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Measuring non-motorized accessibility: issues, alternatives, and execution

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ABSTRACT

While the transportation planning literature contains many examples of the calculation of measures of accessibility for urban areas, these measures are largely restricted to motorized modes and to a handful of destination activities. This paper explores the issues related to the development of accessibility measures for non-motorized modes, namely bicycling and walking. We note that 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 describing and predicting travel by non-motorized modes. We present practical strategies for addressing these issues. The application of these methods is illustrated with the calculation of accessibility measures for a small study area in Minneapolis, MN (USA). The paper concludes with some direction for future development of non-motorized accessibility measures and ideas about their applicability to the practice of transportation planning.

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1. Introduction

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). The Hansen work 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. Improving accessibility has recently re-emerged as a central aim of urban planners and aligned disciplines. However, conventional transportation planning is often focused on improving movement (or mobility) – most often by the automobile. 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 on 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 hypothesized 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 behavior 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 a wide array of destinations and non-auto modes such as walking and cycling has been previously proposed as a much needed aim among planning initiatives (Handy, 1993; Handy and Clifton, 2001; Krizek, 2005). Given the current policy environment of scientific uncertainty surrounding travel and urban form (Levine, 2006), accessibility offers an alternative basis for sustainability policy regarding the built environment and travel – a policy that can be bolstered provided that detailed, reliable, objective and robust metrics are available. Uncovering such measures for walking and cycling would go a long way toward assisting planning efforts with the tools they need to make sounder decisions with respect to the provision of non-motorized transportation facilities.

A central issue is that to date, however, there have been few – if any-examples of measures from which to draw. When it comes to bicycling and walking, measures of accessibility are an endeavor long on rhetoric but short on execution. Much has been written about the topic, even "concept" pieces offering ideas for data to account for (Landis et al., 2001; Guttenplan et al., 2001; Handy and Clifton, 2001; Chin et al., 2008). Where they have been uncovered, the measures are extremely location specific or cover a small geographic area (Ulmer and Hoel, 2003; Achuthan et al., 2007). Given the requisite data, modelers in most metropolitan areas probably know what to do. However, issues including, but certainly not limited to lack of reliable data, computational power, or knowledge of

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non-motorized travel behavior have precluded effective progress on this front, at least when it comes to doing so for entire metropolitan areas.

This paper discusses such hurdles, presents alternatives for overcoming them, and demonstrates a proof of concept application for how accessibility for walking and cycling – and for different types of destinations – can be reliably measured. We focus on explaining specific features of non-motorized 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 illustrated with a sample application in Minneapolis, MN, USA.

2. Measuring accessibility for non-motorized travel

In principle, it is logical to measure accessibility for non-motorized modes using similar methods as for motorized vehicle travel, thereby allowing the user to calculate any of the conventional, location-based measures of accessibility associated with zone-based travel forecasting models (e.g., cumulative opportunities, gravity-based, and utility-based measures). 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:

$$A_i = \sum_j a_j f(t_{ij}) \tag{1}$$

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.One practical reason for considering gravity measures or other location-based measures of accessibility for non-motorized modes is the potential compatibility with regional travel forecasting models which can easily extract zone-to-zone travel times from coded networks. In addition, counts of potential opportunities such as employment are stored at the zone level. Extending this basic framework to measure non-motorized travel encounters serious limitations–limitations which, as will be discussed in greater detail, relate to the representation of non-motorized modes in travel demand models.With respect to travel impedance, the networks used for modeling 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-motorized route choices tend to include factors that may be more qualitative, experiential or difficult to operationalize (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-motorized travelers (Stinson and Bhat, 2003; Weinstein et al., 2007) – just that it is not quite as decisive. Methods for simplifying this problem and adapting zones to fit the needs of non-motorized travel are discussed in the next section.

3. Measurement issues and alternatives

Having discussed central parameters to measure access, generally, as well as access for non-motorized modes, we now turn to addressing specific sources of difficulty encountered with the inputs to accessibility calculations. These issues are fourfold as presented in Table 1 along with proposed solutions the research team employed to address them. The remainder of the paper elaborates on such issues and solutions using the application of a portion of south Minneapolis, MN (USA) as a case study to illustrate how these measures can come to fruition.

3.1. Data

3.1.1. Need for non-motorized travel behavior data

Calculating accessibility measures requires multiple data sets relating to travel behavior and land use, each of which presents unique challenges for analysts addressing non-motorized modes. For example, robust accessibility measures are built around models representing human behavior (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-motorized mode users and their trips are typically aggregated to the same level as motorized trips, rather than being assigned to smaller aggregation units. Information on preferences toward different facilities is typically incomplete at best, and often entirely absent. These data items are not adequately covered in most large scale survey instruments, such as metropolitan travel surveys or the nationwide personal transportation survey (NPTS).

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-motorized behavior, issues related to weather conditions play a big role. Ideally, travel survey data would be collected year

Table 1
Unique issues indicative to measuring non-motorized accessibility and proposed solutions.

Issues	Proposed solution
Lack of reliable non-motorized travel behavior data for a variety of trip purposes	Use a subset of local travel survey data set collected by the metropolitan planning agency
Lack of high-resolution land use data	Collect and prepare detailed land use data set from existing public land use data or private party business inventory data set
Inadequate zonal structure and travel networks	Use Census block-level data for zones (or other small units); employ modified GIS street layers for travel networks, complemented with detailed data (GIS layers) for non-motorized infrastructure
Completely arbitrary impedance functions used for walking and bicycling activity	Estimate impedance functions for non-motorized modes and several destination types using detailed data on trip distribution by time and distance from a variety of sources (e.g., transit on-board surveys, specialized trail use surveys)

round and cover all seasons (Ortuzar and Willumsen, 2001). More commonly, data are collected over a period of several months and reflect weather conditions prevailing at the time the survey data were collected. This is especially important in the case of non-motorized modes and in locations where significant seasonal climate variations exist. For example, if survey data are collected during warmer, drier months it is possible that changes in travel behavior during colder or wetter months might be missed. These changes might include mode shifts, in which case the number of pedestrians and bicyclists might be overestimated during cold weather periods, and changes in destination choice for discretionary trips, which would affect the length or distance of travel, and hence the relevant impedance values.

Estimating specialized impedance functions specific to non-motorized modes requires appropriate travel survey data that can capture pedestrian and bicycling behavior. Ideally, this would involve a focused, special-purpose survey designed to oversample these types of behavior 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-motorized modes. The current 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 under-reported modes in many US cities, any further partitioning of the data can lead to small samples and less robust inferences.

3.1.2. Need for high-resolution land use data

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 organizations. 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 organizations or highly confidential. The data can be costly to acquire and require significant effort in terms of cleaning and preparation for spatial analytical use. Alternate, 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 "neighborhood" 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 specialized, establishment-level data that can be aggregated to relatively small units of aggregation, such as the block groups described earlier. Establishment-level data were purchased from Dun & Bradstreet, Inc. containing attribute information on location, sales, employees, and industry classification. In all, data were available for 135 928 businesses within the region. These data were merged with parcel-level land use data from the Metropolitan Council, the Twin Cities' regional planning agency. The establishment-level data were then recoded into destination categories using the 2–6 digits classifications of the North American Industry Classification System (NAICS). The outcome of this process was a set of parcel-level land use data with information on employment counts and sales volumes. A small sample of this data set, with mapped parcel-level land use for an eight-block area of south Minneapolis, is shown in Fig. 1.

3.2. Inadequate zonal structure and travel networks

In addition, other efforts often 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 neighborhood 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 neighborhood-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 specialized facilities for non-motorized travel, such as sidewalks, exclusive bike paths and on-street bicycle lanes.

Incompatibility between conventional travel forecasting models and travel by non-motorized modes is characterized by travel zones that are too large and networks that are too coarse to provide detailed analysis of destination and route choice behavior 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-motorized modes. These advantages can be operationalized 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. This method was applied to the Twin Cities' network of exclusive bicycle paths, which were recreated from a locally published bicycle system map.

A key assumption of constant travel speeds must be accepted for bicycle and pedestrian travel, in order for this method to be applicable. This allows for simple conversions between measurement of distance and time. As a check on this assumption, El-Gene-

Fig. 1. Parcel-level land use data.

idy et al. (2007) reviewed the literature on travel speeds for pedestrian and bicycle modes and tested the influence of different types of bicycle facilities on travel speeds. Off-street facilities were shown to have a small but statistically significant effect on speeds, lending support to their inclusion as special network links with different cost characteristics. However, this work also noted a high degree of interpersonal variability, indicating that an assumption of constant speeds may be a significant source of uncertainty in accessibility measures.

Another adaptation that allows a better characterization of travel impedance is using smaller zones to identify potential origins and destinations. This method has been used elsewhere (Eash, 1999) to model non-motorized 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.

3.3. 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-motorized 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 motorized 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-motorized 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-motorized 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. Here, we choose 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-motorized modes (Kanafani, 1983). This advantage, along with a record of numerous empirical applications made it an appropriate

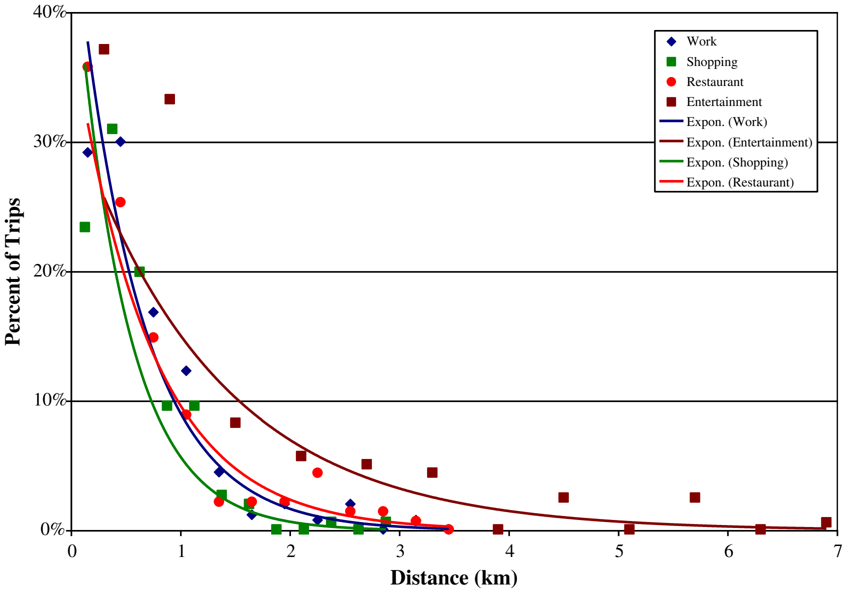

Fig. 2. Impedance functions for walking trips.

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 *generalized cost* concept (Handy and Niemeier, 1997). In the case of non-motorized 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.

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 one, indicating little sensitivity to the specification of impedance variables. Thus, we concluded that either variable would be acceptable.

To calculate impedance values for each mode and trip purpose, household travel survey data were 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 was used for all impedances to ensure consistency of application across modes and trip purposes. A set of impedance functions for walk trips using distance as an impedance measure is provided in Fig. 2. Destinations for which these functions were estimated include work, shopping, restaurant and entertainment trips. The full summary of impedance functions for walking and bicycling is shown in Table 2.

One drawback 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. Nonetheless, this procedure provides a disaggregate alternative to assuming identical travel behavior for all trip purposes.

4. An example of non-motorized accessibility measures

To illustrate the procedures used to produce estimates of non-motorized accessibility, as a proof of concept demonstration, we calculated accessibility measures for a small study area in South Minneapolis.[3] This area contains approximately 1600 block groups, which represent the unit of analysis. The accessibility values calculated for each block group are *integral* accessibility measures (Ingram, 1971; Song, 1996), where the activities in each destination zone, discounted by their associated impedance value, are summed across destinations and normalized by dividing by the total activities in the study area. This method provides a measure that can be easily interpreted and compared across zones on the same zero to one scale. Analytically, this measure is represented as

$$A_i = \frac{\sum_{j \neq i} E_j e^{-\beta x_{ij}}}{E} \tag{2}$$

where:

A_i denotes accessibility evaluated at origin zone i
x_{ij} denotes the distance (or travel time) between zones i and j
E_j denotes the amount of activity in destination zone j
E denotes total activity in the study area, summed across all zones, and
β is a parameter of the impedance function, to be empirically estimated.

Thus, for each accessibility measure, representing a combination of mode and destination type, accessibility is expressed as a decimal indicating proximity to destinations in each location. In the case of each accessibility calculation, an attractiveness measure is constructed for each block group by summing the level of retail sales at each establishment within the block group. Impedance measures are introduced by calculating the shortest path through the network between each block group pair, then using this value to discount activities at the destination using the functional form described previously.

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[3] The study area is bounded on the west by Lyndale Avenue, on the north by Franklin Avenue, on the east by the Mississippi River, and on the south by 50th Street.

Table 2
Summary of impedance functions for walking and bicycling.

	Work		Shopping		School		Restaurant		Recreation	
	Distance	Time	Distance	Time	Distance	Time	Distance	Time	Distance	Time
Walk	$y = .486e^{-1.683x}$	$y = .511e^{-.106x}$	$y = .469e^{-2.106x}$	$y = .368e^{-.094x}$		$y = .524e^{-.106x}$	$y = .388e^{-1.397x}$	$y = .373e^{-.093x}$	$y = .327e^{-.769x}$	$y = .556e^{-.100x}$
Bike	$y = .402e^{-.203x}$	$y = .146e^{-.040x}$	$y = .343e^{-.514x}$	$y = .434e^{-.107x}$	$y = .458e^{-.122x}$	$y = .424e^{-.100x}$			$y = .367e^{-.375x}$	$y = .293e^{-.071x}$

Notes:

(1) For impedance functions where distance is the measure of separation, kilometers are the relevant units. Where time is the measure of separation, units are in minutes.

(2) The dependent variable (y) measures the fraction of trips covering a given distance.

(3) All grayed cells represent impedance functions that could not be estimated due to limited data.

Fig. 3 presents maps displaying measures of accessibility to restaurant destinations for the walking mode. Again, the maps show the same measures calculated using time and distance as alternate measures of travel impedance. Consistent with the findings described earlier, they show a high degree of similarity. Areas near clusters of restaurant destinations are shown to have high levels of accessibility, with a gradual decline as one moves away from these clusters.

Fig. 4 presents a pair of maps showing accessibility to shopping destinations by bicycle with distance and time impedance measures. In this case, destinations are spread more evenly throughout the study area, leading to higher overall accessibility values in each zone. Retail establishments appear to align themselves along linear corridors, reflecting the historical network of streetcar routes in South Minneapolis. One particularly large corridor is found along Lake Street, a major east–west route that lies at the center of the swath of high accessibility shown in both maps. This high-accessibility location results from a combination of clustering of activities and proximity to the Midtown Greenway, a grade separated off-street bicycle facility highlighted in green on the map. The Greenway appears on the map as thin, green strip running east–west through the northern section of the study area, and turning slightly to the north as it approaches Hiawatha Avenue (Highway 55). Lake Street appears immediately to the south of the Greenway and is highlighted by a fairly continuous, linear clustering of retail establishments between the western boundary of the study area and the Mississippi River on the east end.

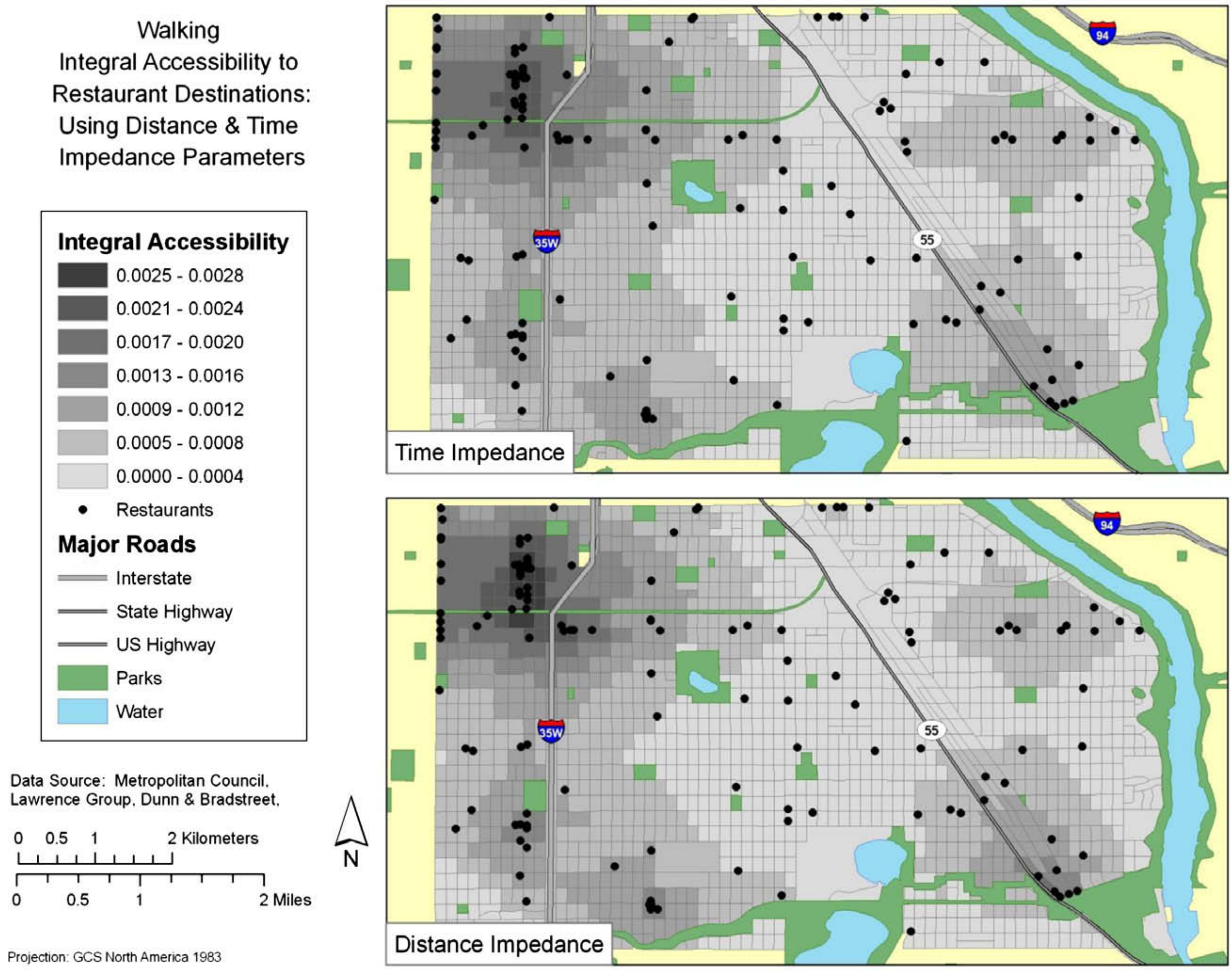

Fig. 3. Walk accessibility to restaurants.

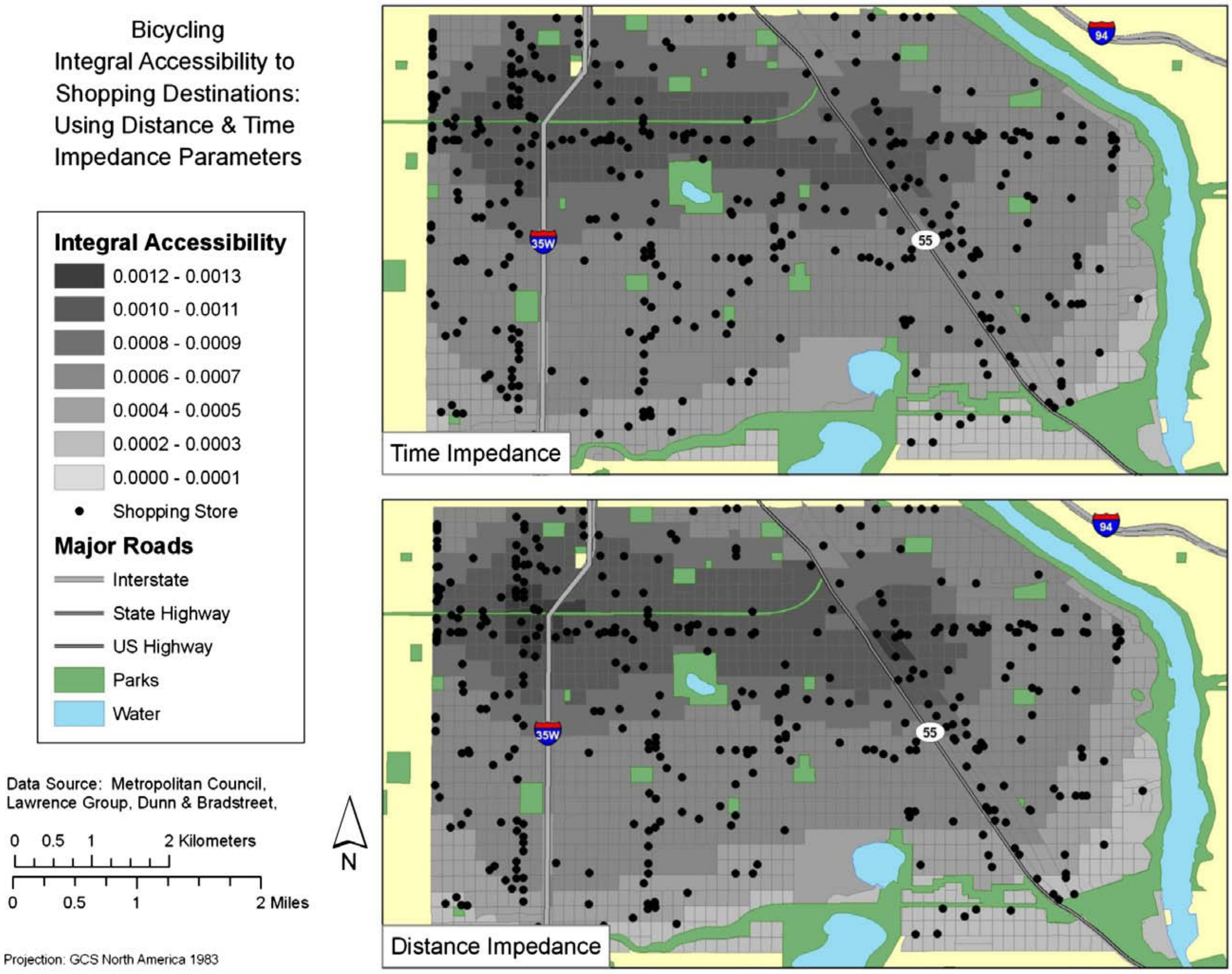

Fig. 4. Bicycle accessibility to shopping.

Together, these two examples illustrate the roles that location and space play in determining non-motorized accessibility, robustly measured, for an urban area, and graphically displays the outcomes associated with the interaction of these forces.

5. Conclusions and prospects

We view the product of developing detailed accessibility measures for non-motorized modes across an entire metropolitan region as a credible accomplishment; more importantly, however, it is an invitation for future work at both the academic and practitioner levels. Each of these ideas is discussed further in this concluding section.

First, we have shown that it is in fact *possible* to construct measures of accessibility for non-motorized modes that are sensitive to spatial scale and that attempt to capture important features of non-motorized travel. We believe this to be an important demonstration, as none of the authors are aware of other efforts that have done so for entire metropolitan regions, been documented in peer-reviewed publications, and that have used original data to provide an empirical basis for the measures. This effort has gone beyond previous work in this area by attempting to introduce more behavioral 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 work therefore 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-motorized travel behavior, 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-motorized 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. These accessibility measures offer advantages in that they can easily be operationalized, 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. 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 accessingthese 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).

The methods presented here are suggestive, and there are many other 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-motorized accessibility calculation within a larger reconceptualization of travel behavior modeling. Much effort in the geographical and planning research fields during the past 10–15 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 behavior 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 behavior by non-motorized 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-motorized accessibility.

While future non-motorized accessibility research may prove fruitful, we also believe that the type of non-motorized accessibility measures 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, the maps in Fig. 3 indicate that there are large portions of the study area with relatively low walk accessibility to restaurants. This finding might prompt efforts to reduce zoning restrictions in certain neighborhoods 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-motorized 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 non-motorized travel in many transportation policy circles, detailed and robust accessibility measures geared to non-motorized modes provide an additional option to form and evaluate land use-transportation planning efforts.

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