Operationalizing Neighborhood Accessibility for Land Use–Travel Behavior Research and Regional Modeling

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Abstract

Many land use–transportation planning proposals aim to create neighborhoods with higher levels of neighborhood accessibility (NA). This article focuses on how such features are operationalized for purposes of research and/or regional modeling. The first section reviews specific variables classified by three basic tenets of NA: density, land use framework, and streets/design. The second section describes challenges in measuring NA to provide a better understanding of how such challenges shape research efforts and applications. The final section creates an NA index that is applied to the Central Puget Sound metropolitan area. The index uses detailed measures of density, land use mix, and street patterns and makes at least five contributions for urban form research.

Keywords: *urban form; local access; travel behavior; transportation modeling; urban design*

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▶ Planning and Policy Context

The effect of accessibility on travel patterns and residential location decisions is a research topic with a long and venerated tradition in literature related to urban economics, planning, geography, and transportation. The recent surge of interest in the potential for neighborhood design to curb Americans' appetite for auto travel has generated increased interest and new questions related to issues of access; more generally, this interest draws increased attention to integrated land use and transportation planning and regional modeling. The chorus of calls echoing throughout the planning community urge compact development, a mixing of land uses, and urban design improvements (e.g., sidewalks, gridded streets, street crossings). Planning proposals with such features have been labeled "neotraditional development," "transit-oriented development," "traditional neighborhood design," or "pedestrian pockets." The recently coined terms "new urbanism" and "smart growth" contain design characteristics that embody each of them.

Different styles of development focus on different aspects (e.g., transit or pedestrian travel); however, each share a common underpinning. Each aims to create development patterns that exhibit higher levels of neighborhood accessibility (NA), thereby providing attractive options for residents to drive less. Many of the basic characteristics—mixed-use zoning, pedestrian-scale design, or reduced setbacks—are terms that easily roll off the tongue of most planners; several publications describe the basic character of this style of development (see Tri-Met 1993). Table 1 and Figure 1 contrast some of the more detailed characteristics for areas with high and low levels of NA.

But how does one operationalize NA for purposes of research or urban modeling? Such a task is a challenging endeavor and one that requires us to capture its myriad dimensions as a measurable entity. The challenge is motivated by two related reasons. First, the influence of neighborhood-scale urban form on travel behavior and/or residential location decisions represents an active research agenda with pressing policy significance. The U.S. Environmental Protection Agency and the U.S. Department of

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Table 1.
Typology of differences between high and low levels of neighborhood accessibility.

	Levels of Neighborhood Accessibility	
	High	*Low (post–World War II development)*
Density	• Relatively higher residential densities • Small home lots	• Relatively lower residential densities • Large home lots
Land use mix	• Mixed land uses and close proximity of land uses • Convenient access to parks, recreation • Distinct neighborhood centers	• Segregated, clustered land uses • Access to a limited number of highly desirable land uses
Circulation framework/ urban design	• Interconnected, street patterns with small block size • Separate paths for pedestrian and bicycles • Narrow streets • On-street parking • Sidewalks, green spaces, and tree lining • Variation in housing design and size • Shallow setbacks • Front porches and detached garages	• Circuitous, meandering streets • Strict attention to hierarchical street patterns (highways, arterials, collectors) • Wide streets without on-street parking • Missing or nonshaded sidewalks • Homogeneous housing design • Relatively large setbacks • Dominating garages and driveways

Transportation Federal Highway Administration have launched numerous programs to reduce mobile emissions and improve air quality. Regional governments strive to mitigate traffic congestion. Local municipalities aim to provide increased travel choices for their residents. Our ability to prescribe policies that reduce auto dependence, for example, requires a better understanding of the relationships between urban form, travel behavior, and residential location. This is a challenge that requires a better understanding and representation of different styles of neighborhood design.

Second, the passage of the Clean Air Act Amendments of 1990, the Intermodal Surface Transportation Efficiency Act and its successor, the Transportation Efficiency Act for the 21st Century, place integrated land use–transportation planning and modeling front and center on the agendas of metropolitan planning organizations. Modeling efforts demand practical means to represent NA and to forecast its influence on travel behavior and/or residential location decisions. Advancing capabilities of geographic information systems technology in concert with more precise data provides new opportunities to respond to these challenges.

To further our understanding of how to measure and operationalize NA, this article reviews previous approaches and methodologies; in addition, it serves as a useful advance to measure popular dimensions of NA. The article is divided into three parts. I first describe the scale of neighborhood tackled in this research and the dimensions of accessibility being addressed. I use three classifications—density, land use mix, and streets/design—to discuss and review variables and research strategies used in previous research and modeling applications. This is followed in the second part by discussing measurement issues related to data availability, units of analysis, and the ability to capture multiple dimensions. The last part proposes a strategy to operationalize a detailed urban form index to measure NA for an entire metropolitan area. Using data from the Central Puget Sound, I discuss how these measures can be formulated into a single index and describe an effort to validate this index as a measure of NA.

▶ Review of Previous Measures

The past decade has seen a wealth of research exploring the interaction between land use and transportation planning. The majority of this research examines the influence of neighborhood-scale urban form on travel behavior (for a thorough review, see Crane 2000). Neighborhood features are most often offered as explanatory variables for household travel; however, the concept of NA is being increasingly applied in studies of residential location choice. In this case, neighborhood type is used as a dependent variable (Waddell 1997; Bagley and Mokhtarian 1999). Throughout such research, there are different definitions of *accessibility*, a term embedded with much ambiguity: access to what and by what means?[1]

Consider the popular policy goal of reducing drive-alone travel. Some research equates decreased auto use with increased walking. In this case, it is important to capture urban form at a scale sensitive to walking behavior (e.g., one-quarter mile). In other instances, reducing drive-alone travel focuses on vehicle miles traveled. This may steer the research toward different (larger) units of analysis that examine auto travel only and may even address differing dimensions of urban form.[2] Planning for increased levels of NA is about reducing vehicle miles traveled and encouraging walking, but it is also about reducing vehicle trips, spurring transit use, promoting cycling, and increasing the effective range of neighborhood choice even for those people whose travel behavior might not be affected significantly by residing in such areas. Each issue is important for land use–transportation planning policy. Higher levels of NA provide attractive multimodal options (auto, transit, cycling, and walking) for a variety of travel purposes both within and between neighborhoods, thereby reducing the amount auto travel is required. If/when auto travel is used, NA is about reducing the extent to which it is employed.[3] It is therefore important that any strategy measuring NA be able to capture multiple scales and multiple dimensions.

Figure 1. *Photographic representations of neighborhoods with high and low levels of neighborhood accessibility (NA). (a) Residential neighborhood exhibiting features characteristic of high NA: nearby commercial uses, narrow streets, on-street parking, sidewalks, and relatively higher density. (b) Residential neighborhood exhibiting features characteristic of low levels of NA: curvilinear streets, driveways, lack of sidewalks, and relatively low density.*

Defining Dimensions of NA

But how many dimensions exist? What is their significance and how do they relate to each other? Such issues remain unresolved in urban form literature. Characteristics that contribute to high levels of neighborhood accessibility are myriad; some can be easily measured, others are considerably more challenging to get our arms around. In many respects, the process of identifying and measuring a neighborhood with a high level of NA is analogous to Justice Potter Stewart's relatively obtuse definition of hard-core pornography: "I'll know it when I see it" (*Jacob Ellis v. Ohio*, 378 U.S. 184 [1964]).

A definition put forth almost a decade ago (Tri-Met 1993) posits that areas with high NA (1) increase concentrations of population and employment in corridors and nodes of good transit service, (2) encourage a mix of appropriate land uses, and (3) design development and public right-of-way improvements to be pedestrian oriented. This definition reduces a complex concept to three tenets. These three tenets (also known as the "3Ds": density, diversity, and design) closely mirror the classification scheme used to categorize variables relating to the built environment in another application (Cervero and Kockelman 1997). Some research has grouped the set of characteristics differentiating high and low NA neighborhoods according to their (1) network, (2) land use, and (3) design characteristics (McNally and Kulkarni 1997). Still other applications capture dimensions related to issues of (1) street crossings, (2) sidewalk continuity, (3) "fineness" of the city blocks (1000 Friends of Oregon 1993) or (1) quality of bicycle/pedestrian infrastructure, (2) land use mix, (3) building setbacks, and (4) transit stop conditions (Maryland-National Capital Park and Planning Commission [MNCPPC] 1993).

Boiling down the rich set of issues associated with NA to only a few categories does not do justice to the complex concept at hand. Some aspects of urban form (e.g., reduced parking) may not neatly fit into a category; other aspects (e.g., floor-area ratios) may span more than one category. Categorizing basic tenets of NA into distinguishable tenets, however, provides a useful framework and taxonomy from which to further explore and explain in detail the underlying foundations of NA. As an initial basis for discussing different dimensions of NA and how they are measured, I offer the following discussion, which is broken into three sections: density, land use mix, and streets/design. These categories represent basic tenets of NA and main categories of urban form found in the literature. For each category, I explain its significance with respect to NA and review variables that have been used in previous efforts to operationalize this concept. A summary of the below discussion can be found in the appendix.

Density

Significance

A rich literature discusses the interaction between urban density, travel behavior, and residential location (see the review in Steiner 1994). For the most part, higher density development reduces the number of trips taken and percentage of trips taken by auto. Residential density is also used in urban modeling applications to predict the location of households. While density is often associated with other features of NA, this may not always be the case. Hess et al. (1999) demonstrated how pedestrian activity varies for neighborhood centers with similar density but different site design characteristics. We begin to see how density provides a critical, though not exhaustive, measure of NA.

Strategies for Operationalizing

Because density is the most readily accessible urban form variable to operationalize, it is more commonly used than any other urban form measure. Two important and often overlooked issues deserve attention. First, the inherent nature of density calculations separate population (household) measures from employment measures. But it is the synergistic relationship between the two that affects travel. A large tract of high-density, residential-only development does little to promote pedestrian travel because of poor accessibility to nonresidential uses. For lack of a good strategy to integrate population and employment density, such measures need to be viewed with caution.

The second issue relates to the manner in which the denominator is measured, thereby affecting measures of gross density and net density. Gross density specifies total land area, including areas devoted to parking lots, roads, and so on. Net density refers to the net land area, excluding roads, public open space, parking lots, environmentally sensitive areas, and other undeveloped land. Most American land use dialogue addresses net density because it refers to dwelling units per residential acre. Net density is more applicable in site-specific purposes because it measures only the available land for development, representing how efficiently land is used on a specific site. But because the size and amount of roadways and parking lots directly influence the quality of pedestrian environments, gross density is preferred when measuring NA. Downs (1992, Appendix B) provided a crude strategy to equate the two measures.

Land Use Mix

Significance

Land use mix refers to the synergy created when banks, restaurants, shops, offices, housing, and other uses locate close to one another, allowing for decreased travel distances between origins and destinations. In some instances, mixed land use may even promote walking or cycling as a substitute for auto travel. From a perspective of residential location, Banerjee and Baer (1984) identify land uses that people value in close proximity to their home. The most desirable uses include a drug store, food market, gas station, post office, specialty food, and bank. Additional benefits of mixed land uses include serving as a means to (1) anchor transit stations and transit service, (2) reduce parking demand (and impervious surface) because spaces can be shared among uses and throughout times of day, and (3) spread the demand for external trips more evenly throughout the day, reducing levels of peak congestion.

Strategies for Operationalizing

Echoing Hess and Moudon (2000), at least two interrelated elements of land use mix need to be considered with respect to influencing less auto-dependent travel. The first is the extent to which the land uses complement one another from a functional standpoint. Do likely pairs of origins and destinations come into contact with one another (Lynch 1981)? For example, a mix of agricultural and residential is unlikely to produce the same benefit as a mix of retail and residential. A second point considers the extent to which land uses complement one another from a spatial standpoint. For the trip types in question (e.g., walking), are land uses that functionally complement one another close to each other? Measurement strategies to capture these dimensions range from simple to complex, with varying degrees of success. To help distinguish between different strategies, I separate the below discussion into three classifications based on strategies to assess land use mix: inspection, employment, and entropy/index of dissimilarity.

By inspection. Most often, land use mix is gauged as a binary variable indicating the presence or absence of nonresidential uses within a neighborhood. The simplest case is where neighborhoods are classified as mixed or not by simple inspection (Friedman, Gordon, and Peers 1994; Cervero and Radisch 1996; Rutherford, McCormack, and Wilkinson 1996). In classifying five case study sites, Kitamura, Mokhtarian, and Laidet (1997) used dummy variables to classify whether an area contained mixed uses. They complemented these binary mixed-use classifications by asking respondents to estimate the distance to the nearest grocery store, gas station, or park to the nearest tenth of a mile.

Cervero (1996) examined the effect of two indications of land use mix using data from the American Housing Survey. One variable was self-reported data indicating the presence of retail shops and other nonresidential activities within three hundred feet of a surveyed household (generally a one- or two-block distance). The second variable identified whether, specifically, there was a grocery or drug store between three hundred feet and one mile of a surveyed residence. In this respect, the first measure identified whether there are nonresidential activities in the immediate vicinity, whereas the second variable specified whether there are food and drug stores in the area but beyond a convenient walking distance.

Extending the binary approach, Handy (1992) employed a quasi-experimental technique to classify mixed-use neighborhoods in a manner consistent with their regional or local accessibility, where high "regional accessibility" was essentially defined as short travel times to the mall and high "local accessibility" was equated with neighborhood features indicative of high NA. A subsequent analysis (Handy 1996b) recorded the percentage of households within walking distance of a commercial area.

Employment data. Other studies use employment data to proxy for land use mix; as described in the appendix, the strategies for doing so are varied. They include examining the number of retail or service employees in a transportation analysis zone (TAZ) (1000 Friends of Oregon 1993; Boarnet and Sarmiento 1998), number of retail workers within one mile of a household location (Lawton 1997), the number of retail and service establishments summed over one-half kilometer increments from both the home and workplace (Hanson and Schwab 1987), and number of establishments by Standard Industrial Code (Clifton and Handy 1998). A unique inquiry averaged the shortest distance that consumers need to travel to buy each of twelve "convenience" goods and services, weighted by the mean expenditure of that good (Guy 1983).

Entropy/index of dissimilarity. The planning literature has recently been introduced to computational approaches to measure land use mix. The first relies on the concept of entropy and has been used in the land use planning literature by Cervero (1989) and others (Frank and Pivo 1994a; Kockelman 1996; Messenger and Ewing 1996; Sun and Wilmot 1998). An entropy index measures how well uses within a given area (e.g., census tract) are balanced relative to uses within the study region.[4] A neighborhood containing each of the land uses in the same proportion to that of the region would obtain a maximum entropy value.

While entropy quantifies the balance of land use categories within a census tract or a TAZ, it is not a particularly good indicator of either functional or spatial complementarity. Entropy measures the presence or absence of land uses, not the type or intensity of mixing. For example, a mix of restaurant, retail, and service-oriented land uses could be considered the same as mixes of office, warehouse, and manufacturing land uses. Likewise, a neighborhood with 10 percent residential and 90 percent commercial would rank the same as if the proportions were reversed. This begs the question of whether land use balance is important from a travel behavior standpoint or merely the presence of different types of services, regardless of their magnitude. A full-service grocery store in the middle of an all-residential neighborhood is a highly cherished example of land use mix, although it may rate low on the entropy index.

To better capture the spatial complementarity, it is necessary to look at the dissimilarity of uses within a given geographical area. A dissimilarity index (see Kockelman 1996; Cervero and Kockelman 1997) assigns a predominant land use to each hectare (2.47 acres) of land and measures the dissimilarity of each hectare based on uses of adjacent hectares. As the number of adjoining squares with uses different from the central cell increases, so does the index value of the central square. The average of these point accumulations across all active units in a tract (or TAZ) represents the overall mix of the tract (or TAZ). However, as identified by Hess and Moudon (2000), the index is only a measure of whether adjoining squares are different (or not) from the central square and is insensitive to the number of uses that are different from the central square.

Streets/Design

Significance

More than a decade ago, Kulash and Anglin (1990) contended that grid-like street patterns function more efficiently than do typical suburban networks because (1) large streets that are typical of a suburban network operate under a deficiency of scale, (2) turning movements are more efficient on smaller streets, (3) the increased route choices offered by gridded streets make real-time route choice possible (drivers are not always forced onto a few large arterials), and (4) uninterrupted flow is more likely to occur in a dense network because smaller streets make it possible to have more unsignalized intersections. Furthermore, gridlike street patterns have been equated with shorter trips because of the more direct route choices available (see Crane 1996). In these accounts, the impacts of gridded streets are translated directly into transportation outcomes.

In other studies, gridded streets are used as a surrogate to measure traditional characteristics of a neighborhood (Cervero and Gorham 1995). Traditional urban forms typically contain characteristics that make transit, walking, or cycling more attractive in contrast to the cul-de-sac-type development new urbanists love to hate. McNally and Kulkarni (1997) found that gridded streets were one of the most influential variables in a cluster analysis used to group traditional versus suburban neighborhoods. Thus, the theoretical underpinning behind measuring the circulation framework remains varied. Some applications use gridded streets to measure the transportation impacts of increased connectivity; others use gridded streets as proxy variables.

Street patterns, however, represent only one aspect of this important dimension. Seminal works by Appleyard (1981), Alexander (1977), Rapaport (1987), Whyte (1988), and Lynch (1962) highlight the importance of considering the effects of "good" design. Specific features of the built environment—sidewalks, building scale, streetscape, and landscaping—have shown to be critical to the quality of pedestrian environments and no less important for cycling or transit.

The elusive nature of design, however, often defies measurement and is sometimes best captured by more qualitative accounts. One need only refer to the vast literature describing the attributes of successful pedestrian environments (Gehl 1987; Rapaport 1987; Whyte 1988; Owens 1993) to understand the difficulty involved in operationalizing this concept. Because design features are important characteristics for promoting NA, our quest to measure them continues. Variables related to streets/design are described below according to four categories: street patterns, pedestrian amenities, experiential elements, and composite indices.

Strategies for Operationalizing

Street patterns. To measure gridlike street patterns, researchers most often examine the nature of roadway intersections, where gridlike street patterns are represented by a higher number of "X," or four-way intersections (in contrast to "T," or three-way intersections). It is important, however, that the researcher differentiate between the geometric design and the grain of the circulation system by examining the intersection density. For example, gridded streets laid out in superblocks with intersections every one thousand or so feet oftentimes do little to promote pedestrian travel; they may actually foster free-flow automobility. A fine grid with intersections every four hundred or so feet is much more representative of high levels of NA because of the impeded and slower travel speeds. Therefore, a preferred strategy captures block size or intersection density rather than the presence or absence of gridded streets.

Studies with fewer numbers of sites have used aerial photographs and maps to count the incidence of four-way intersections (Cervero and Radisch 1996; Handy 1996a, 1996b). Studies with many sites have used a variety of strategies to operationalize intersection density. Because geographic information system (GIS) software more easily facilitates computing the areas of polygons, some applications measure a close derivative of intersection density: block size. Each of these strategies are described in more detail in the appendix.

Pedestrian amenities. The most fundamental urban design feature is the extent to which pedestrian facilities (e.g., sidewalks) are provided. With advancing GIS capabilities, many municipalities now map sidewalk infrastructure. However, it is still uncommon for an entire metro area's pedestrian network to be digitally recorded. Second-best strategies use proxy measures or fieldwork for a limited number of study sites. Consider Seattle, where neighborhoods developed after World War II typically contain a dearth of sidewalks. In this case, the age of buildings has been used as a proxy to assess the extent of the sidewalk system in particular neighborhoods.

More direct measures include computing the ratio of the total length of the sidewalk system to the total length of the block (or street) frontage (Moudon et al. 1997) or proportion of blocks with sidewalks (Cervero and Kockelman 1997). An optimum ratio would be one to one, indicating that both sides of all public roadways have sidewalks. A simpler measure notes whether an area has full, partial, or no sidewalks on each side of a given stretch of road (Handy 1996b). The ratio of sidewalk length to street frontage, however, is less telling of the sidewalk system's continuity, ultimately an important element of a successful pedestrian environment.

Experiential elements. Whereas the presence of pedestrian facilities allows concrete measurement, more opaque elements certainly advance the experiential aspects of NA. For example, fast-moving vehicles, wide turning radii, and difficult street crossings represent auto-dependent settings. To best tease out how these factors could be measured, we look to the following examples.

The general purpose of the right-of-way (ROW) provides one means to discern the overall nature of the street system. Traditional neighborhood streets may have less than half of the actual ROW devoted to actual roadways (this may be higher for traditional commercial streets), whereas in nontraditional scenarios, almost all of the ROW is devoted to moving vehicular traffic (Moudon et al. 1997). Using a similar logic, one could measure the average traffic volumes on a particular street (Handy 1996b; Moudon et al. 1997) or average speed limit for a TAZ (Levine, Inam, and Torng 2000). A relatively data-intensive strategy analyzing fifty neighborhoods measured street lights, planted strips, flat terrain, block length, and distance between overhead street lights along block faces. Using factor analysis, they uncovered a design dimension representing overall walking quality (Cervero and Kockelman 1997).

Composite indices. Aside from the above mentioned research studies, several municipal planning efforts integrate composite urban form indices into travel demand models. In each of these cases, the indices are based primarily—but not exclusively—on design considerations. The widely cited Pedestrian Environment Factor (1000 Friends of Oregon 1993) has been used in Portland LUTRAQ modeling efforts (Rossi, Lawton, and Kim 1993); a similar index is used by the Sacramento Area Council of Governments. For each TAZ, a score is assigned across four different components: the ease of street crossings, sidewalk continuity, topography, and "fineness" of the street grid for local streets. A similar strategy has been employed by the MNCPPC and the San Francisco County Transportation Authority. The MNCPPC derived an index of pedestrian and bicycle friendliness based on a rating of sidewalks, land use mix, setbacks, transit stops, and bicycle facilities. Each process is limited because it relies on a modified Delphi process as the primary mode of assessment. This proves to be prohibitively costly because it requires detailed knowledge of the entire region and substantial effort to manually assess each TAZ.[5,6]

▶ Troubling Issues Related to Measuring NA

Any strategy to operationalize NA needs to be guided by the overall purpose of the study in combination with the nature of available data. Aggregate urban form measures suffice for uncovering general differences between two different neighborhoods (Friedman, Gordon, and Peers 1994). Geographically detailed measures are usually preferred for more disaggregate modeling purposes (Cervero and Kockelman 1997). To understand the nuances involved in operationalizing NA, it is important to understand the troubling and somewhat confounding issues that pervade this research. Based on the review provided in the first part of this article, I describe four important issues to consider in this research: units of analysis, data availability, general research approaches, and capturing multiple dimensions. Each are discussed below.

Units of Analysis

Restricting attention to the physical-spatial dimensions, the neighborhood as first conceived by Perry (1929) was thought of as a geographic unit. He proposed that the neighborhood unit contain four basic elements: an elementary school, small parks, small stores, and buildings and streets configured to allow all public facilities to be within safe pedestrian access. Many studies attempt to measure Perry's concept of neighborhood using a variety of units of analysis. Some efforts use relatively large districts of a metropolitan area (Cervero and Radisch 1996). The other extreme does not describe any neighborhood boundaries; the term *neighborhood* assumes individual meanings for each respondent (Lansing, Marans, and Zehner 1970; Lu 1998).[7] A middle ground defines *neighborhood* using a buffer distance around each household (Hanson and Schwab 1987).

The majority of past research, however, depicts the neighborhood unit by aggregating 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 containing more than one thousand 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. For example, research in

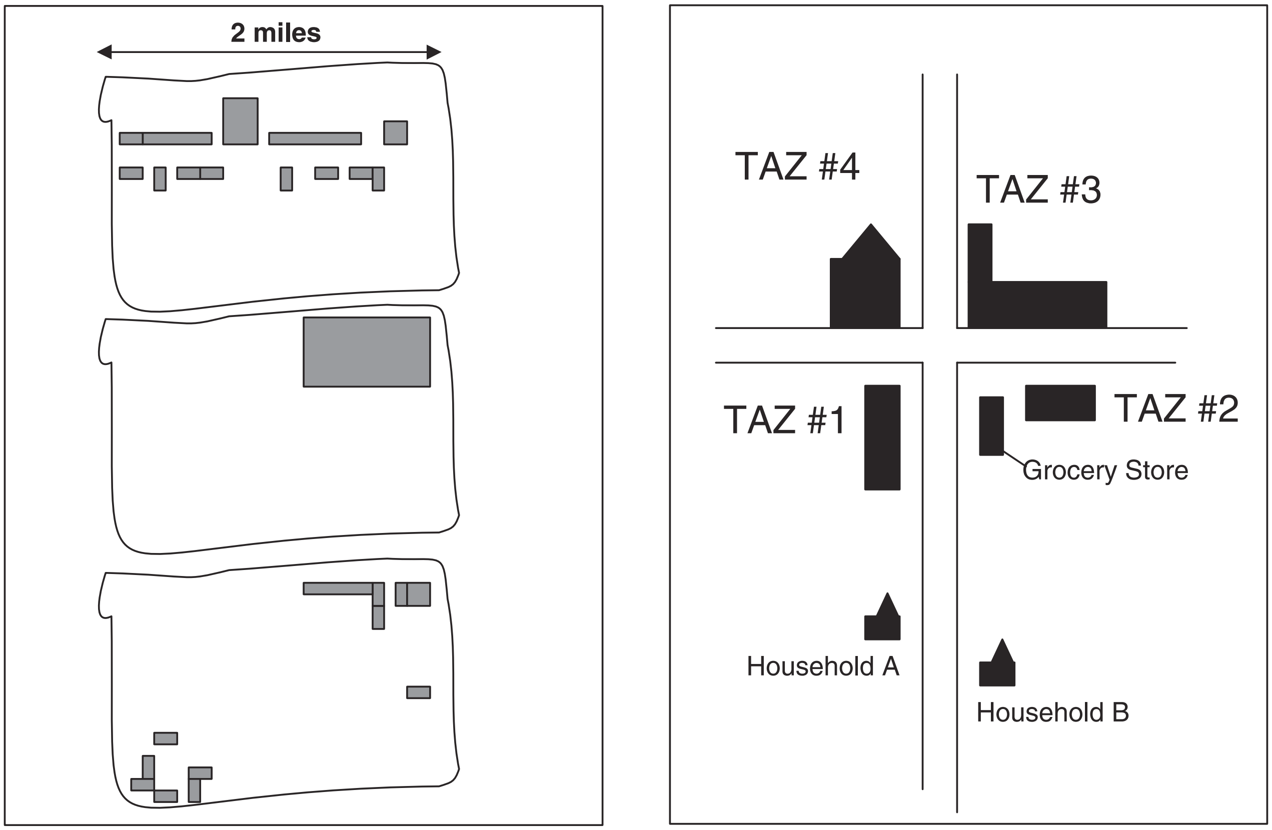


Figure 2. *Confounding issues caused by relatively large units of analysis. (a) Each zone reveals the same urban form measure, although the development pattern is likely to affect travel behavior differently. (b) Household A and B are equidistant from the grocery store, although each are linked to different transportation analysis zones (TAZs). Also, TAZ geography divides the retail center into different zones.*

the Central Puget Sound (Moudon and Hess 2000) identified almost one hundred concentrations of multifamily housing within one mile of retail centers and/or schools. When measures of commercial intensity are aggregated, each zone reveals the same measure despite each zone's exhibiting considerably different development patterns (see Figure 2a). Using census tracks 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.

Furthermore, census tracks or TAZs are often delineated by artificial boundaries (e.g., main arterial streets) that bear little resemblance to the neighborhood-scale phenomenon being studied in terms of their size or shape. Consider two examples graphically displayed by Figure 2b. The first example shows two households living on opposite sides of the street from one another but the same distance to a corner grocery store. Using TAZ geography, household A is linked with TAZ 1 and household B is linked with TAZ 2. The second example shows how a four-way intersection with retail activity on all four corners divides this retail center into different TAZs. Such division dilutes the measure of commercial intensity for any single zone. In terms of affecting travel behavior, however, the commercial intensity of all four corners should be grouped together. Measures of spatial autocorrelation can, to some extent, measure the influence of neighboring regions on one another. 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.

Data Availability

Putting aside units of analysis, other confounding issues stem from lack of available data. Researchers aiming to understand the travel impacts of "new urbanist" developments have been somewhat stumped. Such neighborhoods are difficult to study because they are only slowly being developed and occupied in the United States; few have matured with full residential occupancy and well-established retail or schools.

Researchers therefore rely on second-best strategies to examine the attributes in existing traditional neighborhoods thought to mirror many new urbanist characteristics (thus the term *neotraditional*).

Using traditional neighborhoods as proxies for new urbanist neighborhoods draws attention to our ability to measure the attributes of such neighborhoods. Regional databases, while widely available, provide aggregate measures and/or coarse representations of the street network. Such data are hardly suitable to operationalize the neighborhood-scale issues for NA. Few municipalities maintain databases specifying detailed urban form features, such as the size and type of commercial activity centers, parking supplies, sidewalk and landscaping provisions, or the safety of street crossings. Density measures (available through the U.S. Census) provide block group data that is relatively disaggregate. Parcel-level GIS databases are becoming increasingly available in some metropolitan areas. But being inherently large and messy files, they are incomplete in many instances. Several research efforts have conducted extensive fieldwork to collect primary data, capturing many finer-grained measures of urban form (1000 Friends of Oregon 1993; Cervero and Kockelman 1997; Moudon et al. 1997; Bagley, Mokhtarian, and Kitamura 2000). Although comprehensive in their approach, these efforts usually prove prohibitively expensive to do so over an entire metropolitan area.

General Research Approaches

Research approaches generally measure neighborhood attributes in one of three ways: binomial (matched pair), ordinal, or continuous. The first approach, binomial, is frequently used with quasi-experimental techniques, matching more compact and mixed-use neighborhoods with lower-density, single-use neighborhoods (Handy 1992; Friedman, Gordon, and Peers 1994; Cervero and Gorham 1995; Cervero and Radisch 1996; Dueker and Bianco 1999; Hess et al. 1999). Two classifications, however, tend to define the extremes of development; many neighborhoods contain a mix of attributes. Several studies therefore use ordinal classifications to rank neighborhoods with similar characteristics (Ewing, Haliyur, and Page 1994; Handy 1996b; McNally and Kulkarni 1997; Levine, Inam, and Torng 2000). While both binomial and ordinal approaches are easily understood and relatively easy to operationalize, they are limited in at least two respects. First, they tend to restrict the sample size because of the limited number of neighborhoods in which it is possible to control for other socioeconomic conditions. Second, individual urban form variables are used to group the neighborhoods. This often precludes the ability to assess the independent effect of different elements of urban form.

A third strategy conceptualizes neighborhoods in a continuous manner and is relied on more recently as detailed urban form data become increasingly available (Hanson and Schwab 1987; Frank and Pivo 1994a; Holtzclaw 1994; Ewing 1995; Cervero and Kockelman 1997; Kitamura, Mokhtarian, and Laidet 1997; Boarnet and Sarmiento 1998; Crane and Crepeau 1998; Frank, Stone, and Bachman 2000). Continuous rankings of neighborhoods differ from matched-pair or ordinal rankings because the individual urban form measures are often entered directly into the statistical analysis rather than being used to classify neighborhood types. This allows at least two primary advantages. It typically allows a wider variation between neighborhoods and therefore larger sample sizes. Second, it allows the researcher a means to more easily assess the partial effect of urban form variables on either travel or residential location.

Capturing Multidimensions

A fourth and critical issue centers on the manner in which different dimensions of NA are captured. Density has long been used in land use–transportation research as a powerful predictor of travel behavior. In many contexts, it is the only urban form variable used. Neighborhood attributes such as increased density, mixed land uses, and sidewalks usually coexist; such features represent a package of characteristics usually found together, particularly in areas more traditional in character. The predictive value of density is often relied on as a proxy measure for other difficult-to-measure variables that may more directly affect travel behavior (Steiner 1994; Ewing 1995). In a study of transit-supportive designs across a number of U.S. cities, Cervero (1993) concluded that microdesign elements are often too ‘micro’ to exert any fundamental influence on travel behavior, more macro factors like density and the comparative cost of transit versus automobile travel are the principal determinants of commuting choices.

However, density (or any other single indicator of urban form) cannot always be relied on as a sole measure of NA. Imagine a tight cluster of residential-only apartments located in a suburban community away from other basic services. This cluster of buildings may exhibit a specified density but by itself does little in terms of decreasing travel distance to nonresidential uses. Residents would still need to travel considerable distances to buy a quart of milk.

Even spreading basic services around this residential cluster would not guarantee the neighborhood to be well suited for walking and/or transit. The research by Moudon and Hess

(2000), for example, identified several clusters of relatively high-density residential environments, all with nearby retail. Many of these clusters were found not to stimulate increased pedestrian activity because they lacked, among other things, qualities such as good urban design and/or small block sizes. This finding prompts researchers to more fully consider the variety of characteristics that would promote areas with high levels of NA. Would a neighborhood with high density and sidewalks but no diversity in land use lead to increased pedestrian activity and decreased driving? How about a neighborhood with diversity in land use but that is surrounded by fast-moving vehicles and eight-lane roadways? The concept of NA embodies multiple, perhaps infinite, dimensions.

The conundrum from a research standpoint is uncovering the most effective strategy to capture these myriad dimensions. Measuring a single variable does not do justice to the multiple dimensions of NA. On the other hand, it is difficult to identify the partial effects of one characteristic over another; some contend that it may even be a futile endeavor to isolate the unique contribution of each and every aspect of the built environment (Cervero and Kockelman 1997).

Figure 3. *One hundred fifty–meter grid cells as unit of analysis.*
Source: Graphic courtesy of Paul Waddell and the UrbanSim modeling project.

▶ Devising a Single Measure of NA for a Metropolitan Region

This article first reviewed variables that have been postulated and/or tested in academic or metropolitan planning organization projects to measure NA; second, it discussed confounding issues related to such an endeavor. I now turn to offering a strategy that operationalizes basic tenets of NA for an entire metropolitan area and represents a useful advance in addressing many of the aforementioned issues. The approach brings the power, speed, and precision of geographical information data and software into formal urban analysis. I devise an index that (1) employs highly disaggregate units of analysis, (2) spans an entire metropolitan area, (3) relies on readily available data, (4) captures three different dimensions of NA, and (5) measures NA in a continuous manner.

The setting for this research is the Central Puget Sound in Washington State comprised of King, Snohomish, Kitsap, and Pierce Counties. The size of the study area, an entire metropolitan area, prohibits detailed measurement using fieldwork or maps. I rely instead on highly detailed data for all four counties and urban form measures that can be automated and applied to any site within the region. I begin by dividing the Central Puget Sound into 150-meter grid cells. These units are small enough to introduce site and localized neighborhood characteristics quite efficiently but not ungainly from the standpoint of data management. Figure 3 shows one 150-meter grid cell in a central Seattle neighborhood, over a digital orthophoto and parcel boundaries.

Variables

Existing data sources maintained by the regional planning agency, the Puget Sound Regional Council, provide detailed measures that capture each of the previously discussed tenets of NA: density, land use mix, and streets/design. To measure density, I use U.S. Census block-level data available for the entire Central Puget Sound area. I calculate both housing units and person density and geocode each to an individual grid cell.[8]

To measure land use mix, I employ data for each individual business establishment detailing the two-digit Standard Industrial Classification Code assigned to the business, the number of employees, and the x-y coordinates. Rather than use employment for all sectors, I include only businesses

The Queen Anne neighborhood in Seattle has many businesses within close proximity. This represents greater land use mix, thus higher levels of NA.

In contrast, a northern Seattle suburb has fewer businesses within its neighborhood, typical of post-WWII development.

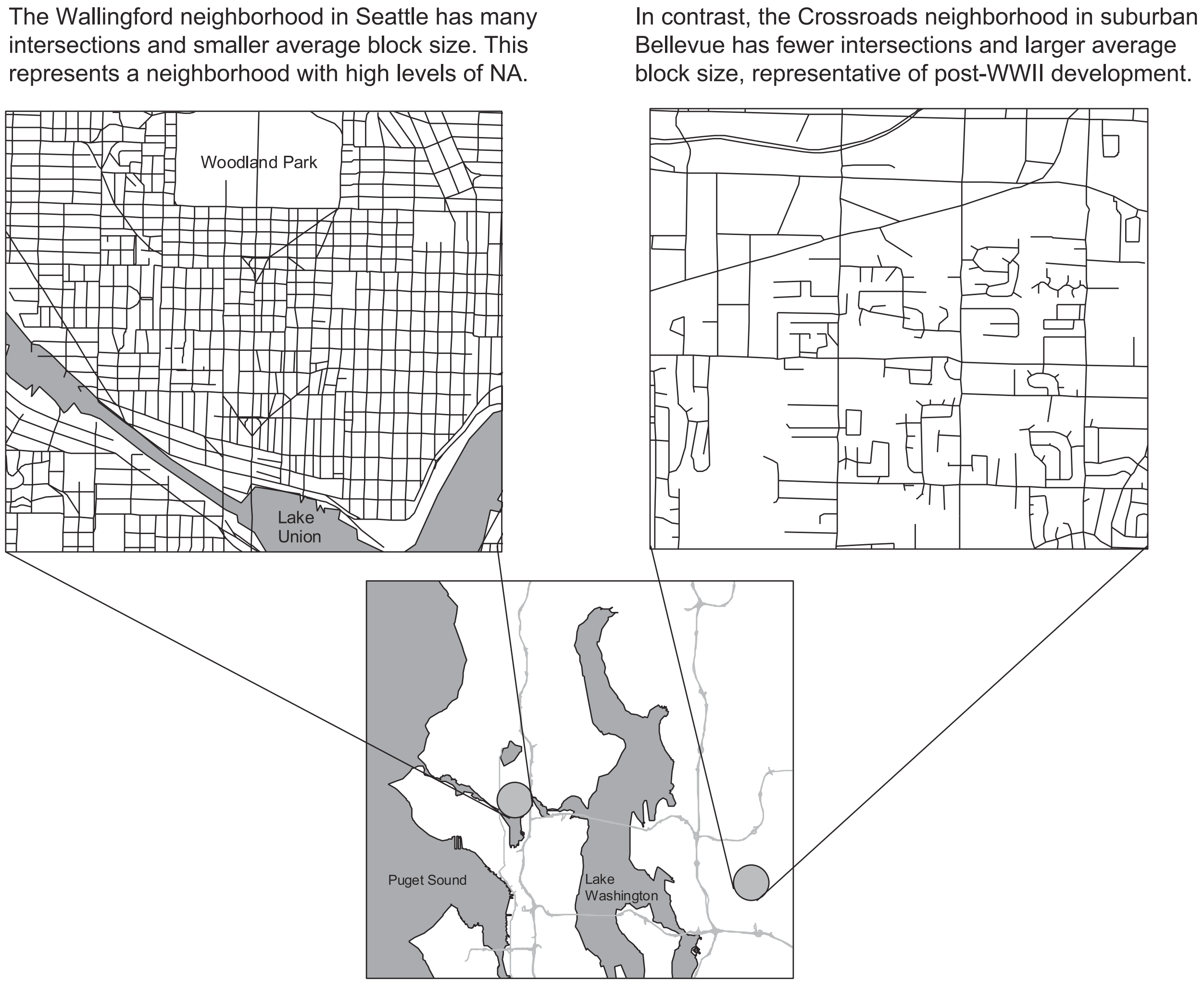
Figure 4. *Graphic depiction of land use mix for neighborhoods with different levels of neighborhood accessibility (NA).*

considered to be representative of areas with high NA. These businesses include general merchandise stores, food stores, eating and drinking places, and miscellaneous retail.[9] To account for differences in drawing power of larger establishments, I tally the number of employees[10] per grid cell (rather than number of businesses).[11]

My approach for operationalizing the streets/design uses U.S. Census Tiger Files, which detail all streets in the four counties, regardless of size or classification scheme. Using GIS technology, I compute block size as defined by the street network.[12] High intersection density corresponds with low average block size and vice versa. Neighborhoods with more intersections per area—or lower average block area—more closely resemble street patterns representative of areas with high NA. Figures 4 and 5 show the land use mix and street designs for neighborhoods with high and low levels of NA.

Deriving an NA Index

For each 150-meter grid cell, the above approach provides continuous measures for (1) housing density, (2) number of employees in neighborhood retail services, and (3) street design. The overall character of an individual grid cell, however, does not lie within the attributes of that cell alone; it is influenced by nearby cells, especially those within walking distance. I therefore average values for all grid cells across a one-quarter-mile radius of each cell.



The Wallingford neighborhood in Seattle has many intersections and smaller average block size. This represents a neighborhood with high levels of NA.

In contrast, the Crossroads neighborhood in suburban Bellevue has fewer intersections and larger average block size, representative of post-WWII development.

Figure 5. *Graphic depiction of block size for neighborhoods with different levels of neighborhood accessibility (NA).*

Each of the three measures could be used independently. In many circumstances, this may be a preferred strategy because a researcher could begin to understand the relative contribution of different urban form dimensions. For example, some applications attempt to tease out the partial effect of one urban form characteristic over another (see, e.g., Boarnet and Sarmiento 1998; Boarnet and Greenwald 2000).

As explained earlier, however, the concept of NA is a multilegged stool that requires multiple tenets to be present. Even if density showed to be the only statistically significant variable in such analysis, this does not devalue the importance in planning for other considerations; from anecdotal evidence, we know that other dimensions are important to capture. To better round out a single measure of neighborhood access, I combine each of the three measures into a single factor—a strategy preferred for at least two reasons. First, the correlation coefficients between the variables are relatively high.[13] This suggests that issues of collinearity may sometimes prevent each variable from being introduced in a statistical sense. Second, for purposes related to land use policy, we know that each of these urban form features tend to vary together, complement one other, and represent NA best when they are used in a combined manner.[14] It is therefore important, at least from a conceptual perspective, to include multiple dimensions in a simultaneous manner.

Using the three continuous variables, I use factor analysis to reduce these three measures—housing density, land use mix, street design—into a single dimension that shows relatively high loadings for each of the measures.[15] A single and interpretable factor was extracted based on the three measures, accounting for 79 percent of the total variation in the three variables. There was only about a 21 percent loss in information incurred by reducing the number of variables from three to one. Factor scores were saved for each grid cell and are hereafter referred to as the NA index.

Validation

The central question, however, persists. How can we be assured that the NA index provides a measure of urban form that captures the phenomenon of interest?[16] As a means to validate the NA index, a panel[17] was asked to assess a sample of seventy neighborhoods throughout the Central Puget Sound according to their degree of NA. They rated each location on a scale of one to six based on (1) detailed aerial photographs depicting a quarter-mile radius around an x-y coordinate and (2) anecdotal evidence of the particular neighborhood. The criteria that they used for evaluation were considerably broader and more subjective than the three previously discussed variables. The panel was asked to rate each location using more qualitative and experiential information that allowed them to place the neighborhood in a broader context and discuss important characteristics.

An ordinary least squares regression model was estimated using the subjectively assigned NA scores as a dependent variable and the three previously described urban form measures—density, block size, land use mix—as independent variables. The model revealed that each of the three variables were statistically significant with an R^2 value of .73, indicating that 73 percent of the variation of the subjectively assigned NA scores assessed by the panel can be explained by these three variables.[18] Similarly, a simple correlation between the NA index and the subjectively assigned NA score revealed a correlation coefficient (r^2) of .86 ($p < .000$), suggesting the two measures are similar.

For example, the panel ranked the location shown in Figure 1a from the Wallingford neighborhood in Seattle as one of the most accessible neighborhoods in the region because of the provision of sidewalks, nearby retail, and other urban design amenities. Accordingly, this location ranked in the ninety-eighth percentile for NA among a sample of more than two thousand residential locations in a Puget Sound travel survey. The location shown in Figure 1b was assessed by the panel as being one of the lesser accessible neighborhoods in the region; accordingly, it ranked in the bottom third of all residential locations in the travel survey.

▶ Conclusions and Future Directions

Continuing debate over the perils and pitfalls of planning for NA has prompted substantial research analyzing how different dimensions of accessibility influence travel behavior and/or residential location decisions. This research has important implications for land use–transportation planners and modelers; it represents an issue of pressing policy significance for decision makers. Much of this research and modeling, however, suffers from several shortcomings, primary among them is how NA is measured.

In response, this article serves at least three purposes in our quest to better operationalize NA. It first systematically reviews past strategies according to three tenets of NA: density, land use mix, and streets/design. More than fifty studies are reviewed to describe how variables were measured, and the article discusses strengths and weaknesses for each measure. Second, it describes four troubling issues in measuring NA, related to matters of units of analysis, data availability, research approaches, and the need to capture multiple dimensions. The article culminates by suggesting a strategy to measure NA for site-specific areas and advances the issues discussed herein.

I describe a process to create an NA index that has at least five advantages over previously employed strategies. First, the 150-meter grid cell scale provides an opportunity to calculate precise measures at a pedestrian-scale resolution. Second, the index uses data sets readily available for metropolitan planning applications. Third, the strategy relies on computational power, not manual measurement (either in the field or using maps). For this reason, it can be calculated across an entire metropolitan area rather than for a limited number of specific case study sites. Fourth, it embodies three different dimensions of NA in a manner that provides a simple and parsimonious variable that can be used for further research and/or modeling. Finally, rather than rely on relatively atheoretical thresholds to determine ordinal classifications, the index measures urban form continuously.

Future Directions

The NA index brings the power, speed, and precision of geographical information data and software into formal urban analysis. As supported by the validation exercise, it provides an index that performs well in measuring the phenomenon of interest: neighborhood accessibility. The review and the constructed index contribute to this dimension of land use–transportation research; however, continued work exists on several fronts. The NA index provides the basis for additional research and modeling related to travel behavior and residential location. For example, further refinements are necessary to integrate an NA index with traditional four-step transportation models of auto ownership, trip frequency, or mode choice (see Parsons Brinkerhoff Quade and Douglas 2000) or land use models of residential location (see Waddell 1998).

Second, continuous variables are advantageous because they provide a measure that is more robust and easily transferable to other urban settings. However, it is important to understand the nonlinearity that may be inherent in such variables. For example, once a neighborhood reaches a threshold of mixed land uses that may all be within attractive walking distance, the relative contribution of a few more shops becomes marginal in terms of advancing pedestrian use. There is likely a point of diminishing returns. In this case, the benefits gained from increasing accessibility may be asymptotic to a given measure of travel behavior (e.g., mode split). Frank and Pivo (1994a) confirmed Pushkarev and Zupan's (1977) assertion that residential densities need to exceed eight housing units per acre before we can expect significant modal shifts from single-occupant vehicle to transit use. Additional research is necessary to identify thresholds similar in nature using more precise measures of urban form. Such thresholds may exist for different dimensions of travel behavior (e.g., mode split versus vehicle travel distance) and/or different ranges of neighborhood measurement (e.g., quarter mile versus one-half mile).

A similar research endeavor relies on our ability to understand the relationships between different dimensions of urban form with specific aspects of travel behavior. For example, can we expect urban design features to influence pedestrian travel differently than automobile travel? Can we expect land use mix to affect vehicle miles traveled differently from the number of vehicle trips taken? All are important for purposes of policy and, as a starting point, this article has broadly defined NA to include each. However, the independent effect of each urban form dimension deserves additional consideration, and a finer parsing of the travel behavior is a topic of interest for basic research.

Finally, the pursuit to assess neighborhoods based on levels of NA represents a fertile research endeavor. The panel of judges in this research relied primarily on experiential knowledge and aerial photographs to assess different neighborhoods. Both the validity and reliability of such an exercise could be strengthened by using aerial photos combined with cross-sectional photos and/or even field visits. Further understanding of the individual aspects for urban form measures is also likely to strengthen our ability to assess various neighborhoods on a continuum. Identifying the extremes of high and low levels of NA is relatively straightforward. The challenge lies in better understanding the middle ground—a challenge that is important to wrestle with since a majority of the built environment falls into this relatively gray area. Answers to each of these questions will inevitably allow planners and modelers to better understand relationships between urban form, travel behavior, and residential location. A more thorough understanding will therefore assist policy makers to construct better-informed policies about our built environment.

▶ Appendix

Criteria used to measure neighborhood accessibility.

Concept	*Strategy for Operationalizing/Comments*	*Citation*
Density		
Population, housing units, or employees per unit area	The most readily accessible urban form variable to operationalize and therefore more commonly used than any other measure	
Intensity of land uses	Density measures of retail, activity centers, public parks, population	Cervero and Kockelman (1997)
Land use mix		
Nonresidential activities in the immediate vicinity	Presence or absence of a retail shop within three hundred feet; any type of nonresidential activity classified as mixed use	Cervero (1996)
Presence of food/drug store	Grocery or drug store between three hundred feet and one mile	Cervero (1996)
Household distance to grocery, gas station, or park	Estimated in tenths of miles by respondent	Kitamura, Mokhtarian, and Laidet (1997)
Walking distance to retail	Percentage of households within walking distance to retail district	Handy (1996b)
Retail employment data	Retail workers within one mile of residence	Lawton (1997)
	Number of establishments summed over one-half-kilometer increments	Hanson and Schwab (1987)
	Number of establishments using Standard Industrial Code data	Clifton and Handy (1998)
	Retail and service employment density per census tract	Boarnet and Sarmiento (1998)

(continued)

▶ Appendix (continued)

Concept	*Strategy for Operationalizing/Comments*	*Citation*
	Averaged the shortest distance need to travel to buy each of twelve "convenience" goods and services	Guy (1983)
Entropy	Evenness of the distribution of built square footage between several land use categories	Cervero and Kockelman (1997); Frank and Pivo (1994a); Sun and Wilmot (1998)
Dissimilarity Index	Mean point accumulation for a tract where each developed hectare is evaluated on the dissimilarity from surrounding hectares	Cervero and Kockelman (1997)
Streets/design		
"X" intersections	Counted manually using aerial photographs and maps	Handy (1992); Cervero and Gorham (1995); Cervero and Radisch (1996)
	Inspected the transportation network within one-half mile of a household to judge streets as either connected, cul-de-sac, or a mix	Crane and Crepeau (1998)
	Randomly sampled twenty block faces within each neighborhood site to derive proportions and averages	Cervero and Kockelman (1997)
	Marked the area around individual households that contained four-way intersections and measured the area with a digital planimeter	Boarnet and Sarmiento (1998)
	Assuming census blocks as the smallest polygons that were fully enclosed, they measured census block density within each tract	Frank, Stone, and Bachman (2000)
	Intersection density per transportation analysis zone (TAZ) (also used street length density)	Levine, Inam, and Torng (2000)
	Number of "X" intersections within one-half mile of household	Lawton (1997)
	Mean block size, manually counted for each study site	Hess et al. (1999)
Miles of streets	Used centerline geographic information system information	Handy (1996b); Levine, Inam, and Torng (2000)
Provision of sidewalks	Ratio of the length of the sidewalk system to the length of all public street frontage	Hess et al. (1999)
	Proportion of blocks with sidewalks	Cervero and Kockelman (1997)
	Full, partial, or no sidewalks on each side of the road	Handy (1996b)
	Mean age of development	
Traffic volumes	Measured for a single street and applied to entire study area	Moudon et al. (1997); Handy (1996b)
Factor: design dimension	Sidewalk and street lights, planted strips, block lengths, flat terrain, walking accessibility	Cervero and Kockelman (1997)
Composite indices		
Pedestrian Environment Factor	Based on the ease of street crossings, sidewalk continuity, topography, and "fineness" of the street grid for local streets	LUTRAQ (1993)
Urban Vitality Index	Same as above, plus a measure of "urban vitality"	Cambridge Systematics
Pedestrian and Bicycle Friendliness	Based on amount of sidewalks, land use mix, building setbacks, transit stop conditions, bicycle infrastructure	Replogle (1995)

▶ Notes

1. It is important that any definition of neighborhood in this line of research distinguish between the effects of urban form at the neighborhood scale as opposed to the regional scale. Household travel behavior and/or residential location decisions may be influenced by both (1) the character of the particular neighborhood in which the household lives and (2) the position of the neighborhood in the larger region. Using a single dimension of urban form, a given place may be very far from a few large activity centers or close to several small activity centers, yet the implications for travel behavior may be very different (Handy 1992). The regional context of a neighborhood, too often neglected in research, may provide more opportunities that mean more travel, or the regional structure may simply dwarf any variations in the local, neighborhood structure.

Notwithstanding the importance that regional accessibility has in urban form, residential location, and travel behavior research, the issue of neighborhood accessibility (NA) continues to represent a poorly understood phenomenon. Many policy initiatives strictly focus on the character of development within neighborhoods; subsequently, this article focuses on aspects central to the neighborhood scale only.

2. Both of these issues are further complicated because different urban form features influence different types of travel. Trips to the dry cleaner, for example, may be primarily influenced by the distance to the nearest establishment; a discretionary stroll around the block may be influenced exclusively by the presence of street trees and a pleasant walking path.

3. NA can be considered similar to notions of the pedestrian environment (1000 Friends of Oregon 1993), local accessibility (Handy 1992), microscale design (Parsons Brinkerhoff Quade and Douglas 2000) or transit-oriented development (Bernick and Cervero 1997).

4. It aims to measure the evenness of the distribution of built square footage among several land use categories in a study area (e.g., transportation analysis zone [TAZ]) relative to regional totals using the following equation:

$$Entropy = \sum_j \frac{\left(P_j x \ln\left(P_j\right)\right)}{\ln\left(J\right)}$$

where P_j is the proportion of developed land in the j^{th} land use type and j stands for the number of land use types considered, for example, single-family residential, multifamily residential, retail, office, parks and recreation, institutional, and industrial/manufacturing. An entropy measure that would be more tailored for measuring the influence of nonwork trips may include only residential, retail, and office to better account for the types of land use mixes most preferred in areas with high NA. Depending on the level of precision, it may be necessary to adapt the measure to avoid bias against smaller tracts or undeveloped tracts (for more complete discussion of such nuances, see Kockelman 1996).

5. The San Francisco case (containing more than 750 TAZs) developed a less fine-grained zone system of around 200 zones. Significant effort went into developing this zone system so that the zones were a coherent reflection of the city's geography. Aggregating to units larger than TAZs, however, only aggravates problems introduced by aggregation bias.

6. However, this effort is not unreasonable relative to the overall effort required to estimate an urban travel model.

7. As a further example, Banerjee and Baer (1984) preferred to use the term *residential area* rather than *neighborhood* because of disagreements over what constitutes a neighborhood (see chap. 2).

8. Although issues of aggregation bias still exist at the block level, its geographical unit—consisting of, on average, no more than thirty housing units or 0.5 square kilometer of land—prescribes a sufficient measure.

9. A more detailed breakdown by four-digit standard industrial classification (SIC) code would be preferred because it more cleanly filters services typically available in areas with high NA. However, issues of confidentiality required only two-digit SIC code data to be released for this research.

10. These businesses are tallied regardless of that fact that many employees may not be employed in the same neighborhood in which they live.

11. To filter for potentially large businesses that run counter to NA principles (e.g., Costco, Home Depot) but may be included in the same classification, no establishment with more than two hundred employees is included.

12. The grid cell measures for both block size and density represent weighted averages of the size of individual street blocks (or census blocks) that intersect (or are contained within) each 150-meter grid cell.

13. Using simple correlation with a sample size of more than 400,000 grid cells, correlation coefficients (r) were block size density = –.807, employment density = .608, employment block size = –.624.

14. The implicit assumption here is that NA features are integrated in a transparent manner to arrive at a measure that lies along a well-defined continuous dimension. In actuality, however, the output of factor analysis merely represents the combination of important urban form features associated with auto dependency.

15. In this context, I used principal components factor analysis for two purposes: (1) to explore the possibility of using a single index by demonstrating that constituent items (density, block size, land use mix) load on the same factor and (2) to create a factor that can be treated as an uncorrelated variable as one approach to handling collinearity issues for further modeling. Based on varimax rotation of the initially extracted factors, factor loadings were housing density-ln = .907, block size-ln = –.910, and land use mix-ln = .828.

16. The NA index could be analyzed relative to different measures of travel (e.g., vehicle miles of travel, number of automobile or pedestrian trips) to discern if and how NA influences travel behavior. However, the tentative relationship between travel and urban form suggests otherwise. In a review of the literature, Crane (2000) concluded that not much can be said to policy makers as to whether the use of urban design and land use planning can help reduce traffic. What remains unclear, however, is whether the uncertainty underlying this finding is because of (1) the weak (perhaps nonexistent) relationship between urban form and travel or (2) our inability to appropriately operationalize urban form in a manner appropriate for such detailed research.

17. The panel consisted of five academics from the fields of urban planning, urban design, geography, public affairs, and transportation and was representative of a group of experts familiar with the concept of accessibility and urban form. They were selected based on two criteria: (1) their extensive spatial knowledge of the Puget Sound region and (2) their knowledge of the basic tenets of urban form and neighborhood access. The first criterion was particularly valuable in the panel's ability to assess specific housing locations.

18. The subjectively assigned NA score was regressed using ordinary least squares on the three independent variables for seventy cases and revealed an F statistic of 63.62 (p = .000). Each of the three independent variables were logarithmically transformed and significant at the .02 level or less with the following coefficients: housing density = .514, block size = –.227, and land use mix = .242. Given the nature of the dependent variable, however, an ordered probit model is technically preferred and was modeled using LIMDEP software. Each of the transformed variables were significant at the following levels: density = .002, block size = .133, land use mix = .002, with the model revealing a pseudo σ^2 of .41.

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