Does Public Transit Counteract the Segregation of Carless Households?

Measuring Spatial Patterns of Accessibility

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Although local transit agencies struggle to keep pace with low-density urban development, most people who depend on transit continue to live in concentrated clusters at the core of metropolitan regions, becoming more distant to the variety of places they need to access. Standard transit performance measures fail to help local transportation agencies adapt their services to changes in demographics and urban form. Geographic information systems (GIS) provide a method for measuring transit service at the neighborhood scale while accounting for land-use changes. The first aim was development of a GIS-based accessibility indicator that is straightforward to calculate, easy to interpret, and flexible enough to use for employment and nonwork travel alike. The second objective was to introduce recent advances in spatial statistics to transportation planners to help them quantitatively assess changes in accessibility patterns over time. A case study is examined of accessibility to supermarkets in Syracuse, New York. The analysis finds that over 7,500 households, representing 12 percent of the city's households, do not have reasonable access to supermarkets. Furthermore, using visual assessment of maps, aspatial database operations, and spatial statistical tests, the study provides statistically significant evidence that poor accessibility is associated both with low-income neighborhoods and with neighborhoods with disproportionately high populations of African Americans.

One goal of federal transportation policy is to provide mobility for people who are too poor to own an automobile. Government subsidies for public transit are justified, in part, by providing mobility for "transit-dependent" people, and federal legislation requires that local governments give special attention to meeting this social goal (*1*). However, several trends in urban development are combining in ways that may worsen the isolation of low-income households. These trends, furthermore, could also inhibit local transit agencies from adjusting to spreading urban land-use patterns. Planners will likely face growing difficulty in meeting the long-standing objective of serving people who depend most on good transit.

Land-use dispersion at the metropolitan fringe is accompanied by increasingly concentrated pockets of poverty at the urban core in some metropolitan regions. Many people in central city neighborhoods are too poor to own a car, and they become more isolated as essential destinations become more distant. Meanwhile, transit agencies faced with the quandary of growing costs and falling revenues find it increasingly difficult to provide sufficient access to the variety of places—like jobs, stores, parks, and museums—offered by a spreading metropolis built for the automobile. Local transit providers are strained not only by the need to follow riders into low-density developments but also by provisions in federal law that seek to strengthen transit in the suburbs to attract suburban "discretionary" commuters away from driving a car. If local agencies shift transit service to suburban constituencies at the expense of local bus service, accessibility from high-poverty neighborhoods may worsen.

Do current trends—worsening isolation together with troubled transit—actually lead to diminishing access to metropolitan opportunities for transit-dependent people? Planners and policy makers do not know because standard transit performance indicators (such as the Federal Transit Administration's National Transit Database) suffer from two shortcomings that prevent the detection of declining accessibility: first, the indicators are reported at the systemwide scale, providing insufficient detail for assessing change at the smaller neighborhood scale even though transit needs vary considerably across neighborhoods; second, the indicators do not account for land-use changes over time. Geographic information systems (GIS) provide a set of tools for overcoming these data limitations.

Measuring the interaction of changes in both land use and the transit network is difficult because of the complexity that the dimension of space introduces into the analysis. *Accessibility* is a concept that captures both land-use and transportation influences, as a measure of the "ease of reaching places" (*2, 3*). Fundamentally, accessibility is determined by two factors: distance to destinations, and the ease of traveling over the distance. The first factor works against inner-city neighborhoods because many essential destinations are moving further away. The effect of the second factor—traveling over these growing distances—is unclear because of simultaneous and opposing influences on inner-city neighborhoods, leaving a tricky spatial problem for planners. On one hand, the inner city is disadvantaged by the travel factor because of low rates of car ownership. On the other hand, inner neighborhoods benefit from the advantage of being centrally located where transit service is typically most abundant. What is the net effect of these overlapping spatial influences? To what extent does transit service compensate for the disadvantage of low vehicle ownership rates in inner-city neighborhoods?

Two methodological points are explained for transit planners, researchers, and community activists. The first point is that GIS can be used to overcome data limitations by developing an easy-to-understand indicator of accessibility, one that works for nonwork destinations as well as for jobs. The second point is that recent methodological advances from the field of regional science—namely, exploratory spatial data analysis linked to GIS—can help transportation planners assess changing spatial patterns of inaccessibility over time by supplementing visual interpretation of maps with quantitative spatial statistics. To illustrate these points, this study examines the location of grocery supermarkets relative to households in Syracuse,

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New York, with the aim of answering the following questions: (*a*) First, how many households in Syracuse have neither a car nor reasonable access to a bus that serves a supermarket? (*b*) Second, can we identify patterns of disparity by race and income in the capacity to access these supermarkets?

Answering such questions is fundamental for achieving equity goals because inner-city neighborhoods tend to be home for a disproportionate number of disadvantaged households, including low-income families and African Americans who are on average more likely to depend on transit service (*4*). Indeed, the Transportation Efficiency Act for the 21st Century acknowledges that transportation policy may fall short in meeting its equity goals by requiring metropolitan planning organizations to "seek out and consider the needs of those traditionally underserved by existing transportation systems, including . . . low-income and minority households" (Title 23 U.S.C., C.F.R. 450.316). Despite mounting expectations for meeting the goals of welfare reform with transit and growing concern over complying with environmental justice provisions, planners and policy makers have insufficient tools for knowing whether public transit is meeting its ultimate goal of connecting people and places. New methods are needed to discover whether some social groups bear a disproportionate burden from transportation and land-use policies, and for addressing recent unanswered questions about discrimination on the basis of race.

THE ISOLATED INNER CITY: CASE STUDY OF SYRACUSE

Syracuse had a metropolitan population of 659,900 and a city population of 163,860 in 1990. Although the economy boomed until World War II, the central city has been losing both manufacturing jobs and people since 1950, when the city population was 220,580. The region shows symptoms of economic decline, suburbanization, and a shrinking city tax base. Several trends suggest worsening accessibility from the urban core.

The first trend is low-density urbanization that pulls jobs and amenities further away from the city core. Land-use development is expanding at the urban fringe at an unprecedented clip in the United States, with land consumption rates far exceeding population growth. Nationwide, for example, over 13 million acres changed to urban uses between 1982 and 1992, representing an increase in urban land of 25 percent, even though population increased by only 11 percent (*5*). Two-thirds of all new jobs nationwide between 1960 and 1980 went to the suburbs, where over 60 percent of all jobs are now located (*6, 7*). In Syracuse, patterns of sprawling land development are reflected in population shifts to the suburbs: although the population of surrounding Onondaga County grew by 11 percent between 1960 and 1990, the central city population declined by 24 percent.

Private retailers respond to the changing geographic shape of their markets, exemplified by large-scale supermarkets that move beyond central city borders. "Megastores"—those that incorporate delicatessens, bakeries, pharmacies, and other amenities—command larger profits than stores that carry food alone. Trends in the supermarket business are toward fewer stores at larger scales that reach much wider market areas. Whereas the median size of a new supermarket in 1953 was 13,600 square feet in the United States, in 1987 it was nearly 47,000 square feet (*8*). Large suburban tracts of land at reasonable prices are attractive to supermarket retailers.

Second, the growing spatial distance between people and opportunities is amplified by an intensifying concentration of urban poverty at the core. High-poverty census tracts—those in which 40 percent or more of residents live below the poverty line—more than doubled in number nationwide from 1,177 in 1970 to 2,726 in 1990 (*9*). In Syracuse, a worsening concentration of poverty outpaced national trends. The number of high-poverty census tracts in the central city jumped from just 2 in 1970 to 14 in 1990. The geographic concentration of blighted areas has the effect of pushing businesses out, putting more distance between essential destinations and the people who remain.

Third, people at the urban core in Syracuse lack not only income but also mobility. More than half of the households in 12 low-income census tracts have no vehicle, and 21 percent of the city's residents live in these 12 tracts. Lack of mobility is not just an income problem but a race issue too: 30.5 percent of African American households nationwide are without cars, compared with 8.7 percent of white households (*10*). But the problem of immobility becomes even more severe at smaller geographic scales: in Syracuse half (49.5%) of all African American households in the central city are carless, but the figure jumps to 62.5 percent in the most distressed neighborhoods of the city, where poverty rates exceed 40 percent (*11*).

People who do not own cars and live in neighborhoods of concentrated poverty without nearby supermarkets must choose either to pay high prices to shop locally or pay with their time, effort, and money to travel. Either option leads to higher costs, and usually for people who can least afford them. The trends in Syracuse illustrate the overlapping and opposing influences on inner-city accessibility. Neighborhoods with the highest rates of carlessness are tightly clustered at the urban core and disadvantaged by long distances to supermarkets. But these same households are advantaged with respect to transit because they are located closest to the hub of a radial bus route system. Given this contradictory combination of disadvantage and advantage, how many people experience the problem of inaccessibility, of being unable to conveniently travel to a supermarket?

MEASURING ACCESSIBILITY AND SPATIAL PATTERNS WITH GIS

Accessibility can be measured with several methods, including the common gravity model formulation (*12, 13*). But GIS allows for an alternative to the gravity model because of its strength in identifying relationships between objects in space. Measuring the geographic *coverage* of transit service (i.e., the number and types of households within walking distance of a transit route) offers several advantages over the gravity model for this study. First, a coverage approach is conceptually easier to do. Second, the approach allows for the use of readily available public data. Finally, it has more intuitive appeal. The coverage model yields an accessibility indicator as a percentage of households in a zone, a result that is more easily interpreted than a dimensionless quantity from a gravity model.

General Formulation of the Accessibility Indicator

This study, using the traffic analysis zone (TAZ) as the unit of analysis, estimates the number of households that have neither a car nor reasonable access to a bus that serves a supermarket in each TAZ in the city. These households will be referred to as *vulnerable households* for shorthand. By assigning socioeconomic data to TAZs we can find out which kind of households are most likely to be vulnerable. Data include geocoded supermarket street addresses, a GIS data file of bus routes provided by the regional transit agency, U.S. Census topographically integrated geographic encoding and referencing system data files, and socioeconomic data from the 1990 U.S. Census Bureau.

The spatial problem is to determine those zero-vehicle households whose people cannot walk to a bus that serves a supermarket, as illustrated in Figure 1. A buffer drawn around a bus line that serves a supermarket represents a reasonable walking distance. Population and households are assumed to be uniformly distributed throughout a TAZ—a reasonable assumption because TAZs are smaller than census tracts in the central city, and census tracts are defined as being homogeneous with respect to socioeconomic conditions. By first finding the proportion of a TAZ's area that lies outside the buffer and then multiplying the proportion by the total number of zero-vehicle households, we can calculate the number of carless households in which individuals cannot reach a bus on foot. Doing this for every TAZ and summing provides an estimate of vulnerable households in the city.

Besides assuming that households are uniformly distributed throughout a TAZ, the method requires several other key assumptions. First, what constitutes a supermarket? Supermarkets beyond 8 km (5 mi) of the city limits are excluded on the basis of inconvenience in travel time. But the analysis is also restricted to large chain stores. The objective is not to find whether people have access to food, but whether they have access to stores that offer high quality food at reasonable prices. Quality and prices vary among stores. In fact, people choose stores for a variety of reasons besides price, including convenience, cleanliness, and discounts. So how can we differentiate between stores on the basis of quality? Quality of service—with regard to offering a wide choice of fresh foods at affordable prices—is generally better for large stores than for small ones. Eliminating convenience stores and imported food stores from this size continuum is fairly straightforward. But should we distinguish between medium-sized independent stores and larger chain stores? Data on market share suggest that we should. The vast majority of people in the region (76 percent) buy their food from large chain supermarkets, indicating that larger stores are indeed most attractive for consumers (*14, 15*). The difference in market share is in part a reflection of the preference for cost-effective shopping, and therefore the analysis is restricted to the seven "most affordable" (or most preferred) chain supermarkets within 8 km of the city.

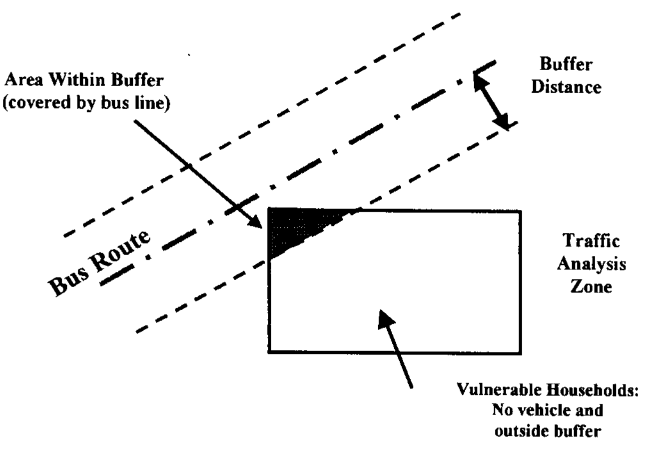

FIGURE 1 Schematic of TAZ area covered by bus route.

A second assumption is to use the industry standard of 0.4 km (0.25 mi) as a reasonable walking distance to bus service (*16*). The buffer would ideally be drawn around bus stops, but because of data limitations it is drawn from the centerline of the route. Third, the analysis assumes no transfers between bus routes. The available data do not permit a more complex analysis, but the assumption is justified on the basis that transferring imposes a considerable burden when carrying groceries.

Turning to the calculation of the accessibility indicator, the concept of vulnerable households allows us to compare across TAZs while controlling for differences in population. The accessibility indicator will be defined as the percentage of vulnerable households in a TAZ, or the number of vulnerable households as a share of all households in a TAZ. A large number for this indicator implies that a high proportion of households lack good access in a TAZ.

This simplified approach, however, requires an adjustment. The problem is that the formulation gives equal utility to riding a bus and driving a car. Notice that all carless households that fall inside the bus coverage are treated as though they have the same accessibility as a household with a car. But riding a bus for shopping is clearly inferior to driving a car. A bus is slower, less flexible, less comfortable, and limits a shopper to about two bags of groceries. And because carless households are disproportionately African American and low income, failing to address this problem would likely lead to unreliable results in assessing equity by population group (*4, 10*). To the extent that African American and low-income households are more likely to live near bus lines, and to the extent that they are more likely to live in carless households, the assumption that buses and cars provide the same degree of access would underestimate the actual disparities in reaching supermarkets. A better measure would assign lower values of accessibility where households depend on a bus.

But how should these households be treated in the analysis? Consider three mutually exclusive conditions of accessibility: (*a*) the "best" condition is the set of households that own cars, regardless of location; (*b*) the "worst" condition is the set of households without cars and without bus service; and (*c*) a condition that lies somewhere between (*a*) and (*b*), which is the set of households without cars but located within the bus coverage buffer. Composite indicators of accessibility that combine different travel modes have long proven to be difficult to model. Because one of the objectives is determination of an accessibility indicator that is readily understandable for nonspecialists (in this case, by defining the indicator as the percent vulnerable households), all households in Condition (*c*) will arbitrarily be distributed evenly between Conditions (*a*) and (*b*) to reflect this intermediate status of accessibility. A more complex formulation is beyond the scope of this preliminary investigation.

After computing the proportion of area outside the bus buffer in each TAZ using GIS, the accessibility indicator is calculated as follows:

$$PCTVHH = \text{Percent vulnerable households in TAZ}$$

$$= \frac{Z[OUTBUF + 0.5\ (1 - OUTBUF)]}{HH} * 100$$

where

Z = number of zero-vehicle households in TAZ,
$OUTBUF$ = proportion of geographic area of TAZ lying outside the coverage buffer, and
HH = number of all households in TAZ.

Empirical Results: Finding the Vulnerable Households

Using the method outlined above, we can estimate that 7,546 households have neither a car nor adequate access to transit lines that serve this set of supermarkets in Syracuse, representing 12 percent of all households in the city. The distribution of households in five categories of accessibility is shown in Table 1, indicating that most households in Syracuse enjoy high levels of accessibility: two-thirds of Syracuse's households are in a TAZ with 20 percent or fewer vulnerable households. As the level of accessibility decreases, so too does the number of households.

The value of GIS presentations is evident from the thematic map of Figure 2, which shows TAZs as a function of accessibility to supermarkets. By indicating measures of accessibility in this visual manner, important relationships in the data—for example, between the bus lines, supermarkets, and vulnerable areas—are more easily understood and communicated. The map suggests that most TAZs have good accessibility, denoted with the lightest shading. But significant exceptions are also evident, and GIS permits further exploration. For example, the map points out TAZs 268 and 283, both dark-shaded. A simple query on the data shows that both have over 300 vulnerable households. TAZ 298, in the southeast corner of the city, appears to be a particularly troublesome region. Besides containing nearly 600 vulnerable households, the map helps us see that this TAZ is essentially "trapped" by expressways, so that even walking to the nearby supermarket may be difficult. Important relationships like these are likely to be overlooked without visual display. Finally, if a planner's objective

TABLE 1 Accessibility to Supermarkets, Syracuse, New York, 1990

Access	Percent Vulnerable Households (%)	No. of Households	Total (%)
High	0-10	16,684	25.7
	10-20	26,821	41.2
	20-30	11,425	17.6
	30-40	6,656	10.2
Low	40 and over	3,455	5.3
	Total	65,041	100.0

Source: U.S. Bureau of the Census 1990, calculations by author.

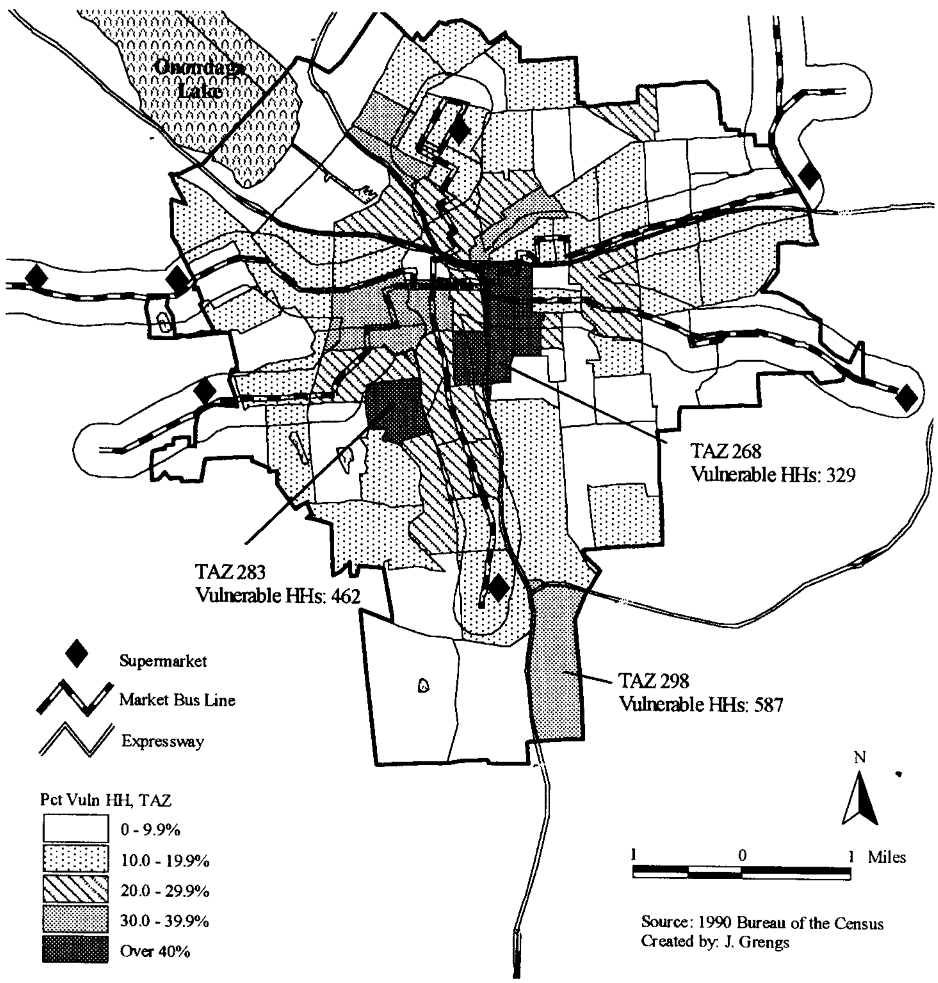

FIGURE 2 Accessibility to supermarkets, TAZs by percent vulnerable households, Syracuse, NY, 1990. (Pct Vuln = percent vulnerable, HH = household)

were to increase accessibility to supermarkets, any dark-shaded TAZ outside the buffer would be an excellent candidate for rerouted bus service.

Equity Analysis: Discovering Spatial Patterns of Inaccessibility with GIS

If a goal of transit policy is to provide a reasonable level of mobility for people without automobiles while ensuring that service is not discriminatory, then measuring spatial patterns of accessibility is fundamental for transit planners. This is because we know that socioeconomic characteristics—like race and income—are not randomly distributed over space. This section addresses equity implications by determining the extent to which accessibility patterns conform to socioeconomic spatial patterns. The analysis is confined to finding differences between African Americans and whites, and among income classes on the basis of median household income. Other important equity questions would include accessibility by age or gender; the issue of need would also be required for a fuller treatment.

Different methods for evaluating spatial arrangements have different strengths. Three methods are demonstrated which, when combined, offer a more complete picture of spatial equity patterns: visual assessment of maps, aspatial statistical tests, and spatial statistical analyses that quantify geographic patterns.

Visual Assessment of Maps

Just as we discovered important pockets of inaccessibility by examining the thematic map of Figure 2, other thematic maps can help identify gaps in transit service for disadvantaged segments of a population. For example, other maps (not shown) indicate that zones with high proportions of African American and low-income households are clustered near the city center, in a pattern of residential segregation common in many Northeastern and Midwestern U.S. cities. Despite being clustered near the center where buses are prominent, however, several of these zones fall outside the bus buffer, suggesting that further analysis is warranted.

Aspatial Statistical Analysis

Maps are useful for discovering places deprived of good access, but alone they tell us little about differences in access among races and income classes. To find differences we must turn to the data behind the maps. First, descriptive statistics show that low accessibility is associated both with high proportions of African American residents and with low-income households. The Pearson correlation coefficient between the percent vulnerable households and the two variables of interest here is 0.48 ($p < .01$) for a log-transformed percent African American population and −0.73 ($p < .01$) for median household income. The results suggest a moderately strong association between zones of low accessibility and high proportions of African American residents. They also imply a strong association between zones of low accessibility and low incomes.

Second, grouping TAZs into categories of accessibility in a cross-classification table further suggests differences in accessing supermarkets. Table 2 compares levels of accessibility by race, showing African Americans as being underrepresented in areas of high accessibility. For example, 26.6 percent of all city residents enjoy the highest accessibility compared with just 5.8 percent of African Americans. A stark difference appears in the category of lowest accessibility as well: 16.4 percent of African Americans endure the worst accessibility in contrast to only 3.5 percent of whites. The row percentages of Table 2 provide yet another perspective. For example, even though African Americans make up only 20.5 percent of Syracuse's population, they account for 54.0 percent of people living in the places of lowest accessibility.

Turning now to testing differences on the basis of income, we can partition both the accessibility and income variables into three categories in a cross-tabulation and apply a chi-square test of independence. The result provides strong evidence that zones with high accessibility are associated with high incomes (chi-square = 46.75, $p < .01$). Table 3 offers another perspective by comparing five levels of accessibility with a weighted average in income, showing that accessibility is consistently better as income increases. The table shows, for example, that median household income is four times greater in the zones of highest accessibility than in those of lowest accessibility.

TABLE 2 Accessibility to Supermarkets by Race, Syracuse, New York, 1990

	Access	Percent Vulnerable Households (%)	Race: White (%)	Black (%)	Other (%)	Total (%)
Column %	High	0-10	33.1	5.8	15.0	26.6
		10-20	41.1	33.2	39.6	39.4
		20-30	13.5	38.5	29.6	19.4
		30-40	8.8	6.0	10.7	8.3
	Low	40 and over	3.5	16.4	5.1	6.2
		All	100.0	100.0	100.0	100.0
Row %	High	0-10	92.8	4.4	2.7	100.0
		10-20	77.9	17.2	4.9	100.0
		20-30	52.0	40.6	7.4	100.0
		30-40	78.9	14.8	6.3	100.0
	Low	40 and over	42.0	54.0	4.0	100.0
		All	74.7	20.5	4.9	100.0

Note: Hispanics are included in all races. "Other" includes all races other than white and black.
Source: U.S. Bureau of the Census 1990, calculations by author.

TABLE 3 Accessibility to Supermarkets by Income, Syracuse, New York, 1990

Access	Percent Vulnerable Households (%)	Median Household Income ($, Weighted Avg)
High	0-10	34,037
	10-20	22,826
	20-30	15,951
	30-40	13,713
Low	40 and over	8,490
	All	22,800

Source: U.S. Bureau of the Census 1990, calculations by author.

Spatial Statistics: Quantifying Patterns of Accessibility

Assessing maps and calculating statistical tests reveal important insights for transit planners, but these approaches have weaknesses as well. Whereas one obvious advantage of maps is that they explicitly account for the spatial relationships between variables, a weakness is that interpreting maps is mostly a subjective activity. For example, we would have a hard time deciding whether the features of a map looked different in 1990 than in 2000 without operationalizing the patterns because visual display is prone to misinterpretation. The statistical tests, by contrast, offer the advantage of quantitative measures that help us make comparisons over time. But the weakness with these tests is that spatial relationships are ignored. How are spatial relationships ignored? Imagine each TAZ as an index card on your tabletop, with each card containing a unique set of attributes (e.g., accessibility indicator, median income, etc.). Notice that shuffling the cards around on the table—to mimic changes in spatial patterns—would have no bearing on the results of statistical tests such as the correlation coefficient or chi-square. The point is that underlying spatial patterns can change in ways that aspatial statistics are not designed to detect. But spatial relationships, complex though they may be, are important in transit planning because transit ridership markets are highly segmented in metropolitan space. Recent advances in spatial statistics linked to GIS allow transit planners to exploit the advantages noted above by calculating quantitative measures that simultaneously account for spatial relationships (*17, 18*).

The purpose here is not to describe the fundamentals of spatial statistics, which can be found elsewhere (*19–21*). Instead, the aim is to introduce techniques for evaluating the net effect of the overlapping contradictory influences on accessibility at the city core—between, on the one hand, the relative proximity to bus lines favorable to accessibility and, on the other hand, the low rates of car ownership that are unfavorable to accessibility. The discussion is on two techniques of spatial statistics and the variables of accessibility, race, and income.

The first technique is to dynamically link statistics to maps, which goes beyond visual assessment of maps by helping us see spatial relationships in the statistics. Figure 3 illustrates the linkage, showing three separate views of the accessibility variable—percent vulnerable households—in one screen. The figure is intended to illustrate how GIS can enhance statistical analysis, so the statistical measures shown will be described only briefly. Figure 3 shows three views on one screen, including a local indicators of spatial association map (to assess clustering), a scatterplot (a distribution of the data on normalized scales), and a boxplot (a way of showing the variance or spread in the data). The key point is that the three views are dynamically linked. An analyst can check multiple relationships at once because dragging a mouse over data in one view highlights the corresponding data in the other two views. In Figure 3, the two most extreme outliers (the two TAZs with the lowest accessibility) are highlighted in all three views. Furthermore, by using this technique to compare other maps similar to Figure 3 (not shown), we discover that five TAZs are common to all of the following: the highest quartile of percent African American population, the lowest quartile of income, and the highest quartile of percent vulnerable households. The spatial overlap of this set of attributes provides additional evidence of disparities in accessibility, by showing that zones are not only correlated statistically but also clustered together in space.

The second technique is to use statistical tests of spatial patterns. A spatial statistics program can model how space influences variables with a *spatial weights* matrix, which defines how the location of a TAZ relates to other TAZs. Patterns of accessibility can then be quantified by using the concept of *spatial autocorrelation* (SAC), which can be thought of as the degree of clustering or dispersion in data. Positive SAC occurs when data are clustered, whereas negative SAC occurs when data are dispersed. To illustrate, assume TAZ X has high accessibility. Then positive SAC exists when zones surrounding TAZ X also have high accessibility. Negative SAC, by contrast, exists when nearby TAZs have low accessibility. If zones of high accessibility are randomly distributed—that is, neither clustered nor dispersed—we say that spatial autocorrelation does not exist.

A common measure of SAC is Moran's I [the equation is complex and beyond the scope of this article's purpose; interested readers can consult the references (*18, 19*)]. Like the familiar correlation coefficient of basic statistics, the value of Moran's I ranges from −1 to 1, with large positive values indicating a tightly clustered pattern.

We can use the concept of spatial autocorrelation to test the effect of transit on inner-city accessibility. If transit service were successful at compensating for the clustered segregation of certain variables like carless households, for example, we would expect Moran's I to indicate a greater degree of dispersion in accessibility than in zero-vehicle households. The assumption is that spatial inequity occurs not when all TAZs fail to experience the same accessibility, but rather when the levels of accessibility are clustered in distinct patterns—especially when the clustered patterns correlate with the patterns of race or income.

Calculating Moran's I for the variables of interest, using a first-order contiguity weights matrix, and testing statistical significance against the null hypothesis of complete spatial randomness, yields the following: accessibility indicator, $I = .333$ ($p < .01$, z-value = 4.59); zero-vehicle households, $I = .523$ ($p < .01$, z-value = 7.05); percent African American population, $I = .559$ ($p < .01$, z-value = 7.54); and median household income, $I = .459$ ($p < .01$, z-value = 6.22). None of the variables, according to these results, are randomly distributed in space. All four variables suggest a moderate level of positive spatial autocorrelation (clustering) although in varying degrees.

The findings suggest that transit is helping to overcome the disadvantage of carlessness, because our expectation that accessibility is more dispersed than zero-vehicle households is met: Moran's I for accessibility (.333) is less than Moran's I for zero-vehicle households (.523). On the other hand, the transit service is not sufficient for achieving the condition of "perfect equality" in access, because Moran's I for accessibility is not zero (not a completely random distribution). Notice, however, that achieving complete randomness in accessibility is not possible using the accessibility indicator as defined in this study, as long as zero-vehicle households remain clustered. The technique thus makes clear that the concentration of carless households in the city center is so pronounced that no amount of transit service could compensate for the distance to markets. Achieving the goal of random distribution of inaccessibility, under this scenario, may therefore require policy intervention to address the segregation in automobile ownership.

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Summary of Equity Analysis

The three approaches to assessing equity provide consistent evidence to suggest that African Americans and low-income residents are likely to be experiencing disadvantages in their efforts to reach supermarkets. First, visual assessment of maps allowed us to pinpoint areas in which these social groups are experiencing particularly troublesome inaccessibility. Second, statistical tests confirmed that African Americans are more likely to experience inaccessibility than whites, and that poor households are the least accessible in the city.

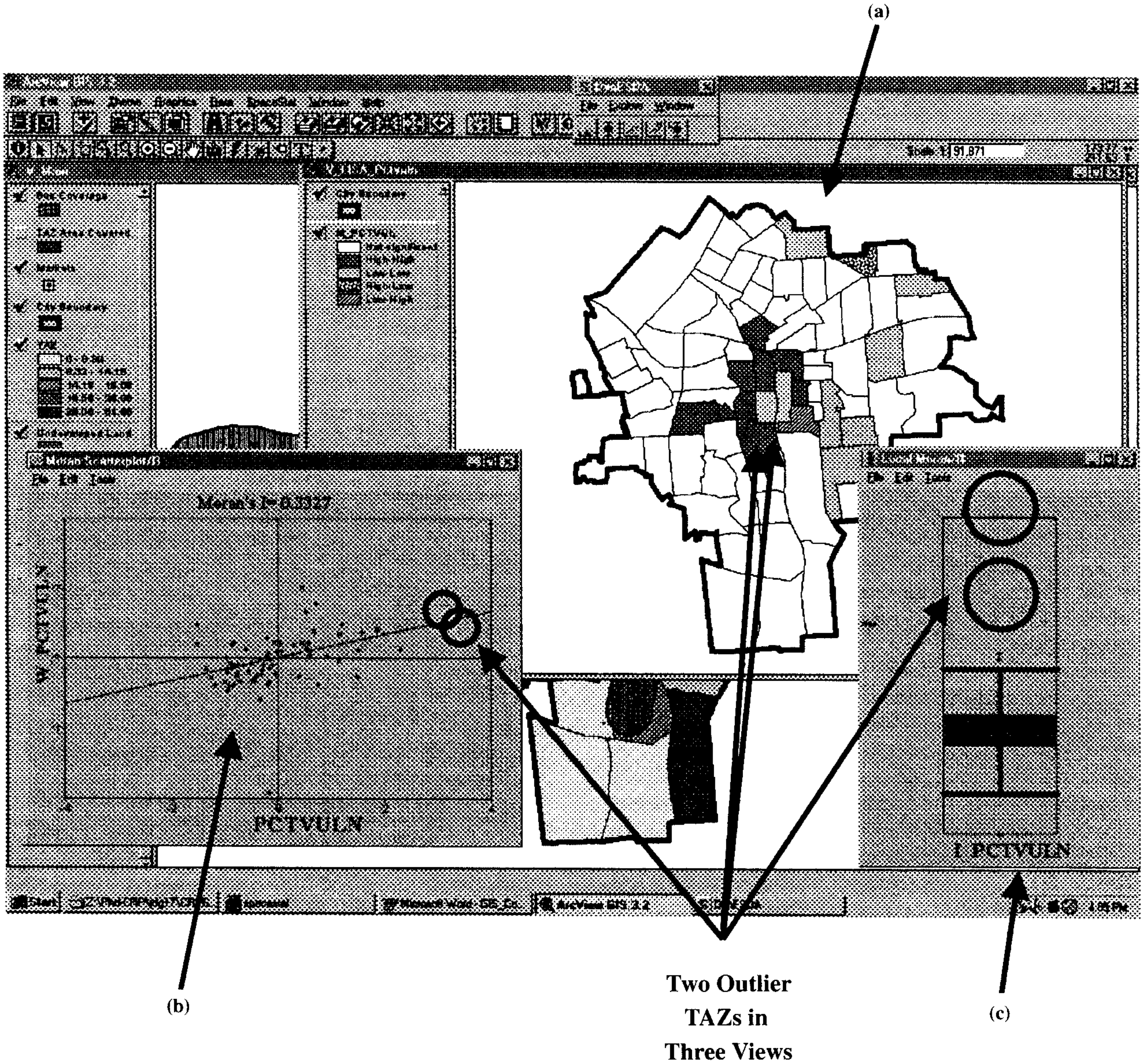

FIGURE 3 Statistics dynamically linked to GIS in (*a*) local indicators of spatial association (LISA) map, (*b*) scatterplot, and (*c*) boxplot.

Finally, spatial statistics helped us see that variables were not only associated with one another but also clustered together geographically. These tentative results further suggested that transit service is compensating to some extent for the concentration of zero-vehicle households but not enough to achieve the "equitable" condition of randomness in accessibility. Furthermore, the quantified spatial patterns could be used to assess whether accessibility has improved or worsened with future changes in transit service and land use.

Limitations of the Analysis

The results should be interpreted with caution and with a full understanding of the limitations. First, 1990 Census Bureau data are nearly a decade old and may not accurately reflect conditions today. Second, measures of accessibility are sensitive to the analyst's judgment about what constitutes reasonable transportation service. The assumption that reasonable bus service consists of routes within 0.4 km (0.25 mi) walking distance and no transfers is restrictive. Third, the simple conceptual approach to measuring accessibility, although offering the advantage of being easy to compute and interpret, does not account for bus frequency, travel times, hours of service, or travel conditions. Finally, the assumption that households and people are evenly distributed in TAZs is reasonable for most of the city but likely masks important variations within TAZs in dense areas such as the downtown district or Syracuse University.

CONCLUDING REMARKS

The simple method outlined here may be useful for several kinds of work. First, by building thematic maps to reveal pockets of vulnerable households, transit planners might find low-cost routing modifications that help people access critical places. Second, the case underscores the need for better coordination between land-use and transportation planning, an institutional barrier that has long prevented sensible regional planning in U.S. cities (*22*). Transit agencies cannot be expected to keep up with changing urban land patterns that result from businesses like supermarkets moving to the periphery of metropolitan regions. This method may be useful for designing strategies to develop land in ways that place less stress on a transportation system. As an example of such a measure, the Minnesota state legislature passed a bill in 1995 that offers a 10 to 15 percent tax break for development within 0.4 km (0.25 mi) of fixed-route transit lines (*23*).

Third, the case may be useful for community-based organizations—which traditionally focus on issues of housing and financial credit—to introduce transportation issues into neighborhood development agendas. Although transportation may be a less immediate burden for people in inner-city neighborhoods, it has widespread consequences by influencing a person's range of opportunities. Community-based organizations might use results like these to initiate joint ventures among private retailers, public agencies, and other community organizations to coordinate transportation services to food stores. The results might also help to persuade supermarket retailers to build stores in inner-city neighborhoods, which would eliminate the need for travel altogether. Finally, supermarkets themselves might take steps to fill the needs revealed by this case study. Short of establishing new stores in the inner city, supermarket retailers might find ways to reach inaccessible pockets with van service that brings customers to their stores (*24*).

In conclusion, the aim of developing a straightforward technique for estimating the magnitude of accessibility to a range of important destinations has been achieved. The technique is straightforward enough that organizations with small technical capacity—community-based organizations and small planning agencies, for example—might carry out the analysis as a preliminary exploration of changes in local accessibility patterns and for pinpointing gaps in service. The method also offers insight into shortcomings of a transportation system that often go undetected by more traditional methods of measurement in transportation planning. Traditional methods sometimes fail to address social equity questions because of a lack of data. Indeed, existing databases often drive the questions that planners ask (*25*). Planners need a way to measure accessibility to a variety of places.

The second aim was to illustrate that spatial statistics can play a complementary role in assessing equity in transit service provision. Two techniques—visual assessment of maps and basic descriptive statistics—alert planners to how transportation systems provide different benefits among social groups. Unfortunately, the results from these techniques, although notable, are mostly generalizations with which most planners are already familiar. By quantifying the patterns of inaccessibility with spatial statistics, however, planners and policy makers can better assess how transportation systems are adapting to changing land patterns over time and how accessibility changes relative to socioeconomic patterns. Using spatial statistics might take transportation planners one step closer to a better understanding of the causal relationships in the complex and dynamic patterns of urban space.

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