ESTIMATING TRANSIT ACCESSIBILITY USING AN ALTERNATIVE METHOD: EVIDENCE FROM BROWARD COUNTY, FLORIDA

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ABSTRACT

Scientists have attempted to measure accessibility in several ways – gravity-based measure being the most widely used among those. A typical gravity-based model estimates accessibility on a zonal basis, as being a function of the sum of total opportunities weighted by the distance/time/cost needed to travel from the origin zone to those dispersed opportunities. The model includes a parameter that represents distance-decay relationship and takes an exponential form. Unfortunately, most scientists have arbitrarily chosen the value of distance-decay parameter instead of estimating it from field survey data. Also, a typical model does not have any parameter attached to the socio-economic variable(s). This study utilizes distance-decay parameters estimated using the survey data in Sacramento County, California to estimate transit accessibility to jobs in Broward County, Florida. Assuming that transferability of distance-decay parameters is possible from one geographic area to another, it then explores such transferability of parameters from Sacramento County to Broward County by analyzing the spatial distribution of transit accessibility, and compares the effectiveness of estimated transit accessibility to traditional transit accessibility measure – proportion of a geographic unit covered by ¼-mile buffer from a transit route. Results indicate that accessibility indices estimated using the method presented in this paper reflect what one would expect in reality – much better than what a simple ¼-mile transit buffer would produce. The paper explores that distance-decay parameters estimated in one geographic unit is transferable to another. It advances the knowledge of accessibility measuring method that would help solve long-standing debate on what parameters to use for distance-decay and socio-economic variables going into the accessibility model. Future research needs to focus on validating such transferability of distance-decay parameters from one study area to another.

INTRODUCTION

Accessibility is one of the most widely used terms in urban and regional planning, urban economics, geography, and transportation planning. Scientists of planning, economics, and geography have treated accessibility in different ways. Despite its importance and overwhelming use in local, regional, and national analysis of spatial patterns, meaning of accessibility remains unclear because of the absence of its clear-cut definition (*1*, *2*). Hanson (*3*) defines accessibility as the "number of opportunities…available within a certain distance or travel time" (p. 4). It is the ease and convenience of access to spatially distributed opportunities with a choice of travel. Unfortunately, it is not easy to quantify the ease and convenience of access.

The objectives of this paper are threefold: i) introduce an alternative method of estimating transit accessibility indices using estimated distance-decay parameters, ii) explore the possibility of transferring distance-decay parameters from one geographic unit to another by analyzing the spatial distribution of transit accessibility, and iii) compare the effectiveness of estimated transit accessibility to traditional transit accessibility measure – proportion of a geographic unit covered by ¼-mile buffer from a transit line. The paper uses distance-decay parameters calculated using Sacramento County, California data to estimate accessibility indices of traffic analysis zones (TAZs) in Broward County, Florida. It proposes a transit accessibility function that has a vector of empirically-derived attraction variables and another vector of empirically-derived transit impedance variables.

REPRESENTATIVE DEFINITIONS OF TRANSPORTATION ACCESSIBILITY

Accessibility is an indicator of potential spatial interaction. It is the ease with which spatially distributed opportunities may be reached from a specific place (hence, the origin) by means of a particular transportation system (*4*, *5*, *6*). This definition includes the place of origin, distribution of opportunities over space, and the means to reach those opportunities. Hansen (*7*) defines accessibility as the potential of opportunities for interaction. He proposes that "the accessibility at point 1 to a particular type of activity (say employment) at area 2 is directly proportional to the size of the activity (number of jobs) at area 2 and inversely proportional to some function of the distance separating point 1 from area 2" (p. 73).

Accessibility can be of place or zone and person or individual. Accessibility of places/zones is defined as how easily certain places/zones can be reached, while accessibility of people is defined as how easily a person or a group of people can reach activity sites. The zonal level definitions assume that all individuals inside a zone experience same set of opportunities, and that these definitions clearly neglect the distribution of activity sites within a zone. The zonal level definition of accessibility also neglects different levels of accessibility to transportation modes experienced by different individuals within a zone, which causes differing abilities of different people to reach the activity sites. In contrast, individual level accessibility measure enables to generate measures of the traveler's accessibility to opportunities from home and workplace (*8*).

Accessibility has also been defined in terms of transportation options or other personal constraints. Mobility is a critical component of accessibility, and accessibility extends the concept of mobility a further step by incorporating information on the structure of networks and relative locations (*9*, *10*). If two people are living in the same residential location, but one has automobile while the other does not, each person's accessibility to opportunities are likely to be different.

Accessibility could be divided as relative accessibility between two points and integral or total accessibility at a point. Relative accessibility is the ease of accessing one point from another on the same surface, i.e., the degree of interaction between two points on the same surface (*4*). However, the relative accessibility of two points in relation to each other on the same surface may not be equal in intensity. The integral accessibility of a place or point, on the other hand, is defined as the degree of interaction with all other points on the same surface. It is, however, dependent on several relative accessibilities of a place and it can be interpreted as an integration of the relative accessibilities over all places (*7, 11*).

Accessibility could also be categorized as trip-based accessibility (TBA) and activity-based accessibility (ABA). TBA considers one trip type at a time while ignoring scheduling and trip chaining. Trip type could include recreation trip, work trip, shopping trip, and such. ABA, in contrast, takes into account all activities a person is performing every day and the constraints to engage into those activities, scheduling, and chaining (*12*).

Apart from the above, a handful number of scientists have dealt with the accessibility issue. Most of them use the established and early-developed definitions of accessibility with some modifications for their research purpose as needed. However, the basic concept of accessibility remains unchanged in these studies.

MEASURING TRANSPORTATION ACCESSIBILITY: A BRIEF OVERVIEW

It has proven a daunting task to measure accessibility. Transportation planners have approached this challenge in several different ways. Four major ways of measuring accessibility exist: i) distance-based measure of accessibility (DBMA), ii) cumulative opportunities measure of accessibility (COMA), iii) utility-based measure of accessibility (UBMA), and iv) gravity-based measure of accessibility (GBMA). COMA is also known as isochronal measure of accessibility.

DBMA involves only the distance to and from an origin and destination of a trip or a transit station. Many transit planners, for instance, use a ¼ mile buffer around a transit stop, sometimes measured as the crow flies but occasionally refined to reflect true walking distance. They designate locations that lie within the buffer as having access to transit, and those outside as lacking transit access. In most metropolitan areas, this approach leaves very little territory outside the buffer. Gurmu, Ihlanfeldt, & Smith (*13*), Sanchez (*14*), and Sawicki and Moody (*15*) take this approach to measuring access to transit. DBMA also uses the average travel time to work from an origin zone (*16*). If travel time is greater, residents of the zone are disadvantaged in terms of access. But there is some difficulty interpreting this measure. A longer travel time could be a function of a large percent of residents in the zone using transit, as opposed to jobs being located further away (*17*).

COMA draws an isochrone around a zone, such as a line representing a 25- or 30-minute travel time. Opportunities that lie inside the isochrone are considered accessible while those lying outside are considered inaccessible (*18, 19*). A simple COMA measure can be expressed by Equation 1:

$$COMA_i = \sum_j X_j O_j \qquad \text{Equation 1}$$

where $COMA_i$ is the cumulative opportunities measure of accessibility index of zone i to be estimated; O_j represents the opportunities such as employment in zone j; X_j equals 0 if $r_{ij} > r^*_{ij}$, and 1 otherwise; r_{ij} represents the resistance or friction between zones i and j while r^*_{ij} is the isochrone radius such as 30-minue search boundary within which the opportunities are enumerated. It is easy to estimate the accessibility indices using a COMA approach and it is easy to understand. However, the size of the job search radius sensitively affects the accessibility indices. The main part of the calibration of COMA is the choice of a cut-off travel distance or time (*20*). COMA represents a specific type of GBMA, with resistance function equal to zero if the opportunity is outside the job search radius, and one otherwise.

UBMA is grounded on random utility theory which explains that consumers (people) choose the best-utility alternative, i.e., the one attached to highest utility (*21*, *22*, *23*). It is derived from the calibration of destination choice models. It assumes that the probability of an individual making a particular choice depends on the utility of that choice relative to the utility of all choices (*20*). Based on the assumptions that a traveler assigns utility to each destination and mode choice based on her/his preferences followed by choosing the best alternative that maximizes her/his utility, UBMA approach defines accessibility index as the logsum, i.e., the denominator of the multinomial logit model (*12*, *24*) shown in Equation 2:

$$UBMA_i = \ln\left\{\sum_{\forall \in C_i} \exp\left(A_{i(c)}\right)\right\} \qquad \text{Equation 2}$$

where $UBMA_i$ is the utility-based measure of accessibility index of an individual, i; $A_{i(c)}$ represents observable alternative components of utility of choice c, and C_i is the choice set – both for person i. The strength of a UBMA approach shown by Equation 2 is that it includes a person's tastes or utilities according to her/his preferences (*2*), attributes or characteristics of travel destinations, and characteristics of travel resistance or friction to be overcome to reach the destination (*20*).

GBMA, on the other hand, provides a more realistic approach to measuring accessibility. Equation 3 presents a simple GBMA model:

$$GBMA_i = \sum_{j=1}^{n} \frac{O_j}{r_{ij}^{\,b}} \qquad \text{Equation 3}$$

where $GBMA_i$ = gravity-based accessibility in zone i; O_j= employment in zone j; r_{ij} = travel time or distance or cost between zones i and j; there are n zones; and, b is a parameter to be estimated.

This formulation calculates accessibility on a zonal basis, as being a function of the sum of total opportunities weighted by the distance or time needed to travel from the origin zone to those dispersed opportunities (*2*, *25*). The formula includes a parameter that represents the distance-decay relationship. Hansen (*7*), the first scientist to introduce GBMA, explores based on different empirical examinations that the distance function should be of exponential character, i.e., measurement of distance between different areas (points) should be raised to some power. Shen (*26*) argues that there are limitations in the traditional Hansen-type gravity models because the non-uniform spatial distribution of demand is not taken into account by this model.

NATURE OF DISTANCE-DECAY PARAMETERS AND ITS ESTIMATION

Typically, one of two approaches has been taken to estimate the parameter value for the travel impedance function in a gravity-based model, with the first approach by far the most common. The first approach involves the assignment of an arbitrary value to the parameter. Sanchez (*14*), Shen & Sanchez (*27*), Thompson (*28*), and Thompson (*29*) take this approach. However, this approach is flawed because the parameter is not based on empirical data, instead arbitrarily defined by the researcher. The measure of accessibility changes as the value of the parameter changes – thus there is the potential for widely varying accessibility results depending on the parameter value selected. However, in the absence of other empirical data, this approach still yields more realistic results than three other approaches to measuring accessibility discussed earlier – DBMA, COMA, and UBMA.

The second approach is to estimate the parameter using other survey data. Isard (*30*) explores that the distance decay component of a gravity-based accessibility function is the same concept as the distance decay component in a gravity based demand model. Thus the distance decay parameter of a direct demand model can be used as the distance decay parameter of gravity based accessibility equation. The direct demand model of Isard (*30*) states that the number of trips made by the travelers from an origin to a destination is a function of number of travelers living in the origin subarea multiplied by the number of population in the destination subarea discounted by the friction factor between the origin and destination. The friction may be time required to travel from the origin to destination, distance between the origin and destination, or cost of travel from the origin to the destination.

Based on this concept of Isard (*30*), Thompson (*28*, *31*) and Raphael (*32*) derive their gravity model parameters from direct-demand models estimated from on-board survey data of transit users. When the parameter is estimated from on-board survey data, it reflects how people actually perceive the friction associated with travel time or cost or distance, and thereby removes the arbitrary nature of the parameter (*31*). Thompson's (*28*, *31*) access measures are similar to Raphael's with a couple of key distinctions. First, Thompson's expression of the transit accessibility function was a linear combination of several different variables, including door-to-door transit travel time, door-to-door highway travel time, and physical distance between census tracts. A further refinement over Raphael (*32*) is that Thompson's (*28*, *31*) attraction variable represents more than just employment, which is the standard approach. He includes a parameter that weights employment based on how important it is to the user and also includes other variables that may be important to the transit user, including density and a dummy variable representing the central business district. Other scientists, however, have estimated the distance-decay parameter using other methods as well, for example, binomial count model derived from 1990 Census Transportation Planning Package commuting data (*33*).

Kawabata (*34*), and Sanchez, Shen, and Peng (*35*), drawing on Shen (*26*, *36*) use a gravity formulation based on labor market theory. The attractions represent surplus jobs or job growth. These are the open jobs available to the individuals who are seeking employment. However, their measure of accessibility is problematic. Their measure of zonal attraction, which is employment, has no parameter attached to it. Their measure of transit impedance is defined as transit time, but the type of transit travel time is not defined, nor is the method for estimating the parameter described. There are many types of transit time: line haul time, walking time, and door-to-door time, to name few. Door-to-door time, in turn, is composed of several components, each of which is typically given a different weight. The Quick Response System of demand modeling provides recommendations for such weights (*37*).

ESTIMATION OF TRANSIT ACCESSIBILITY

The transit accessibility variable (TA_i) estimated and analyzed in this study is derived from a gravity model predicting transit patronage. The model shown by Equations 4 and 5, estimated from an on-board survey of bus riders in Sacramento, California reflects transit user preferences, including the types of destinations that are important to them, the "attractions" that those destinations have on the riders, and the degree to which length of travel, measured in both time and distance, works against that "attraction" (*25*, *28*, *32*). The general model, shown in Equation 4, predicts transit usage between two neighborhoods as a product of the variables producing transit trips in the origination neighborhood, variables attracting transit trips in the destination neighborhood (the “ATTRACTION”), and variables describing friction (the “FRICTION”) between two neighborhoods.

$$T_{ij} = \left(\underline{PDN}_i^{\underline{p}}\right) * \left(\underline{ATN}_j^{\underline{a}}\right) * \left(\underline{F}_{ij}^{\underline{f}}\right) \quad \text{Equation 4}$$

where T_{ij} = transit trips between neighborhoods *i* and *j*; $\underline{PDN}_i$ = a vector of transit trip production variables and their estimated parameters in neighborhood *i*; $\underline{ATN}_j$ = a vector of transit trip attraction (the “ATTRACTION”) variables and their parameters in neighborhood *j*; $\underline{F}_{ij}$ = a vector of friction (the “FRICTION”) variables and their parameters that transit users encounter when traveling between *i* and *j*; and, $\underline{p}$, $\underline{a}$, and $\underline{f}$ are vectors of parameters to be estimated.

The accessibility index is created from Equation 4 by summing the equation over all *n* neighborhoods in the region. This is shown in Equation 5.

$$\sum_{j=1}^{n} T_{ij} = P_i = \left(\underline{PDN}_i^{\underline{p}}\right) * \sum_{j=1}^{n} \left[\left(\underline{ATN}_j^{\underline{a}}\right) * \left(\underline{F}_{ij}^{\underline{f}}\right)\right] \quad \text{Equation 5}$$

Equation 5 states that transit trips produced in neighborhood *i* (denoted as P_i) are the potential for neighborhood *i* to produce trips (denoted as $\left(\underline{PDN}_i^{\underline{p}}\right)$) multiplied by the transit accessibility of neighborhood *i* to all destinations in the region. This is shown as TA_{ij} in Equation 6.

$$TA_{ij} = \sum_{j=1}^{n} \left[\left(\underline{ATTRACTION}_j^{\underline{a}}\right) * \left(\underline{FRICTION}_{ij}^{\underline{f}}\right)\right] \quad \text{Equation 6}$$

Equation 6 is the specification of the accessibility index used in this paper. It has the general form of Equation 3 shown earlier. Each of the vectors of variables shown in Equation 6 corresponds to a variable in Equation 3. The parameter vector $\underline{f}$ in Equation 6 corresponds to the parameter *b* in Equation 3. Equation 3 has no parameter for the employment variable, but Equation 6 has a vector of parameters, $\underline{a}$ to be estimated for the attraction variables. The $\underline{a}$ and $\underline{f}$ vector parameters were estimated using an origin-destination survey data using Equation 5. The use of such estimated exponential parameters addresses the arbitrary selection of exponential factor in the accessibility equation used by earlier studies.

The vector of variables that were used to specify $ATTRACTION_j$ and $FRICTION_{ij}$ are shown in Table 1. These are variables that were used in an earlier study in Sacramento, California (*28*). Ideally, this study should have calculated all the parameters associated with different variables used in the gravity-based accessibility model using the onboard origin-destination survey of the study area. Unfortunately, Broward County does not have the recent record of onboard survey that could be used for this study. Therefore, the study uses the calculated values of exponential distance-decay parameters of Sacramento study by Thompson (*28*). By doing so, the study gets around the weakness of Thompson (*29*) and Sanchez (*14*, *18*) in that they used –2 as an arbitrary value of the distance-decay parameter of transit travel time.

Table 1 also shows the parameters that were estimated for each variable in that study. Each parameter reflects how important that variable is to transit users. The table generally shows that transit friction between two zones is increased by greater distance between the zones (HDIS) and by longer door-to-door transit travel times between the zones (TTIM). On the other hand, with longer highway times (HTIM), because for example the absence of freeways in paths connecting the zones, transit friction is reduced. The table also shows that the attractiveness of a zone for transit patrons is increased if it has more jobs, more job density, and more population density. If the zone lies in a CBD or on the edge of a CBD, it also is more attractive than other zones, presumably because parking fees make auto use less attractive.

TABLE 1 Variables Entering into Evaluation of Transit Accessibility Index for Zone *i*

Explanatory Variable	*Description*	*Estimated parameter*	*t-statistic*
Vector of variables entering into transit friction between zones *i* and *j*			
TTIM	door-to-door transit time between zones *i* and *j*	-0.006067	-5.12
HTIM	door-to-door highway time between zones *i* and *j*	0.122780	5.91
HDIS	door-to-door highway distance between zones *i* and *j*	-0.250210	-7.05
Vector of variables entering into attractiveness of zone "j" for transit trips			
DPOP	population of destination zone "j"	0.000008	2.88
DPOPDEN	population density of destination zone	0.036496	0.91
DJOBS	number of jobs in destination zone	0.000058	7.55
DJOBDEN	job density in destination zone	0.036647	8.46
DSPLIT	percentage of destination zone within one quarter mile of bus stop	0.013648	6.11
DDTN	dummy variable indicating zone on edge of CBD, 1=yes; 0=no	0.324140	3.15
DCBD	dummy variable indicating CBD zone, 1=yes; 0=no	0.372820	2.20

Adapted from Thompson (1997), Table 4, Run 3.

In calculating accessibility indices of different geographic areas previous studies (*14*, *18*, *29*) on this topic considered only transit travel time as the only friction variable. In contrast, this paper introduces a more comprehensive way of calculating accessibility indices incorporating transit travel time, highway travel time and highway distance from each TAZ to all other TAZs as the friction variables. The source for the transport related frictional variables was the output from the Year 2000 network of the Broward County Metropolitan Planning Organization urban transportation modeling database. Florida Standard Urban Transportation Modeling Systems Version 4 (FSUTMS V.4) Transportation Network Model with the year 2000 Alternative Data of Broward County was run to get the values of the above-mentioned variables.

However, FSUTMS V.4 model output does not provide transit travel time *per se* as the result. Rather, it produces data on door-to-bus stop walk time in the origin zone, wait time at the bus stop, in-vehicle travel time, transfer time from one route to another, bus stop-to-door walk time in the destination zone, HTIM, and HDIS. First five variables were used to estimate TTIM. Components of TTIM were abstracted from the shortest transit path between each pair of TAZs and applied default weights recommended for Quick Response System modeling (*37*). For paths where transfers were involved, the paper used a penalty of 23 minutes, recommended for untimed transfers in Horowitz (*37*), because transfers are untimed in Broward County. However, FSUTMS does not produce any of these variables in organized and/or sorted form. So a computer program, consisting of several sub-programs was written using C++ language to read the data, organize them, and calculate TTIM. This process yielded TTIM between each pair of TAZ. The formula that was used to estimate TTIM is given by Equation 7 (*38*).

TTIM = 1.3 * Walk Time + 0.95 * Wait Time + 8.4 Minute Wait Time Penalty + 0.8 * Transfer Time + a Transfer Penalty of 23 Minutes for Un-timed Transfer and 12 Minutes for Timed Transfer + In-vehicle Travel Time Equation 7

There are a total of 932 TAZs in Broward County of which 40 TAZs are external.

External TAZs are connected to the outside world. There is no household information for these TAZs. Therefore, these TAZs were excluded from the database. Once TTIM was estimated, it was used as one of three transportation measures to calculate the accessibility indices of 892 internal TAZs of the county. In addition to transportation measures, methodology for accessibility indices estimation of this research includes seven socio-economic attributes of destination TAZs. It is unlike other existing studies that use the number of jobs in the destination zone as the sole socio-economic attribute (*14*, *18*, *29*). The socio-economic variables come from the ZDATA2 file of the Broward County Transportation Modeling Database while the data in ZDATA2 table are abstracted from the Census 2000 database. As mentioned above, FSUTMS output produces raw data in fragmented matrices that are unusable in any statistical software package. The raw data are also not printable as they are huge. Therefore, similar to estimation of TTIM from its components, a computer program was written to read and tabulate the values of three frictional variables – TTIM, HTIM, and HDIS from each TAZ to each other TAZs of the county, and another program was written to read the socio-economic data from ZDATA2 file. Lastly, the final program was written to estimate the accessibility indices of each TAZ. The program was written in such a way so that the transit accessibility indices (TA_{ij}) from each TAZ to each other TAZ were estimated first as shown by Equation 6. Then the accessibility indices from one specific TAZ *i* to all 892 TAZs were added to get its comprehensive accessibility index, TA_i as shown by Equation 8. All the computer programs of this study were combined and run altogether at a time.

$$TA_i = \sum_{j=1}^{n} TA_{ij} \qquad \text{Equation 8}$$

n = 892, since there are 892 TAZs in Broward county, Florida.

TA_i estimation could be simplified by a small example. Say, there are only four TAZs in a county: TAZ 1, TAZ 2, TAZ 3, and TAZ 4. Their attributes are: $TTIM_{11} = 0$; $TTIM_{12} = 59.845$; $TTIM_{13} = 63.665$; $TTIM_{14} = 56.405$; $HTIM_{11} = 0$; $HTIM_{12} = 2$; $HTIM_{13} = 2$; $HTIM_{14} = 2$; $HDIS_{11} = 0$; $HDIS_{12} = 0.4$; $HDIS_{13} = 0.7$; $HDIS_{14} = 1$; $POP_1 = 1014$; $POP_2 = 1712$; $POP_3 = 0$; $POP_4 = 1324$; $POPDEN_1 = 3.37$; $POPDEN_2 = 3.05$; $POPDEN_3 = 0$; $POPDEN_4 = 3.32$; $JOB_1 = 424$; $JOB_2 = 235$; $JOB_3 = 6$; $JOB_4 = 342$; $JOBDEN_1 = 1.41$; $JOBDEN_2 = 0.42$; $JOBDEN_3 = 0.02$; $JOBDEN_4 = 0.86$; $BUFFER_1 = 61.81$; $BUFFER_2 = 65.92$; $BUFFER_3 = 47.29$; $BUFFER_4 = 100$; $CBD_1 = 0$; $CBD_2 = 0$; $CBD_3 = 0$; $CBD_4 = 0$; $DTN_1 = 0$; $DTN_2 = 0$; $DTN_3 = 0$; and $DTN_4 = 0$.

By plugging in these numbers in Equation 6 and using the distance-decay parameters presented in Table 1, the transit accessibility to jobs of TAZ 1 over TAZ 4 could be estimated as below:

$$TA_{14} = \left(\begin{array}{l} [\left(56.405^{-0.006067}\right) + \left(2^{0.122780}\right) + \left(1^{-0.250210}\right)] \times [\left(1324^{0.000008}\right) + \left(3.32^{0.036496}\right) + \\ \left(342^{0.000058}\right) + \left(0.86^{0.036647}\right) + \left(100^{0.013648}\right) + \left(0^{0.372820}\right) + \left(0^{0.324140}\right)] \end{array} \right)$$

$TA_{14} = 15.6436$.

Similarly, TA_{11}, TA_{12}, and TA_{13} are estimated as 0, 16.8407, and 9.2211. Using Equation 8, comprehensive transit accessibility to jobs (TA_i) of TAZ 1 over these four TAZs can be estimated as:

$$TA_1 = \sum_{j=1}^{4} TA_{ij} = \sum_{j=1}^{4} TA_{1j} = TA_{11} + TA_{12} + TA_{13} + TA_{14} = 0 + 16.8407 + 9.2211 + 15.6436$$

$TA_1 = 41.7054$.

Originally, *transit accessibility to service jobs*, *transit accessibility to commercial jobs*, and *transit accessibility to industrial jobs* were estimated. However, pair-wise correlation suggests the presence of multicollinearity among these three accessibility measures. Therefore, the paper used the *transit accessibility to service jobs* as the proxy for other two.

CASE STUDY: BROWARD COUNTY, FLORIDA

Broward County, Florida is bounded by West Palm Beach in the north, Miami-Dade County in the south, everglades in the west, and the Atlantic Ocean in the east. Following is a reflection on spatial setting and estimated transit accessibility to jobs in the study area.

Spatial Setting of Broward County

Figure 1 shows the locations of CBD and downtown TAZs, and major transit routes in the study area. Ideally the CBD TAZs are contiguous and have the highest non-industrial employment density in the region. They have high parking rates. They have little residential use. The downtowns are TAZs surrounding these. They also are contiguous, have lower employment density, but some of it might be industrial. Some down town TAZs have high population density. Parking is also expensive and/or restricted. However, for this research the CBDs and down towns were selected based on different variables so it reflects the impact of parking fees to a large extent. Using this rationale, any collections of TAZs with parking fees attached to them were considered as downtown TAZs, even if they are not contiguous to the CBDs. The CBD TAZs in Figure 1 are the hearts of the Fort Lauderdale metropolis. It is the place where the central

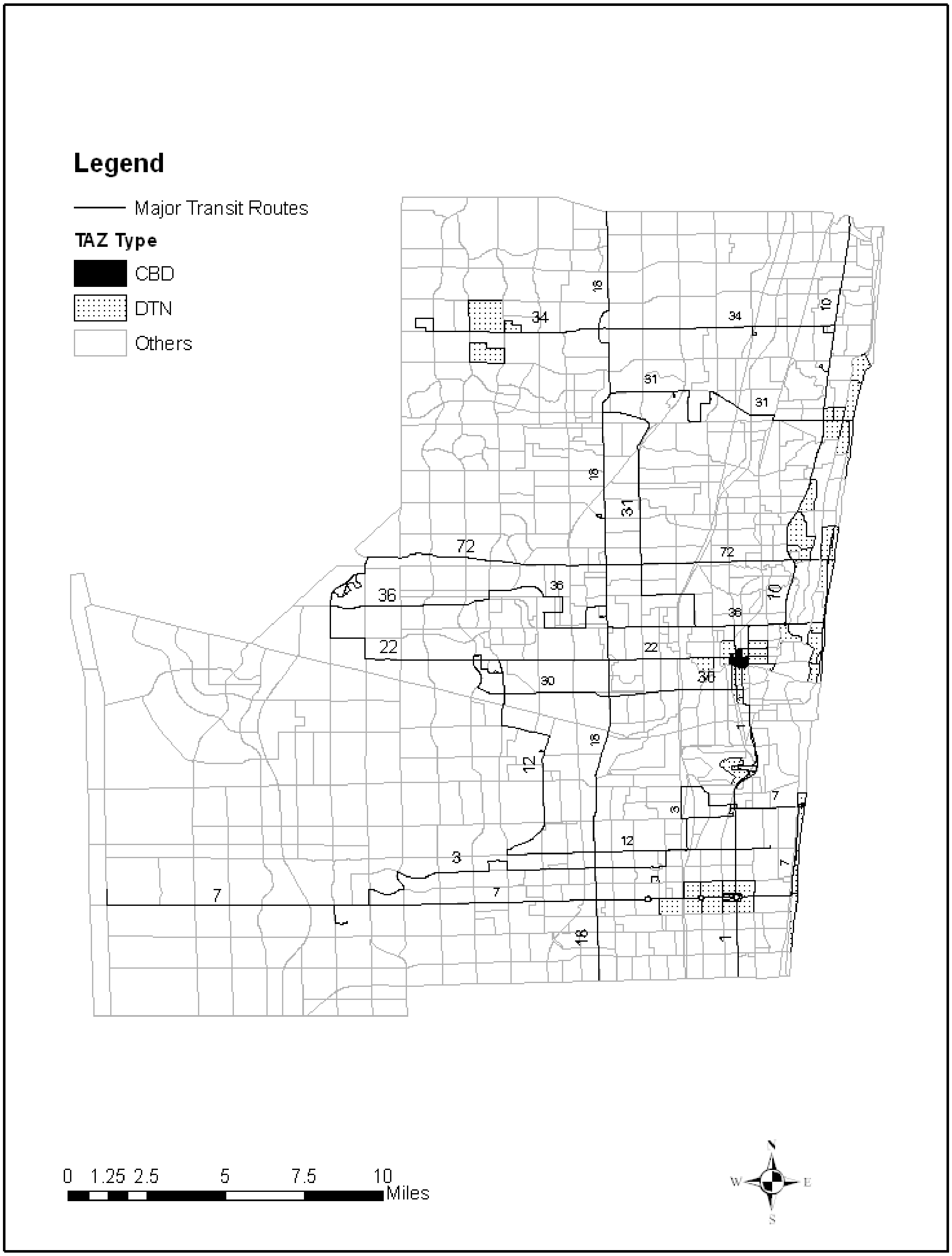

FIGURE 1 Spatial distribution of CBD, downtown, and major transit routes in Broward County, Florida

terminal of Broward County is located and where more than ten transit routes start/end. Figure 1 depicts that all but three of the downtown TAZs are also located in the eastern side of the county. Some of these surround the CBD TAZs and others are in the north and south sides of the CBD. The figure further shows that there are no downtown or CBD TAZs in the southwest or middle-west sides of the county. The reason behind this is that the southwestern sides as well as some parts of the mid-western side of the county and its adjacent counties are conservation areas.

TABLE 2 Descriptive Statistics of Independent Variables Going into Accessibility Indices

Variable	N	Range	Minimum	Maximum	Mean	Std. Deviation
TTIM	892	132.225	0.000	132.225	51.388	50.110
HTIM	892	41.000	0.000	41.000	7.720	8.746
HDIS	892	28.100	0.000	28.100	4.583	5.498
DPOP	892	11244.000	0.000	11244.000	1783.957	1874.729
DPOPDEN	892	14.640	0.000	14.640	1.727	1.582
DJOBS	892	8086.000	0.000	8086.000	702.280	939.767
DJOBDEN	892	55.090	0.000	55.090	1.267	3.275
DSPLIT	892	100.000	0.000	100.000	65.177	33.912
DCBD	892	1.000	0.000	1.000	0.007	0.082
DDTN	892	1.000	0.000	1.000	0.059	0.237

Table 2 shows the descriptive statistics of the independent variables (IVs) going into the accessibility index. It explores that all the minimum values for all the IVs are zeros. The mean transit travel time (TTIM) from the centroid of a TAZ to another is nearly an hour while highway travel (HTIM) takes an average of only nearly eight minutes. The average physical distance (HDIS) between the centroids is little over four and one-half miles. The average of both population density (DPOPDEN) and job density (DJOBDEN) are less than two per tenth of hectare of land. It is important to note that the mean transit coverage (DSPLIT) is over 65 percent indicating that most parts of the county are within the ¼-mile transit buffer. The variables DCBD and DDTN are dummy variables. The value of it is 1 when a TAZ is CBD or downtown; and 0 otherwise. The table shows that only 0.7 percent of the TAZs are categorized as CBDs while 5.9 percent as downtowns.

Spatial Pattern of Transit Accessibility to Jobs in Broward County

After estimating the transit accessibility of each TAZ, the paper mapped the spatial distribution of transit accessibility and then compared the resulting pattern with the transit route coverage, i.e., proportion of a TAZ covered by ¼-mile buffer around a transit line. Figure 2 shows the spatial distribution of transit accessibility, as classified based on natural breaks in the data. The figure shows that the areas with the highest transit accessibility are located in an east-west bulge located in the center of the county and in north-south bands located several miles inland from the coast that nearly run the length of the county. The band with the highest levels of transit accessibility follows approximate path of BCT Route 18. The minimum, maximum, mean and std. dev. of transit accessibility to jobs are 0, 8507, 3063.02 and 2213.96, respectively.

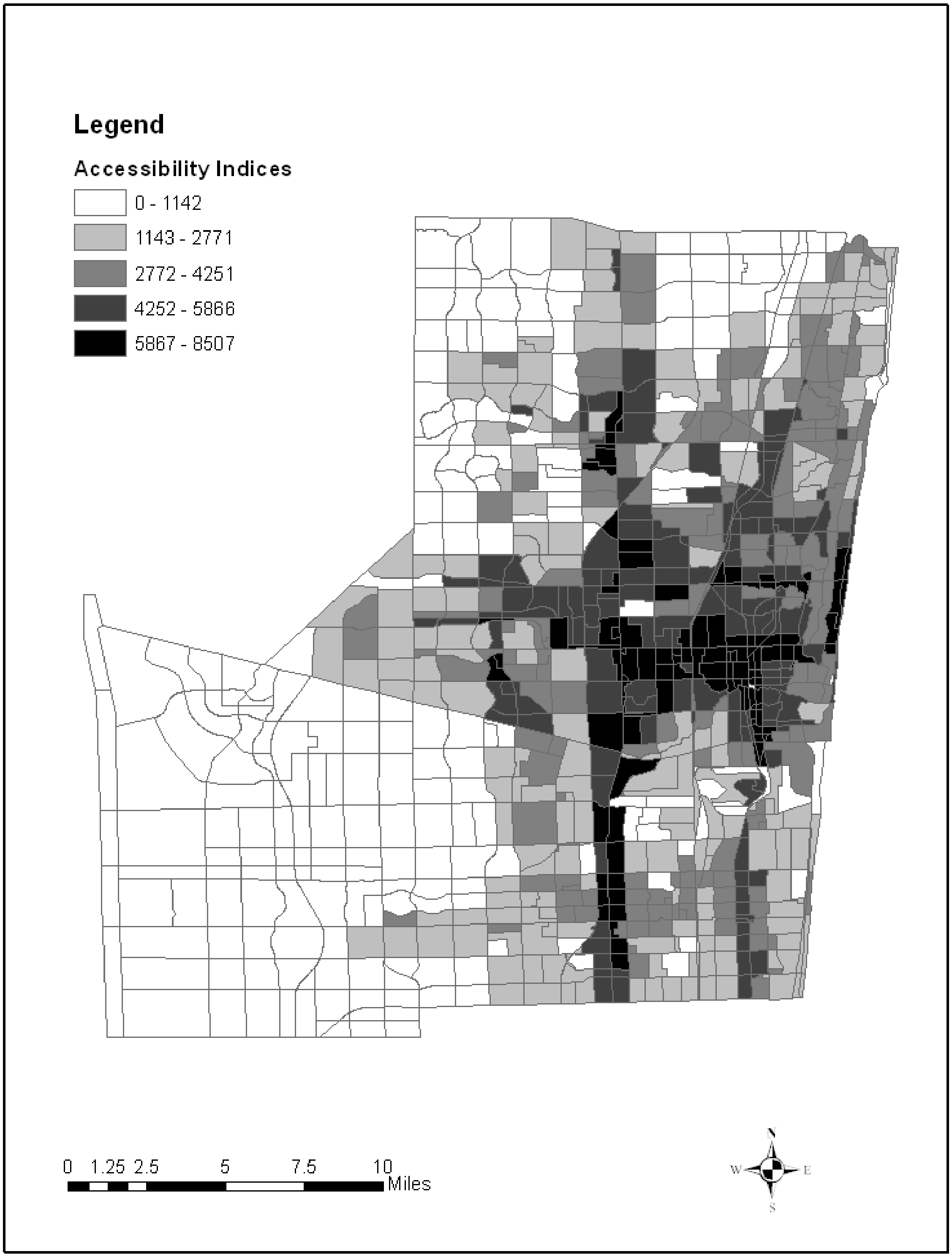

FIGURE 2 Transit accessibility to jobs in Broward County, Florida

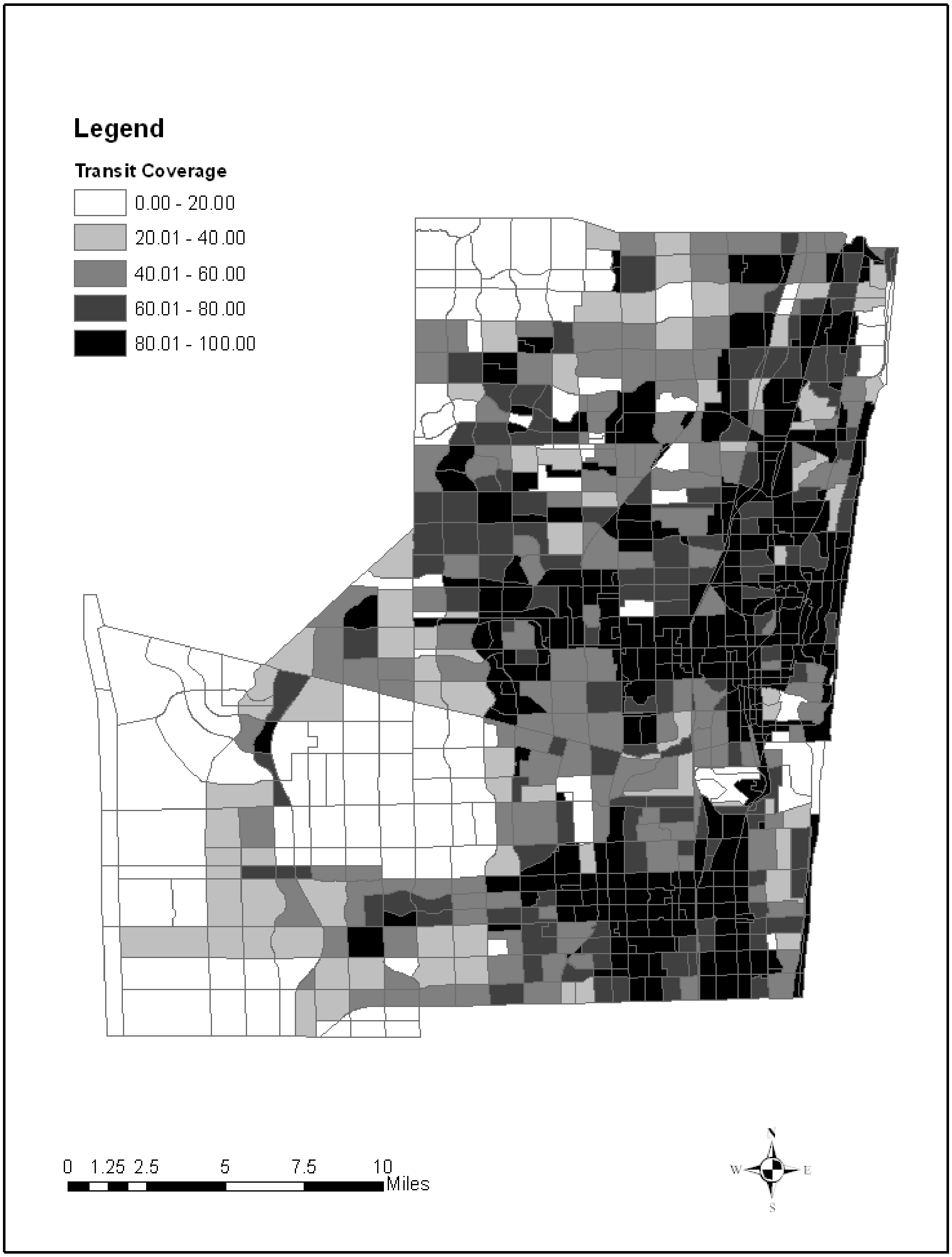

FIGURE 3 Transit route coverage in Broward County, Florida

Figure 2 also shows that the TAZs including and surrounding the CBDs have highest accessibility indices. Some other TAZs through which a north-south and an east-west transit route pass also fall into this group. These routes provide transit services every 15 minutes interval and are highly efficient and effective. For example, the figure shows that the high accessible TAZs make a sign like a cross (+) at the center of the county. It is because of the intersection of north-south transit route 18 with the east-west transit routes 22, 30, 36 and 72 at the center of the county. Transit route 18 also intersects with east-west routes 3, 7 and 12 in the south, and with routes 31 and 34 in the north of the county. The surrounding TAZs of the central TAZs have second highest accessibility indices. The north-south routes 1 (in the southern part of Fort Lauderdale) and 10 (in the northern part of Fort Lauderdale) intersect with the above-mentioned east-west transit routes that help the respective TAZs to be associated with high transit accessibility.

Figure 2 explores that the southwestern TAZs of the county have accessibility indices varying from 0-1142, or the lowest of the five relative categories. It is important to mention that the southwestern TAZs, which do not have transit route(s) passing through it, are associated with zero accessibility. Although it cannot be completely generalized, it can be assumed that to a large extent, the figure indicates that the accessibility indices decrease with the increase of distance from the CBD and downtown TAZs at the centre. However, this hypothesis is not true for the middle and right side of the southern part of the county through which the routes 18 and 1 pass, and have high accessibility indices.

Figure 3 depicts the proportion of TAZs within ¼-mile of a surface street bus route, i.e., the percentage of the total area of a TAZ that is covered by ¼-mile buffer from the centerline of the transit routes. It is the traditional measure of transit accessibility (*13*, *14*, *15*). The figure shows that 85 (9.5%) TAZs have absolutely no transit coverage, 124 (13.9%) have less than 20% transit coverage, 391 (43.8%) TAZs have more than 80% transit coverage, and 177 (19.8%) have 100% transit coverage. It also reveals that 285 TAZs, which is equivalent to 31.9% of all TAZs, have less than 50% transit coverage. The figure further displays that the TAZs located in the middle-middle-eastern and southeastern parts have more transit coverage than the southwestern TAZs. Most of the southwestern TAZs do not have any transit coverage except those through which the transit routes run. The northwestern part of the county is also associated with no transit coverage at all, as these TAZs do not have any transit routes as well. The smaller TAZs have more transit coverage than the bigger TAZs as ¼-mile distance from a transit route is more likely to cover a whole small TAZ but not a big one.

Because Figure 3 shows the transit accessibility indices estimated by traditional ¼-mile buffer technique, it is important that this figure is compared with Figure 2 that represents transit accessibility indices estimated by the approach presented in this paper. It is worthwhile to note that the areas shown to be highly transit accessible in Figure 2 differ considerably from the ¼-mile transit buffers shown in Figure 3. For example, many areas in the southeastern part of the county that lie within the transit buffer and would be considered accessible in Figure 3 turn out to have very low levels of accessibility in Figure 2. Figure 3 depicts that more TAZs are attached to very high transit accessibility indices than that depicted by Figure 2. However, this depiction by Figure 3 is not correct because this figure is not prepared using the attraction and friction variables needed to estimate transit accessibility indices. The pattern of accessibility in Figure 2 reflects the multi-destination nature of the transit network. In a multi-destination network, accessibility is dispersed, whereas in a radial network accessibility is concentrated at the center, where the routes converge.

A small TAZ may be fully covered by ¼-mile transit buffer while not having any transit station in it or its neighboring TAZs. It may happen only because a transit line passes through the small TAZ. The TAZ may even have a transit station, but very long transit service frequency like an hour or two. Such a TAZ with high transit coverage but poor transit services is no better than a TAZ with low transit coverage but frequent/better transit service facilities. Transit coverage itself does not guarantee better transit services to its users. The comparison of Figures 2 and 3 establishes that physical coverage of a zone by transit route does not necessarily mean that it has high accessibility index. The transit coverage is just one of the variables that play a role in the calculation of accessibility indices. If other variables going into the accessibility equation of a zone are not significant, the zone will not have high transit accessibility to jobs although it may be attached to high transit coverage. That is why a remarkable number of high transit coverage TAZs in Figure 3 does not have high transit accessibility to jobs indices depicted in Figure 2.

CONCLUSION

The use of GBMA is not easy despite its high level of popularity among the planners, economists, and geographers. However, an alternative GBMA has been presented in this paper that is based on the basic concept of traditional gravity-based accessibility model (*7*, *14*, *18*, *29*), yet takes into consideration of other important factors ignored by traditional models. This method addresses the issue of arbitrarily assigning an exponential parameter value (-1 or -2) to a friction factor by means of estimated parameters from on-board travel survey data. It also assigns estimated parameters to socio-economic variables while traditional gravity-based models do not have parameters attached to such variables. The model presented in this paper includes three important variables related to friction between each of the TAZs and seven socio-economic variables that typically attract people from an origin to a destination. The paper shows that accessibility indices calculated using the presented model produces a better reflection of reality compared to traditional measures of accessibility – the proportion of TAZs covered by ¼ mile of transit buffer, which is usually a crow fly distance but occasionally representing true walking distance. One-fourth mile of transit coverage could cover 100% of a small TAZ generating an impression that the TAZ has highest level of transit accessibility. However, this notion is misleading since the transit service could be intermittent and it may not connect the TAZ to those variables attached to highly attractive job opportunities. The model presented in this paper addresses these issues. The paper explores the extent to which accessibility indices calculated using the estimated parameters from onboard travel survey data produces what one would expect in a real world scenario. It also explores the possibility of transferring estimated distance-decay parameters from one geographic unit to another, like in this case, Sacramento County, California to Broward County, Florida. Future research needs to focus on validating such transferability of parameters.

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