Measuring accessibility: prescriptions for performance measures of the creative and sustainable city

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Abstract: Urban journalists and researchers seek performance measures on how one city fares versus another in any dimension. An increasingly important performance measure relates to how well cities advance one important dimension of sustainability – decreased mobile source pollutants and decreased travel for vehicles – and how much driving and congestion is occurring. But is congestion really the problem?

This paper argues that a superior metric to measure the sustainability of a city's transportation system should centre around accessibility: resident's ease to visit destinations to meet their needs. This paper explores the issues related to the development of accessibility measures for non-motorised modes, namely bicycling and walking. We describe how difficulties in calculating accessibility measures arise primarily from problems with data quality, the zonal structure of transportation planning models, and the adequacy of models and travel networks for walking and cycling. Drawing from a larger research initiative (www.accesstodestinations.org), we present practical strategies for addressing these issues.

Keywords: sustainability indicators; pedestrian; bicycling; accessibility; travel behaviour.

Reference to this paper should be made as follows: Krizek, K.J. (2010) 'Measuring accessibility: prescriptions for performance measures of the creative and sustainable city', *Int. J. Sustainable Development*, Vol. 13, Nos. 1/2, pp.149–160.

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1 Introduction

Urban journalists and researchers seek various performance measures to inform residents and planners about how one city fares versus another in any particular dimension. An increasingly important performance measure relates to how well cities advance one important dimension of sustainability-decreased mobile source pollutants and decreased travel for vehicles relying non-renewable energy. An often relied on performance indicator is traffic congestion. Politicians, traffic engineers, planners, and residents take more than feigned interest in ratings of congestion because to date, such rankings are usually widely available and assess progress toward an issue that is front and centre on the front of the minds of many residents.

But is congestion really the problem? Do the measures reported – e.g., estimated hours spent in traffic – capture what is important for creative and sustainable cities? Isn't congestion (and hours of delay) just a symptom of the real problem – the lack of accessibility in cities? Congestion in cities is a serious issue. But counting cars and clocking speeds fails to tell enough about the transportation and land use characteristics of the region. What if solid research showed that even as congestion is getting worse, many residents in cities worldwide find it easier to get where they need to go? That is a provocative prospect worth looking at – a prospect that might go a long way toward better understanding the structure of cities and their ability to foster sustainable transport and land use practices.

This paper urges new approach to understand how people use the transportation system and how transportation and land use interact – all with an eye towards urging more useful metrics. At the heart of this approach is the concept of accessibility: the ability of people to reach the destinations that they need to visit in order to meet their needs. By focusing on accessibility – rather than simple congestion measures – this approach produces a more complete and meaningful picture of transportation and its role in sustainability initiatives.

The approach has several advantages, some of which are only touched on herein. For example, it is becoming increasingly understood that travel-behaviour studies are subject to methodological uncertainty regarding the direction of causation. What are the strongest factors influencing travel: socio-demographic, land use, lifestyle? Researchers have spent considerable time and energy to discern such, unfortunately with relatively little success. On the other hand, the determinants of accessibility are clear: an area is more accessible when a person can reach more destinations from it with a given time and money budget. Thus when one compares the change in accessibility of an area over time – or the accessibility of one area compared to another – the determinants can be definitively decomposed into the nature and number of the destinations reachable from that area and the characteristics of the transportation network connecting the area with others. Subsequently, relatively straightforward policy remedies stand out. One prevalent idea, for example, is that mixed-use development, combining a variety of destination types in a close-knit grouping, will attract residents and lead to reductions in automobile use. Advocates of new urban development models often cite a 'quarter-mile rule' (400 metres) to explain how far people will ordinarily walk to a destination. Is that assumption valid? And what about trips by bicycle?

To better address many of the outstanding questions presented above, this paper is divided into four parts. We first introduce how and why the concept of accessibility is a superior measure for understanding coordinated land use-transport patterns and some past struggles in execution. Part 2 broadly outlines key issues for effective measurement. The heart of the paper, Part 3, discusses strategies for how various issues could be addressed and alternatives for doing so. Finally, the last section summarises key contributions and touches on matters for future research.

2 Introducing accessibility

In the current policy environment of scientific uncertainty, the concept of accessibility offers an alternative basis for sustainability policy regarding the built environment. Accessibility has been a well-known concept in the transportation planning field since the 1950s when it was defined as the ease of reaching desirable destinations (Hansen, 1959). This represented one of the first efforts by planners to develop measures that linked land use and activity systems with the transportation networks that serve them. However, conventional transportation planning has often focused on improving movement (or mobility) – most often by the automobile. The differences are important. Accessibility is traditionally defined as the 'ease of reaching destinations', as opposed to mobility, which is the 'ease of movement'. Where destinations are nearby, high accessibility can be provided even with low mobility; conversely, where origins and destinations are spread broadly, even great mobility does not ensure high accessibility. The two concepts can be readily distinguished through an understanding of the meaning of a change in each: an improvement in mobility is a reduction in the time-plus-money cost of travel per mile, while an improvement in accessibility is a reduction in the time-plus-money cost per (value of) destination.

To the extent that accessibility has been measured or used in transportation planning, such measures have also been auto-based (Handy and Clifton, 2001). In addition, many studies limit their focus to access to employment. The emphasis on employment accessibility is understandable, given its link to other important aspects of urban structure, such as choice of residential location, and also to outcomes hypothesised to be related to urban structure, such as social exclusion (Preston and Raje, 2007). However, access to other types of destinations, such as retail, are also important because they strongly influence various dimensions of travel behaviour such as trip frequency (Daly, 1997), destination choice (Handy, 1993), mode choice, and trip or tour complexity (Hanson and Schwab, 1987). Higher access levels to activities such as shopping and recreation are also thought to improve the general quality of life.

Broadening the scope of accessibility to include additional types of destinations and non-auto modes such as walking and cycling has been proposed previously as an objective worthy of further study in the land use-transportation field (Handy 1993; Handy and Clifton, 2001). To date, however, there have been few examples of the successful execution of non-motorised accessibility measurement to draw from. Issues including, but certainly not limited to lack of reliable data, computational power or knowledge of non-motorised travel behaviour have prevented widespread application of such measures.

In the end, approaches stemming from civil engineering, urban planning, geography and other related disciplines have the rubrics of a relatively powerful idea. A limiting issue, however, is that the potency of the concept of accessibility has not fully settled in a manner to address the potential of sustainable modes of transportation (cycling, walking, transit) in advancing it. This paper discusses such hurdles and presents alternatives for circumventing them; it describes how accessibility for sustainable modes such as walking and cycling – and for different types of destination – can be reliably measured and important factors in doing so. We focus on explaining specific features of non-motorised transportation that complicate the development of accessibility measures, and offer solutions that conform to conventional transportation planning practice. The development of these accessibility measures is pulled from applications based in Minneapolis, Minnesota, USA and the specific description of these measures if more fully described them in other applications. In sum, our central aim in this piece is to offer, from the perspective of land use and transportation, a complete, parsimonious, and meaningful strategy to develop indicators of one important dimension of sustainability initiatives.

3 Measuring accessibility, generally

There is no mutually agreed one way to measure accessibility. But over the near half century in which this concept has been studied, several techniques stand out prominently. One of the earliest, the cumulative opportunity, basically counts the number of potential opportunities that can be reached within a certain distance or travel time. Counting is useful but conclusions drawn from counting are limited. This method accounts neither for costs (time, fuel) nor for differences in 'attraction' power across destinations. People may strongly prefer to get to some places that are difficult to access.

The most widely used measure is gravity-based. This measure considers destinations of interest along with the costs of travel (by any mode), and it incorporates more complexity into the calculation of 'opportunities' (another way of describing a valued destination). So, frequency of bus service could be a value factor in calculating access to transit. But this method also has limitations. It assumes that everyone in a measured zone has the same level of accessibility, thereby ignoring all the individual preferences that characterise human behaviour. The strength of a measure lies in the degree to which important and sometimes detailed phenomena are accounted for.

In principle, it is logical to base measures of accessibility for non-motorised modes using similar methods that have been use motorised vehicle travel, thereby allowing the user to calculate any of the conventional, location-based measures of accessibility associated with zone-based travel forecasting models. The measures most often used are gravity-based or other types of location-based measures, in part due to their relative ease of calculation and interpretation (Handy and Niemeier, 1997; Geurs and van Wee, 2004). Gravity-based measures are derived from the denominator of the gravity model (Ingram, 1971) and can be described with the general form:

$$A_i = \sum_j a_j f(t_{ij})$$

where A_i represents accessibility at zone i, a_j represents activity in zone j, and t_{ij} represents travel impedance between i and j, which can be expressed at time, distance, or cost, and $f(t_{ij})$ is a function of t_{ij} introduced to express the dampening effect of separation or cost on travel. Thus, at a minimum, accessibility reduces to a function of the size or availability of activities in each zone and the cost of accessing those activities. More recent interpretations of the components of accessibility stress the inclusion of a *temporal* component, reflecting the availability of opportunities at different times of day and available time to allocate to accessing these opportunities, as well as an *individual* component, which reflects individual-level constraints and characteristics that might affect the measurement of accessibility (Geurs and van Wee, 2004). Sometimes these individual-level constraints require accounting for consumer tastes. For example, most people seek access to a grocery store, but for some people that means finding the closest location for milk, while for others only a gourmet food store will suffice.

With respect to travel impedance, the networks used for modelling vehicular flows are too coarse to represent the route choices typically exercised by pedestrians and bicyclists. Also, the zones of these models are poorly matched to the spatial scale of movement by these modes, resulting in a considerable number of intrazonal trips (Eash, 1999). While vehicular travel tends to be most sensitive to travel times and levels of network congestion, non-motorised route choices tend to include factors that may be more qualitative, experiential or difficult to operationalise (Page, 2005), such as facility design and aesthetic treatments that may fall under the broad category of 'environmental factors' (Porter et al., 1999; Tilahun et al., 2007; Hunt and Abraham, 2007). That is not to suggest travel time is not an important determinant of route choice for non-motorised travellers (Stinson and Bhat, 2003; Weinstein et al., 2007) – just that it is not quite as decisive.

4 Measurement issues and alternatives

Creatively, comprehensively, and robustly measuring accessibility non-motorised modes requires the analyst to be aware of several important factors. We now turn to addressing specific sources of difficulty encountered with the inputs to accessibility calculations, namely issues stemming from data, zonal structure, networks, and travel behaviour. The discussion of each issue contains a strategy for overcoming the difficulties identified therein. These strategies are fourfold, including:

1. addressing the network and zonal aggregation issues using block-level data and special networks
2. preparing detailed land use data
3. collecting appropriate travel survey data
4. developing impedance measures.

4.1 Data

4.1.1 Travel

Calculating accessibility measures requires multiple data sets relating to travel behaviour and land use, each of which presents unique challenges for analysts addressing non-motorised modes. For example, robust accessibility measures are built around models representing human behaviour (e.g., who shops where and how far they travel for such). Unfortunately, the data necessary to reliably build such models are often in short supply for walking and cycling. User and trip characteristics at a suitable level of aggregation, along with user preferences for facility design characteristics are currently of limited quality and are considered a high priority for improvement (USDOT, 2000). Characteristics about non-motorised mode users and their trips are typically aggregated to the same level as motorised trips, rather than being assigned to smaller aggregation units. Information on preferences toward different facilities are typically incomplete at best, and often entirely absent. These data items are not adequately covered in most large scale survey instruments.

Such issues often result in analysts borrowing assumptions from analysis designed for other purposes. A common example is an analysis borrowing impedance values from a locally-calibrated travel model. The values extracted from these data may be sensitive to the environment in which they were collected; particularly for non-motorised behaviour, issues related to weather conditions play a big role. Ideally, travel survey data would be collected year round and cover all seasons (Ortuzar and Willumsen, 2001).

Estimating specialised impedance functions specific to non-motorised modes requires appropriate travel survey data that can capture the modes of interest, namely pedestrian and bicycling behaviour. Ideally, this would involve a focused, special-purpose survey designed to over sample these types of behaviour or data collected from global positioning systems – a relatively costly alternative. In the absence of such data, a regional household travel survey can be used to the extent that it specifically includes trips by non-motorised modes. The previously referenced study employed household survey data collected in 2000 for the Minneapolis-St. Paul region. A limitation of this approach, however, is the variety of destinations that can feasibly be studied. Given that walking and bicycling tend to be less heavily-used and often underreported modes in many US cities, any further partitioning of the data can lead to small samples and less robust inferences.

4.1.2 Land use

The quality of land use data also affects the accuracy of accessibility measures. Improving the accuracy or robustness of accessibility calculations requires data at a spatial resolution that is not typically available in most planning organisations. There are sources of establishment-level data on attributes such as employment, sales and other variables that could potentially serve as good proxy variables for attractiveness and be easily scaled to different levels of geographic aggregation. However, these sources are typically private financial organisations or highly confidential. The data can be costly to acquire and require significant effort in terms of cleaning and preparation for spatial analytical use. Other low-cost sources of data, such as business directory telephone listings have been employed elsewhere (Handy and Clifton, 2001) in the context of the calculation of measures of 'neighbourhood' accessibility, though these data sets apparently contain limited information on size or quality of establishments.

Developing measures of attractiveness at a more detailed level than the zones used in travel forecasting models requires specialised, establishment-level data that can be aggregated to the level of small units, such as the block groups described earlier. For example, in US contexts, establishment-level data can be purchased from Dun & Bradstreet, Inc. which contains attribute information on location, sales, employees, and industry classification. Such data can be merged with parcel-level land use data from regional planning agencies. The establishment-level data can be recoded into destination categories using the two to six-digit classifications of the North American Industry Classification System (NAICS). The outcome of this process is a set of parcel-level land use data with information on employment counts and sales volumes.

4.2 Zonal structure and travel networks

Most analyses of this type use zones as units of analysis that do little justice to the detailed nature of pedestrian or bicycle travel. For example, they may aggregate information to census tracts, zip code areas or TAZs. These units often do little justice to the central aim; they can be quite large, almost two miles wide and contain over 1000 households. The problem is that an ecological fallacy arises because average demographic or urban form characteristics are assumed to apply to any given individual neighbourhood resident. When measures of commercial intensity are aggregated, for example, each zone could, in principle, reveal the same measure of intensity, despite each zone exhibiting considerably different development patterns. This assumption of homogeneity may also be viewed as an instance of the modifiable areal unit problem (Openshaw, 1984). Using census tracts or TAZs, concentrations of development may be averaged with adjacent lower-density development thereby making it difficult to associate many neighbourhood-scale aspects with travel demand. This distinction is particularly important for pedestrian travel, where travel sheds for different types of trips may encompass only a fraction of a TAZ or similar aggregation unit. The heart of the problem – and the ability to detect such subtle geographical differences – lies with the size of the units of analysis that are employed.

Networks employed for purposes of regional travel models typically replicate roadways. Networks for walking and cycling are often different and need to be drawn at a finer scale. Specifically, the network structure is too coarse to trace the paths chosen by pedestrians and cyclists, and the zones are too large to differentiate many of the shorter trips made by bicycle and on foot. Also, few networks contain links with specialised facilities for non-motorised travel, such as sidewalks, exclusive bike paths and on-street bicycle lanes.

Incompatibility between conventional travel forecasting models and travel by non-motorised modes is characterised by travel zones that are too large and networks that are too coarse to provide detailed analysis of destination and route choice behaviour by pedestrians and bicyclists. This is one area where compromise solutions must be adopted in order to make the research problem tractable.

The task of calculating travel times via a network model is one that is not easily resolved. One way around this problem is to use street network layers encoded as geographic information system (GIS) files as the basis for calculation of a minimum-cost path (with distance as a proxy measure for cost) between an origin and destination point, assuming agreement between the minimum-cost path and the actual chosen path (Witlox, 2007). This method ignores the matter of congestion on networks, since it is costly and not terribly practical to code an entire street network with the appropriate capacity data. However, many studies of accessibility choose to ignore congestion effects and simply use free-flow travel times as a reasonable approximation.

GIS networks can be manually modified in order to incorporate the presence of special facilities, such as exclusive bicycle paths or joint use bike/pedestrian paths. In principle, these links are chosen because they offer travel time, quality or other advantages that lower the perceived 'cost' of travel by non-motorised modes. These advantages can be operationalised by giving these links a lower cost than other unimproved links. Were the data available, one possible additional modification would be to adjust link costs to account for the density of traffic signals. If data on exclusive pedestrian and bicycle facilities are not available in a digital format, they can be checked against published maps or other available sources.

Another adaptation that allows a better characterisation of travel impedance is using smaller zones to identify potential origins and destinations. This method has been used elsewhere (Eash, 1999) to model non-motorised destination choice, using zones roughly aligned with census tracts. An alternative – and smaller – zone designation used in the twin cities application is to use grid cells or census block groups, which are similar in size and function.

4.3 Estimating travel impedance

Related to the issue of inadequate networks and data is the applicability of model components of four-step transportation planning models to non-motorised modes. Most relevant to accessibility calculations is the impedance function, representing the influence of travel time, money and other costs on the willingness of individuals to travel longer distances. In transportation planning practice, it has been common to use gravity or other synthetic models to forecast the spatial distribution of trips, from which an impedance value can be estimated. While this approach works reasonably well for motorised modes, which tend to have a more regional distribution, there are often a large number of origin-destination pairs with zero observations. This problem, known as the sparse matrix problem (Ortuzar and Willumsen, 2001), is exacerbated by the application of such models to origin-destination data for non-motorised modes, which tend to have a more concentrated spatial distribution.

Since the full specification of the gravity model is not applicable for forecasting the distribution of trips by non-motorised modes over a large area, some modifications must be made. One option is to estimate impedance directly from the frequency distribution of trip lengths. While this approach is feasible, it has some serious limitations. Estimating an impedance parameter in the absence of information about the spatial distribution of activities (as is provided in the gravity model) is equivalent to assuming that activities are evenly distributed in space (Sheppard, 1995). Clearly this assumption is not reasonable for most metropolitan regions and can lead to biased results.

A second caveat relates to the functional form of the impedance function. While many different specifications of the impedance function have been used, there is little available evidence to suggest *a priori* which one might be superior. Most of the specifications differ in their treatment of the effects of distance, which would in turn affect accessibility measurement. A common approach employs the negative exponential form ($e^{-\beta x}$). This function has the advantage that it declines more gradually than the power function, and thus better estimates shorter trips, such as those made by non-motorised modes (Kanafani, 1983). This advantage, along with a record of numerous empirical applications made it an appropriate functional form to be estimated for the set of impedance functions applied in the current study.

In addition to choosing a form for the impedance function, the analyst must specify which variable is being used to measure separation or impedance (time, cost or both). In practice, both measures have been used, along with some examples of the use of the *generalised cost* concept (Handy and Niemeier, 1997). In the case of non-motorised travel, however, the options appear to be limited to the use of distance, due to the problems associated with extracting accurate travel times from existing network models for bicycling and walking.

Past research has suggested that using either time or distance as an impedance variable is acceptable (Handy and Niemeier, 1997), though very detailed and data-rich applications might use the logsum of the mode choice calculation for a given origin-destination pair. Intrinsically, time is an appealing measure, since it represents a scarce resource that must be expended during travel. It also carries the advantage of widespread application in other areas of travel modelling. At the same time, the methods outlined here for approaching the problem of dealing with non-motorised travel suggest that distance data may be easier to obtain.

To resolve the matter of which impedance variable to use in our example, both were tested in the calculation of accessibility measures and compared. Gravity-based accessibility measures were calculated for work, shopping and restaurant trips by walking and bicycling modes using time and distance variables. Simple correlation coefficients between the time and distance-based measures ranged from approximately 0.92 to just under 1, indicating little sensitivity to the specification of impedance variable. Thus, our research concluded that either variable would be acceptable. To calculate impedance values for each mode and trip purpose, household travel survey data can be used to fit a negative exponential curve that provided a continuous approximation to the shape of the trip length distribution, using both trip duration and distance data. The same functional form can be used for all impedances to ensure consistency of application across modes and trip purposes.

One drawback, however, of this method is that it imposes the same functional form on each impedance function regardless of the underlying distribution, thus producing a poor fit in some situations. Another important issue is that the impedance functions are estimated without reference to the spatial distribution of activities, meaning that the estimated impedance parameter may mask a significant amount of variation between geographic locations. Nonetheless, this procedure provides a disaggregate alternative to assuming identical travel behaviour for all trip purposes.

5 Conclusions and prospects

For many years now, the bulk of existing work related to cities and transportation has focused on strategies to modify transportation phenomena or behaviour often absent specific reference to the policy-related forces that have shaped it all along. For example, considerable research seeks improved models of travel behaviour. Furthermore, it tries to draw close associations to environmental outcomes; alternatively, research might seek to put more accurate dollar figures on various intangibles, etc. The intent is that such research will enhance policy making. Implicit in this line of reasoning is that shortcomings in transportation policies in the past were primarily attributable to lack of accuracy in this kind of knowledge. By reducing uncertainty in these areas, it is thought that more effective policies could be uncovered.

But what if weaknesses in the policies are derived from sources other than gaps in this kind of knowledge? What if they come from inferior definitions of the problems and associated indications of these problems (e.g., mobility vs. accessibility)? This research suggests that problem definitions can be reformed to bring them in line with current transportation goals and also prescribed several important issues to consider to provide measures of such as issues of mobile source pollutants, consumption of non-renewable resources, and global climate change rise in prominence, increasing attention focuses on urban development strategies to alleviate these concerns. Indicators to comprehensively measure the performance of the combined transport *and* land use system are valuable in such an endeavour.

The concept of accessibility offers a compelling alternative basis for sustainability policy regarding the built environment. In this application we view the process of developing accessibility measures for non-motorised modes as both an accomplishment and an invitation for future work at both the academic and practitioner levels.

We describe matters to show that it is in fact possible to construct measures of accessibility for non-motorised modes that are sensitive to spatial scale and that attempt to capture important features of non-motorised travel. This effort has gone beyond previous work in this area by attempting to introduce more behavioural realism into accessibility calculations and doing so for relatively small units of analysis. Such realism is accomplished primarily through the use of impedance measures estimated for each separate combination of mode and trip purpose and highly detailed land use data. This represents an improvement over previous studies, which often borrowed values from other studies or relied on assumptions about the true value or aggregate values for a large area. Furthermore, the estimation of the impedance measures was aided by the use of a specially-constructed network that was designed to capture a fuller range of route choices for pedestrians and cyclists than most travel model networks allow. One limitation was that the assumption of shortest-path routes may not hold for certain types of non-motorised travel behaviour, as in the case of walking trips for recreation or leisure purposes, where travel cost minimization may not be as important a criterion.

In developing non-motorised measures of accessibility using the methods described here, we sought to strike a balance between practical considerations and theoretical rigor. For example, we chose location-based measures of accessibility, namely gravity-based measures, as our units of analysis (Iacono et al., 2010). These accessibility measures offer advantages in that they can easily be operationalised, and are relatively easy to interpret and communicate (Geurs and van Wee, 2004). On the other hand, location-based measures ignore the temporal and individual components of accessibility, and thus offer an incomplete picture of access as experienced by most individuals.

The methods presented here are suggestive, and there are many possible ways to approach the methodological problems we have identified. We chose to work within the framework of existing travel forecasting methods, which are well adapted to producing location-based measures of accessibility. A promising direction for future research would be to frame the problem of non-motorised accessibility calculation within a larger reconceptualisation of travel behaviour modelling. Much effort in the geographical and planning research fields during the past ten to 15 years has been devoted to adapting accessibility measures to concepts of space and time geography, thus resulting in the development of person-based accessibility measures (Kwan, 1998; Miller, 1999). This is a critically important concept in both travel behaviour and accessibility research, since temporal and individual or household-level constraints can often have a great influence on the level of accessibility a person actually experiences at a given location (Weber, 2006), something that cannot be demonstrated using location-based measures. Being able to account for individual-level characteristics or constraints, such as car ownership (or perhaps bicycle ownership), gender, household structure and other variables would allow for a more nuanced understanding of the relationship between accessibility and travel behaviour by non-motorised modes. One could even extend the analysis to situations of group travel and 'joint' accessibility, as is described by Neutens et al. (2007). The possibilities for this type of research seem boundless, given that much of the basic methodology has already been established and could, with some effort, be focused on the issue of non-motorised accessibility.

While future non-motorised accessibility research may prove fruitful, we also believe that the type of transportation and sustainability initiatives described in this paper may also have value at the practitioner level in terms of informing the design of instruments of accessibility-related policies (Farrington, 2007), scenario building and sketch planning applications. For example, low levels of accessibility in certain areas might prompt efforts to reduce zoning restrictions in certain neighbourhoods to allow new restaurants to locate in underserved areas. Or perhaps it may indicate that improvements to the pedestrian infrastructure are warranted. Either approach could be employed to address the stated goal of improving access. In addition to formulating planning goals, non-motorised accessibility measures can provide one important component of an overall system for monitoring and evaluating the transportation and land use system in an urban region. With a growing level of interest in sustainable modes of travel in many transportation policy circles and more broadly in cities, detailed and robust accessibility measures geared to help advance these planning efforts.

References

Daly, A.J. (1997) 'Improved methods for trip generation', in *Proceedings of the 25th European Transport Conference*, Vol. 2, pp.207–222, PTRC, London.

Eash, R.W. (1999) 'Destination and mode choice models for nonmotorized travel', *Transportation Research Record*, Vol. 1674, pp.1–8.

Farrington, J.H. (2007) 'The new narrative of accessibility: its potential contribution to discourses in (transport) geography', *Journal of Transport Geography*, Vol. 15, No. 5, pp.319–330.

Geurs, K.T. and van Wee, B. (2004) 'Accessibility evaluation of land-use and transport strategies: review and research directions', *Journal of Transport Geography,* Vol. 12, pp.127–140.

Handy, S.L. and Clifton, K.J. (2001) 'Evaluating neighborhood accessibility: possibilities and practicalities', *Journal of Transportation and Statistics,* Vol. 4, Nos. 2–3, pp.67–78.

Handy, S.L. and Niemeier, D.A. (1997) 'Measuring accessibility: an exploration of issues and alternatives', *Environment and Planning,* Vol. 29A, No. 7, pp.1175–1194.

Handy, S.L. (1993) 'Regional versus local accessibility – implications for nonwork travel', *Transportation Research Record,* Vol. 1400, pp.58–66.

Hansen, W. (1959) 'How accessibility shapes land use', *Journal of the American Institute of Planners,* Vol. 25, No. 1, pp.73–76.

Hanson, S. and Schwab, M. (1987) 'Accessibility and intraurban travel', *Environment and Planning,* Vol. 19A, No. 6, pp.735–748.

Hunt, J.D. and Abraham, J.E. (2007) 'Influences on bicycle use', *Transportation,* Vol. 34, No. 4, pp.453–470.

Iacono, M., Krizek, K.J. and El-Geneidy, A. (2010) 'Measuring non-motorised accessibility: issues, alternatives, and execution', *Journal of Transport Geography*, Vol. 18, pp.133–140.

Ingram, D.R. (1971) 'The concept of accessibility: a search for an operational form', *Regional Studies,* Vol. 5, pp.101–107.

Kanafani, A.K. (1983) *Transportation Demand Analysis*, McGraw-Hill, New York.

Kwan, M-P. (1998) ‚Space-time and integral measures of individual accessibility: a comparative analysis using a point-based framework', *Geographical Analysis,* Vol. 30, No. 3, pp.191–216.

Miller, H.J. (1999) 'Measuring space-time accessibility benefits within transportation networks: basic theory and computational procedures', *Geographical Analysis*, Vol. 31, No. 2, pp.187–212.

Neutens, T., Witlox, F., van de Weghe, N, DeMaeyer, P. (2007) 'Space-time opportunities for multiple agents: a constraint-based approach', *International Journal of Geographic Information Science,* Vol. 21, No. 10, pp.1061–1076.

Openshaw, S. (1984) *The Modifiable Areal Unit Problem*, Geo Books, Norwich, UK.

Ortuzar, J.D.D. and Willumsen, L.G. (2001) *Modelling Transport,* 3rd ed., John Wiley and Sons, Inc., New York.

Page, M., (2005) 'Non-motorized transportation policy', in K.J. Button and D.A. Hensher, (Eds.): *Handbook of Transport Strategy, Policy and Institutions,* pp.581–596, Elsevier, Amsterdam.

Porter, C., Suhrbier, J.H. and Schwartz, W.L. (1999) 'Forecasting bicycle and pedestrian travel: state of the practice and research needs', *Transportation Research Record,* Vol. 1674, pp.94–101.

Preston, J. and Raje, F. (2007) 'Accessibility, mobility and transport-related social exclusion. *Journal of Transport Geography,* Vol. 15, No. 3, pp.151–160.

Sheppard, E. (1995) 'Modeling and predicting aggregate flows', in S. Hanson, (Ed.): *The Geography of Urban Transportation*, 2nd ed., pp.100–128, Guilford Press, New York.

Stinson, M.A. and Bhat, C.R. (2003) 'Commuter bicyclist route choice: analysis using a stated preference survey', *Transportation Research Record,* Vol. 1828, pp.107–115.

Tilahun, N.Y., Levinson, D.M. and Krizek, K.J. (2007) 'Trails, lanes, or traffic: valuing bicycle facilities with an adaptive stated preference survey', *Transportation Research, Part A: Policy and Practice,* Vol. 41A, No. 4, pp.287–301.

U.S. Department of Transportation, Bureau of Transportation Statistics (2000) *Bicycle and Pedestrian Data: Sources, Needs, & Gaps,* Publication BTS00-02, US Department of Transportation Washington, DC..

Weber, J. (2006) 'Viewpoint: reflections on the future of accessibility', *Journal of Transport Geography,* Vol. 14, pp.399–400.

Weinstein, A., Bekkouche, V., Irvin, K. and Schlossberg, M. (2007) 'How far, by which route, and why? A spatial analysis of pedestrian preference', in *Proceedings of the 86th Annual Meeting of the Transportation Research Board*, 21–25 January 2007, TRB, Washington, DC.

Witlox, F. (2007) 'Evaluating the reliability of reported distance data in urban travel behaviour analysis', *Journal of Transport Geography,* Vol. 15, No. 3, pp.172–183.