Measuring Change in Small-Scale Transit Accessibility with Geographic Information Systems

Buffalo and Rochester, New York

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A new method has been developed to measure directly changes in transit accessibility—the combined spatial effect of shifts in land use patterns and transit service—between metropolitan jobs and census tracts with high proportions of the people who most depend on good transit. Through focused analysis of transit routes serving one neighborhood in Buffalo and one neighborhood in Rochester, New York, two main questions are addressed. First, did transit-dependent poor people who lived in inner-city neighborhoods lose capacity to access jobs by transit during the 1990s? Second, if so, how much of the reduction in accessibility was due to changes in transit service rather than to dispersion of land use? Steps include formulating a gravity model using geographic information systems (GISs), calculating an accessibility index at two times during the 1990s at the census tract level, and disaggregating the accessibility change into subcomponents of change in land use and change in transit service by holding relevant variables constant to a base year. Findings do not support the a priori expectations: the transit component of change does not appear to contribute to a loss in accessibility from high-poverty neighborhoods. The model provides insights into the causes of accessibility change, the geographic distribution of accessibility change, and better assessments of whether transit agencies are successfully adapting to changes in land use.

Several trends appear to contribute to lessened access to jobs during the 1990s for transit-dependent people who live in high-poverty neighborhoods of central cities. Dispersion of land use at the metropolitan fringe was accompanied by increasingly concentrated pockets of poverty at the urban core in many metropolitan regions. Transit agencies that faced growing costs and falling revenues found it increasingly difficult to provide sufficient access to the various locations of a spreading metropolis built for transit by automobile (1).

Transit planners do not know the magnitude or rate of this hypothesized loss in access to opportunities for two main reasons. First, planners rely on indicators that are insufficient for evaluating transit accessibility. They use standard performance indicators such as those in the National Transit Database that are not designed to track change at the neighborhood scale, even though transit needs vary considerably within a metropolitan region. Furthermore, when planners do use models of accessibility, the models usually are based on assumptions that do not accurately account for the unique needs of high-poverty neighborhoods. The second reason is a lack of reliable data. Most employment data are available at the county scale—sufficient for measuring change in the aggregate but far too large for designing effective transit routes.

The objective of this paper is to address the first of these two problems by explaining a gravity-based spatial interaction model that builds on recent advances in accessibility research but is modified to answer questions specific to public transit and the special needs of people who do not have access to automobiles and live in high-poverty neighborhoods. It focuses in particular on separating the combined spatial effect of shifts in land use patterns and transit service. The second problem—the lack of job data—is resolved by using a technique in geographic information systems (GISs) to estimate local employment changes at a small geographic scale; this technique is explained in detail in chapter 2.

The method is demonstrated by using Buffalo and Rochester, New York, as case studies to directly measure changes in transit accessibility during the 1990s. The case studies address two main questions:

- Did transit-dependent poor people who live in inner-city neighborhoods lose capacity to access jobs by transit between 1990 and 1997, the years of the Intermediate Surface Transportation Efficiency Act of 1991 (ISTEA)?
- Is the hypothesized change in accessibility caused in part by changes in transit service rather than purely a result of land use dispersion?

BACKGROUND

Measuring Access to Jobs by Transit

Welfare reform laws in 1996 brought a renewed interest in studying how well public transit provides access to entry-level jobs. One study found that even though welfare recipients in Boston, Mass., generally live near transit lines, they could reach only 14% of entry-level jobs by transit within 60 min. Only 32% of all potential employers—entry-level or not—were within 0.25 mi (0.4 km) of a transit route (3).

Although studies like this provide valuable information for social service providers about the difficulty of finding work by transit, they provide little guidance to the people who plan transit systems because all jobs are weighted equally, regardless of how far a worker...
must travel. And transit planners know that such a shortcoming is serious, because a rider’s willingness to travel to a job diminishes exponentially as distance increases.

Some researchers have turned to more sophisticated measures of transit accessibility by using a gravity model to more accurately reflect the travel conditions that contribute to the problem of spatial mismatch. One study developed a gravity-based indicator to measure accessibility throughout a metropolitan region and concluded that low-density development disproportionately reduces accessibility to employment for poor neighborhoods (4). However, the computational complexity of the technique limited the analysis to automobile commuting, and the authors acknowledged that a fuller understanding would require incorporating other travel modes into the model.

Other studies explicitly include public transit in gravity models. For example, a detailed analysis of the spatial distribution of jobs in Boston advanced the art of gravity models in two important ways (5, 6). First, the model accounted for not only the supply of but also the demand for entry-level jobs. The model therefore measures a worker’s proximity to jobs but weighted by the number of other workers competing for the job. Second, the model is a composite score that includes accessibility by automobile and public transit. Another study focused exclusively on public transit found that good access to public transit was a significant factor in labor force participation in Portland, Oregon, and Atlanta, Georgia (7). The study recognized that to accurately measure accessibility to public transit, a fine-grained analysis is required. The model advanced the study of transit accessibility by using block groups rather than travel analysis zones (TAZs) at the residential ends of the commutes, achieving small-scale analyses at one end of each work trip.

Adapting Gravity Model for Inner City

Despite the advances made by recent modelers, several issues continue to hinder the accuracy of accessibility measurement when applied to the special needs of transit-dependent travelers in high-poverty neighborhoods.

First, studies that use the gravity model typically aggregate data on workplace location at the centroid of a large zone like a TAZ. But such zones present two problems for the study of transit accessibility in a spatial mismatch context: Transit riders are restricted to jobs reachable on foot from a transit stop, and TAZs tend to cover broader areas at a greater distance from the urban center, thus increasing the error associated with aggregating data at the centroid. A more accurate measure of transit accessibility requires the use of data on job destinations disaggregated to smaller zones. A key feature of the proposed model is that variables are derived from GIS spatial queries at a scale small enough to estimate jobs within walking distance of transit stops.

A second adjustment to standard accessibility models is required because people who live in high-poverty neighborhoods are not typical commuters. Nearly all accessibility studies use empirically measured data such as commute time, but commuting data exclude unemployed individuals. Measures of accessibility based on empirically observed travel behavior assume that revealed demand reflects a person’s ability to reach opportunities. This assumption is inappropriate for studying neighborhoods with high rates of unemployment because it fails to capture the effectiveness of transit for people who are not working. The model assesses accessibility potential based on the actual transit network, not on counts of trips taken by working people observed between zones.

Finally, this study is different from others because it measures how accessibility is changing. With some important exceptions (6, 8), surprisingly few accessibility studies examine whether the inaccessibility problem is getting worse. The model proposed in this paper compares accessibility at two points in time, 1990 and 1997, to assess changes in accessibility in light of the important shifts in federal policy under ISTEA.

The model follows specifications for similar gravity models (9–11) but with several key modifications to measure the effect of changes in a transit system from the viewpoint of workers without access to automobiles who are likely to seek entry-level jobs, some of which may fall outside of standard business hours. To answer the questions of this study, a model is needed that

- Estimates job locations on a very small geographic scale at the destination end of a work trip, because riders are limited to work sites reachable by foot from a transit stop;
- Is based on the actual transit network rather than trip data, because many of the riders in the neighborhood of study are unemployed and do not show up in such counts;
- Detects changes in the quality of service provided to a neighborhood, such as the availability of stops and the frequency of runs;
- Accounts for the availability of transit outside of the most common work hours, because entry-level jobs may have unusual schedules;
- Accounts for a return trip home, because a one-way trip to a job is virtually useless; and
- Is based on data from two points in time to measure changes in service over the life of ISTEA, from 1991 to 1997.

NEIGHBORHOOD ACCESSIBILITY INDEX

In contrast to transportation, which can be thought of in terms of the “ability to move around,” accessibility can be considered the “potential of opportunities for interaction” or the “ease of reaching places” (12, 13). The goal of transportation planners has historically been to ease mobility, that is, to overcome distance by facilitating movement from point A to point B, with little regard for the underlying land use patterns. Unfortunately, despite a well-known interaction between land use and transportation, planners in the United States rarely incorporate the influence of both land use and transportation in their decisions (14).

By changing the goal from to mobility to accessibility, attention becomes less narrowly focused on infrastructure and more broadly focused on connecting people to places. This more comprehensive approach considers such dimensions as land use, personal choice, and degree of comfort—dimensions that extend beyond transportation infrastructure. Thinking in terms of accessibility leads to different solutions to transportation problems. Bringing urban activities closer together, for example, can reduce travel costs. Accessibility is a powerful conceptual tool because it provides a link between a transportation network and its surrounding land use conditions, providing practitioners with a basis for making trade-offs between policies for land use and policies for transportation (15). Measures of accessibility offer a "systematic relationship between the spatial distribution and intensity of development, and the quantity and quality of travel within a region" (16).

The most common method for measuring accessibility is the gravity-based model, because it captures the potential created by not only the transportation network itself but also the geographic distri-
bution of the places it serves. The model developed in this paper results in the dimensionless neighborhood accessibility index (NAI) derived from a gravity model. It can be thought of as a summation of the number of entry-level jobs within a 45-min bus ride from a neighborhood, adjusted according to the relative difficulty of travel and frequency of transit service. The analysis is limited to high-poverty central city neighborhoods, entry-level jobs within 0.25 mi (0.4 km) of a transit stop, jobs within a 45-min commute, and travel cost in units of time.

The general relationship takes the following form:

\[ \text{NAI} = f(P, F, T, E) \]  \hspace{1cm} (1)

where

\( P \) = proportional coverage, that is, the proportion of a neighborhood within walking distance of a transit stop (e.g., adding a bus stop in a neighborhood increases \( P \), thus increasing accessibility);

\( F \) = frequency factor, a measure of how often transit passes through a neighborhood (e.g., scheduling a bus to operate every 15 minutes rather than every 30 minutes increases \( F \), thus increasing accessibility);

\( T \) = travel time, used as a proxy for the relative cost of making a trip (e.g., as \( T \) between any two locations decreases, a person’s likelihood of making the trip increases, which increases accessibility); and

\( E \) = employment within walking distance of a transit stop, where the number of jobs serves as a proxy for the relative attractiveness of a location (e.g., a transit stop is expected to attract more transit riders if \( E \) increases—all else being equal—which in turn increases accessibility to that stop).

To develop the model more formally, consider a worker who lives in an inner-city neighborhood and is evaluating the prospect of taking a distant job that requires traveling by bus. The basic gravity model suggests that, all else being equal, a worker is more likely to travel to a particular destination if that place has more rather than fewer opportunities, and if the cost of overcoming the spatial separation is low rather than high. Using the number of jobs as a proxy for the relative attractiveness and the travel time as the cost of the separation results in

\[ \text{NAI}_k = \sum_{j=1}^{n} E_j (T_{ij})^{-\beta} \]  \hspace{1cm} (2)

where

\( \text{NAI}_k \) = index indicating accessibility between Census Tract \( k \) and the set of \( j \) destination transit stops,

\( E_j \) = number of jobs at Transit Stop \( j \),

\( T_{ij} \) = travel time by transit between Census Tract \( k \) and Transit Stop \( j \), and

\( \beta \) = constant to represent distance decay.

Several adjustments to Equation 2 are required to meet the needs of transit travel from inner-city neighborhoods. First, travel time varies by time of day. Travel time increases during peak hours because congestion slows traffic. To indicate that travel time is different for the peak and base periods, a superscript is added to denote the travel period (\( \Phi \)). Second, both travel time and employment differ for each year of study, so a superscript is added to denote the year (\( Y \)). Equation 2 then becomes

\[ (\text{NAI})^{\Phi,Y} = \sum_{j=1}^{n} E_j (T_{ij}^{\Phi,Y})^{-\beta} \]  \hspace{1cm} (3)

But a worker’s decision to travel will be based on more than only jobs and travel time. Several factors related to the quality of transit service also will influence the decision (17). First, the worker is more likely to take a bus if a bus stop is located near home, at the destination end of the trip, the industry standard is 0.25 mi (0.4 km) for a reasonable walking distance to a bus stop (17, 18). \( P \) can serve as a proxy for walking access to a transit route, as a variable ranging from 0 to 1 based on the proportion of the worker’s census tract that lies within walking distance of a route. To illustrate, \( P_{14} = 0.36 \) would indicate that 36% of Census Tract 1 is within 0.25 mi (0.4 km) walking distance of Route 1.

A third factor is relevant for measuring the quality of transit service. A person cannot feasibly use transit for a work trip without the assurance of a return trip home. Therefore, the frequency factor is constrained by a dummy variable \( R \) to preclude routes that do not offer a return trip home approximately 8 hours later.

Adding these factors and summation symbols to include all the routes serving all the census tracts that make up a neighborhood into Equation 3 results in a more formal definition of NAI. NAI measures access from a neighborhood (defined as a set of census tracts) to metropolitan jobs by mass transit, at travel period (\( \Phi \) peak or base) and year (\( Y \) refer to Figure 1 for a schematic of the variables):

\[ (\text{NAI})^{\Phi,Y} = \sum_{k=1}^{K} \left[ \sum_{i=1}^{I} P_{ki} (F_i)^{\Phi,Y} \sum_{j=1}^{n} E_j (T_{ij}^{\Phi,Y})^{-\beta} \right] \]  \hspace{1cm} (4)

where

\[ (F_i)^{\Phi,Y} = R^\Phi (1 - 0.5^{s_i}) \]  \hspace{1cm} (5)

and all variables and their data sources are as defined in Table 1.

Equation 4 is formulated as a series of summations so that the NAI can be disaggregated into components of smaller geographic scale for additional analysis. The first summation (over \( i \)) is route specific, so indices can be compared across routes. The second summation (over \( k \)) gives an index for a census tract, allowing for comparison across tracts. The final summation (over \( k \)) provides an index for what is referred to in this paper as a neighborhood, or a set of contiguous census tracts. Note also that Equation 4 is specific to a particular year (\( Y \)) and travel period (\( \Phi \)) because travel time (\( T \)) and frequency of service (\( F \)) may change from year to year and by time of day.

One final adjustment is required to meet the needs of this study. Bus service varies by time of day, offering more service to match the greatest demand during the busiest times of travel, during the peak hours in early morning and late afternoon. But focusing on the peak periods would be a mistake in this case because entry-level jobs often require atypical schedules. Workers are more likely to use transit if buses are available at various times of day. In both Buffalo and Rochester, the ratio of commuters traveling during the base period to commuters traveling during the peak period is approximately 0.60 (19). Therefore, a weighted score that combines the peak and base travel periods in year \( Y \) is defined as

\[ (\text{NAI})^{Y} = (\text{NAI})^{\text{peak},Y} + 0.6 (\text{NAI})^{\text{base},Y} \]  \hspace{1cm} (6)

An increase in the index suggests that a person in the neighborhood of study is likely to find more opportunities at existing work
sites, that traveling to those work sites became easier, or both. More specifically, the model predicts that NAI will increase as

- Entry-level employment increases (jobs in retail trade and services are used as an approximation of entry-level employment),
- Jobs shift closer to the neighborhood,
- Transit frequency increases,
- Number of transit stops within walking distance of the neighborhoods increases, or
- Transit service becomes available for a return trip home after an 8-hour work shift if it was not available before.

**TABLE 1  Variables in the NAI**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>( (E_j)^Y )</td>
<td>Number of retail trade and services jobs within a quarter-mile of a destination transit stop ( j ), in year ( Y ).</td>
<td>Economic Census zip code files 1987 (23) and New York state real parcel tax assessment data. Published schedules from transit agencies and GIS queries.</td>
</tr>
<tr>
<td>( (T_{ij})^{a,r} )</td>
<td>Travel time (minutes) from centroid of census tract ( k ) to transit stop ( j ), at travel period ( f ) and year ( Y ).</td>
<td>GIS queries</td>
</tr>
<tr>
<td>( P_{ik} )</td>
<td>Proportion of census tract ( k ) within quarter-mile walking distance of route ( i ); Ranges between 0 and 1.</td>
<td>Published schedules from transit agencies</td>
</tr>
<tr>
<td>( (F_i)^{q,r} )</td>
<td>Frequency factor based on number of vehicles passing residential census tract ( k ) on route ( i ), at travel period ( f ) and year ( Y ); Ranges between 0 and 1.</td>
<td>Published schedules from transit agencies</td>
</tr>
<tr>
<td>( N^* )</td>
<td>Number of vehicles passing census tract ( k ) during one hour of travel period ( f ); Peak period hour assumed 7:00 to 7:59 am; base period hour assumed 1:00 to 1:59 pm.</td>
<td>Published schedules from transit agencies</td>
</tr>
<tr>
<td>( R^* )</td>
<td>Dummy variable; if at least one vehicle makes a return trip about eight hours after departing a census tract for the period ( f ), then 1, else 0. (Eight hours after peak period: 3:00 to 3:59 pm, after base period: 9:00 to 9:59 pm.)</td>
<td>Published schedules from transit agencies</td>
</tr>
<tr>
<td>( \beta )</td>
<td>Constant impedance coefficient.</td>
<td>None</td>
</tr>
<tr>
<td>( j )</td>
<td>Index for Stops = 1, ..., ( n ); where ( n ) is the number of employment transit stops on route ( i ), all ( j \leq 45 \text{ minute commute threshold.} )</td>
<td>1990 Census Transportation Planning Package (19)</td>
</tr>
<tr>
<td>( i )</td>
<td>Index for Routes = 1, ..., ( m ); where ( m ) is the number of routes intersecting census tract ( k ).</td>
<td>None</td>
</tr>
<tr>
<td>( k )</td>
<td>Index for Census Tracts = 1, ..., ( q ); where ( q ) is the number of census tracts comprising the neighborhood.</td>
<td>None</td>
</tr>
</tbody>
</table>

**TESTING THE MODEL**

The objective of this paper is to adapt a gravity model to account for the special needs of transit travel from high-poverty neighborhoods. This section applies the model to the questions posed in the introduction, evaluating whether accessibility worsened in high-poverty neighborhoods.

The unit of analysis is a high-poverty, inner-city neighborhood—a location uniquely characterized by its geographic isolation of poor people of color, a neighborhood that social scientists study as an underclass (20–22). Variables are used to understand better how
transportation might contribute to the causes of persistent, concentrated, racially isolated poverty commonly found in cities of the Northeast and Midwest. Because the areas of interest are the effects on neighborhoods of not only racial isolation and poverty but also lack of access to an automobile, the neighborhood is defined as four to six census tracts in the central city that meet the following six conditions:

- High poverty rate (at least 40% of households live below the federally designated poverty line);
- 90th percentile of the county on households with no vehicle;
- 90th percentile of the county on households receiving public assistance;
- 90th percentile of the county on households headed by African Americans;
- 80th percentile of the county on working-age persons unemployed; and
- A contiguous set of tracts meeting all of the previous conditions, and fully surrounded by other tracts with high poverty, to capture the effect of concentrated poverty.

The case study neighborhoods in Buffalo and Rochester are located adjacent to the downtown areas, consisting of five tracts in Buffalo and four in Rochester, as illustrated in Figure 2. Table 2 summarizes selected variables about the case study neighborhoods.

The analysis is restricted to only transit routes with stops in the neighborhood and commutes no longer than 45 min. A route is defined as each unique pattern appearing in a published schedule. Most numbered routes have slight variations in destination or schedule. Defining each unique combination as an individual route captures these variations.

GIS transit data were not available as a connected network, so all routes were constructed in a GIS from road files. The study therefore is further restricted to assuming no transfers. Building a network to include transfers complicates the computations exponentially and is beyond the scope of this study. This assumption probably has little effect on the results because the objective is to measure losses in accessibility over time; it is reasonable to assume that if accessibility declines without transfers, it is likely to decline with transfers as well.

Data Sources

The key sources of data include

- TIGER/Line files published by the U.S. Bureau of the Census for GIS mapping of roads, hydrology, jurisdictional boundaries, and census tracts;
- Tax assessment data from the Office of Real Property Services of New York for Erie and Monroe Counties, 1990 and 1997;
- Retail trade and services employment data from 1987 Economic Census zip code files (23) and 1997 Zip Code Business Patterns (24);
- 1990 Census of Population and Housing (25) for demographic and socioeconomic data at the census tract level; and
- Transit maps and schedules obtained from the Niagara Frontier Transportation Authority (NFTA) for Buffalo in 1992 and 1997 (the study period is 1990 to 1997, but NFTA had no schedules for before 1992) and from the Rochester–Genesee Regional Transportation Authority for Rochester in 1990 and 1997.

Findings

First, did transit-dependent poor people who live in inner-city neighborhoods lose capacity to access jobs by transit during the 1990s? A negative value for change in NAI (ΔNAI) would support the hypothesis that accessibility declined.

\[
\Delta \text{NAI} = (\text{NAI}^{1997} - \text{NAI}^{1990}) < 0
\]  
(7)

**FIGURE 2** Case study neighborhood locations, 1990: (a) Buffalo and (b) Rochester.
### Table 2: Case Study Neighborhoods, Buffalo and Rochester, 1990

<table>
<thead>
<tr>
<th></th>
<th>Race</th>
<th>Zero-Vehicle Households</th>
<th>Poverty Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>White (%)</td>
<td>Black (%)</td>
<td>Other (%)</td>
</tr>
<tr>
<td>Buffalo Region</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case Study Neighborhood</td>
<td>5.37</td>
<td>93.54</td>
<td>1.08</td>
</tr>
<tr>
<td>Erie County</td>
<td>85.89</td>
<td>11.34</td>
<td>2.76</td>
</tr>
<tr>
<td>Rochester Region</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case Study Neighborhood</td>
<td>8.22</td>
<td>79.23</td>
<td>12.55</td>
</tr>
<tr>
<td>Monroe County</td>
<td>84.08</td>
<td>11.91</td>
<td>4.01</td>
</tr>
</tbody>
</table>

1. Buffalo neighborhood consists of census tracts 14.02, 15, 25.02, 26, and 31. Based on 1990 definitions.
2. Rochester neighborhood consists of census tracts 13, 14, 15, and 91. Based on 1990 definitions.

The model results are listed in Table 3. Results are presented separately for retail trade and services to distinguish between shifts in accessibility by industry. Because NAI is dimensionless, its magnitude has meaning only relative to another index. An increase in NAI implies that the number of jobs increased at previously existing bus stops, new bus stops were added in places where jobs were located, traveling to job sites became easier, or some combination of these three options.

The results offer no support for the hypothesis that accessibility worsened during the 1990s. Contrary to expectations, the model suggests that accessibility increased during the study period in both the Buffalo and Rochester neighborhoods. Furthermore, the increase appears to be substantial, although the magnitude of the percent change in the index has little meaning without additional investigation. The results also suggest that accessibility to service jobs increased more than accessibility to retail trade in both regions. The Buffalo neighborhood appears to have gained more access to jobs overall than the Rochester neighborhood.

Second, how much of the hypothesized change in accessibility is due to changes in transit service rather than to dispersion of land use? NAI is a function of both land use and transportation variables. Answering this question requires disaggregating the index into components of each. Recall the four major variables of the index given by Equation 1: $P$, $F$, and $T$ depend on the transit system; $E$ is a proxy for land use. By holding $E$ constant, one can find the portion of the change in NAI due to changes in transit. Let $(\text{NAI})_{1990}$ denote the accessibility index in 1997 with employment held constant at 1990. In other words, $(\text{NAI})_{1997}$ is calculated using 1997 values for $P$, $F$, and $T$ but using the earlier 1990 value for $E$, as if the spatial distribution of jobs did not change between 1990 and 1997. Then the portion of accessibility change attributable to transit is given by

$$\Delta \text{NAI} = (\text{NAI})_{1997} - (\text{NAI})_{1990}$$  \hspace{1cm} (8)

If local transit decisions were contributing to accessibility changes, then $\Delta \text{NAI}$ would be expected to be significantly different from 0. But to make this measure more intuitively clear, let the variable $\text{TransitShare}$ represent the share of accessibility change attributable to transit, calculated as a proportion of the original change in accessibility:

$$\text{TransitShare} = \frac{\Delta \text{NAI}}{\text{NAI}}$$  \hspace{1cm} (9)

$\text{TransitShare}$ varies from 0 to 1. A value of 0 for $\text{TransitShare}$ suggests that a transit system remained unchanged over time, so all of the change in accessibility from a neighborhood—positive or negative—is caused entirely by changes in land use. Conversely, if $\text{TransitShare}$ is 1, then all of the change in accessibility would be attributed to changes in the transit system. Please note that values of $\text{TransitShare}$ between the extremes of 0 and 1 should be interpreted with caution because the relationships among the variables for transit and for land use are not linear. A more complex treatment would undermine the intuitive appeal of the measure. Nevertheless, $\text{TransitShare}$ is useful for highlighting the interaction of influences from changes in transit and in land use. The results for Buffalo suggest that a substantial portion of the change in the index ($\text{TransitShare} = 0.54$) was due to changes in transit service. By contrast, for Rochester, none of the gain in accessibility was due to transit. In other words, all of the gain in accessibility in Rochester appears to be from shifts in the number or location of jobs.

### Table 3: NAI: Buffalo and Rochester Regions

<table>
<thead>
<tr>
<th>Metropolitan Region</th>
<th>Industry</th>
<th>1992</th>
<th>1997</th>
<th>Change</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Retail Trade</td>
<td>196</td>
<td>1,228</td>
<td>1,032</td>
<td>526</td>
</tr>
<tr>
<td></td>
<td>Services</td>
<td>124</td>
<td>1,280</td>
<td>1,156</td>
<td>929</td>
</tr>
<tr>
<td></td>
<td>Total (Retail and Services)</td>
<td>321</td>
<td>2,508</td>
<td>2,188</td>
<td>682</td>
</tr>
<tr>
<td></td>
<td>Retail Trade</td>
<td>633</td>
<td>829</td>
<td>196</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Services</td>
<td>510</td>
<td>2,183</td>
<td>1,673</td>
<td>328</td>
</tr>
<tr>
<td></td>
<td>Total (Retail and Services)</td>
<td>1,142</td>
<td>3,012</td>
<td>1,869</td>
<td>164</td>
</tr>
</tbody>
</table>
because they are limited by employment data that may not be reliable—an issue that is not the focus of this paper. Instead, the objective is to demonstrate how the model provides several important insights into assessing the outcomes of transit decisions.

Lessons from Model

The model results clearly indicate that accessibility changed in the two cases for substantially different reasons. Buffalo gained accessibility by changing its bus system; Rochester gained accessibility because jobs grew near existing bus lines. One strength of the model is that it can be used to discover the causes of accessibility change by investigating the components of the NAI. Table 4 shows different causes of accessibility change by listing detailed change at two bus stops. Stop 5378 contributed an NAI increase of 12 to Census Tract 25.02. The change in the travel time (ΔT) of 26.13 indicates that this stop probably was added between 1992 and 1997 (because such a large change in travel time at a previously existing stop is unlikely), which was confirmed by further investigation. In this particular example, the Buffalo neighborhood gained accessibility because a new stop captured 29 jobs that had not been accessible to transit in 1992. At Transit Stop 5450, Census Tract 26 gained accessibility with an NAI increase of 59, but the cause of the increase was the creation of 199 new jobs at a previously existing stop, not adding a new stop.

The model provides insights into transit’s role in accessibility change in other ways as well. It is formulated in a way that helps decompose accessibility change into smaller geographic units. For example, if transit significantly improved accessibility from a neighborhood, then one might next ask whether the changes in transit service were applied similarly to all routes serving the neighborhood. In other words, is the effect of transit service change felt similarly among all census tracts that make up the neighborhood? Figure 3 illustrates that improved accessibility was not evenly distributed in the Buffalo neighborhood; Census Tracts 15 and 25.02 benefitted from above-average accessibility growth between 1992 and 1997.

Assessing Transit Decision Outcomes

The variable TransitShare, which measures the influence of transit in accessibility change of a neighborhood, offers additional insights. TransitShare allows one to answer this vital question: Do agencies change their transit systems to adapt to changing land use conditions? If government intends to mitigate the effects of spatial mismatch on inner-city neighborhoods with transit solutions, then it is imperative that planners adjust transit systems to respond to the rapidly changing development patterns they serve.

To show how the model provides a convenient way of assessing this vital question, the Buffalo neighborhood is used to illustrate change between 1992 and 1997. Imagine the spatial distribution of jobs and transit stops in four separate layers. Two layers display jobs—one with the spatial distribution of jobs in 1992, and the other in 1997. Two other layers display the spatial arrangement of bus stops—one for 1992, and the other for 1997. Now consider the decision to add a stop at a new location. All else being equal, a good decision in terms of increasing job accessibility would mean that the number of jobs at any new stop should exceed the number of jobs at that same location in 1992. It can be tested by comparing the job layers in both years. By contrast, to test the success of a decision to remove a stop, the decision might be considered successful if the number of jobs diminished at the stop location between years 1992 and 1997.

These criteria are expressed mathematically in Table 5. Let NEWSSTOPs be the set of all stops added between 1992 and 1997. The bold text in the table denotes the number of jobs located within an imaginary 0.25 mi (0.4 km) buffer zone of a transit stop, but where a transit stop does not actually exist. So, for example, E_j is the number of jobs in 1992 that would have been accessed by a bus stop had a stop been located there in 1992; similarly, E_j' is the number of jobs in 1997 that are no longer accessed by transit because the stop was removed. The decision criteria are listed in the last column of Table 5.

The results from the model suggest that changes to the transit system in Buffalo were generally successful according to the rules of Table 5. Looking first at the stops that were added between 1992 and 1997 (NEWSSTOPs), 30 of 30 stops met the criteria for success: at each bus stop, the number of jobs increased over the period. In fact, the results suggest that the addition of these 30 stops brought more

![Change in NAI for Neighborhood](image)

**FIGURE 3** Change in NAI by census tract, Buffalo neighborhood (NBHD), 1992–1997.

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**TABLE 4** Components of Change at Two Bus Stops, Buffalo, 1992–1997

<table>
<thead>
<tr>
<th>Stop No.</th>
<th>Census Tract</th>
<th>Route</th>
<th>ΔNAI</th>
<th>ΔP</th>
<th>ΔF</th>
<th>ΔT (min)</th>
<th>ΔE (Jobs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5378</td>
<td>25.02</td>
<td>4H</td>
<td>12</td>
<td>0</td>
<td>0.40</td>
<td>26.13</td>
<td>29</td>
</tr>
<tr>
<td>5450</td>
<td>26</td>
<td>59</td>
<td>0</td>
<td>-0.38</td>
<td>0.00</td>
<td></td>
<td>199</td>
</tr>
</tbody>
</table>

*Notes:* See Table 1 for full variable definitions. ΔNAI = change in accessibility; ΔP = change in route coverage at neighborhood; ΔF = change in transit frequency factor; ΔT = change in travel time; ΔE = change in number of jobs at destination stop. The two stops shown in the table were selected to illustrate the method.
TABLE 5 Decision Criteria for Assessing Changes in Transit Stops

<table>
<thead>
<tr>
<th></th>
<th>1992</th>
<th>1997</th>
<th>Success if:</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEWSTOPS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$E'_{ij}$</td>
<td>$E_{ij}$</td>
<td>$E_{ij} &gt; E'_{ij}$</td>
</tr>
<tr>
<td>LOSTSTOPS</td>
<td>$E_{ij}$</td>
<td>$E'_{ij}$</td>
<td>$E_{ij} &lt; E'_{ij}$</td>
</tr>
</tbody>
</table>

than 6,000 jobs within reach of the neighborhood by bus. Only by disaggregating the components of the model could one discover this kind of result.

CONCLUDING REMARKS

Even though the results of the model did not conform to initial expectations, a great deal can be learned because the model is formulated in a way that separates the combined spatial effect of shifts in land use patterns and in transit service. For instance, in the two cases, the observed changes in accessibility had different causes. In the Buffalo study neighborhood, accessibility improved primarily because of changes in transit service. In the Rochester study neighborhood, accessibility improved mainly because of changes in land use (i.e., job growth at existing transit stops), not transit. A basis for evaluating the changes that were made in transit provision also was found. Evidence suggests that Buffalo planners made strategic decisions to change the bus system in a way that considerably improved job accessibility for the neighborhood. By contrast, the Rochester bus system remained stable during the study period. Transit routes serving the Rochester study neighborhood were not changed, but accessibility increased regardless because of job growth at existing stops; determining whether these routes were deliberately left unchanged would require further investigation.

The primary objective of this paper was to address shortcomings in accessibility methods for public transit. Even though the steps require a level of data preparation that may not be available to organizations with limited technical capacity, the technique allows for using readily available public data to help planners better answer questions specific to public transit and the special needs of people without access to automobiles who live in high-poverty neighborhoods.

The consequences of failing to address the current shortcomings in data and methods are serious. Despite mounting expectations for meeting the goals of welfare reform with transit and growing concern overcomplying with environmental justice provisions, planners and policy makers have inadequate tools for assessing whether public transit is meeting its ultimate goal of connecting people and places. Transit planners need a new technique that more suitably measures changes in public transit accessibility if they hope to ensure a minimum linkage to jobs for the people who most depend on public transportation.

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REFERENCES


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