead to serious biases. Secondly, in the case of land-use policies, infrastructure policies or combined land-use and infrastructure policies, utility-based measures show diminishing returns, as the measures incorporate non-linear relationships between accessibility improvements and user-benefit changes. As a result, the measure may indicate that it is better to improve accessibility for individuals at locations with low accessibility levels (e.g. peripheral regions) than at locations that are already highly accessible (e.g. central urban areas) (see, for example, Koenig, 1980; Geurs and Ritsema van Eck, 2001). This is clearly relevant for social and economic evaluations of land-use and transport projects.

9.7 Conclusions and future trends in accessibility studies

The most important conclusions of this chapter are summarized as follows:

1. The conclusions on accessibility strongly depend on the definition of accessibility used and operationalization of the accessibility measure. It is therefore very important to make careful decisions on the definition and operationalization of accessibility. The four criteria on which decisions can be based are (1) purpose of the study, (2) scientific quality, (3) operationalization (cost, effort) and (4) interpretation and communication.
2. In practice, the accessibility measures used are often those that are easy to operationalize and interpret, rather than those that satisfy more stringent theoretical criteria. Applying a full set of scientific quality criteria

would imply a level of complexity and detail that is difficult to achieve in practice. This means that different situations and study purposes demand different approaches. However, it is important to recognize the implications of ignoring one or more of these criteria.

3. Location- and utility-based accessibility measures can be considered effective measures of accessibility, which can also be used as input for social and economic evaluations. These measures overcome the most important shortcomings of infrastructure-based measures and can be computed with state-of-the-practice land-use and transport data and models. It is sensible to use accessibility measures which incorporate competition effects when interpreting the analysis of accessibility to destinations where available opportunities have capacity limitations (e.g. in the analysis of jobs or recreational or health-care facilities) or where competition effects might occur on destination locations (e.g. nature areas). Utility-based measures capture the valuation of accessibility by individuals, providing a useful basis for user-benefit evaluations of both land-use and transport investments.

We now discuss a potentially important trend in accessibility measures: in academic literature, there is a continuing trend towards more complex and disaggregated accessibility measures, partly in response to the recognition that the aggregate measures lack many important details. These trends partly result from improvements in the techniques to construct location-based accessibility indicators. These techniques have evolved from very simple calculations to more complex and detailed methods that use algorithms within a geographic information systems (GIS) platform to extract and assemble data from multiple spatial databases at very fine levels of spatial resolution (see, for example, Kwan, 2000; Chen et al., 2011). In addition, the temporal component of accessibility and person-based accessibility measures seems to be enjoying a rapid increase in popularity amongst academics in transportation and geography (see, for example, Ettema et al., 2007; Schwanen and Kwan, 2008; Neutens, 2010).

Indeed, this type of accessibility measure is potentially very useful in transport policy evaluations and social evaluations. The measures may also be tied to the utility-based approach, which opens up the possibility of using them in economic evaluations. There are two important trends which will better enable the development of disaggregated accessibility measures. Firstly, recent studies have shown the possibilities of synthetic data to reduce the enormous data collection effort, particularly for person-based accessibility measures (see, for example, Veldhuisen et al., 2000; Arentze et al., 2008). In California, an activity-based travel demand model is under development which synthetically generates the entire population and aims to simulate activities at a very fine level of spatial and temporal disaggregation (second-by-second and parcel-by-parcel level) (Chen et al., 2011). Secondly, ICT developments will hugely increase the possibilities for detailed data collection. The fast penetration of smartphones provides great opportunities for researchers to improve the quality of accessibility analysis. Berg Insight (2010), for example, forecasts that, by 2014, 60 per cent of new phones sold worldwide will be GPS enabled. This new type of ICT is likely to become more important than PC use at fixed locations. Data collection using smartphones can potentially reduce the burden for respondents in participating in longitudinal travel surveys, and this opens up new possibilities for monitoring travel behaviour and individual accessibility over relatively long time periods (months and years).

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