Analyzing Neighborhood Accessibility via Transit in a GIS Environment

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Abstract

Most existing research on accessibility and spatial mismatch deal with commutes via private automobile. Low-income inner city residents, who tend to have lower rates of car ownership, rely more heavily on public transport for commuting. This paper analyzes the role that public transport plays in providing accessibility to the opportunities provided by various industries in Milwaukee. Based on an integration of place and location accessibility and network analysis technology, the paper develops a new accessibility measurement technique that is better suited for commuting by transit. The analysis indicates that neighborhoods of Milwaukee's inner city north, where there is a high concentration of African-American population, has poor accessibility by transit to urban opportunities in most industries. The results support the spatial mismatch hypothesis that central city residents suffer from poor accessibility to jobs because current public transport facilities were designed to carry workers from suburbs to CBD.

I. INTRODUCTION

Accessibility and spatial mismatch are keys to the research on joblessness, neighborhood transition, residential segregation, and poverty. Debates on the validity and significance of the spatial mismatch hypothesis have continued since Kain (1968) proposed the hypothesis in the 1960s. The spatial mismatch hypothesis argues that suburbanization of jobs would adversely affect African-American inner city residents who would suffer from decreased accessibility to well-paid jobs (Gottlieb and Lentnek, 2001; DeRango, 2001; Martin, 2001). Studies have found strong evidence that African American workers' access to jobs is inferior to that of white workers (e.g., Martin, 2001). Bauder and Perle (1999) demonstrated that African American youths do have much lower employment probabilities and higher travel times to work than white youths, no matter where they live or which occupation they have. Research on employment suggests that spatial and skill mismatches are interlinked (Immergluck, 1998; Bauder and Perle, 1999). Although commute has commonly been used as a proxy of spatial mismatch, some authors have argued that it is an inappropriate measure (Ihlanfeldt and Sjoquist, 1991; DeRango, 2001). Taylor and Ong (1995) found that the commute patterns of white and minority workers appear to be converging rather than diverging over time, even among low-skilled workers. Contrary to the spatial mismatch hypothesis, African American and Hispanic workers living in minority areas had both shorter commutes and commutes that increased more slowly during the study period as compared to workers in other areas. Moreover, the average commute times of non-moving minority workers in predominantly minority areas decreased during the study period.

Location and the nature of locally available employment opportunities shape labor force participation, job type, and wages. Accessibility is an effective indicator for measuring the impact of location on the labor market (Hanson 1997), and can be used in the analysis of spatial mismatch. It is generally referred to as a measure of opportunity or activity sites available (within a certain distance or travel time) to people or places (Hanson, 1997, Kwan, 1998, Miller, 1999a). Given a set of opportunity sites distributed in a space and the location of a person or a place, the accessibility of this person or place is generally computed as the sum of accessible opportunities adjusted by the distances measured by space or time between each opportunity and the location. Space can be taken into account by distance in the Euclidian coordinate system. It can be better represented by travel distance or time in transportation networks with the assistance of network analysis techniques in GIS (Wang, 2001).

Most of the studies on accessibility and spatial mismatch are based on private automobile transportation because it is the predominant transportation mode in the United States. Study based on public transit systems is very limited, although transit is widely used among low-income minorities. Moreover, studies on spatial mismatch are limited at the macro-level across metropolitan areas, and lack a micro-scale intra-urban analysis (Wang, 2001). Lastly, labor market fragmentation theory argues for a dual labor market characterized by well-paid, advanced business service jobs and poorly paid, low-order service jobs. Existing research has rarely given attention to accessibility and spatial mismatch across different job types.

The research of Shen (1998) on low-wage workers living in the inner city of Boston is an outstanding exception. It is characterized by the fact that, in measuring accessibility, it takes into consideration both supply and demand factors, transportation modes, as well as job types. Strongly contrast to the results of many other empirical research that suggests

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that inner city residents have poor accessibility to job opportunities and that their situation is getting worse. Shen revealed that auto ownership is a much more important determinant, and that most inner city low-income automobile owners in Boston have quite good accessibility (some are much higher than average), while for workers who commute by public transit, their accessibility to employment opportunities is much lower. In addition, a considerable amount of local spatial variation was identified for transit riders.

This research is not aimed at examining the validity of the spatial mismatch hypothesis by measuring accessibility, nor the accessibility discussed in this paper specific on employment. The major purpose of this paper is to test a measure of accessibility to urban opportunities via transit, which may account for just a small portion of the comprehensive accessibility in an urban space, but could be extremely important to some inner city lower-income residents who have no access to automobiles. By saying "urban opportunities," we mean all opportunities, including employment and consuming (e.g. shopping, entertainment), education, health care and etc. In fact, general urban opportunities are the objectives of individual accessibility research that emphasizes individual activities and chain trips. In addition, the paper tries to examine whether the traditional spatial mismatch in transit systems and services exists in Milwaukee based on the results.

II. ACCESSIBILITY

There are three focuses in accessibility research: accessibility of individuals, accessibility of locations, and accessibility of places (Table 1). The first emphasizes activities of individuals, and is based on space-time constraint approaches. Given a set of fixed locations where one must be present at specific times (usually home and workplace), the accessibility of the person is computed as the number of other opportunities or locations that he/she may attend with the given space and time constraints (Hanson, 1997; Kwan, 1998; Miller, 1999a). This kind of accessibility is capable of capturing detailed interpersonal differences, and is gender sensitive (Kwan, 1999). However, this method needs either very detailed personal trip diaries and/or Automatic Vehicle Locator (AVL) data collected at the individual trip level. This data requirement limits wide application and comparative analysis. In addition, although individual accessibility measurement takes spatial and temporal constraints into account, it groups all opportunities together at the same level of importance. Moreover, because surveys conducted for individual accessibility tend to be home-work-shopping-home models, individiual accessibility measurements tend to be consumming opportunities oriented, in which employment is not emphasized. Furthermore, transportation planners have noticed that predictions based on individual behavior are not necessarily more accurate than aggregated approaches based on census data, such as census tracts (Sheppard, 1995). Information acquired at the individual level is good for understanding behavior, while location or place oriented policy-making demands spatially aggregated information.

Accessibility of location indicates how easily certain places can be reached (Guy, 1983; Hanson and Schwab, 1987, Kwan, 1998). It is in fact a measure of benefit provided to individuals (or locations) by the transportation land-use system (Miller, 1999a, b). Examples of location accessibility are works of Lee and Lee (1998) and O'Sullivan *et al.* (2000). Location accessibility does not take into account the socio-economic characteristics of the population. Instead, it depends largely on transportation facilities and services they provide.

Place accessibility, sometimes referred to as integral accessibility (Hanson 1995, 1997; Kwan, 1998; Miller, 1999a), measures opportunities accrued by people residing in certain area units. Researchers in favor of individual accessibility approaches have pointed out that it does not take the time constraint into account, fails to recognize trip linking or trip chaining, and has problems in measuring inter- or intra- zonal distance. Individual accessibility advocators also criticize the integral method for taking zones as evenly distributed area units in which significant variation in individual accessibility exists (Hanson and Schwab, 1987; Linneker and Spence, 1992).

It should be noted that each accessibility measurement approach has strengths and weaknesses depending on its

Table 1. A comparison among different accessibility measurements

	Individual	Location / Infrastructure	Place / Integral
Object	Individual persons	Transit facilities	Group of people sharing space
Major data sources	Individual trip diary, survey	Facilities, services, schedules	Census, surveys and statistics
Advantages	Capable of capturing interpersonal differences; handles chain trips; gender sensitive	Measures transit system performance; suited for facility and service planning	Data easily available; place, opportunities are focused
Drawbacks	High data demands; low operability; differences among opportunities ignored	People and opportunities are not identified	Individual behavior is not identified

applications. Table 2 provides a brief comparison between the individual, location, and place accessibility measurements. The individual approach is suitable for revealing individual behaviors, and takes account of chain trips that are a common practice in daily life. Location accessibility has the strength of displaying services provided by transportation facilities in space. Place/integral accessibility is good at providing information for place-oriented policy making or planning. This paper will be based on a combination of location and place accessibility.

In fact, some of the problems of place accessibility can be relaxed. For example, using assumed uniform zones has long been a practice in geographic analysis, and it is the basis of vector-based GIS. Although intra-zonal differences do exist, the use of census tracts, TAZs, and other zonal units have their logical and statistical backgrounds, because the size and boundaries of these statistical zone units are designed to meet statistical standards according to respective purposes. It has been demonstrated that census tract provides adequate spatial detail for dealing with policy questions such as how transit improvements will affect choices of residential location (Horowitz, 1995). The TAZs are relatively homogeneous areas of residential and employment populations (Nyerges, 1995); therefore, they have higher resolution and precision in transportation and spatial analyses.

Another reason for using a combination of location and place accessibility is that place-oriented policy making depends on information about the relevant places. Place accessibility is not merely a description of how easily places can be reached: it is an important attribute of people residing in areas where the residents share many similarities, e.g. race, household income, education level, etc. Conventional accessibility measures provide valuable indicators of place accessibility (Kwan, 1998). In addition, census, survey and statistical data are usually readily available for geographic units such as census tracts and TAZs, and some data is available at block level. Data availability and consensus in data quality provide great convenience for research and for inter-regional comparisons. Finally, by using place directly, it is not necessary to add predictions of individual actions in order to predict aggregate urban travel patterns (Sheppard, 1995).

III. MILWAUKEE

Milwaukee is a Midwestern city characterized by considerable traditional manufacturing industries. It has experienced dramatic changes in economic structure, population distribution, and urban space in the past several decades. The city has been troubled by the decline of manufacturing jobs and residential segregation. In the 1980s while Milwaukee's MSA increased a total of 100,377 jobs, the manufacturing sector experienced a reduction of 32,309 jobs. A trend in population decentralization had been firmly established between 1970 and 1990 (Verela, 1999), and continued in the 1990s (Table 2). the population of the city of Milwaukee has been declining with the loss of manufacturing jobs and the relocation of the population to suburban areas. The percentage share of Milwaukee County in the total MSA population declined while the MSA experienced continuous growth. The labor market also shows a trend similar to the change of total population.

Milwaukee is one of the most segregated cities in the United States, with a large population living in poverty and a persistent crime rate. The poverty rate in Milwaukee increased from 14% in the 1970s to 22% in 1990. The inner-city north houses nearly half of the city's poor population during the same period (Verela, 1999). With a small the African American middle class, the suburbanization of African American population in Milwaukee has been limited. As shown in Figure 1, African-Americans are heavily concentrated in the inner-city, followed by the northwest areas, while the suburban areas in the northeast, west, and south have a much lower African American population.

IV. METHODOLOGY AND DATA

A generic accessibility measurement can be expressed as (Hanson, 1995, 1997; Kwan, 1998, Miller, 1999a):

$$A_i = \sum_j O_j d_{ij}^{-b} \qquad (1)$$

where A_i is accessibility of geographic unit i, O_j represents attraction of opportunity j in the space of the study area, d_{ij} is the impedance between the opportunity and target (i) of the study, i.e. a place, a group of people, or an individual. The impedance is usually represented by spatial distance or travel

Table 2. Population change in Milwaukee

	1970	1980	1990	2000	1970-80 Change	1980-90 Change	1999-2000 Change
MSA*	1,403,688	1,397,143	1,432,149	1,500,741	-0.47%	2.51%	4.79%
Milwaukee County	1,054,249	964,988	959,275	940,164	-8.47%	-0.59%	-1.99%
Milwaukee City	717,372	636,295	628,088	596,974	-11.30%	-1.29%	-4.95%

Source: U.S. Bureau of Census. Note: * Milwaukee-Waukesha Metropolitan Area

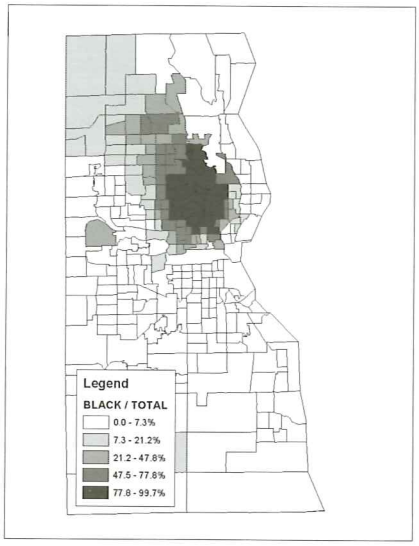

Figure 1. Distribution of African-American population in Milwaukee, 1990.

time. It could also be other indicators measuring costs induced by spatial separation.

Obviously, this generic accessibility equation is automobile oriented because only distance (time) is taken into account as an impedance factor. Because of the essential difference between the transit network and the street network (Huang and Peng, 2001), distance or travel time only is not enough to account for how convenient it is to reach opportunities. Additional factors have to be taken into account in formulating accessibility equations for transit systems, i.e. transit facility and service factors must be taken into account. Therefore, a new generic equation is designed in this study:

$$A_i = \sum_j (O_j D_{ij} S_{ij}) \qquad (2)$$

where D_{ij} is an index of network distance between opportunity j and the census tract i under study, and S_{ij} represents services between opportunity j and census tract i provided by the transit system.

Distance represents the degree of separation or closeness in geographic space. Tobler's (1970) First Law of Geography states that, "everything is related to everything else, but near things are more related than distant things". Before the GIS technology and network analysis modules were available, Euclidean distance was used as spatial impedance in conventional accessibility measurements. Although convenient, it does not reflect the impacts of transportation facilities and services provided by them. This paper explores accessibility of neighborhoods using distance over the transit network.

Traditionally, the role of distance had been widely modeled by gravity models. However, it has been found that gravity models decrease too fast in many case and exponential models are sometimes used for better effects (Kwan, 1998). The network distance between target neighborhood and opportunity is computed based on the transit network. Physical distance is standardized to a distance index by the following equation:

$$D_{ij} = e^{-((p-\mu d_{ij})/\lambda)^2} \qquad (3)$$

where d_{ij} is the distance between place i and opportunity j in mile. P is a parameter that determines the location of peak attraction. λ determines the rate of distance decay. The greater the value of λ is, the slower the distance decay in attraction. μ is a parameter that influences both peak attraction location and gradient of distance decay. We assume that if the workplaces of all workers are two miles from their homes, and there are convenient transit links between the workplaces and homes, everybody would take transit to work. Moreover, by taking the average trip to work time in Milwaukee as 45 minutes, which is equivalent to 11.25 miles in distance by transit (bus speed 15 mile per hour), and the average bus ridership (7.77%), a distance decay curve can be established (Figure 2). Therefore, parameters in the exponential model are calibrated as p = 2, λ = 6 and μ = 1, so that the distance index is 1 at 2 (miles) and 0.0777 at 11.25 (miles).

Bus service can be measured by the number of runs available to census tracts and opportunity sites. An index of bus service is computed as the total of standardized number of runs per day at a origin neighborhood (i) and an opportunity site (j), adjusted by standardized number of bus routes shared by both locations.

$$S_{ij} = (e^{-\mu R_i^{\nu}} + e^{-\mu R_j^{\nu}}) e^{-(c_{ij}+\alpha)^{-\beta}} \qquad (4)$$

where R_i and R_j are number of runs per day at neighborhood i and opportunity site j respectively. C_{ij} is number of bus routes shared by both locations (i and j). Parameters in the equation are defined by statistical properties of bus runs and shared routes.

A GIS transit network was created based on bus route information provided by the Milwaukee County Transit System (MCTS). Distances between census tracts and opportunity

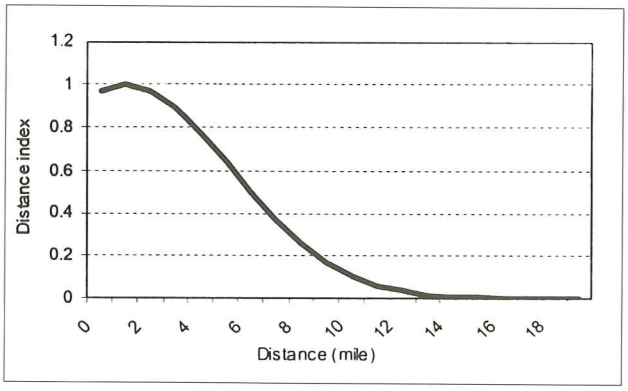

Figure 2. Distance decay in accessibility measurement

points in the area are computed using a network analysis Avenue in ArcView 3.2. Service capability is accounted by the number of runs of bus routes.

This research uses building area and lot size of business and industrial land parcels as proxies of the attraction of urban opportunities. Attraction of opportunities could be well represented by the size of firms. However, detailed information about individual firms, such as number of employees and revenues is not available in public data sources and is usually very hard to obtain. Although the Census Transportation Panning Package (CTPP) Urban Element Part 2 has the job distribution date at the TAZ level, the focus of this data set is for job trip analysis. For the purpose of accessibility to general urban opportunities, including employment, consumption, education, health care, and etc., however, land use data derived from municipal property data could provide complete coverage of all the business and industrial opportunities with exact locations. This data completeness and location accuracy are incomparable to any means of survey and statistics. Although the building area proxy may not apply across different industries, it makes sense for comparisons within industries. For example, in the retail industry, bigger stores tend to have more employees and attract more customers than small ones; bigger schools tend to have more students and teachers. In this research, building area (in square feet) is standardized to values between 0 and 1 using exponential transformation.

$$O_j = e^{-\alpha l_j^{\beta}} \tag{5}$$

where l_j is the building area of business or industrial land parcel j.

Milwaukee is among the few cities in the U.S. that have a well-maintained property database. The Milwaukee Property (MPROP) file maintains nearly 160,000 property parcels of the city. It has over 80 fields describing many attributes of the parcels, including land use. The database has been updated every year since 1975. 7,584 business or industrial parcels are identified from the 2000 property file (Table 3).

The parcels are classified into 11 classes in the study according to the Standard Industrial Code (SIC). Building area is recorded for most parcels in the Milwaukee property file. But for some properties, especially public facilities and manufacturing industries, building area is not complete, so lot area has to be used. Based on statistical characteristics of parcel size, we adopted the following parameter sets:
For building area

$$O = e^{-10000l^{-1}} \tag{6}$$

For lot area

$$O = e^{-100000l^{-1}} \tag{7}$$

Census data for this study is derived from 1990 census STFT3. Census tract level population statistics, household information including a work trip survey are derived from this source.

In equation 2, because $\limsup_{l\to\infty} O_j = 1$, $\limsup_{d_{ij}\to 2} D_{ij} = 1$ and $\limsup_{R_i,R_j,c_{ij}\to\infty} S_{ij} = 2$, $\limsup A_i = 2j$, which means that the theoretical maximum value of accessibility of any neighborhood i is twice the total number of opportunities in the study area.

V. FINDINGS

With industrial restructuring and suburbanization, privately-owned vehicles have become a fundamental transportation tool. The number of vehicles owned per household provides a good indication of the socio-economic status of the people. Figure 3 shows that average number of vehicles available to households varies from neighborhood to neighborhood. Lower

Table 3. Business and Industrial land use parcels

Industry	SIC	# of Parcels
Education*	8200-8299	243
Engineering & Management	8700-8799	307
Financing, Insurance & Real Estate	6000-6799	171
Health Services	8000-8099	233
Lodging, Personal, Business, Automobile Services	7000-7999	2,086
Manufacturing*	2000-3999	776
Public Administration*	9100-9799	100
Retail	5200-5999	1,466
Social, Art, Museum, Membership, Legal Services	8100-8199, 8300-8699	1,047
Transportation, Communication	4100-4999	770
Whole Sale	5000-5199	385
Total		7,584

* Lot area is used

value neighborhoods are mainly located in inner city north with a few census tracts in inner city south. High private vehicle ownership neighborhoods are located in the northeastern, southern and southwestern suburbs.

Milwaukee has a relatively high rate of commute to work by transit. In 1990, 7.77%[1] of work trips were made by public transit in Milwaukee County. The rate was 4.90%[2] in the Milwaukee-Racine Metropolitan area, which is much higher than the average (1.91%) for all 284 metropolitan areas in the U.S. Moreover, the variation of trip to work by transit in Milwaukee is remarkable. In some inner city neighborhoods, the rate reaches as high as 17%. Public transit is essential to some inner city neighborhoods and university students as an alternative mode of transportation. It is noticeable that the route layout and bus service contrast strongly to household vehicle ownership: areas with lower vehicle ownership tend to have higher transit service density (Figure 4). Another feature of the transit system of Milwaukee County is a radial pattern of bus route layout. The central city is a predominant transit center with almost all the bus routes converging in the downtown area. Two sub-centers of higher service intensity are identified: eastern neighborhoods and northwest industrial areas.

Accessibility for 299 neighborhoods in Milwaukee County is computed in terms of eleven classified industrial sectors. Selected maps resulting from the computation are shown in Figure 5a–e. Values of accessibility for each industrial group are between 0 and $j \cdot 2$ where j is the total number of opportunities in the area. Natural break classification is used in creating thematic maps in figure 5a-e. It is easily discerned that, for all industries, there is a high accessibility center at the CBD. This is due to the fact that most of the county's bus routes converge at the downtown transportation center. Neighborhoods in the downtown area have the highest accessibility to many industries by bus. This phenomenon reflects the impact of transportation facility and service on accessibility.

Unlike individual accessibility, which does not take nature of opportunities into account, accessibility in this study is sensitive to the industrial types. Patterns in accessibility distribution for different industries can be distinguished from maps.

Accessibility to educational institutions is relatively evenly distributed, with a concentration at the central city. It decreases towards suburbs moderately (Figure 5a). It can be discerned that there is a moderate hollow at the inner city north neighborhoods, which indicates that accessibility to education opportunities by transit remains less favorable in these neighborhoods. For retail service (figure 5b), except for the downtown area, high accessibility sub-centers can be identified at the Northbridge Mall area in the northwest and at Mayfair Mall in the west. For the wholesale industry, a sub-center of accessibility is located at the northwest as well.

Financial and managerial positions are often considered high-order services, which tend to have higher wages and better opportunities for career advancement. Financial services are highly concentrated in the CBD, and accessibility to financial services is downtown centered (Figure 5d). Accessibility of inner city north to financial opportunities is poor. Two relatively high accessibility sub-centers can be identified in

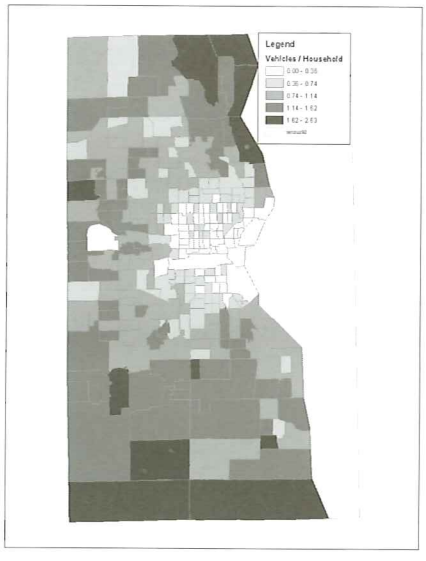

Figure 3 Average number of vehicles owned per household.

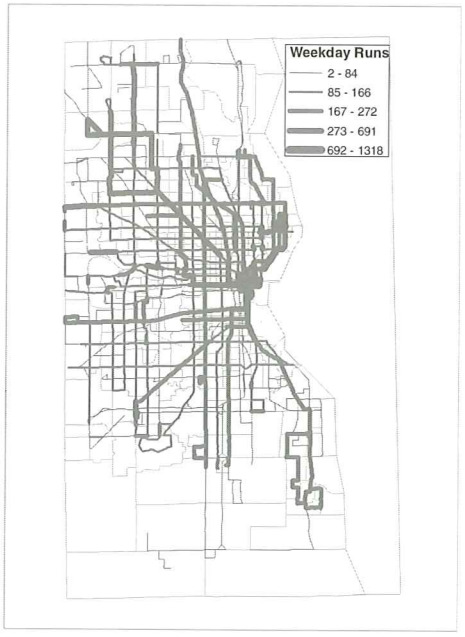

Figure 4. Bus routes and service capacity of Milwaukee County Transit System. (Note: thickness of line indicates capacity)

[1]Source: Census Bureau, STFT3, 1990.
[2]Source: Census for Transportation Planning Package, 1990.

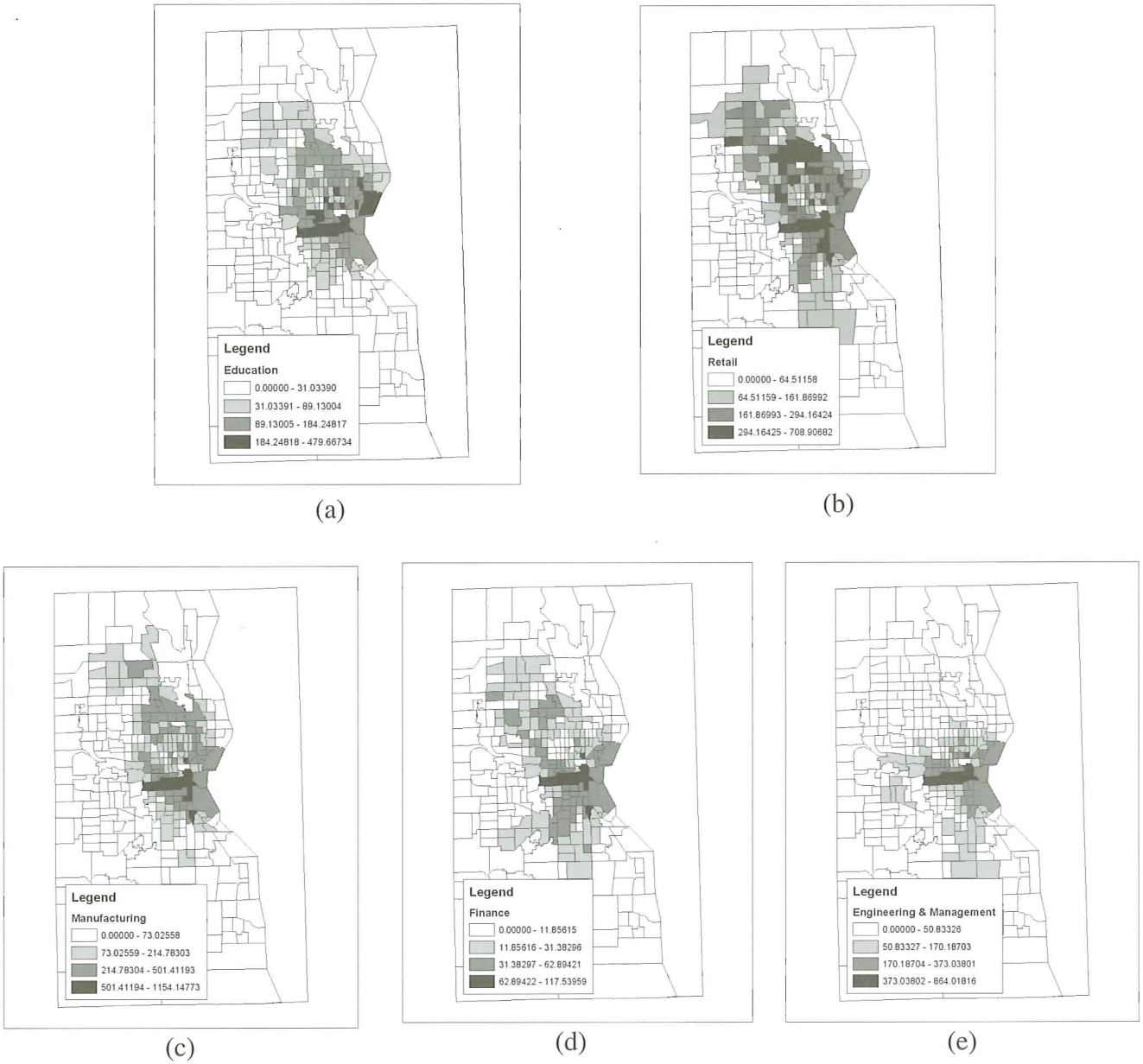

Figure 5. Accessibility based on industries. (a) Education; (b) Retail; (c) Manufacturing; (d) Finance; and (e) Engineering and Management.

the northwestern transition zone and suburb.

Accessibility to engineering and management opportunities is centered in the CBD and the east of the city (Figure 5e). The general pattern of distribution follows the pattern of highways in Milwaukee. It can be noticed that the inner city north has very poor accessibility to managerial job opportunities.

In general, the city center has the highest accessibility for most industries (except manufacturing),, although it is not necessarily the center of job opportunities for all industries. For example, the city center is not the dominant center of retail industries, which are dispersed throughout the city (Figure 6). However, accessibility to retail industries displays highly concentrated patterns (Figure 5b). This spatial inequality in accessibility is mainly due to the fact that transit routes and bus services converge in the city center (Figure 4). On the other hand, patterns of accessibility are heavily influenced by spatial patterns of job opportunities. Accessibility to manufacturing opportunities by transit, for example, displays a similar pattern of job locations.

Inner city north has the lowest accessibility to many opportunities. Accessibility to financial and managerial jobs is the poorest. Since these two sectors tend to be well paid and represent the effects of recent globalization, the large population of African Americans in the inner city are not benefited from recent globalization and economic restructuring. Moreover, accessibility to manufacturing is also poor for inner city north neighborhoods. Accessibility in retail

is relatively better, but most of the jobs in this sector pay a minimum wage, and offer little opportunity for advancement. Accessibility to educational opportunities is among the best for inner city north. The analysis in general shows poor job accessibility for African-Americans, despite the fact that Milwaukee has a well-developed transit system. In other words, the current transit system in Milwaukee has not been effective in addressing job accessibility of African-Americans and spatial mismatch.

VI. CONCLUSION

This study has shown the existence of substantial spatial disparities in accessibility in the urban opportunities available in Milwaukee. We have found that much of the public transit in Milwaukee is centered on the downtown area, while poorer minority residents, who use the transit as a primary mode of transportation, concentrate in inner-city north. Inner-city north residents in general have poor accessibility. While education is relatively accessible to African Americans, inner city neighborhoods have the poorest accessibility to financial and managerial sectors.

This study further suggests the existence of job inequality and spatial mismatch in Milwaukee. Jobs, especially well-paid financial and managerial jobs, are in general not located in poor inner cities. Such uneven distribution of urban opportunities has not been solved by the public transit system, and spatial mismatch still exists. Our analysis indicates the problem of unemployment and poverty among inner city residents, and confirms the fact that Milwaukee remains a segregated city. Improving urban accessibility is an important public policy issue in addressing problems of joblessness, residential segregation, and poverty in Milwaukee.

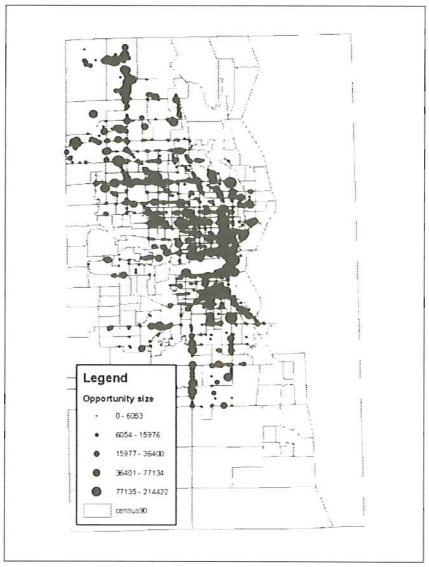

Figure 6. Opportunities in retail.

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