Transportation Research Part D 86 (2020) 102461

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Equity of transit accessibility across Chicago

Alireza Ermagun[a,*], Nebiyou Tilahun[b]

[a] Department of Civil and Environmental Engineering, Mississippi State University, 501 Hardy Road, Mississippi State, MS 39762, USA
[b] Department of Urban Planning and Policy, University of Illinois at Chicago, 412 South Peoria Street, Chicago, IL 60607, USA

ARTICLE INFO

Keywords:
Public transit
Accessibility
Equity
Transit operation
Justice
Transportation

ABSTRACT

This article studies the equity of transit accessibility in the City of Chicago. We measure the accessibility of different cohorts including minority and low-income populations, the elderly, people with disabilities, those with lower education levels, and households without a car to six different destinations by public transit. The destinations are jobs, parks, groceries, hospitals, schools, and libraries. We show that there are clear inequalities across cohorts in the distribution of benefits that the transit system provides as measured by the number of reachable valued destinations. The results indicate that areas of low accessibility have a higher percentage of African-Americans, Hispanics, Asians, low-income workers, low-educated citizens, and the elderly. The most affected cohort are low-income workers, for whom access to jobs, parks, groceries, hospitals, and libraries decline as their number grows. The findings also highlight that inequities are most severe, in order, to jobs, hospitals, and grocery stores when examining the different cohorts. While transit agencies must deploy service with the existing demand in mind, the observed inequities behoove decision makers to make accessibility and equity considerations explicit in transit service decisions.

1. Introduction

Throughout the 20th century, minority groups and low-income populations have fought for equal access to education, jobs, healthcare, and public transit. In 1955, African Americans in Montgomery, Alabama began The Bus Boycott, which ended up going before the Supreme Court and integrating transportation across the United States (Glennon, 1991). The Bus Boycott was the first ripple in a wave that led to the signing of the Civil Rights Act in 1964, under which, "All persons shall be entitled to the full and equal enjoyment of the goods, services, facilities, and privileges, advantages, and accommodations of any place of public accommodation … without discrimination or segregation on the ground of race, color, religion, or national origin" (Civil Rights Act, 1964). Though circumstances have changed, gaps in mobility options persist. In 2015, for example, 19.7% of African American households nationally had no car, while the comparable number for White households was 6.5%. In the city of Chicago, where this study is based, 36.9% of African American households had no vehicle compared to 23.2% of White households (National Equity Atlas, 2016), reflecting a similar percentage gap as the one observed at the national level. A question that remains is whether this and other mobility gaps are remedied by the provision of public transportation. While the answer may vary across cities, those cities with strong rail and bus service are best suited to close this gap.

This paper answers this question for the city of Chicago and contributes to the current literature by examining accessibility across racial lines, income, and other sociodemographic variables to different types of valued destinations. The overarching goal of this

* Corresponding author.
E-mail addresses: aermagun@cee.msstate.edu (A. Ermagun), ntilahun@uic.edu (N. Tilahun).

https://doi.org/10.1016/j.trd.2020.102461

paper is to study the equity of access to different valued destinations by public transit in the city of Chicago by exploring the extent of uneven distribution of access among cohorts. We approach the analysis with the view that under an equitable distribution, higher transit accessibilities would be observed in disadvantaged areas. Under these conditions, the transit system would work to enhance access in an attempt that rectify mobility constraints different economic, racial or social disadvantages enforce. A less stringent threshold would be equality of accessibility across groups regardless of disadvantage. An inequitable distribution would disfavor disadvantaged areas.

The literature demonstrates that accessibility is associated with employment, welfare enrollment, and commute outcomes, among others. Our analysis focuses on Chicago for several reasons. First, in 2019 the Governor of Illinois signed into law in a 6-year, $45 billion capital campaign for transportation projects, with $900 million allocated to Chicago transportation projects (Smith, 2019). Of this money, $110 million will be allocated to maintenance of Blue and Green lines operated by the Chicago Transit Authority (CTA). Second, Chicago is ranked 3rd for greatest accessibility by transit, and 4th for greatest accessibility by walking. Chicago is also ranked 5th for job accessibility by automobile (Access Across America, 2019). This places Chicago as one of the best suited cities to close the mobility options gap between prosperous and disadvantaged areas. Third, we chose Chicago due to its diversity. According to the most recent census data, the Chicago population consists of 49.1% of individuals who identify as white, 30.5% who identify as African American, 29% Hispanic or Latino, and 6% Asian (Brown University's American Communities Project, 2019). However, along with this rich diversity, Chicago is ranked 3rd in the nation for residential segregation (Brown University's American Communities Project, 2019).

We examine how accessibility is distributed across block groups in the city of Chicago in terms of race, level of income, level of education, vehicle ownership, age, and disability. After dividing the city into high, medium and low transit accessibility areas, we show the sociodemographic composition in each of these areas. A set of generalized linear regression models are then used to assess the level of accessibility to different destinations and answer the following questions:

- How is transit-based accessibility to a destination distributed between different cohorts of the population?
- How is accessibility by transit to different destinations distributed within a cohort of the population?
- How equitable is accessibility across Chicago for citizens?

The remainder of the paper is structured as follows. First, we review previous studies exploring equity of access among different cohorts including low income individuals, minorities, women, and persons with disabilities. Second, we give an overview of the accessibility measurement used for this analysis, the study area, and the data extracted for augmenting the core accessibility data. Third, we represent the methodology and model specifications. Fourth, we provide an in-depth discussion on how and to what extent access to different destinations is disparately distributed among minority, low-income, the elderly, and low educated populations. Fifth, we close the paper by summarizing the key results, planning suggestions, and further research avenues.

2. Review of literature

Accessibility, by definition, is the ease of reaching valued destinations by different modes of travels at different times of the day. While transportation research had often focused on mobility, the amount of research focused on accessibility, which ties mobility with land use, has been increasing (Borowski et al., 2018; Palmateer et al., 2016; Ermagun and Levinson, 2015). The literature has examined how accessibility affects lower wage workers and has shown that some dimension of accessibility is related to employment outcomes (Sanchez, 1999; Thakuriah and Metaxatos, 2000; Berechman and Paaswell, 2001; Kawabata, 2003; Ozbay et al., 2006; Wang and Chen, 2015; Pyrialakou et al., 2016) and reduced welfare enrollment (Blumenberg and Ong, 1998) in explaining differences in employment rates (Ihlanfeldt and Sjoquist, 1990; Ihlanfeldt, 2006) and in commute outcomes (Levinson, 1998; Tilahun et al., 2016a, 2016b).

Research has also focused on how accessibility is distributed among different sociodemographic groups. For minority populations in the U.S. for example, findings on accessibility levels are mixed depending on the urban location and type of access that is being studied. The bulk of the studies that have looked at the effects on minorities mainly paid attention to African Americans (Grengs, 2010; Dai, 2011; Tilahun and Fan, 2014; Grengs, 2015; Chen and Akar, 2017). Wang and Chen (2015) examined the "spatial mismatch" between Asian populations in Ohio and their access equity, as housing for large Asian populations is clustered far from transit and the main employment area. However, for African Americans there is a positive correlation as most of their residential clusters are located downtown, giving them high access to transit (Wood and Horner, 2016). The idea that the degree of spatial mismatch differs by race is backed up by Grengs (2010), who showed a wide gap between where African Americans live and jobs. Due to the lack of transit from their homes to central working areas, only African Americans with access to automobiles have a positive correlation with having a job (Shen, 1998). This spatial mismatch not only applies to access to work, but also access to greenspace. For example, Dai (2011) shows that African Americans and Asians living in downtown Atlanta have low access to greenspaces within a 10-minute walking or biking distance.

In El-Geneidy et al. (2016a, 2016b) study of the greater Toronto area, socially disadvantaged individuals who live and work in the inner city are found to have better access to transit throughout the day and have shorter commute times. One area where low wage workers do not have an advantage is in their ability to access supermarkets. In Larsen and Gilliland (2008) study of the Canadian cities of London and Montreal, low wage workers who rely on public transit and live in an inner city do not have direct access to supermarkets, as they only exist in suburban areas that are off transit lines. These "Food Deserts" can have an impact on the diet and health of low wage workers, as they are more likely to shop at convenience stores, which are more likely to be located along their transit routes. These stores typically do not carry healthy food selections (Larsen and Gilliland, 2008). This is compounded when looking at stores that accept Supplemental Assistance Nutrition Programs (SNAP), the federal food assistance program for low income people (Wood and Horner, 2016). While most areas have a SNAP store within 20 driving minutes, very few of these are located on transit routes or within walkable distances (Wood and Horner, 2016).

Work has also focused on how accessibility levels may be improved. Tilahun and Fan (2014), studying the Minneapolis-St. Paul area, found that accessibility gains would be maximized if both housing and job locations were clustered together along transit routes in the Minneapolis-St. Paul metropolitan area. They found such a growth strategy would particularly advantage lower income areas of the Twin Cities. One reason for this could be that inner-city residents live near jobs that are clustered in cities (Hu, 2015) though there is significant variation across accessibility to jobs in different sectors due to sectoral differences in location choice (Tilahun and Fan, 2014; Farber and Marino, 2017). This idea also promotes having low income housing within the proximity of job clusters (Fan et al., 2014; El-Geneidy et al., 2016a, 2016b). These findings are in line with Welch, et al. who state having Section 8 housing built along existing transit routes has a positive correlation with employment (Welch, 2013).

The two least studied groups concerning transportation equity are women and persons with disabilities. For women, transportation equity can be even more difficult when they are the head of the household or primary caregiver to a child (Grisé et al., 2019). Grengs (2010) study of Detroit showed that 70% of women headed households in poverty tend to be outside of the central part of the city. Women, therefore, rely on “trip chaining,” or adding multiple modes of transit to get their final place of employment. This adds obstacles for women who work non-traditional shifts, such as evenings or weekends. In certain cities, such as Fresno, CA, transit service for evening hours or weekends is limited or potentially nonexistent (Blumenberg and Shiki, 2003). For both women and persons with disabilities, their supermarket accessibility is very limited. Due to their “restricted mobility” (i.e. multiple bus stops, or wheelchair access) women and the disabled are positively correlated with “Food Deserts” (Larsen and Gilliland, 2008). Since there are so few studies taking into consideration the equity access of these groups, these groups should be the topic of future research.

3. Data

The accessibility data for this study come from the Metropolitan Chicago Accessibility Explorer (Tilahun et al., 2016a, 2016b), which uses the cumulative opportunities accessibility measure. The approach counts the number of opportunities (e.g. jobs) that can be reached in some travel time threshold (e.g. 30 min) by a particular mode (in this case, transit) from each block group in the city of Chicago. Block group centroids are used as origins and destinations to compute travel times between block groups. Travel time estimates include walking, in-vehicle, transfer, and wait times. Accessibility for a given time threshold is calculated as a simple sum of all opportunities in a block groups that can be reached within the predesignated time threshold. Mathematically, leaving mode and threshold indexes for simplicity, this can be written as:

$$A_i = \sum_{j=1}^{n} O_j f(T_{ij}) \tag{1}$$

where i and j index block groups, O represents the opportunities for which accessibility is computed (e.g. jobs, parks, etc.) and $f(Tij)$ represents a cost function which takes the value of 1 when the travel time between the origin–destination pair ij is less than or equal to the specified travel time threshold (30 min in this study) and 0 otherwise. Block group to block group transit travel times in the metro area are computed based on published General Transit Feed Specification (GTFS) schedule data and accounting for pedestrian travel times based on a pedestrian network derived from OpenStreetMap (OSM). Origins and destinations are assumed to be block group centroids. Opportunities for which accessibility is computed for are jobs, parks, grocery stores, schools, hospitals, and libraries. Land use data for jobs came from the Workplace Area Characteristics (WAC) of the Local Employment Dynamics (LED) data from the U.S. census. The job numbers count the number of opportunities that can be reached in the designated travel time in the city of Chicago. The data for the remaining opportunities came from the City of Chicago’s open data portal and includes only opportunities available in the city of Chicago. A consequence of this may be that for peripheral areas of Chicago, access to these opportunities may be underestimated. A full description of the methodology adopted to compute accessibility is given in Yin et al. (2015).

We augmented the data by socioeconomic and demographic information extracted from 2014 American Community Survey (ACS) and network design characteristics obtained from 2014 Smart Location Database (Ramsey and Bell, 2014). The American Community Survey is the premier source for detailed socioeconomic, demographic, and housing information at the national level. The 2014 Smart Location Database was developed by the Environmental Protection Agency and summarizes demographic, employment, and built environment variables commonly known as “D” attributes for every Census block group (CBG) in the United States. The Ds consist of (1) residential and employment density, (2) land use diversity, (3) design of the built environment, (4) access to destinations, and (5) distance to transit. Out of all variables provided by the 2014 Smart Location Database, we extracted and tested residential and employment density and design of the built environment. Table 1 summarizes the definition and statistics of data measured and extracted for our analysis.

One way to explore the equity of accessibility is to look at the populations that live in the places with the least, moderate, and highest levels of accessibility. Fig. 1 depicts the job accessibility in the region by dividing it into three categories: the bottom third, middle third, and top third. Though accessibility levels vary by the type of destination, in general higher levels of accessibility can be observed in the northern parts of the city. The far south, south west and north west of the city are amongst areas with low levels of accessibility.

Tables 2 and 3 show how Chicago’s population and households break down in these three area categories. For instance, 30% of

Table 1
Summary of variables.

Variable	Definition	Average	St. Dev.	Min	Max
Job Access	Accessibility to jobs by transit in 30 min at the census block group level	12,2897.5	192,224.2	421	792,368
Park Access	Accessibility to parks by transit in 30 min at the census block group level	41.1	24.1	0	124
Grocery Access	Accessibility to groceries by transit in 30 min at the census block group level	40.2	21.8	0	122
Hospital Access	Accessibility to hospitals schools by transit in 30 min at the census block group level	3.4	3.1	0	14
School Access	Accessibility to school schools by transit in 30 min at the census block group level	69.3	33.3	0	181
Library Access	Accessibility to libraries schools by transit in 30 min at the census block group level	5.5	2.6	0	17
High Education	Percent of population with Master's degree and above	9.2	10.5	0	86.9
Low Education	Percent of population with high school degree and below	24.6	13.4	0	100
School Children	Percent of children aged between 5 and 18 years	24.7	10.8	0	63.9
Transit Share	Share of work trips using public transit	28.3	16.8	0	100
Road Density	Length of the road network in mile divided by the total land area in square miles	23.5	7.1	0.9	111.7
Low Income	Percent of workers earning $1250 per month or less	23.5	5.5	7.7	41.4
Zero Auto	Percent of families without a car	24.8	17.4	0	100
Asian	Percent of population that is Asian	5.0	9.7	0	100
Hispanic	Percent of population that is Hispanic	25.6	30.2	0	100
African-American	Percent of population that is African-American	34.1	39.2	0	100
Disabled	Percent of people with disabilities	9.5	7.6	0	60.8
Elderly	Percent of people older than 65 years	11.5	8.4	0	75.0
Population Density	Population density on unprotected land (people/acre)	33.3	37.4	0	938.8

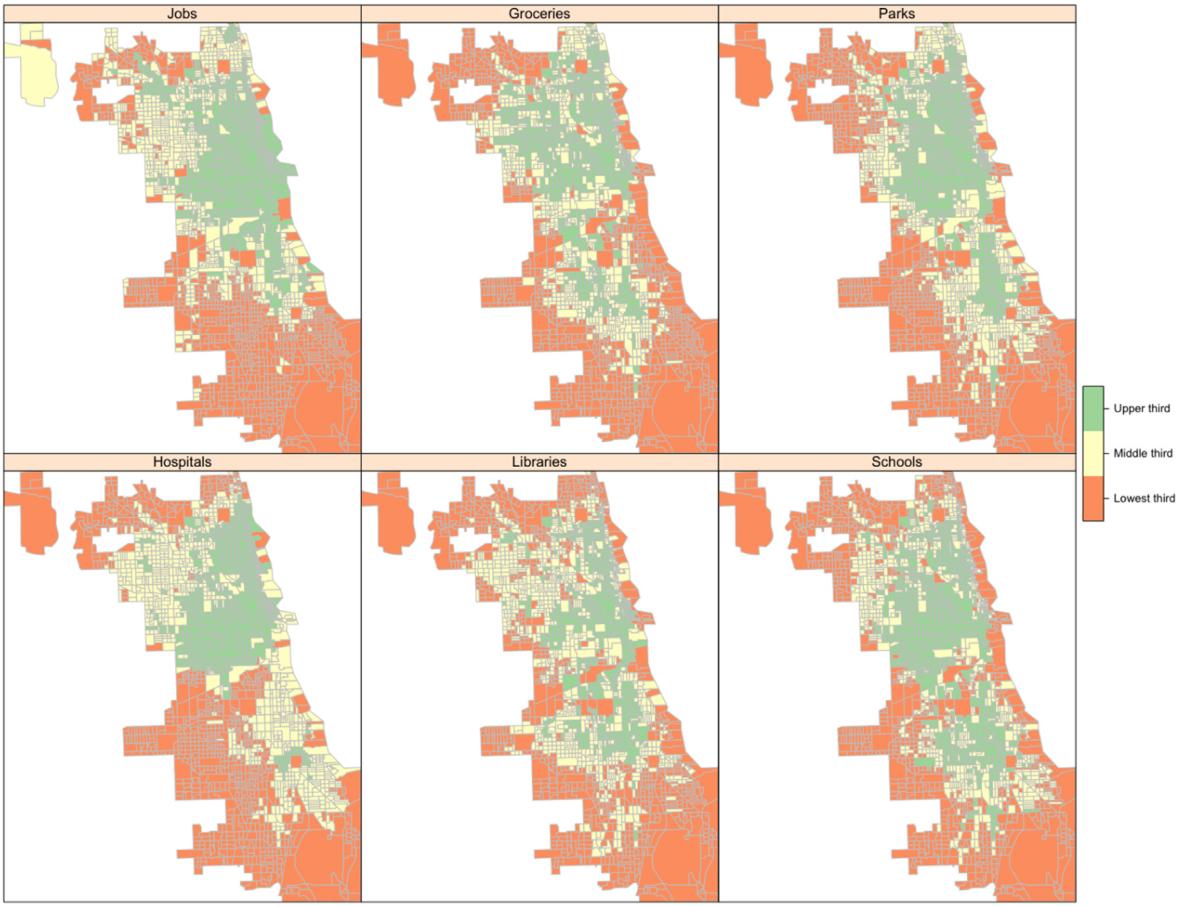


Fig. 1. Chicago's block groups grouped into thirds by accessibility levels to different destinations.

Chicago's population lives in areas where accessibility to jobs is in the lowest third among city block groups. If we look at the African American population separately, 50% live in these same areas. These lowest third accessibility areas for jobs also contain 21% of the city's White population and 25% of the Hispanic population. Clearly, African American residents disproportionately live in areas of low accessibility to jobs.

Table 2
Percent of population living in the lowest, middle, and highest third of transit accessibility areas.

Population Cohort	Accessibility	Jobs	Groceries	Parks	Hospitals	Libraries	Schools
All population	Lowest	30%	33%	33%	35%	36%	35%
	Middle	35%	33%	34%	35%	42%	33%
	Upper	35%	34%	33%	30%	22%	32%
African American	Lowest	50%	45%	24%	35%	42%	30%
	Middle	29%	36%	33%	43%	42%	37%
	Upper	21%	19%	43%	21%	16%	32%
Hispanic	Lowest	25%	25%	37%	43%	33%	37%
	Middle	49%	38%	36%	35%	50%	34%
	Upper	26%	37%	28%	22%	17%	29%
White	Lowest	21%	28%	39%	33%	34%	37%
	Middle	34%	29%	33%	29%	39%	29%
	Upper	45%	42%	27%	38%	27%	34%
Unemployed	Lowest	37%	36%	30%	38%	36%	33%
	Middle	34%	35%	34%	37%	44%	35%
	Upper	28%	29%	36%	25%	20%	31%
Elderly	Lowest	38%	42%	36%	39%	43%	40%
	Middle	32%	31%	34%	36%	39%	36%
	Upper	30%	27%	30%	25%	17%	24%
Persons with Disabilities	Lowest	35%	36%	30%	34%	39%	34%
	Middle	37%	35%	34%	40%	43%	34%
	Upper	28%	29%	35%	26%	18%	32%

Table 3
Percent of households living in the lowest, middle, and highest third transit accessibility areas.

Household Cohort	Accessibility	Jobs	Groceries	Parks	Hospitals	Libraries	Schools
All households	Lowest	27%	32%	32%	30%	34%	33%
	Middle	31%	31%	32%	34%	40%	33%
	Upper	42%	37%	36%	36%	26%	34%
Households with no vehicles	Lowest	22%	26%	25%	22%	28%	25%
	Middle	28%	31%	30%	33%	40%	35%
	Upper	50%	42%	46%	45%	32%	40%
Households in poverty	Lowest	29%	31%	27%	30%	33%	30%
	Middle	34%	36%	32%	37%	43%	34%
	Upper	37%	34%	41%	33%	24%	36%

One simple measure to show overrepresentation or underrepresentation is to take the ratio (R) of the proportion of a group that lives in a certain quantile of accessibility to the proportion of the whole population that lives in the same quantile. Ratios greater than one would show over-representation for that group and ratios below 1 would show under representation. Since some random variation is expected, we can take a somewhat arbitrary cutoff of $R > 1.2$ for large overrepresentation and $R < 0.8$ for large underrepresentation. These can be applied to any of the accessibility categories but are informative from an equality perspective for the lowest third (for overrepresentation) and upper third (for underrepresentation). Using the 1.2 criterion, African Americans are overrepresented in the lowest third for jobs ($R = 1.66$) and groceries ($R = 1.37$), Hispanics to hospitals ($R = 1.23$), the unemployed to jobs ($R = 1.24$), and the elderly to jobs ($R = 1.26$) and groceries ($R = 1.28$). In the same token, African Americans are underrepresented in the upper third for jobs, groceries, hospitals, and libraries ($R = 0.6$, $R = 0.57$, $R = 0.71$, and $R = 0.72$, respectively), Hispanics for jobs, hospitals, and libraries ($R = 0.73$, $R = 0.73$, and $R = 0.76$, respectively), the elderly to groceries, libraries, and schools ($R = 0.79$, $R = 0.78$, and $R = 0.76$, respectively), and persons with disabilities to jobs ($R = 0.78$). Such a ratio helps to quickly show inequalities and to make judgements on importance and for tailoring solutions.

Table 3 presents similar numbers for household level variables. Households with no vehicles are overrepresented in the top third areas consistently for each of the six accessibilities we measured ($R > 1$). The ratio is greater or equal to 1.2 for jobs ($R = 1.2$), parks ($R = 1.28$), hospitals ($R = 1.25$), and libraries ($R = 1.22$). No vehicle households are also underrepresented in low accessibility areas with R ranging between 0.72 and 0.83 across the six accessibility types. Transit accessibility thus largely aligns with households with no vehicles. For households in poverty, the ratio R ranges between 0.83 and 1.15 across all types of accessibilities and quintiles, suggesting accessibility does not differ greatly from different households. In sum, high accessibility is the most congruent with the location of households with no vehicles. It does not appear to pay special attention to the needs of households in poverty, and the racial dimension suggests that minorities, particularly Blacks, live in low accessibility areas. In Section 5, we further examine how accessibility levels in the city vary as the sociodemographic characteristics change.

4. Method and model

The continuous and positive nature of our endogenous variable led us to choose the generalized linear model framework. The generalized linear model is an extension of the simple linear regression model that provides a choice of distributions and a choice of scale independent from the choice of distribution. The choice of distributions includes Gaussian, Poisson, Binomial, Gamma, Inverse Gaussian, and Negative Binomial family distributions. We tested different choices of distribution on our data and judged the suitable distribution by measuring Akaike Information Criterion (AIC). Generally, for comparing the fit of models, a lower AIC value indicates a better fit. The model selected in the estimation of parameters is the linear model, which is expressed as Eq. (2). In this equation, Y_i is the vector of the endogenous variable, X_i is the vector of the exogenous variables, β_0 and β are regression coefficients estimated by maximum likelihood, and u_i is the Gaussian distributed error term.

$$Y_i = \beta_0 + \beta X_i + u_i \tag{2}$$

Among different functional forms including the log-linear models, semilog models, reciprocal models, and the logarithmic reciprocal models, we chose no transformation as (1) we are interested in absolute accessibility for interpretation and (2) the transformation does not significantly improve the models. In Eq. (2), β indicates the change in average absolute accessibility followed by a unit increase in the exogenous variable, all other variables held constant. It stands for marginal effects, which measure the impact that an instantaneous change in one exogenous variable has on the accessibility to jobs by transit and it is constant across all values of the accessibility to jobs. To study the equity of access, we regress the accessibility at the block group level against a set of exogenous variables summarized in Table 1.

As alluded to previously, we measured accessibility to six different destinations, namely (1) jobs, (2) parks, (3) groceries, (4) hospitals, (5) schools, and (6) libraries. This yields six different models. Table 4 depicts the results of all six models. We pursued the following criteria to achieve a parsimonious model that is easy to present and interpret in practice:

- Considering accessibility as an endogenous variable, we used the forward selection process to develop the multivariate regression models.
- We judged the statistical significance of variables using P-value and embedded variable tested significant at 90% confidence.
- If two variables are highly correlated during the forward selection process, we judge the variable inclusion selection by comparing AIC. For example, if X_1 and X_2 are highly correlated and the inclusion of both of them causes the multicollinearity, we keep X_1, if its inclusion results in a better fit than the inclusion of X_2.
- We calculated the Pseudo R-squared, which ranges between 0 and 1 and the greater the value is the better the fit of model becomes. This index measures the improvement of a fitted model over a null model.

Table 4
Results of six separate models.

Variable	Model 1: Jobs	Model 2: Park	Model 3: Grocery	Model 4: Hospital	Model 5: School	Model 6: Library
Population Density	207.3 (2.23)	0.05 (4.27)	0.06 (5.98)	0.01 (9.09)	0.01 (2.05)	0.005 (4.06)
Elderly	−2891.6 (−6.72)	−0.72 (−13.09)	−0.72 (−13.91)	−0.10 (−13.08)	−1.09 (−13.06)	−0.07 (−11.67)
Disability	insignificant	insignificant	insignificant	0.05 (5.86)	0.03 (3.07)	insignificant
African-American	−436.5 (−3.25)	insignificant	−0.04 (−2.90)	insignificant	0.19 (7.47)	−0.004 (−2.73)
Hispanic	−332.0 (−1.63)	0.03 (1.81)	0.09 (5.00)	−0.01 (−4.25)	0.19 (5.47)	insignificant
Asian	insignificant	0.11 (2.59)	insignificant	−0.02 (−3.85)	insignificant	insignificant
Zero Auto	3092.7 (14.79)	0.51 (19.54)	0.38 (14.80)	0.83 (1.90)	0.55 (13.49)	0.04 (13.81)
Low Income	−11021.3 (−12.13)	−0.44 (−4.05)	−0.35 (−3.41)	−0.04 (−2.51)	insignificant	−0.04 (−2.84)
School Children	−2232.3 (−5.49)	−0.36 (−7.03)	−0.39 (−7.96)	−0.05 (−7.79)	−0.45 (−5.83)	−0.03 (−5.38)
Low Education	−830.9 (−3.03)	−0.24 (−7.16)	insignificant	insignificant	insignificant	insignificant
High Education	insignificant	insignificant	insignificant	0.04 (6.38)	0.44 (6.21)	0.01 (2.78)
Road Density	5652.8 (11.97)	0.39 (6.48)	0.26 (4.46)	0.03 (3.88)	0.65 (6.94)	0.05 (7.10)
Constant	312372.7 (13.86)	53.54 (18.68)	47.90 (17.58)	4.60 (8.45)	45.58 (11.18)	5.16 (12.19)
Adj. R-squared	0.421	0.393	0.288	0.258	0.227	0.240
No. of Observations	2187	2187	2187	2187	2187	2187

As depicted in Table 4, all variables are significant at the 90% confidence interval. The most significant variables are road density, car ownership, and the elderly in each block group. On the contrary, the percentage of people with disabilities and percentage of Asians are the least significant variables across six models. The Adjusted R-squared varies between 0.240 and 0.421. The Adjusted R-squared of accessibility to jobs equals 0.421 indicating the full model achieves a 42% improvement over the null model. This measure equals 0.393, 0.288, 0.258, 0.227, and 0.240 for accessibility to parks, groceries, hospitals, schools, and libraries, respectively.

5. General discussion

We tested the distribution of access to six different destinations among (1) the elderly, (2) persons with disabilities, (3) African Americans, (4) Hispanics, (5) Asians, (6) people without a car, (7) low-income people, (8) school children, (9) low-educated people, and (10) high-educated people. Looking at Table 4, two outcomes are captured immediately:

- Access to each destination by public transit is not evenly distributed across different cohorts.
- Access to different destinations by public transit is not evenly distributed within each cohort.

This section expands the dialogue over these two outcomes and provides an in-depth discussion on the "equity" of access to valued destinations.

5.1. Equity over cohorts

Our results echo previous research by showing low-income workers have the steepest decline in accessibility to jobs as compared to other cohorts. This is followed by the elderly and families with school children. Quantitatively, a unit increase in the percent of a low-income population at the block group level is associated with a decrease in average accessibility to jobs by transit by 11,021 units. The low-income population is also deprived when it comes to accessibility to parks, groceries, hospitals, and libraries. Their accessibility to parks drops more precipitously than any other variable tested except for the elderly. A unit increase in the percent of low-income population at the block group level is associated with a decrease in average accessibility to jobs by transit by 0.44 units. The models also show that Hispanics have better access to groceries than African Americans. Comparing the marginal effects, a unit increase in the percent of Hispanics increases accessibility to groceries by a 0.09 unit, while a unit increase in the percent of African Americans is linked to a 0.04-unit decrease in accessibility to groceries. Once more, the low-income population has the least access to groceries hand in hand with the the school-age child population in comparison with other cohorts, except for the elderly. Accessibility to groceries drops almost 9 times as much for a one-unit change in the percentage of low-income population than a similar change in the percentage of the African American populations. This is in line with previous research showing low-income individuals are less likely to be able to reach grocery stores via transit, and only have an advantage if they have an automobile. The lack of access to grocery stores can have a significant impact on their health and wellness, as they will have limited access to healthy food options. This can lead to health problems such as obesity.

Looking at accessibility to hospitals, all cohorts have a statistically significant correlation with accessibility except the African American and low-income populations. The largest drops in accessibility that are associated with increases in populations are the elderly, low-income, and families with children between 5 and 19 years old. Despite the need of these cohorts to have access to healthcare and hospitals, public transit does not serve them well, while providing better access to areas with higher percent of highly-educated people. We observe a similar pattern of accessibility to schools and libraries among different cohorts. For example, highly-educated populations have better access to both schools and libraries, while low-income families are not served well by public transit. The only differences between accessibility to schools and libraries falls in the categories of race and ethnicity. While we found a unit increase in African American populations diminishes the accessibility to libraries by public transit, there is a positive correlation between this variable and accessibility to schools.

5.2. Equity over destinations

Fig. 2 depicts the distribution of accessibility to different destinations in each cohort. The unit of accessibility to destinations is their number, except for jobs, which is scaled to 1000 jobs for the sake of visibility of all marginal effects. Although the marginal effect of each cohort varies from one destination to another, the sign of marginal effect is almost consistent between destinations. Fig. 2a shows the elderly population has less access to valued destinations, particularly to jobs, schools, and groceries. A unit increase in the percent of a population of people older than 65 reduces access to jobs, schools, and groceries by 2891, 1.09, and 0.72 units, respectively. They, however, have better access to libraries and hospitals among other destinations, perhaps a reflection of the significant area that the city dedicates to libraries and its distribution. A unit increase in their population at the block group level is associated with a diminish in average accessibility to hospitals and libraries by a 0.1 and 0.07 unit. A similar trend is observed among low-income individuals. As shown in Fig. 2b, increases in the percent of low-income people has greater associations with declines in access to jobs, parks, and groceries than to hospitals and libraries. A unit increase in the percent of a low-income population at the block group level diminishes the accessibility to jobs, parks, and groceries by 11,021, 0.44, and 0.35 unit, respectively. We speculate this is a result of low-income individuals being priced out of wealthier areas, and clustered in areas that are less accessible to transit lines and generally contain fewer job opportunities in close proximity. On the contrary, if the percentage of people without a car increases in a block group, their accessibility across all destinations increases according to Fig. 2c. This positive correlation between

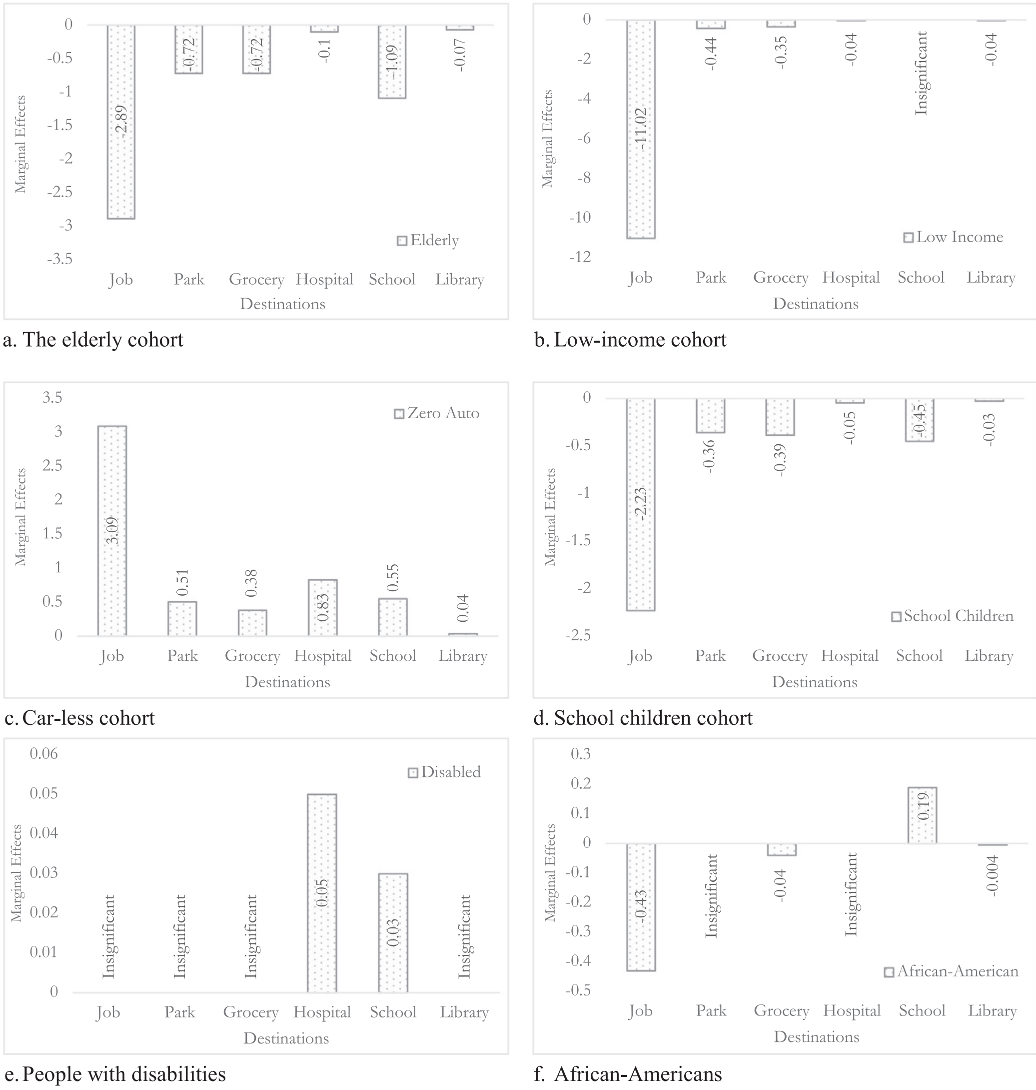


Fig. 2. Distribution of accessibility to different destinations in each cohort (job scale is thousand jobs).

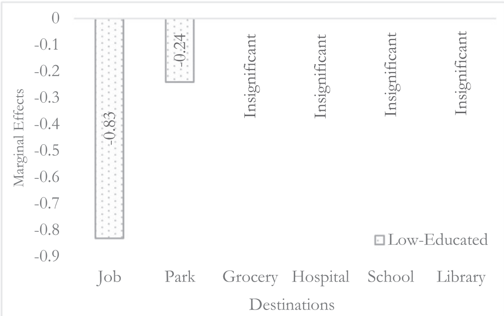
the percentage of people without a car and accessibility to destinations by public transit is most likely due to the self-selection of residential location. Captive transit riders “who do not have a private vehicle available or cannot drive (for any reason) and who must use transit to make a desired trip” are willing to live in areas with better access to transit and accessibility to destinations for their daily commute. In Chicago, many areas of high job accessibility close to the CBD are also areas of high income and lower vehicle ownership.

The percentage of people with disabilities at the block group levels, as depicted in Fig. 2e, is positively correlated with accessibility to hospitals and schools. Again, this could be due to self-selection into areas that will have these destinations closer as they will need them more frequently than access to jobs. Quantitatively, a unit increase in the percentage of people with disabilities escalates accessibility to hospitals and schools by 0.05 and 0.03 unit, respectively. Fig. 2f–h portrays the disparity of access among different racial and ethnic groups. Higher concentrations of African Americans are associated with lower access to jobs and groceries than other destinations. Comparing the marginal effects, it is found that their accessibility to jobs drops ten times more rapidly than accessibility to groceries with a percentage increase in the African American population. Although a unit increase in the percentage of Asians at the block group level results in an increase in the average accessibility to parks by 0.11 unit, it reduces the average accessibility to hospitals by 0.02 unit. As depicted in Fig. 2h, Hispanic people have mixed accessibility to different destinations. We found a negative significant correlation between the percentage of Hispanics at the block group level and two valued destinations, namely jobs and hospitals. There, however, is a positive correlation between the percentage of Hispanics and accessibility to parks, groceries, and schools by public transit. We speculate that this is due to self-selection into predominantly Hispanic neighborhoods, where smaller businesses designed to serve this community are more prevalent.

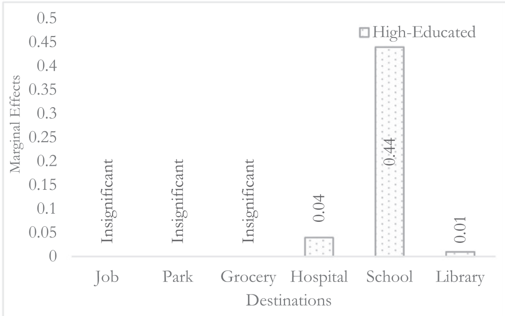
The last two subgraphs represent the disparity of access among two cohorts of education. The percentage of people with a high

g. Asians

h. Hispanics



i. Low-educated cohort



j. High-educated cohort

Fig. 2. (*continued*)

school degree or less is negatively correlated with accessibility to jobs and parks. It is inferred that a unit increase in the percentage of low-educated people causes a decline in accessibility to jobs and parks by 830 and 0.24 units, respectively. Dissimilarly, accessibility to hospitals, schools, and libraries is positively distributed among people with a Master's degree or higher. Highly-educated people have better access to schools, libraries, and hospitals than other destinations to the extent that their accessibility to schools is ten times that of their accessibility to hospitals.

As depicted in Fig. 2, variables that reflect some aspect of disadvantage either because of income, disability, aging, or minority status are predominantly associated with a decline in transit accessibility. The variable that shows a strong positive association with accessibility, proportion of households that are carless, is not a strong indicator of disadvantage. While a positive correlation exists between different measures of disadvantage such as poverty and being car-less, many well-off households are also car-less by choice. According to the 5-year ACS data from 2013, the average percentage of households with no vehicles for census tracts in the most disadvantaged quartile by median income is 24% (range 5–68%) while in the most advantaged quartile, the average car-less percentage is 14% (range 0–52.6%). Some of the areas of high income and high proportion of car-less households are areas around the CBD shown as high job-accessibility areas in Fig. 1. On the other hand, the south side of Chicago, which is predominantly African American and low-income, is among the least accessible areas of the city.

As we discuss in the introduction, the underlying assumption behind our analysis and interpretation is that in an equitable world, transit service would work to enhance the accessibility of disadvantaged groups (i.e. parameter estimates for variables associated with disadvantage would be positive in our models). If that is not met, a fairer distribution may show transit accessibility that is not sensitive to socio-demographic variables, particularly to those of race and income, or other measures of disadvantage (i.e. parameter estimates for these variables would be zero/insignificant in our models). What we observe, unfortunately, is that parameters for measures of disadvantage are often negatively associated with accessibility. The overall accessibility pattern also rewards those with no vehicles and with higher education. Residential self-selection, pricing poor people out from certain areas, segregation, and the location choices made by employers are all factors that play into the observed inequities in addition to transit service. In the short term, transit providers must ask what they can do to overcome the observed inequities. In the medium to long term, a closer integration of land use and transport decisions is needed. Otherwise, these inequities will continue to raise questions about the social goals that transit providers ought to fill particularly in regards to communities of disadvantage. At a minimum, the apparent inequities in access call for making both accessibility and its distribution part of the decision-making process in transit planning.

6. Closing remarks

While social equity has been incorporated into urban transportation plans, not all residents have similar levels of accessibility to valued destinations. This is in part due to self-selection, land use, and transit service deployment decisions. If the equity of access is defined by the number of jobs different cohorts can reach using public transit, it is clear that the distribution of these benefits the Chicago transit system provides is not equal. This research has added to the existing literature on equity of access, which in bulk has focused on either a particular cohort or a specific destination, by examining access to six different destinations and for ten cohorts of populations. Through our analysis, we have answered the questions brought up in the introductory section:

- How is transit-based accessibility to a destination distributed among different cohorts of the population? We found transit-based accessibility is unequally distributed over different cohorts of the population, with lower levels observed in areas with higher percentages of African-Americans, Hispanics, low wage workers, low-educated citizens, and the elderly. The most underserved cohort is low wage workers, who have the lowest access to jobs among other services and facilities. This cohort is followed by the elderly and citizens with lower levels of education.
- How is accessibility by transit to different destinations distributed in a cohort of the population? We found transit-based accessibility for each cohort is unequally distributed over different destinations. Accessibility in Chicago is most inequitable when it comes to jobs by public transit. This is followed by access to hospitals and grocery stores.
- How equal and inequal is accessibility across Chicago for citizens? The general concern is that minorities, the poor, the elderly, and low-educated citizens may lack access to services and facilities such as jobs, parks, groceries, hospitals, schools, and libraries. In this respect, our results have identified no apparent equities in access at the system level in Chicago. The accessibility peters off in geographical areas with larger populations of minorities, the poor, and low-educated citizens.

Several conclusions can be drawn from our analyses. From a policy perspective, our results indicate that more can be done to make accessibility more equitable in Chicago. The results show that transit accessibility increases with the prevalence of car-less households, but declines with the prevalence of low-income households. For opportunities such as jobs and groceries, accessibility declines with a rise in the African American population. Accessibility also declines with a rise in the lower educated population and increases where more highly educated people live. As alluded to previously, some of these patterns may be due to residential self-selection. However, accessibility outcomes are also a result of land use and transit service deployment decisions. As depicted in Fig. 1, the transit accessibility to jobs is relatively low in the predominantly African American areas in the south side of Chicago which are also lower income areas.

We recognize that transit agencies must deploy services with the existing demand in mind and that pressures on revenue collection also reinforce such deployment patterns (see Walker (2012), Ch. 10 for a discussion on the conflicting responsibilities that transit agencies have). However, the positive association between transit accessibility and different labor market outcomes behooves decision makers to make equity and equality considerations explicit in transit service decisions. Nuanced service decisions may be required that consider both the resident population characteristics and the appropriate destinations that the service should connect to, which would address existing spatial and skill mismatches to achieve gains in employment and other outcomes. We also recognize that the solutions to the apparent accessibility inequality cannot be about transit service alone. Access to groceries, for example, is low in the far south neighborhoods of Chicago (Fig. 1). Given the fewer grocery store locations in Chicago as compared to jobs, and the general travel preference to shop closer to home, grocery accessibility inequities would be easier to address by luring new grocers to areas lacking them rather than enhancing transit service to grocery destinations in different parts of the city. It is up to planners and city decision makers to explore the right incentives that would be necessary to address these inequities on a case-by-case basis. However, a starting point is to recognize the existing state of accessibility equity and to push for the inclusion of equity metrics in both transit and land use policies.

CRediT authorship contribution statement

Alireza Ermagun: Conceptualization, Writing - original draft. **Nebiyou Tilahun:** Visualization, Writing - review & editing.

References

Access Across America, 2019. http://access.umn.edu/research/america/ (accessed on July 31, 2019).

Berechman, J., Paaswell, R., 2001. Accessibility improvements and local employment: an empirical analysis. J. Transp. Stat. 4 (2/3), 49–66.

Blumenberg, E.A., Shiki, K., 2003. How welfare recipients travel on public transit, and their accessibility to employment outside large urban centers.

Blumenberg, E., Ong, P., 1998. Job accessibility and welfare usage: Evidence from Los Angeles. J. Policy Anal. Manage. J. Assoc. Public Policy Anal. Manage. 17 (4), 639–657.

Borowski, E., Ermagun, A., Levinson, D., 2018. Disparity of Access: Variations in Transit Service by Race, Ethnicity, Income, and Auto Availability. Retrieved from the University of Sydney Digital Conservancy. http://hdl.handle.net/2123/18780.

Brown University's American Communities Project. https://s4.ad.brown.edu/Projects/Diversity/SegSorting/Default.aspx (accessed on July 31, 2019).

Civil Rights Act. Civil Rights Act of 1964. https://www.transportation.gov/civil-rights/civil-rights-library/civil-rights-act-1964 (accessed on July 31, 2019).

Dai, D., 2011. Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? Landsc. Urban Plann. 102 (4), 234–244.

El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D., Loong, C., 2016a. The cost of equity: Assessing transit accessibility and social disparity using total travel cost. Transp. Res. Part A: Policy Pract. 91, 302–316.

El-Geneidy, A., Buliung, R., Diab, E., van Lierop, D., Langlois, M., Legrain, A., 2016b. Non-stop equity: Assessing daily intersections between transit accessibility and social disparity across the Greater Toronto and Hamilton Area (GTHA). Environ. Plan. B: Plan. Des. 43 (3), 540–560.

Ermagun, A., Levinson, D., 2015. Accessibility and Transit Performance. Retrieved from the University of Minnesota Digital Conservancy. http://hdl.handle.net/11299/179832.

Farber, S., Marino, M.G., 2017. Transit accessibility, land development and socioeconomic priority: A typology of planned station catchment areas in the Greater Toronto and Hamilton Area.

Fan, Y., Allen, R., Sun, T., 2014. Spatial mismatch in Beijing, China: Implications of job accessibility for Chinese low-wage workers. Habitat Int. 44, 202–210.

Glennon, R.J., 1991. The role of law in the Civil Rights movement: the Montgomery bus boycott, 1955–1957. Law Hist. Rev. 9 (1), 59–112.

Grengs, J., 2010. Job accessibility and the modal mismatch in Detroit. J. Transp. Geogr. 18 (1), 42–54.

Grengs, J., 2015. Nonwork accessibility as a social equity indicator. Int. J. Sustain. Transp. 9 (1), 1–14.

Grisé, E., Boisjoly, G., Maguire, M., El-Geneidy, A., 2019. Elevating access: Comparing accessibility to jobs by public transport for individuals with and without a physical disability. Transp. Res. Part A: Policy Pract. 125, 280–293.
Chen, N., Akar, G., 2017. How do socio-demographics and built environment affect individual accessibility based on activity space? Evidence from Greater Cleveland, Ohio.
Hu, L., 2015. Job accessibility of the poor in Los Angeles: Has suburbanization affected spatial mismatch? J. Am. Plan. Assoc. 81 (1), 30–45.
Ihlanfeldt, K.R., 2006. A primer on spatial mismatch within urban labor markets. A companion to urban economics, pp. 404–417.
Ihlanfeldt, K.R., Sjoquist, D.L., 1990. Job accessibility and racial differences in youth employment rates. Am. Econ. Rev. 80 (1), 267–276.
Kawabata, M., 2003. Job access and employment among low-skilled autoless workers in US metropolitan areas. Environ. Plan. A 35 (9), 1651–1668.
Larsen, K., Gilliland, J., 2008. Mapping the evolution of'food deserts' in a Canadian city: Supermarket accessibility in London, Ontario, 1961–2005. Int. J. Health Geogr. 7 (1), 16.
Levinson, D.M., 1998. Accessibility and the journey to work. J. Transp. Geogr. 6 (1), 11–21.
National Equity Atlas, 2016. Percent of households without a vehicle by race. Retrieved in April 2020 from: https://nationalequityatlas.org/indicators/Car_access/By_race~ethnicity:49791/United_States/Chicago_City,_IL/.
Ozbay, K., Ozmen, D., Berechman, J., 2006. Modeling and analysis of the link between accessibility and employment growth. J. Transp. Eng. 132 (5), 385–393.
Palmateer, C., Owen, A., Levinson, D.M., Ermagun, A., 2016. The Role of Transit Service Area Definition in Accessibility-based Evaluation. Retrieved from the University of Minnesota Digital Conservancy. http://hdl.handle.net/11299/181536.
Pyrialakou, V.D., Gkritza, K., Fricker, J.D., 2016. Accessibility, mobility, and realized travel behavior: Assessing transport disadvantage from a policy perspective. J. Transp. Geogr. 51, 252–269.
Ramsey, K., Bell, A., 2014. The Smart Location Database: A nationwide data resource characterizing the built Environment and destination accessibility at the neighborhood scale. Cityscape 16 (2), 145–162.
Sanchez, T.W., 1999. The connection between public transit and employment: the cases of Portland and Atlanta. J. Am. Plan. Assoc. 65 (3), 284–296.
Shen, Q., 1998. Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers. Environ. Plan. B: Plan. Des. 25 (3), 345–365.
Smith, R., 2019. Here's what Pritzker's $45B capital bill means for Chicago transportation projects. https://chicago.curbed.com/2019/7/2/20677903/illinois-capital-bill-chicago-transportation-projects (accessed on July 31, 2019).
Thakuriah, P., Metaxatos, P., 2000. Effect of residential location and access to transportation on employment opportunities. Transp. Res. Rec. 1726 (1), 24–32.
Tilahun, N., Thakuriah, P.V., Li, M., Keita, Y., 2016a. Transit use and the work commute: Analyzing the role of last mile issues. J. Transp. Geogr. 54, 359–368.
Tilahun, N., Fan, Y., 2014. Transit and job accessibility: an empirical study of access to competitive clusters and regional growth strategies for enhancing transit accessibility. Transp. Policy 33, 17–25.
Tilahun, N., Yin, S., Li, M., 2016. The Metropolitan Chicago Accessibility Explorer. Technical Report.
Walker, J., 2012. Human transit: How clearer thinking about public transit can enrich our communities and our lives. Island Press.
Wang, C.H., Chen, N.A., 2015. A GIS-based spatial statistical approach to modeling job accessibility by transportation mode: case study of Columbus, Ohio. J. Transp. Geogr. 45, 1–11.
Welch, T.F., 2013. Equity in transport: The distribution of transit access and connectivity among affordable housing units. Transp. Policy 30, 283–293.
Wood, B.S., Horner, M.W., 2016. Understanding accessibility to snap-accepting food store locations: Disentangling the roles of transportation and socioeconomic status. Appl. Spat. Analysis Policy 9 (3), 309–327.
Yin, S., Li, M., Tilahun, N., Forbes, A., Johnson, A., 2015. Understanding transportation accessibility of metropolitan Chicago through interactive visualization. In: Proceedings of the 1st International ACM SIGSPATIAL Workshop on Smart Cities and Urban Analytics, pp. 77–84.