Transit in theory and in practice:

Incorporating aspects of lived experience into measures of transit accessibility and justice

By Jada Potter

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Faculty Advisor: Emily Talen

Environmental and Urban Studies Preceptor: Nina Olney

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Abstract

Although the accessibility and equity of public transit in American cities has been well studied, there is often a discrepancy between the findings of studies utilizing system-level data such as scheduled travel times (*processes*) and the actual experiences of transit users (*outcomes*). Studies of transit outcomes have shown various additional factors, including walkability, safety, and comfort, to greatly impact the degree to which one can access opportunities via transit. I therefore propose a new method for evaluating transit accessibility that integrates process-based methods with user outcomes in order to more accurately identify transit gaps and inequities. The implementation of this method is demonstrated in the context of the Chicago region by combining schedule data from the Chicago Transit Authority (CTA) with data on various *subjective impedances* related to walkability, perceived safety, total wait time, and the number of transfers taken on a trip in order to account for transit outcomes. By comparing the results of this metric with another metric that utilizes schedule data alone, I identify locations in which traditional, process-based methods may overestimate transit access by failing to account for subjective impedances. The gap between these metrics is also unequally distributed, with areas with higher Black populations and populations below the poverty line particularly affected, pointing to possible issues of equity and justice. This study therefore demonstrates how transit access measures can be adapted to be more reflective of human experience, while also pointing to issues of equity and justice that failing to do so could perpetuate.

Table of Contents

I. Introduction

During the middle of the 20th century, the landscape of land use and transportation in America shifted violently. To avoid reckoning with recent civil rights rulings and legislation intended to integrate neighborhoods and schools, middle-class white residents fled to the rapidly growing suburbs (Frug & Barron, 2008; Rothstein, 2018). Federal incentives, such as the Servicemen's Readjustment Act (commonly known as the G.I. Bill) and government-backed mortgages from the Federal Housing Authority (FHA) offered opportunities for education, suburban housing, and building wealth, which were systematically denied to Black veterans and homebuyers (Herbold, 1994; Rothstein, 2018). However, underlying this new form of segregation was a massive shift in government spending on transportation infrastructure towards the automobile. In 1956, the U.S. Congress passed the Federal-Aid Highway Act to fund the construction of 41,000 miles of new interstate highways (*National Interstate*, 2022). These new highways not only connected cities to each other, but cities to their suburbs as well, meaning suburbanites could escape the city but remain just a short drive away from the jobs and opportunities they left behind. As a result, central city populations across the United States declined by an average of 28% from 1950 to 1990, while an estimated 8% increase would have occurred over the same time period if no interstate highways had been built (Baum-Snow, 2007). Together, federal funding for suburban home loans and highway construction represents what scholar Dr. Lawrence T. Brown deems "one of the greatest federal instances of affirmative action in American history for the benefit of White people" (Brown, 2021, pp. 47–48).

At the same time, this shift toward the automobile led to the widespread destruction of Black neighborhoods, through which new highways were often routed under the euphemisms of "urban renewal" and "slum clearance" (Rothstein, 2018). It also signaled a decline in investment in public transportation, leading to the widespread closure of streetcar lines and rapid transit stations (Rothstein, 2018). Figure 1 below depicts the rapid transit system of Chicago in 1943, before all streetcar lines were removed, along with many elevated rail branch lines, such as the Humboldt Park branch of the Metropolitan West Side Elevated and the Stockyards and Kenwood branches of the South Side Elevated. The divisions that these policies created have endured through the present day; Chicago is currently one of the most segregated cities in the country, with vastly different realities of housing, neighborhoods, schools, and transportation, particularly between its white and Black residents (Serrato et al., n.d.).

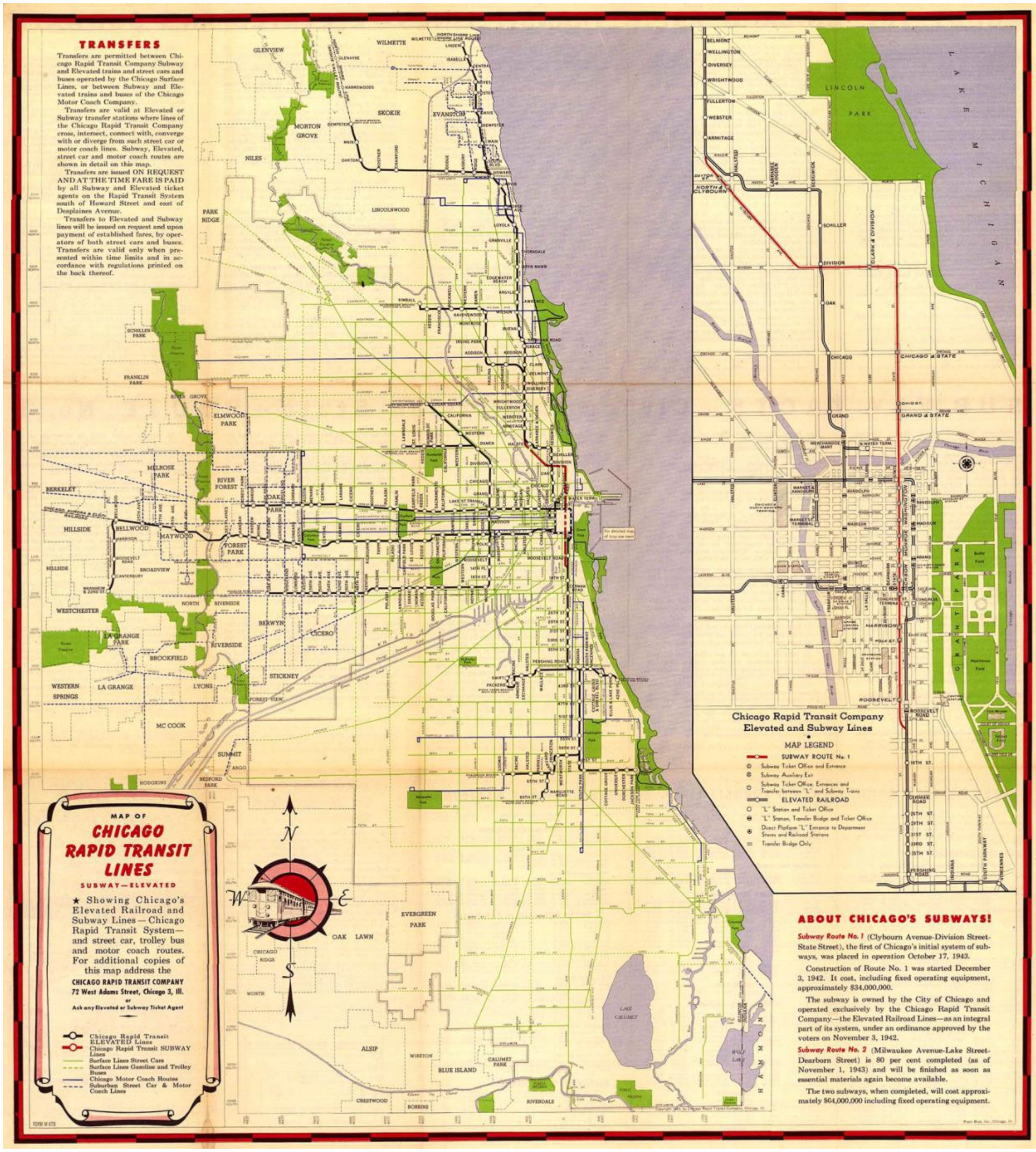


Figure 1: A map of Chicago's rapid transit lines, including elevated railways, subways, streetcars, and buses, in 1943 (Chicago Rapid Transit Company, 1943).

Thus, the current state of public transportation in America is inextricably linked to its history of racial segregation and discrimination. Accordingly, widespread public reinvestment in public transit is not only a practical necessity, but a matter of equity and racial justice.

In order to help facilitate such reinvestment, studies on public transit access, the ease with which one can reach important destinations by transit, abound. The Metropolitan Chicago Accessibility Explorer (MCAE) is one example of a tool that researchers can use to evaluate the accessibility of jobs and other opportunities via transit (Tilahun et al., 2016b).[1] By selecting a type of destination, departure time, and maximum travel time, one can use the tool to classify all Census Block Groups in the Chicago region by the number or percentage of destinations reachable. Notably, the website uses transit schedule data to calculate travel times. As is discussed in the literature review, Morris et al. (1979) would classify this approach as utilizing *process* indicators of transit access, which they define as "measures of the supply characteristics of the system" (92). In other words, studies that utilize process indicators are concerned with how a transit system is planned to operate.

However, transit schedules are often not reflective of the actual experience of taking transit, especially in cities in the United States. In my personal experience of taking public transit in Chicago I have encountered long delays, "ghost buses,"[2] missed transfers, 20-minute wait times, difficult weather, unwalkable station areas, line closures, harassment, and robbery. For individuals with disabilities who cannot use stairs, transit accessibility is far worse; in Chicago only 70% of "L" stations are compliant with the Americans with Disabilities Act (Chicago Transit Authority, 2024), while in New York City only 23% of subway stations are compliant

[1] As of May 5th, 2025, the MCAE web domain is no longer active. A screenshot of the tool is included in the appendix for reference. Information on the tool can also be accessed at https://udv.lab.uic.edu/our-work/collaborations/metropolitan-chicago-accessibility-explorer/.

[2] A popular term for buses that appear on schedules and tracking applications but are not actually running

(New York City Council, 2019). Thus, without the incorporation of lived experience as a factor of transit accessibility, studies cannot accurately measure accessibility and equity of transit systems. Morris (1979) categorizes such factors as *outcome* indicators of transit access, in contrast to process indicators.

However, while transit outcomes are successfully identified and measured by various studies, they are generally not translated into alternate measures of access. Instead, such studies identify aspects of human experience overlooked by process-based approaches (e.g., Lowe et al., 2023) without offering concrete solutions for incorporating outcomes into the process-based measures they critique. Thus, there exists a methodological gap in the study of transit access, particularly within studies that measure access at the scale of entire cities or transit networks. This results in two notable consequences. First, efforts to improve access to transit systems based on current (generally process-based) access metrics often fail to account for human experience, and thus critical barriers to transit use may be overlooked. And second, the injustices caused by racially biased city and transportation planning may not be fully accounted for, leading to potentially inequitable or unjust outcomes when relying upon existing metrics.

Using Chicago as a case study, this study therefore raises the following questions: How could researchers create and utilize a better measure of transit access that is reflective of both processes and outcomes (RQ1)? Furthermore, to what extent do traditional process-based measures under- or overestimate transit access, as compared to a method that accounts for both processes and outcomes (RQ2)? And in light of the injustices perpetrated by white flight, racial segregation, urban renewal, and transit disinvestment since the mid-20th century, what are the consequences of these discrepancies for advancing equity and justice (RQ3)? As the following analysis shows, the slight modification of existing process-based metrics to account for data related to the human experience of transit can produce a method capable accounting for both transit processes and outcomes. The wide and unequally distributed gap between the output of this metric and the output of traditional process-based metrics further demonstrates that such modifications are needed to more accurately, equitably, and justly measure transit access in cities like Chicago in order to inform transit improvements that most directly benefit historically marginalized communities.

This thesis therefore demonstrates the implementation of this combined methodology in an effort to bridge the gap between process-based and outcome-based studies. This is demonstrated through statistical and spatial analysis based on a classification of areas by transit access in the Chicago region, similar to the MCAE. Travel times based on schedule data are used to create a Baseline metric of accessibility that emulates current process-based studies. Meanwhile, various indicators related to the human experience of transit use (*subjective impedances*) are combined with travel times to create an Enhanced measure of accessibility. Subjective impedances addressed in this study include walkability (the safety and quality of the walking environment), perceptions of safety, wait times for transit vehicles to arrive, and the number of transfers between transit routes, chosen due to the substantial impact such factors can have on transit access according to outcome-based studies. The gap between the Baseline and Enhanced metrics is examined in order to identify areas in which transit access may be overestimated using current process-based methods. Finally, this study uses a spatial comparison of this gap with demographic data on race and poverty in order to evaluate the metrics through the lenses of equity, whether the varying needs of different populations (in this case, for transit to be accurately measured) are met appropriately, and justice, whether historical injustices and harmful systems are corrected. Where inequities and injustices are found, they could indicate that by overlooking subjective impedances, current approaches to studying and improving transit are inadequate if their goal is to reverse the historical pattern of transit disinvestment prevalent in marginalized communities. Thus, the goals of this study are twofold: to demonstrate how researchers and transportation planners can measure and address transportation access in a manner that is more accurate and reflective of human experience, and to illustrate the impacts that such a method could have on advancing transportation equity and justice, particularly in the Chicago region.

II. Literature Review

Throughout the literature, transportation access, equity, and justice are measured using a variety of methods. This review first establishes an understanding of these three concepts as they are defined in the social sciences and transit literature. Then, it evaluates the extent to which existing process- and outcome-based methods accurately and systematically measure transit access. By identifying the benefits and drawbacks of these methods, this review further attempts to identify how such methods could complement each other if combined.

1. *Accessibility, Equity, and Justice*

Accessibility is the primary measure by which the efficacy of a transit network can be measured. Unlike mobility, which only measures the ease of travel along a network irrespective of the destinations that can be reached, accessibility is primarily concerned with the ability of users to arrive at destinations or opportunities (El-Geneidy & Levinson, 2006). Thus, a transit system that is fast and widely available is not accessible if it does not connect users to useful opportunities. Accessibility measures therefore tend to combine data on the importance of various locations and the distance one has to travel to reach them, such as in Hansen's (1959) prominent analysis on the impact of accessibility on residential development. The author defines accessibility as a "potential…for interaction" (73), measured by dividing the size or importance of a destination by some function of the distance to that destination, similarly to the physical model for gravity (this connection will be explored further below). Another influential definition of accessibility comes from Penchansky and Thomas (1981) in which they conceptualize access in the study of healthcare service provision as "representing the degree of 'fit' between the clients and the system" (128). They proceed to identify five characteristics of a system that together constitute its accessibility to users (the five 'A's): availability (whether the supply of resources is sufficient), accessibility (distance or travel time to resources), accommodation (whether resources are available at times and in ways that meet the needs of users), affordability (whether the cost of the system matches its perceived benefits and if users have the financial means to utilize it), and acceptability (whether users are comfortable with accessing the resources that are available). Thus, in their view, accessibility does not merely pertain to the ease of arriving at an important destination, but the ease with which a user may utilize opportunities at the destination as well. The primary difference between the two models is that Hansen's (1959) is explicitly spatial, while critiquing the other type of model for only measuring the "ease of interaction" (73), with distance as merely an ancillary component. Perhaps because transit is a public service inherently interacted with through space, Hansen's (1959) approach is more widely adopted in the transit access literature, particularly in process-based studies. However, in taking a purely spatial approach, process-based studies ignore other aspects pertaining to the "degree of fit" of a system identified by Penchansky and Thomas (1981), such as its level of accommodation, affordability, and acceptability, which can pose significant barriers to transit access as well. Outcome-based studies primarily evaluate transit systems by these additional criteria. As a primary goal of this study is to bridge the gap between process- and outcome-based methods, this study integrates these two respective definitions by evaluating access both as a function of travel time and as a matter of a system's ability to meet its users' subjective needs.

Access carries with it important social implications that can be evaluated as well, such as equity and justice. Equity is a concept that can be hard to define, as it depends on the values of a society, which often differ among its members (Talen, 1998), but is generally conceptualized as a fair distribution of resources. In a study on municipal service provision, Lucy (1981) identifies five different ways that planners might conceptualize equity: equality, need, demand, preference, and willingness to pay. However, in light of the systemic racism and inequitable investment that has and continues to pervade through transportation planning (see introduction; Baum-Snow, 2007; Brown, 2021; Frug & Barron, 2008; Herbold, 1994; *National Interstate*, 2022; Rothstein, 2018; Serrato et al., n.d.) many of these measures of equity do not make sense in the context of transit access. For instance, demand or willingness to pay may be lower for some individuals, not because they have no need for public transit but because they either cannot afford to pay more for transportation or are unemployed and therefore do not commute, both of which could be remediated through an improvement in transit infrastructure. Therefore, within Lucy's (1981) framework, this paper's choice of equity metric is simple; only a need-based conceptualization of equity can adequately address transit deficiencies in a reasonable manner.

Meanwhile, within Litman's (2002) framework, the choice is slightly more complicated. Litman first distinguishes between two basic types of equity relevant to transit access, horizontal, in which transit networks prioritize all individuals equally (i.e., equality), and vertical, in which transit access is prioritized for specific groups or uses. However, within the category of vertical equity, Litman (2002) notes that various groups or uses could reasonably be prioritized, such as populations with lower incomes, people who cannot access other modes of transportation as readily (including people with disabilities or without cars), or trips to access necessities rather than luxuries. There is no social consensus on which prioritization is most fair, and different priorities may even conflict, for instance, between individuals without cars traveling to nonessential amenities or low-income individuals with ready access to cars. Because transportation access is an issue so deeply rooted in racism and discrimination (Rothstein, 2018), this study will evaluate the equity of the system based on levels of access among Black, Latine, and populations living in poverty; however, future studies could analyze equity through various other lenses of vertical equity as well.

On the other hand, due to this connection to historical injustices, the framework of justice may be better suited to evaluate the outcomes of transportation planning. In *A Theory of Justice*, Rawls (1971) argues that all individuals are entitled to the same equal basic liberties, and that resources must be distributed in a manner as to maintain those liberties. Though this framework appears similar to that of need-based equity at first glance, justice considers more than merely the immediate needs of individuals; it is founded upon the belief that individuals have inherent rights and is contextualized in the history of how those rights have been violated in order to allow for remediation (Yeganeh et al., 2018). It therefore follows that it is just to invest more in historically underserved communities to allow them to reach the same level of opportunity. However, a just outcome in transportation access is less clear than one that is equitable. While Yeganeh et al. (2018) argue that cities with a greater ratio of public transportation access for low-income nonwhite populations compared to high-income white populations are more *equitable*, their analysis fails to question why low-income nonwhite populations are often dependent on a different form of transportation in the first place. This pattern has emerged from the historical context of white flight and urban disinvestment that led to the segregation of transportation systems, with well-maintained highways serving suburban white populations and neglected public transportation systems serving urban Black and other nonwhite populations (Rothstein, 2018). One might argue that a system that upholds this pattern may indeed be *equitable* if it provides public transit for those with the greatest need for public transit, but that is also *unjust* because it does not counter the systems of discrimination and segregation that created the disparity in need in the first place. As the question of justice is far more nuanced than equity, this study will not rely on any specific criteria to measure justice but will instead include reflection on the potential implications of its findings for challenging unjust structures of power.

Thus, to evaluate the efficacy of transit access methods, this study assesses their ability to account for the dimensions of access described by Hansen (1959) and Penchansky and Thomas (1981), as well as to promote need-based equity and remedial justice. The following section explores the existing classes of methods used in the literature, identifying their shortcomings for measuring access in an equitable and just manner.

2. *A Taxonomy of Methods*

While existing methods of measuring transit access vary across a myriad of dimensions, Morris et al. (1979) present the primary distinction of interest to this study, between process-based metrics, which measure the theoretical operation of the transit system based on scheduling data (like the MCAE), and outcome-based metrics, which measure the quality of transit users' experiences. Geurs and Van Wee (2004) present a similar distinction, differentiating between location-based measures, which evaluate access to destinations on a broad scale through a transit system's theoretical workings (analogous to process indicators), and person-based measures, which evaluate access for individuals based on the destinations they need to reach and the impedances they face when traversing the transit network to reach them (analogous to outcome indicators). Within the category of location-based measures they further distinguish between distance measures, in which accessibility is calculated by the number of opportunities available within a transit isochrone[3] surrounding each origin; gravity-based measures, in which accessibility is calculated in a manner similar to that described by Hansen (1959), calculating the total "gravity" of opportunities on an origin as an inverse function of travel time to each; and variations of the previous two measures that account for additional factors like competition between users. Both Morris et al. (1979) and Geurs and Van Wee (2004) agree that there is no single "best" method of measuring transit access; rather, "systematic errors are associated with every approach, and the problem becomes one of choosing the measure which best suits the problem at hand from the available alternatives" (Morris et al., 1979, 94). Both process-based (i.e., location-based) and outcome-based (i.e., person-based) metrics and their uses in the literature are explored in this section.

Process-based (or location-based) metrics are generally easier to operationalize at large scales and thus are often used to make broad claims about transit accessibility within one or multiple metropolitan areas. The MCAE (Tilahun et al., 2016b) and the related analysis by Ermagun and Tilahun (2020) are relatively straightforward examples of process-based studies that use a distance measure to calculate accessibility to jobs and amenities from Census Block Groups in Chicago. Yeganeh et al. (2018) likewise use process indicators and a distance measure to evaluate transit access more broadly across U.S. cities. Both Ermagun and Tilahun (2020) and

[3] A shape encompassing every possible location an individual could travel to from a given starting point by a specified mode (in this case transit) over a specified period of time.

Yeganeh et al. (2018) further assess transit equity by measuring differences in levels of access among disadvantaged groups. A key limitation of the distance measure used by these studies is its binary distinction between areas inside and outside of an isochrone, which are deemed entirely accessible and entirely inaccessible respectively, while in reality accessibility is generally experienced along a gradient (Geurs & Van Wee, 2004). Several other process-based studies respond to this limitation by using gravity measures instead, such as Foth et al. (2013) and El-Geneidy et al. (2016). Additional considerations that process-based studies address include the oft-overlooked impact of departure time on accessibility (El-Geneidy et al., 2016; Owen & Levinson, 2015), as well as the impact of competition, which is especially important for studies of access to opportunities where one individual's access can impede another's, such as with jobs (El-Geneidy et al., 2016). While process indicators are used effectively by these studies to measure theoretical levels of transit access across entire metropolitan areas, process-based studies generally fail to account for the subjective experience of taking transit and the outcomes it might entail.

On the other hand, outcome-based (or person-based) metrics address various subjective impedances to transit but generally do not provide measures of access that are as concrete or operable at a large scale. Lowe et al. (2023) directly engage with South and Southwest Side residents in Chicago through focus groups, finding that subjective factors like safety, comfort, walkability, and personal outlook contribute greatly to the perceived impedance of taking transit or residents' willingness to take transit at all. These findings on walkability and perceptions of safety are corroborated Tilahun and Li (2015) and Tilahun et al (2016a) in their studies on last mile barriers (subjective impedances encountered when walking between a transit stop and a final destination) in Chicago. Using a stated choice survey (Tilahun & Li, 2015), as well as data on modal choice, commuting patterns, demographics, and walkability (Tilahun et al., 2016a), they show that last-mile barriers related to safety and sidewalk access can significantly reduce transit access, particularly on the South and West Sides of Chicago, as well as in the suburbs. The authors estimate that the absence of a sidewalk or a unit increase in crime perception (on a Likert scale of 1 to 5) creates a barrier approximately equivalent to an additional six minutes of walking time for last-mile trips. Thus, an environment that feels unwalkable or unsafe to residents can greatly impede transit access, regardless of how short actual travel times may be (see also Tiznado-Aitken et al., 2018). However, the studies above do not offer an alternative method of measuring transit access that incorporates their outcome-based findings.

A further complication revealed by outcome-based studies is that perceived impedances not only vary by location, but by the demographics of users as well. Chia et al. (2016) find that age, income, and occupation greatly influence the distance that "nontrue transit captive users" (transit users who have access to alternative modes like a private vehicle) are willing to walk to reach transit stops, thereby challenging the conventional 400-meter distance band used by many process-based studies to demarcate a station's walking "catchment area." Furthermore, while wait times are perceived as longer than they really are by transit users in general (thus presenting another subjective barrier overlooked by process-based studies), this effect can be especially pronounced for women and gender minorities due to heightened safety concerns (Fan et al., 2016).

Other outcome-based studies address various subjective impedances imposed by transit routes themselves. Nassir et al. (2015), for instance, compare surveyed travel paths of transit users to a set of computer-generated paths optimized to reduce travel time, finding that routing choices made by the studied users were even more influenced by walking distance and the number of transfers along a route than travel time, strongly problematizing the sole reliance of process-based studies on travel time as a measure of access. Furthermore, the authors find route characteristics such as the presence of bus shelters and the availability of alternative route options to have a marked impact on user choices as well. Nassir et al. (2016) use these findings to develop a systematic measure of transit impedance for different localities within a transit network, thus taking a major stride towards operationalizing transit outcome measures in a concrete and large-scale manner, though falling short of integrating them into existing measures of access.

Thus, while outcome-based studies offer valuable insights into the impact of subjective impedances on access, they generally do not demonstrate how such impedances could be integrated into existing process-based measures of transit access in order to make them more reflective of human experience. One notable exception is presented by Tiznado-Aitken et al. (2021), who develop an alternative measure of access that adjusts travel times by the prevalence of crowding, walking time, wait time, and number of transfers along a route for the context of school access in Santiago, Chile. The authors compare this metric to travel time alone (a process-based metric), demonstrating that the method they develop can identify inequities in access that are otherwise not apparent if subjective impedances are not accounted for. These results not only provide insights into the equity of access to education but also demonstrate that the integration of transit outcome indicators into process-based methods is a feasible and effective means of improving transit access metrics.

The present study therefore expands on this nascent paradigm, using a similar method to evaluate transit access, though for a different geographic context, variety of destinations, and set of subjective impedances. This type of analysis could help bridge the current gap in the literature between process-based and outcome-based studies and demonstrate how doing so may reveal undiscovered inequities and injustices in transit access.

3. *Synthesis*

Accordingly, in this study a method is developed for evaluating transit access that incorporates both travel times (processes) and data related to the human experience of taking transit (outcomes). Its use is demonstrated in the context of the Chicago metropolitan region, while its efficacy is evaluated through the frameworks of equity and justice. The method is not intended to offer an end-all-be-all solution for measuring transit access in a comprehensive manner, but rather to demonstrate one of many possible ways in which transit access researchers can leverage both process and outcome indicators to better identify barriers to transit access.

III. Methods and Data

In light of the current gap in the literature between methods, in the following analysis an Enhanced metric of transit access is developed to account for both transit processes and outcomes (RQ1). This Enhanced metric is then compared to a Baseline metric, which is based on process indicators alone, to identify whether the latter overestimates access by not accounting for subjective impedances, and if so, whether the gap between the two metrics is spatially distributed in an unequal manner (RQ2). Finally, the distribution of this gap is compared to demographic data on race and poverty to examine its potential implications for equity and justice (RQ3).

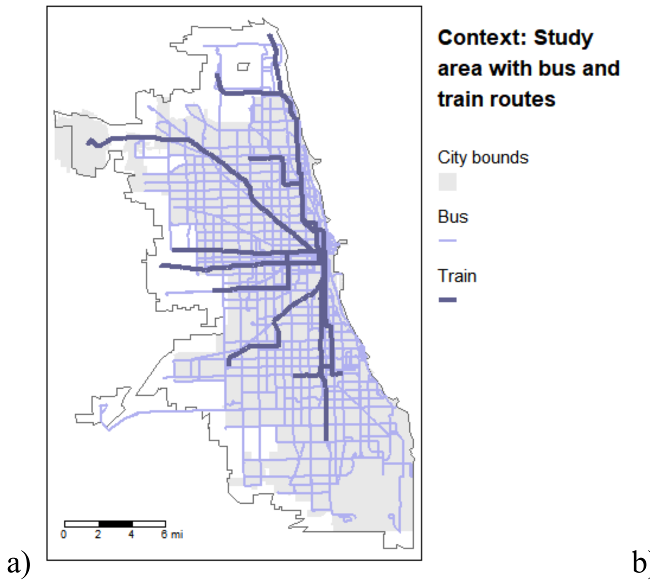
1. Study Area

The Baseline and Enhanced metrics are evaluated in the context of the Chicago metropolitan area. Though multiple transit agencies serve the region, only the Chicago Transit Authority (CTA) bus and train network is included in this study, though future iterations could apply this study's methods to additional transportation networks and regions.

The basic spatial unit of analysis, for which values for the Baseline and Enhanced accessibility metrics are calculated, is the Census Block Group. Block Groups are chosen as they are fairly uniform in size, provide far more granularity than Census Tracts, and are more manageable in quantity than individual Census Blocks. These are also the spatial units used by the MCAE (Tilahun et al., 2016b) and various other studies, thus allowing for more direct comparison of results.

For this analysis, all Census Block Groups within 2 km of a CTA stop or station are extracted using the R package "tidycensus" (R Core Team, 2021; Walker & Herman, 2025).[4] CTA line and station spatial data are downloaded from the Chicago Data Portal (City of Chicago, 2023a, 2023b, 2024, 2025). Figure 2a below shows the outline of all Census Block Groups used in this study, contextualized by the Chicago city boundary and the locations of CTA rail and bus lines. Block Groups can also be contextualized by the general part of the city they are in. Figure 2b classifies Block Groups by Equity Zones, six city regions designated by the Chicago Department of Public Health to support local health and equity initiatives (City of Chicago, 2022).

[4] 2 km is chosen arbitrarily so as to make the study area slightly larger than the area within walking distance to ensure as few trips as possible are excluded. Extra Census Block Groups do not affect the results, as those that are too far away to allow for any connections receive access scores of 0 and are thus excluded as lower outliers.



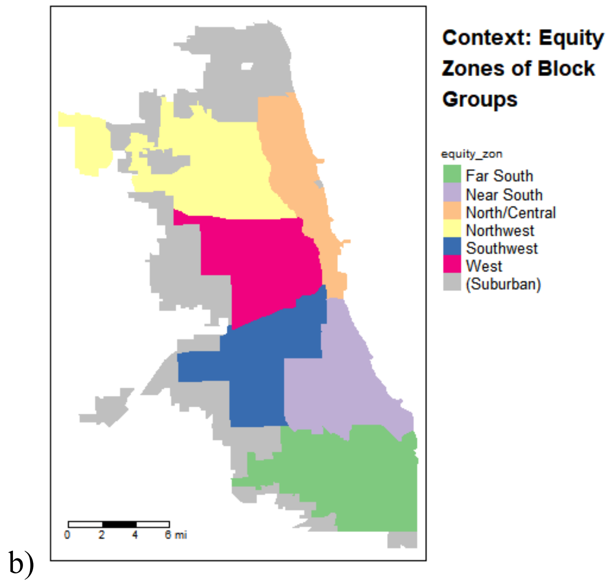


Figure 2: Outline of Block Groups within the CTA's "service area" (with city bounds, bus lines, and train lines added for context) (a) and classified by Equity Zone (b). All map figures are made using the "tmap" R package (Tennekes, 2018).

Centroids of Block Groups are used as origin and destination points for travel time calculations. Though access at the centroid may not be representative of the whole Block Group, exact points are needed for travel time calculations and Block Groups are small enough for there not to be too major of a difference in access between the centroid and the rest of the Block Group. However, as accessibility measures the ease of reaching opportunities, not merely arbitrary locations (El-Geneidy & Levinson, 2006), each Block Group must also be characterized by the number of jobs (for commuting trips) and points of interest (for non-commuting trips) available within it. These two categories of opportunities are chosen due to their use in existing studies, like the MCAE (Tilahun et al., 2016b; see also Ermagun & Tilahun, 2020) to allow for greater comparability. By measuring access to opportunities, rather than to Census Block Groups alone, a Block Group with good transit nearby may still be categorized as having poor transit access if opportunities take a long time to reach.

For data on job locations, this study uses U.S. Census Bureau Longitudinal Employer-Household Dynamics (LEHD) data from 2022, the most recent year available (U.S. Census Bureau, 2024a). LEHD job data are provided at the Census Block level but are aggregated to Census Block Groups. For simplicity, jobs are not stratified by eligibility criteria, wages, or other factors, which could lead to a mismatch between the opportunities available and those that a given transit user can actually utilize (El-Geneidy et al., 2016). Future analyses could analyze access to jobs of various sectors and income groups separately.

Opportunities reached by non-commuting trips are categorized as points of interest (POI), and include shops, schools, hospitals, civic buildings, parks, and various other amenities. To include POI both within and outside the city of Chicago, the Places data set from Overture Maps is used, which provides open-source data on the locations of points of interest worldwide (Overture Maps Foundation, 2025). The Places data set includes a confidence score, which roughly indicates the likelihood that a given location exists. Based on Overture documentation and exploratory analysis of personally familiar areas, only locations with a confidence score of over 95% are kept. Once the data are filtered, their point locations are merged into the Block Group data set using a point-in-polygon spatial operation in R (Pebesma, 2018; Pebesma & Bivand, 2023). Like with jobs, this study only measures POI by their total count, which could cause the model to overlook mismatches between need and the services available. Though this goes beyond the scope of this study, further research on access to specific categories of opportunities based on local need is warranted. The table below summarizes each of the variables used to characterize each Census Block Group, along with each Block Group's population:

Variable	Description	Min	Max	Median	Mean
GEOID	FIPS code for the Block Group	–	–	–	–
Population	Population of the Block Group	0	6,030	1,172	1,265
Job count	Number of jobs in the Block Group	0	270,976	111.0	649.0
POI count	Number of POI in the Block Group	0	1,965	12.0	21.2

Table 1: Variables in the Census Block Group data set

In general, a key limitation of studies that use opportunities like jobs or POI to measure transit access is that results may reflect underlying disparities in resource distribution that improving transit cannot fix, an issue especially pertinent to Chicago due to its extensive food (and other resource) deserts (Lowe et al., 2023). This does not invalidate the findings of this study, as it is still important for transit access measures to more accurately reflect real-life experiences. However, the policy interventions responding to the findings of such measures should not focus solely on transit improvements, but on improving the distribution of opportunities one might need to reach by transit as well.

2. *Measuring Access*

A further consideration is the method used to relate travel times to an access score. The Baseline metric should be similar to other process-based metrics used in the literature, and should have enough flexibility to allow for subjective impedances identified by outcome-based studies to be factored in. Within the realm of process-based metrics several possible applicable methods exist. One very common method is the distance measure, or isochrone, which classifies a point by the number of destinations that can be reached within a given travel time (Ermagun & Tilahun, 2020; Owen & Levinson, 2015; Tilahun & Fan, 2014; Tilahun et al., 2016b; Yeganeh et al., 2018). While a distance measure is perhaps the simplest to operationalize, its binary classification of destinations as either accessible or inaccessible based on an arbitrary time cutoff is not reflective of the continuous nature of accessibility, as generally experienced by transit users (Geurs & Van Wee, 2004). Additionally, this binary classification does not lend itself well to the inclusion of additional accessibility factors, subjective impedances in particular. Each destination either can or cannot be reached within a given timeframe; no consideration is made for how difficult it is to get there. A useful alternative to the distance measure is the gravity, or potential, measure (El-Geneidy et al., 2016; Foth et al., 2013), which classifies a point by the total "gravitational pull" of surrounding destinations, in a manner similar to the physical model for gravity. Every destination contributes a varying amount to the total gravity on the origin, determined by factors such as travel time from the origin, the "size" of the destination (the number of jobs at the destination, for instance), and the difficulty of getting there. A limitation of the gravity measure is its comparatively lower interpretability; total gravity is a far more abstract concept than the total number of reachable destinations. Furthermore, gravity models generally cannot account for competition, a factor of particular importance for job accessibility that is often overlooked in the literature (El-Geneidy et al., 2016).[5] Nevertheless, the gravity model is chosen for this analysis, as its continuous representation of accessibility is more reflective of human experience and is far more capable of accounting for subjective impedances and other accessibility factors independent of travel time, thus allowing outcome-based measures to be integrated into the gravity model with little difficulty. This decision is also supported by the recommendation of Nebiyou Tilahun, an Associate Professor in the Department of Urban

[5] Though several studies successfully modify gravity models to account for competition (Geurs & Van Wee, 2004), these models require additional pairwise access calculations for each origin-destination pair. As the number of pairs scales with the square of the number of locations, this would require a prohibitive amount of computation. Furthermore, as this study only measures access by transit, only competition from other transit users would be accounted for, while in reality transit only makes up a small percentage of Chicago's mode share (U.S. Census Bureau, 2024b).

Planning and Policy at the University of Illinois Chicago, and lead developer of the MCAE (personal communication, November 21, 2024).

Therefore, a gravity model is implemented for both metrics (Baseline and Enhanced). The equation used to classify each Census Block Group by its accessibility to opportunities (A_i), adapted from Geurs and Van Wee (2004), is shown below:

$$A_i = \sum_{j=0}^{N_j} n_j \, e^{-\beta \, t_{ij} \, s_{ij}} \tag{1}$$

Where:

- A_i is the accessibility from origin i
- i is an origin Block Group
- j is a destination Block Group
- N_j is the total number of Block Groups
- n_j is the number of opportunities (jobs or POI) within Block Group j
- β is the cost sensitivity parameter[6]
- t_{ij} is the travel time from i to j
- s_{ij} is the subjective impedance experienced between when travelling between i and j

A negative exponential function is chosen for the gravity model based on the findings of Handy and Niemeier (1997), who demonstrate a strong link between the function and travel

[6] The cost sensitivity parameter β adjusts the steepness of the decay curve and should be decided on a case-by-case basis according to the local context (Geurs & Van Wee, 2004). In this case, exploratory analysis of different β values reveals that 1/30 (if t_{ij} is measured in minutes), or 2 (if t_{ij} is measured in hours), strikes a good balance between weighting nearby areas more strongly but preventing the metric from becoming too localized. The resulting curve has a half-life of around 20 minutes, meaning that opportunities are weighed twice as strongly as those 20 minutes farther away.

behavior theory. A sensitivity analysis comparing the output of the exponential function to a logistic function, another viable alternative, yields results that are roughly the same, indicating that the method is not highly sensitive to the function chosen. Because opportunities may include jobs or POI, accessibility is calculated twice for each metric (once for Baseline and once for Enhanced) to account for each opportunity type.

The only difference between the metrics lies in the value of the subjective impedance factor s_{ij}, which remains constant for all origin-distance pairs for the Baseline metric ($s_{ij} = 1$) and varies for the Enhanced metric. The following sections explain how t_{ij} and s_{ij} are calculated.

3. *Calculating Travel Time*

Both the Baseline and Enhanced metrics utilize the travel time parameter t_{ij}. Travel time is calculated using "r5r," an R package that uses the R5 routing engine to calculate travel times by transit or other modes (Conway et al., 2017, 2018, 2019; Pereira et al., 2021). "r5r" is only one of various routing tools available for this type of analysis but is chosen for its more user-friendly interface and built-in functionality for measuring access. For it to calculate transit travel times, two data inputs are required. The first is a spatial data representation of the local street grid, needed to identify where transit users can walk to access, leave, or walk between stations. This is sourced from OpenStreetMap (OSM), an open-source, queryable world map, using Interline OSM Extracts (OpenStreetMap contributors, 2025; *OSM Extracts by Interline*, n.d.). Second, "r5r" uses transit network data compiled in the General Transit Feed Specification (GTFS) format, which is made up of various text files that list agency information, routes, transit stops, stop times, transfers, and other system data. GTFS data for January 2025 from the CTA are downloaded from the CTA's website (Chicago Transit Authority, 2025). The "r5r" package is then used to generate a matrix of travel times between each pair of Census Block Groups, which can be used to find t_{ij}.

Several parameters can be specified to modify the matrix output to account for different conditions, such as walk speed, maximum walking time, maximum transfers, and departure time, which may vary greatly between users (e.g., Chia et al., 2016; El-Geneidy et al., 2016). However, these parameters are not modified in this study, as this would require pairwise travel times, already a computationally expensive task, to be recalculated as many times as the number of parameter combinations explored. This is a major limitation that should be addressed through further study on the impact of each parameter. It should thus be acknowledged that while this analysis is able to identify differences between the outputs of the Baseline and Enhanced metrics for a general user, it is not able to evaluate how these metrics might vary between users with different needs and abilities that affect the routes they can take.

For this analysis, important parameters include maximum walk time, which is set to 10 minutes (to roughly match the general findings of Chia et al. (2016)), and departure time, which is set to 8 AM on a weekday in January 2025. Importantly, included departures should not only take place at the exact time specified, as travel times can vary greatly within a short time frame depending on how soon the next transit vehicle arrives on a given route. Thus, travel times are calculated every minute throughout a ten-minute window following the initial departure time, the average of which is then used as the t_{ij} score for that origin-destination pair.

Finally, because the selection of Block Groups for this study includes a slight buffer to avoid missing locations near the edge of the CTA service area, around 14% of Block Groups have no or nearly no access at all. These are excluded as lower outliers before applying the Baseline and Enhanced metrics.

4. Calculating Subjective Impedances

Only the Enhanced metric uses the subjective impedance factor s_{ij}, an index accounting for the various difficulties unrelated to travel time one might experience when travelling along the route generated by "r5r." The chosen factors contributing to s_{ij} are based on the findings of outcome-based studies from the literature review and include waiting time (Fan et al., 2016), number of transfers (Nassir et al., 2015; Tiznado-Aitken et al., 2021), walkability (Lowe et al., 2023; Tilahun & Li, 2015; Tilahun et al., 2016a; Tiznado-Aitken et al., 2018), and perceptions of safety (Lowe et al., 2023; Tilahun & Li, 2015; Tilahun et al., 2016a).

Data on waiting time and number of transfers relate to the route taken itself and are thus directly provided by the matrix produced by "r5r." Data on walkability and safety must be sourced elsewhere, as both are used characterize the areas through which a route passes. To account for walkability, Block Groups are characterized using the "Character" variable from the Chicago Metropolitan Agency for Planning (2024) Walkability data set, which assesses the physical character of the walking environment by combining various factors such as intersection density, tree cover, and pedestrian fatality rates. This data set is chosen over other data on walkability due to its coverage over the entire study area, open access, and more relevant selection of variables. Data on safety perceptions are sourced from the Chicago Health Atlas (2025), indicating the percentage of residents in a given neighborhood who feel safe all or most of the time based on a local public health survey. Though this data set does not cover areas outside of the city boundaries, it provides the most comprehensive measure of safety perception that could be found. Perception of safety is chosen as a variable rather than less subjective statistics like crime rate to allow the Enhanced metric to correspond more directly with the human experiences and perceptions of transit users. Furthermore, crime rate cannot be used as a proxy for perceived safety, as safety perceptions can vary greatly and do not necessarily scale linearly with crime rate (Tilahun & Li, 2015). Next, an area-weighted average algorithm (Siddiqui, 2023) is used to aggregate walkability and safety data to Census Block Groups, as both are originally provided using other spatial units. Finally, the impedance of walkability and safety of each trip (contributing to s_{ij}) is calculated by taking the average scores of the origin Block Group, destination Block Group, and each Block Group in which a transfer between routes takes place.

Once all four variables are calculated for each trip, each variable is converted linearly into an index ranging from 1 (least impedance) to 2 (greatest impedance), and the indices are multiplied with each other to produce a total subjective impedance score s_{ij}.[7] If s_{ij} is 1, access remains unmodified from the Baseline metric, but if its value is higher, the accessibility score for that origin-destination pair is lowered (see Equation 1). Figure 3 below summarizes the factors included in the subjective impedance index, and thus accounted for by the Enhanced metric.

[7] Safety and walkability are averaged first to prevent areas outside the city limits from receiving lower s_{ij} values simply by virtue of not having a safety score. Though the maximum impedance value of 2 is chosen arbitrarily, changing the maximum value would adjust the Enhanced access scores for all Block Groups uniformly. Because the numerical unit of access used by both metrics is arbitrary and thus only allows for ratio comparisons between values, such a change would be effectively meaningless.

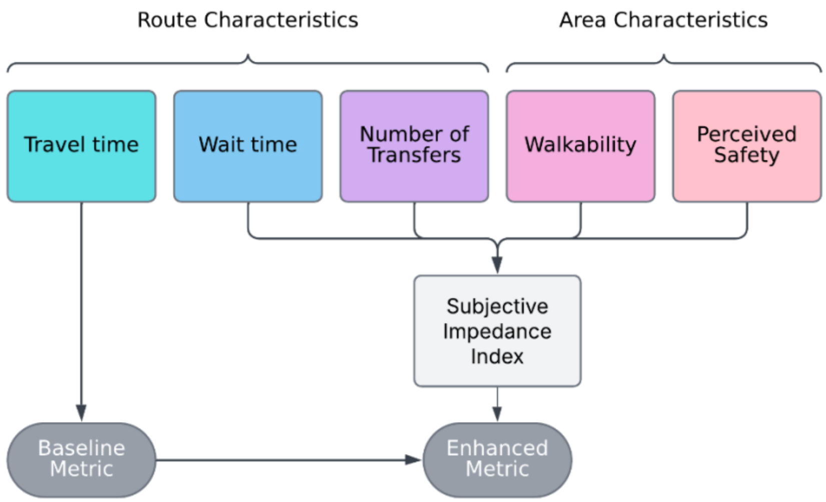


Figure 3: Flowchart of data inputs for both metrics, including the subjective impedance index used by the Enhanced metric.

5. Ratio between Metrics

To assess the gap between the Baseline and Enhanced metrics (RQ2), a ratio is taken between the two. The ratio is analyzed spatially on a map and comparatively between Equity Zones (see Figure 2b). The ratio a key variable; if a given Census Block Group has a low ratio value, this indicates that there is a large disparity between the ability of the Baseline and Enhanced metrics to adequately measure transit access in that location. Accordingly, process-based studies are likely to overestimate transit access at that location by only accounting for travel time in their cost calculations. Furthermore, this indicates that subjective impedances pose a comparatively major barrier to transit access in that Block Group, and that initiatives to improve transit in that area should focus on mitigating subjective impedances as well.

6. Assessing Equity and Justice

While disparities in transit access and in its measures are certainly a spatial phenomenon, the history of transportation planning in the United States, as recounted briefly in the introduction, illustrates that they are a socioeconomic phenomenon as well. Therefore, to assess whether process-based metrics are able to adequately measure transit access for marginalized groups, the ratio described above is compared to distributions of three major marginalized populations in Chicago, Black, Latine, and people living below the poverty line. Demographic data on race and poverty are obtained from the U.S. Census Bureau using "tidycensus" (U.S. Census Bureau, 2023, 2024b; Walker & Herman, 2025). After analyzing the relationship between these variables, this analysis discusses the implications of these findings for need-based equity, based on the assumption that greater levels of access should be available in locations and for populations with greater need. For instance, if transit access is found to be low in an area with a majority-Black population using the Baseline metric, but even more so with the Enhanced metric, this will point to an issue of transit access equity that is currently being overlooked by existing methods that fail to consider the impact of subjective impedances. Finally, this analysis concludes with a discussion on the implications of its findings for justice, which may differ subtly from equity. For instance, a finding of lower transit accessibility in a majority-white and wealthy neighborhood, while acceptable under an equity paradigm, could be a sign of social exclusion and segregation if analyzed through a justice-based lens.

IV. Results and Analysis

By combining process and outcome indicators, the Enhanced metric developed in this study is able to estimate transit access in a manner that accounts for both the theoretical workings of a transit system and the human experience of a system's users. As the results below show, there is a wide and unevenly distributed gap between the results of the Baseline and Enhanced metrics, indicating that Baseline metrics may overestimate access in areas with high levels of subjective impedances, thus obscuring possible barriers to transit access that residents might face. In the CTA service area, the areas with the largest gaps between the two metrics are on the region's periphery and on the Far South Side, the latter of which is predominantly Black, and both of which have relatively high levels of poverty. Indeed, lower transit access and greater gaps between metrics directly correlate with the percent Black population and percent of the population below the poverty line in each Block Group, indicating not only that transit access is inequitably distributed, but inequitably measured as well. Finally, this section concludes with a discussion of the differing implications of these findings for transit equity and justice.

1. Baseline Metric

First, a Baseline metric is calculated by setting the subjective impedance factor (s_{ij}) to 1, making access entirely determined by travel time (t_{ij}). This yields a classification of Census Block Groups by their Baseline level of access to POI and jobs, which is summarized in the top two rows of Table 2 below and mapped in Figure 4 below.

Variable	**Description**	**Min**	**Max**	**Median**	**Mean**
Baseline metric (POI)	POI access by Block Group, irrespective of subjective impedances	1,700	14,809	6,293	6,530
Baseline metric (jobs)	Job access by Block Group, irrespective of subjective impedances	54,761	709,879	209,237	224,474
Enhanced metric (POI)	POI access by Block Group, accounting for subjective impedances	157	9,627	2,049	2,604
Enhanced metric (jobs)	Job access by Block Group, accounting for subjective impedances	4,448	574,766	67,369	92,508

Ratio (POI)	Ratio of Enhanced to Baseline metric for POI	0.083	0.65	0.33	0.36
Ratio (jobs)	Ratio of Enhanced to Baseline metric for jobs	0.072	0.81	0.33	0.36

Table 2: Descriptive statistics of Baseline and Enhanced metrics, as well as the ratios between them, for both POI and jobs.

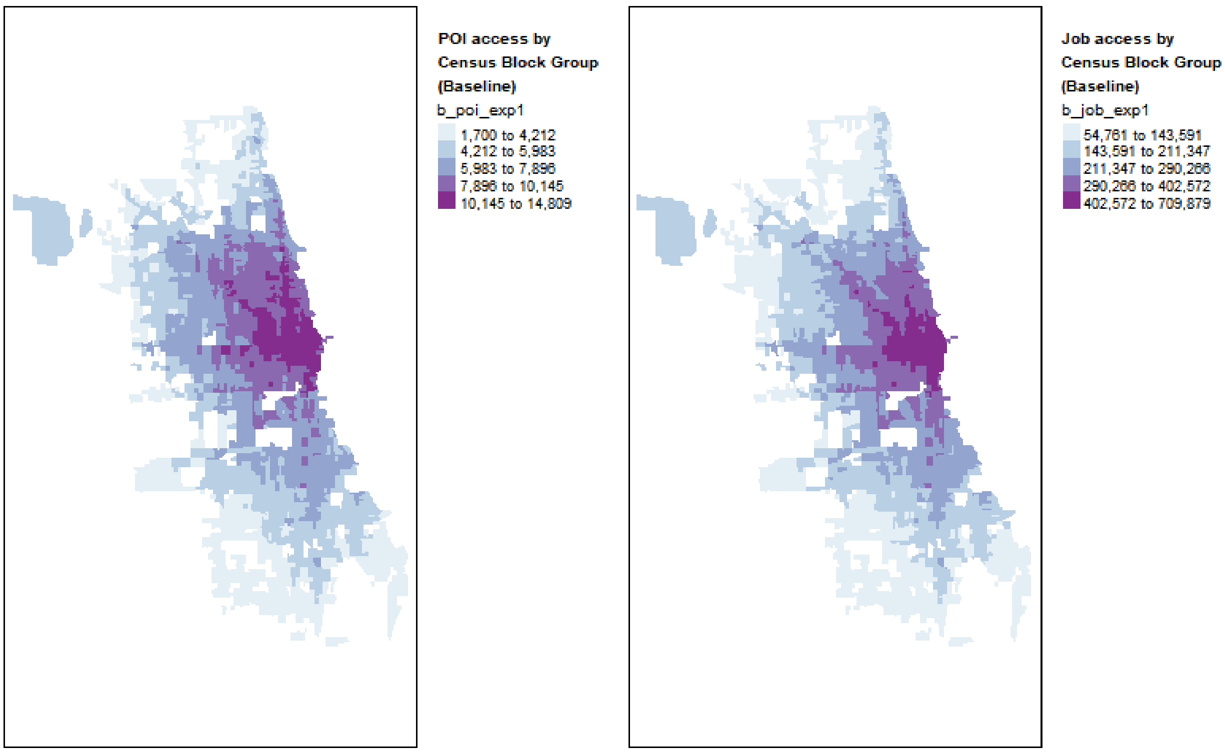


Figure 4: Baseline metric by Census Block Group for POI (left) and jobs (right), grouped using a Jenks classification scheme.[8]

As depicted above, POI and job access are heavily concentrated in the Loop (Chicago's downtown, center right on the map), along transit corridors to the north and northwest, and less so to the west and south. Transit access gradually reduces with distance from the center, reaching

[8] The Jenks, or Natural Breaks, classification scheme divides data points into classes such that the difference between a value and the mean of its class is minimized and the differences between the means of classes are maximized.

a minimum in the suburbs. This is hardly surprising, as POI and jobs are heavily concentrated in and near the Loop. Furthermore, CTA rail lines converge in the Loop, increasing access within the neighborhood and along the radial corridors connected to it (see Figure 2a). It is also evident that job access follows roughly the same distribution as POI access, only at a larger scale. There are no areas with major discrepancies between these two types of access.

Though the exact meaning of the numerical output from the Baseline metric may not seem entirely intuitive, it can perhaps be conceptualized as the effective number of opportunities one can reach from a given Block Group, where each opportunity counts less toward the total if it is harder to reach. In theory, if all other Block Groups could be reached instantaneously from a given point, its Baseline accessibility score would be equal to the total number of POI or jobs in the entire study area. However, because of the impedances of travel time (and other subjective factors, as explored below), this output is always lower.

Notably, the geographic distribution of the Baseline accessibility score is not much different from the distributions exhibited by existing process-based transit access studies in Chicago (e.g., Ermagun & Tilahun, 2020; Tilahun et al., 2016b). This indicates that the Baseline metric does a good job at emulating the methods of those studies, as intended, facilitating comparison and demonstrating that their methods could likely be adapted to account for subjective impedances in a similar manner.

2. *Exploratory Analysis of Subjective Impedances*

To better understand the factors that form the subjective impedance index, and thus the Enhanced metric, the following maps illustrate the distributions of each of the subjective impedances.

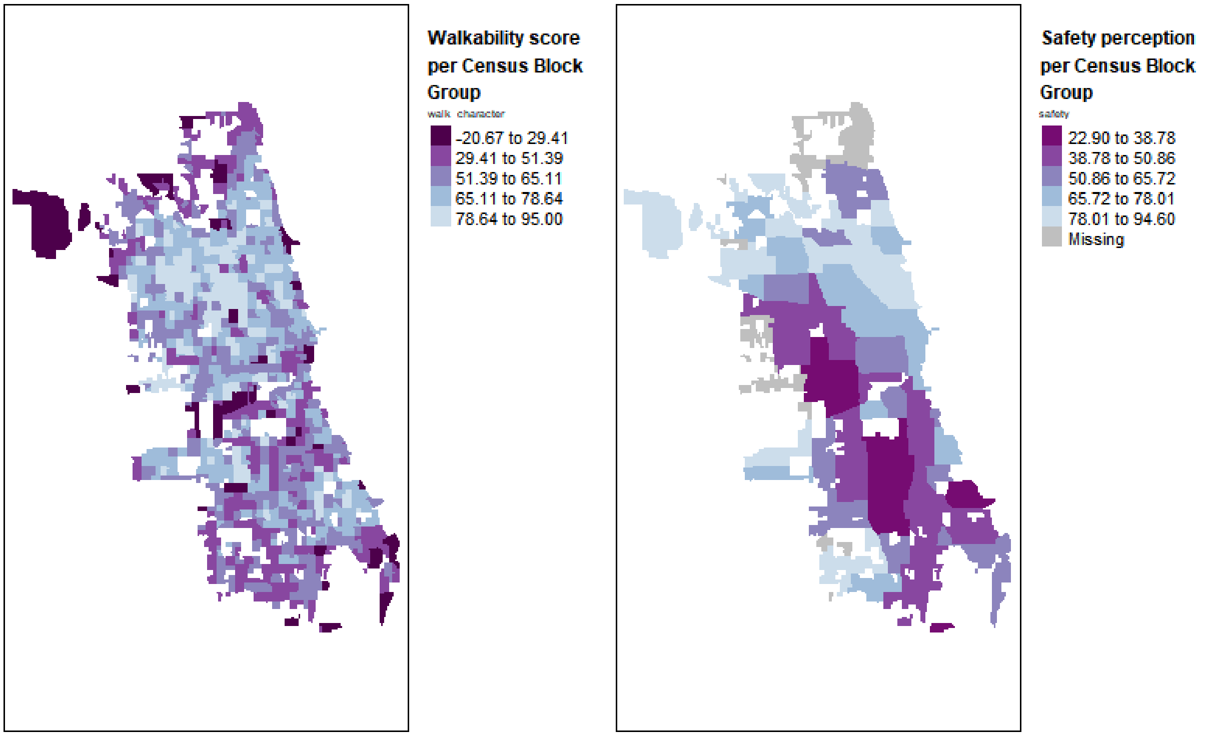


Figure 5: Walkability score (left) and safety perception scores (right) by Census Block Group. The walkability score, created by the Chicago Metropolitan Agency for Planning (2024), combines factors including intersection density, tree cover, and pedestrian fatality rates to determine the quality of the walking environment. Safety perceptions originate from the Chicago Health Atlas (2025) and measure the percentage of residents who feel safe most or all of the time in their neighborhood. Note that darker colors are used to indicate areas with lower scores to indicate greater presence of subjective impedance.

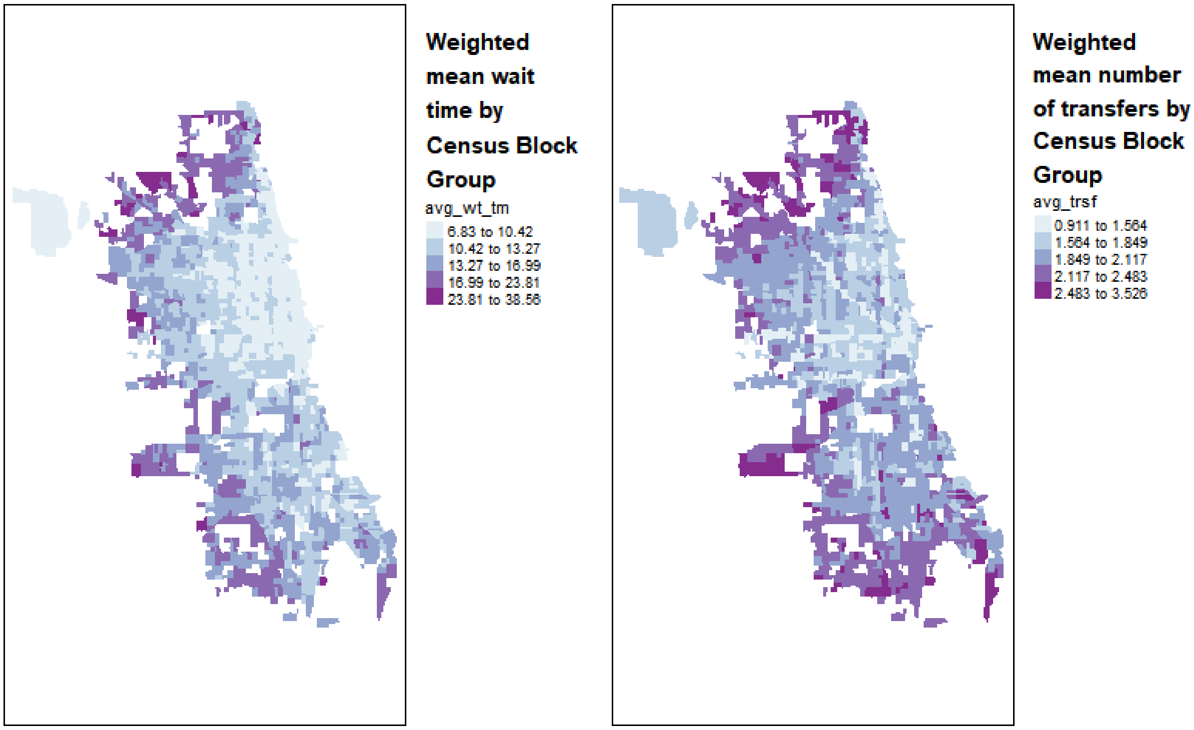


Figure 6: Mean wait times (left) and number of transfers (right) for all routes originating at each Block Group, weighted by the job access score of each route (using POI access score produces a similar result). Wait time is measured in minutes.

While subjective impedances in general follow a similar spatial pattern (lower near the city center and on the North Side and greater on the South Side and periphery), various differences emerge between their distributions as well. For instance, suburban areas on the periphery of the map tend to have transit routes that require a large number of transfers and long wait times but also tend to have better perceptions of safety and mixed levels of walkability. The South Side has poor safety perceptions but moderate values for the other factors. Interestingly, while the Loop serves as the central hub for the many CTA routes, its levels of subjective impedance are mixed, with low wait times and numbers of transfers, but medium levels of perceived safety and walkability impedances. These discrepancies illustrate that subjective impedances are not monolithic; while this analysis combines all four to construct the subjective impedance index, further study is needed on the differing impacts of each one on transit access overall. Furthermore, if studying or improving transit access in an individual area, it is important to distinguish between types of subjective impedances to ensure that they are each addressed appropriately according to local need.

3. *Enhanced metric*

As described above, the Enhanced metric differs from the Baseline metric by its dependence on the subjective impedance index (s_{ij}), the product of the walkability, safety, transfer, and wait time indices. As access is inversely related to travel time and impedance, a higher subjective impedance index yields a lower score. Summary statistics for the Enhanced metric are listed in Table 2 above.

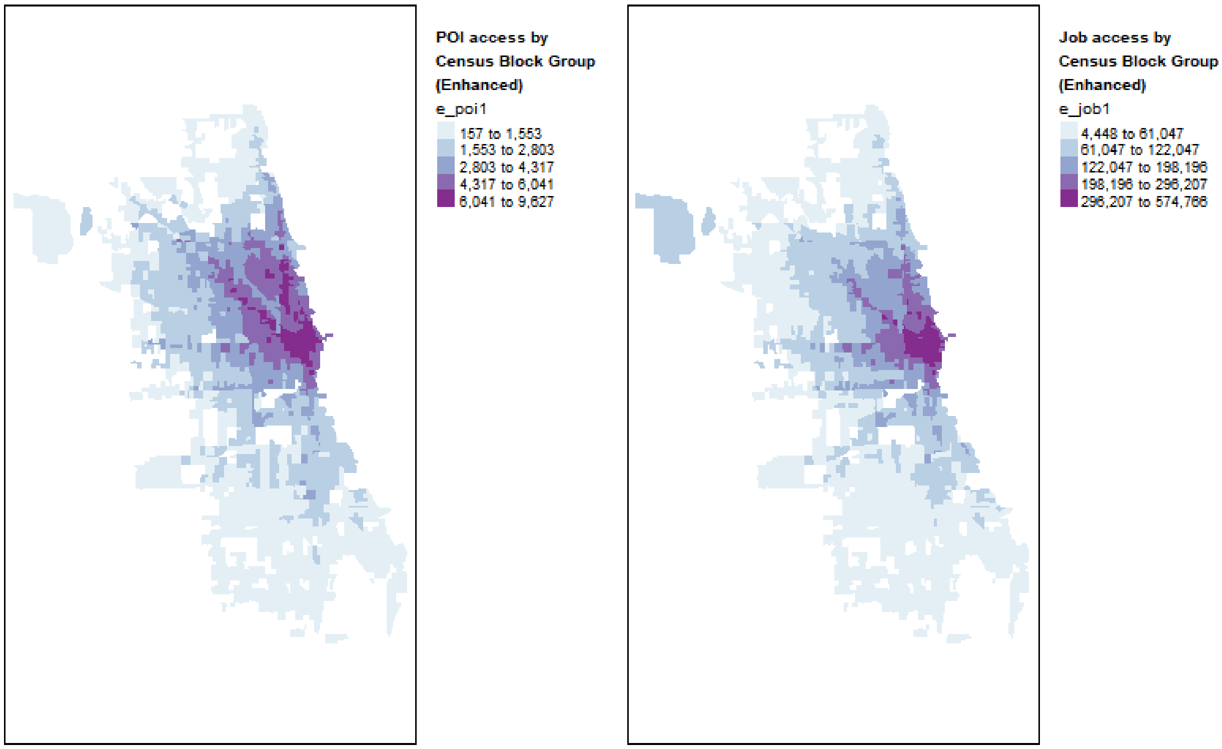


Figure 7: Enhanced metric by Census Block Group for POI (left) and jobs (right), grouped using a Jenks classification scheme.

Though the two maps depicting the Enhanced metric appear similar to the Baseline metric, the differences between the two are more apparent if the ratio between the two is taken, as shown in Figure 8. A higher ratio indicates an area where the Enhanced metric produces a result more similar to the Baseline metric, and thus that process-based methods would likely not overestimate transit access in that area as severely. However, a lower ratio indicates that there is a large gap between the two metrics, and therefore that a process-based method would be insufficient to fully address transit access barriers in that area by not accounting for subjective impedances. Summary statistics for the ratio are also listed in Table 2 above.

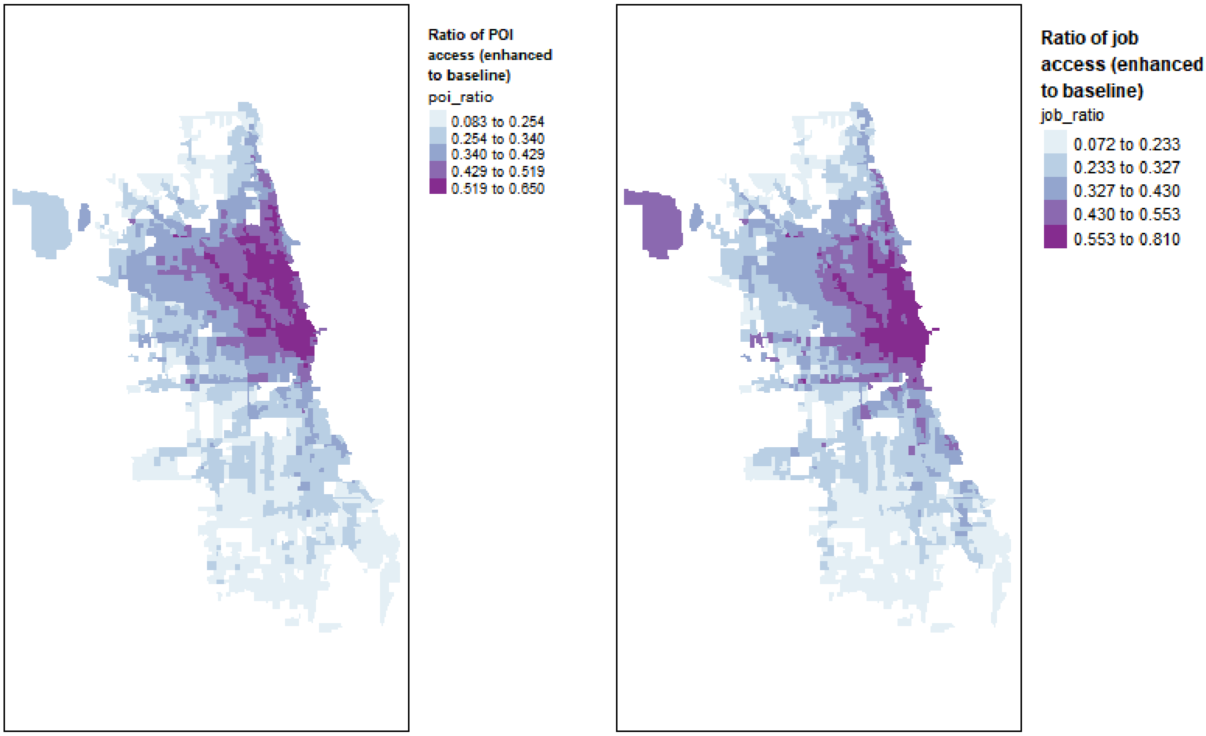


Figure 8: Ratio between Enhanced and Baseline metrics for POI (left) and jobs (right), grouped using a Jenks classification scheme.

The two maps above display similar patterns for the ratio between job and POI access. Both show that the gap between the two access scores is fairly small in the Loop and on the North and Northwest Sides, and to some extent on the West and South Sides. Meanwhile larger gaps are present on the Far South Side and in the suburban areas on the region's periphery. The box plot in Figure 9 shows the distribution of ratio values among Block Groups within each of the six equity zones (see Figure 2b) and the suburbs. Unsurprisingly, ratios are highest in the North/Central, Northwest, and West zones, though more variability is apparent on the West Side, a region that also includes substantial demographic variation (see Figure 11 below).

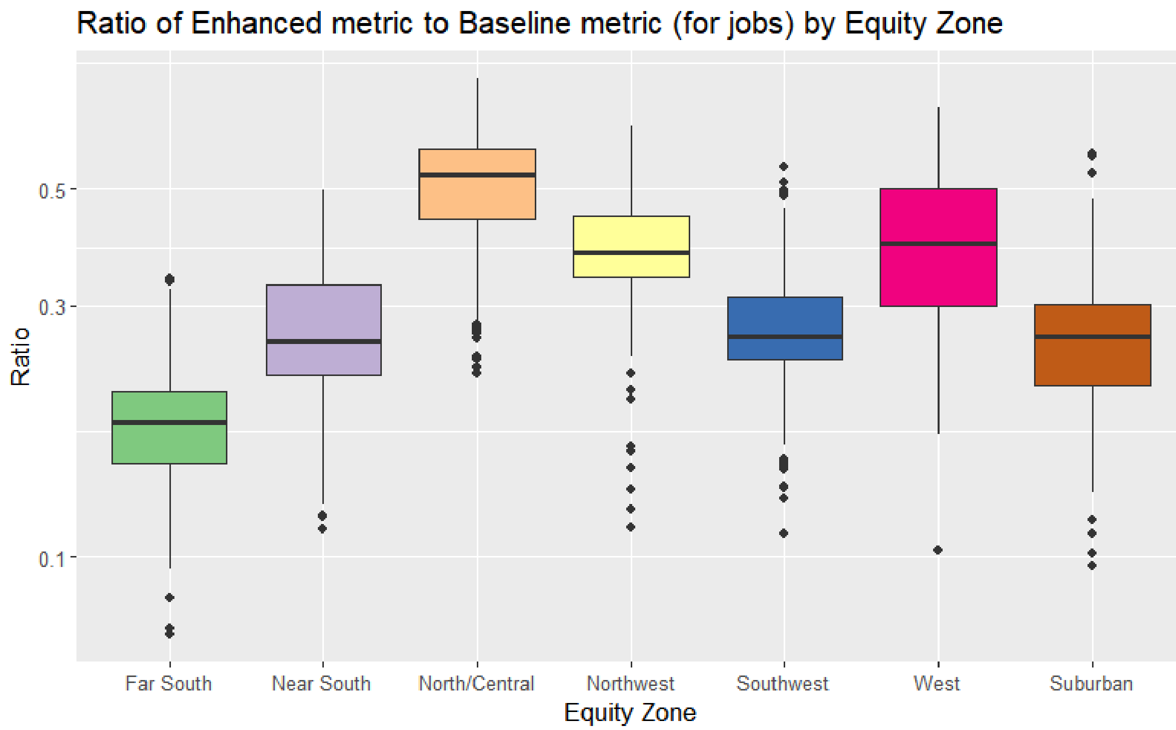


Figure 9: Box plot of ratio by Equity Zone (see Figure 2b). Note that a logarithmic transformation is applied to the y-axis for clarity.

Moreover, a comparison between the ratio variable and the Baseline metric reveals that while access to transit is not equally distributed, the Baseline metric is more likely to overestimate transit access in areas it finds to have lower levels of access. This is illustrated by Figure 10, which shows that Block Groups with low levels of access, as measured by the Baseline metric, tend to have a much smaller ratio (that is, a larger gap) between the metrics. This finding adds to the pertinence of the Enhanced metric, particularly for measuring transit access in Chicago, as it indicates that the impact of subjective impedances is particularly strong in areas that already have relatively low levels of access, thus compounding existing inequalities. It also indicates that interventions to improve transit access should rarely address travel times or subjective impedances alone, as the two are very closely linked.

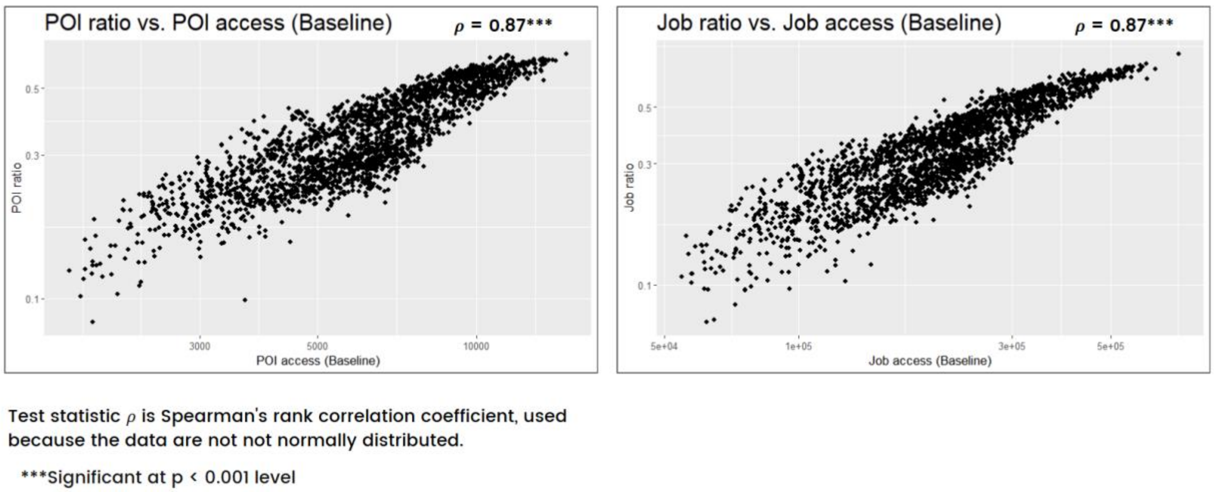


Figure 10: Ratio between Baseline and Enhanced metrics plotted against Baseline access for both jobs and POI. Areas with worse transit access according to the Baseline metric also have lower ratios (wider gaps) between the Baseline and Enhanced metrics, indicating that they coincide with areas more impacted by subjective impedances.

4. Demographic Analysis

The capability of metrics to accurately assess transit access is not only a spatial phenomenon, but a socioeconomic one as well. While studies on Chicago have already established that racial and economic disparities in transit access are significant (e.g., Ermagun & Tilahun, 2020), less is known about whether the metrics used are able to accurately and equitably measure access in the first place. Thus, Census data on the percent Black population, Latine population, and population living below the poverty line are compared to the ratios calculated above. For brevity, only a comparison with the ratio of job access is shown, as the results so far have illustrated that access and ratio values for jobs and POI are very similar.

Figure 11 illustrates the spatial distribution of each of the three demographic variables, with the ratio variable for job access added for context. At a glance, there appears to be some overlap between areas with low job access metric ratios and areas with high Black, Latine, and populations living in poverty, particularly on Chicago's majority-Black Far South Side. However, spatial patterns besides this are hard to discern by visual analysis of maps alone.

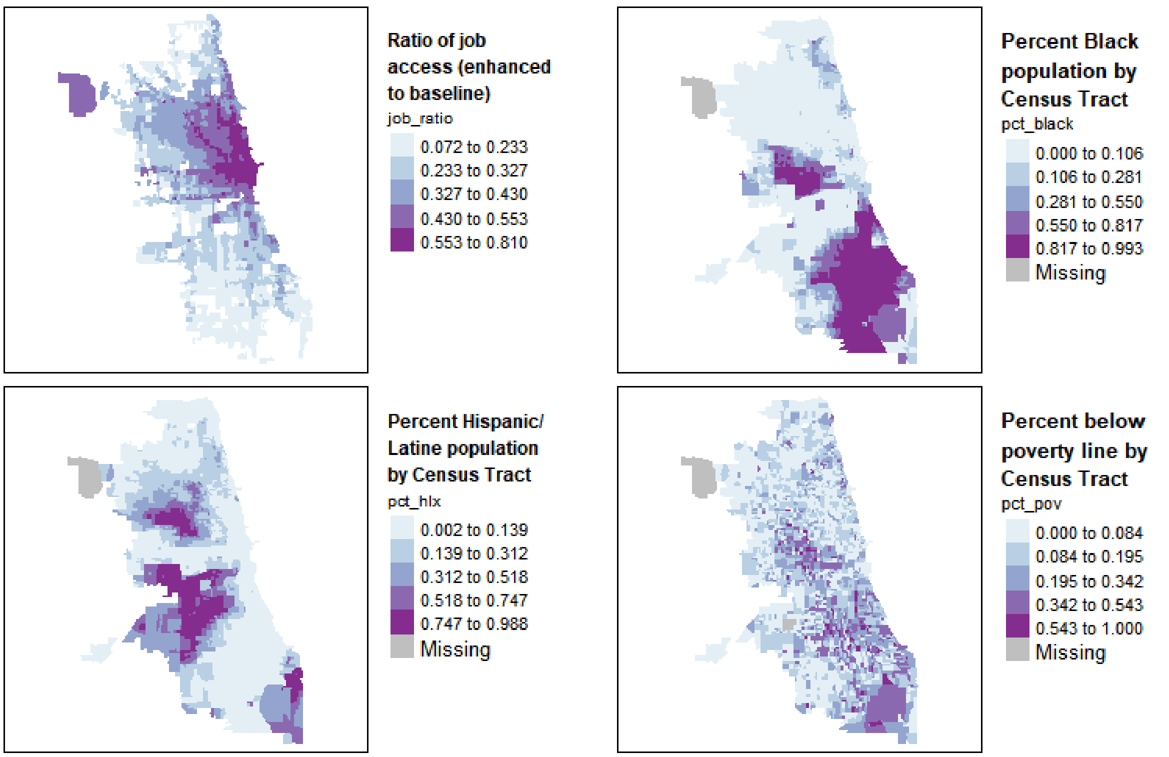


Figure 11: Spatial distributions of the ratio of access scores, percent Black population, percent Latine population, and percent population below the poverty line.

Thus, to more directly observe their interactions, scatter plots comparing each of the three demographic variables with the ratio between transit access metrics (for jobs only) are presented below in Figure 12. Of the three demographic variables, percent Black population and percent below poverty line exhibit a statistically significant negative correlation with the ratio, but percent Latine population does not. This suggests neighborhoods with a higher Black population and higher population below the poverty line are generally not evaluated as accurately by traditional, process-based transit access metrics, likely due to the prevalence of subjective impedances. Therefore, the Enhanced metric of transit access can better account for socioeconomic gaps in transit access, particularly for Black populations and populations living below the poverty line in Chicago.

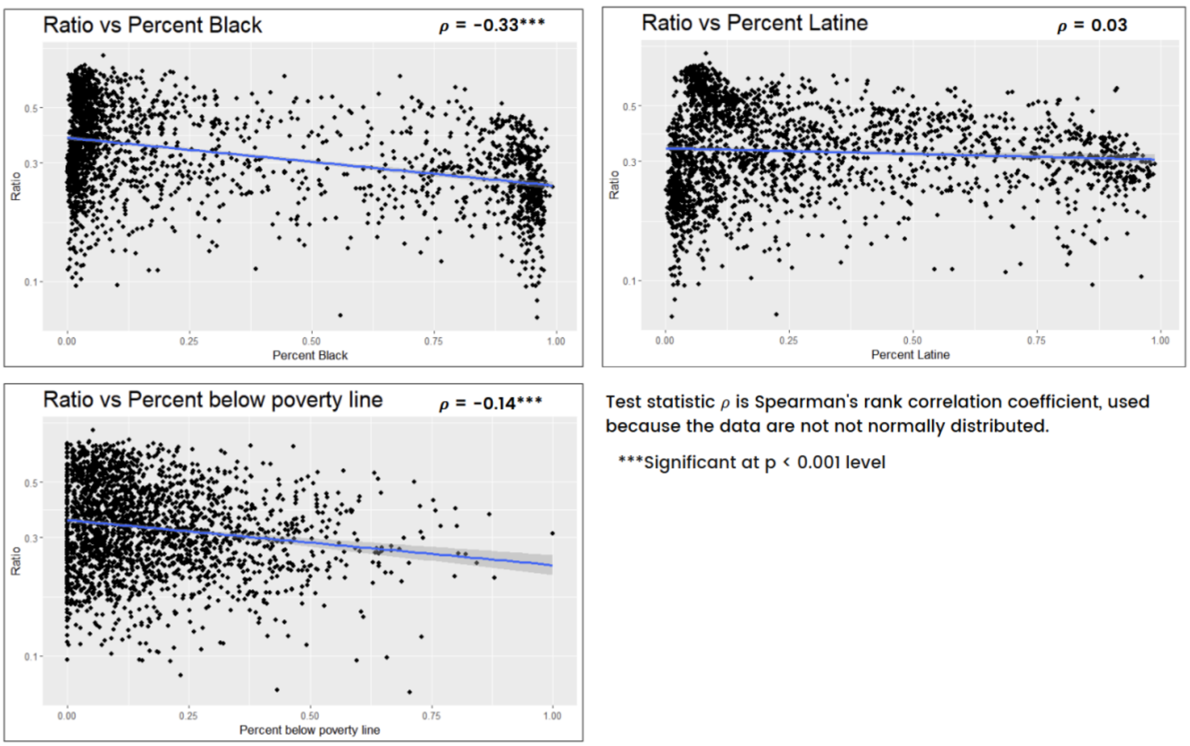


Figure 12: Scatter plots showing the ratio of access measures (for job access) and all three demographic variables.

However, while there is no statistically significant correlation present between the ratio of the metrics and percent Latine population, this result should be interpreted with caution. Though it does indicate that process-based metrics likely do not measure access among Latine populations less accurately overall, Latine populations in certain areas may still be negatively impacted by the lack of consideration for human experience in process-based methods. After all, there are still many Block Groups with high Latine populations and wide gaps between access metrics (Figure 12). Furthermore, high transit accessibility or ability to measure access in one area does not counterbalance poor accessibility or ability to measure access in another.

Accordingly, a local analysis on the interaction between each of the demographic variables and the metrics ratio is conducted using a Local Indicators of Spatial Association (LISA) test, as shown in Figure 13. This test is used to identify Block Groups with high Black, Latine, or populations living in poverty that are surrounded by clusters of Block Groups with low ratio values (referred to as a high-low cluster), where process-based metrics are likely to overestimate transit access. As might be expected, high-low clusters are highly prevalent for Black populations and populations living below the poverty line on the South and Far South Sides. However, there also appears to be a sizeable region of clustering among Block Groups with high Latine populations and low ratio values on the Southwest Side. While overall, process-based metrics are perhaps no more likely to overestimate access in Block Groups with high Latine populations, Block Groups with high Latine populations on the Southwest Side tend to coincide with regions where the gap between the metrics does indeed tend to be fairly large. Therefore, locally, certain Latine communities are disproportionately affected by this gap, even if Latine populations do not tend to be overall.

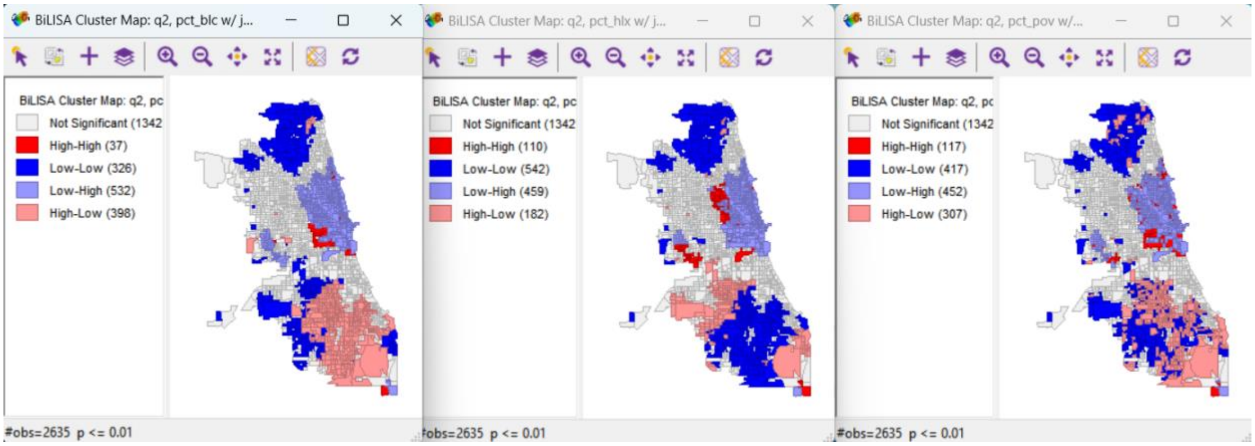


Figure 13: Bivariate Local Moran's I analysis of demographic variables (from left to right: percent Black, percent Latine, and percent living below the poverty line) and the ratio between the access metrics in surrounding Block Groups. [9] High-low clusters are of greatest interest and indicate areas with high populations of the demographic group of interest and low ratio values (that is, a wider gap between the two metrics).

5. *Discussion: Equity and Justice*

The Enhanced transit access metric discussed in the previous section provides a novel way of conceptualizing transit access that combines the benefits of existing process- and outcome-based methods. By incorporating data on subjective impedances, the Enhanced metric reveals a much lower level of transit access on the Far South Side and along the CTA service area's periphery than a traditional process-based method might detect. This alone indicates a degree of *inequality* in the efficacy of process-based methods to accurately measure transit access.

[9] The Bivariate Local Moran's I test is conducted using a second-order queen contiguity weight, verified by sensitivity analysis to not greatly impact the resulting distribution. A significance filter of 0.01 is applied to avoid unnecessary noise while still being able to illustrate the overall spatial pattern of clustering. Finally, 999 permutations are run for each test to ensure that results are not an artifact of insufficient randomization.

However, this study is further concerned with the *equity* and *justice* of transit access and its measures. As illustrated by the demographic analysis above, the limitations of existing transit access metrics are inequitably distributed as well; the Baseline metric tends to overestimate transit access to a greater degree in Block Groups with higher Black population and population living below the poverty line, as well as for Latine populations locally on the Southwest Side. These findings indicate that, through an equity lens, future transit improvements should focus on improving transit access for those populations, not only by reducing travel times to destinations, but by mitigating transit outcomes like long wait times and poor walkability as well. It is somewhat encouraging that the CTA is currently planning on improving transit access on the Far South Side, an area consistently found to have the greatest transit deficiencies and inequities in this study, through the current Red Line Extension project (Chicago Transit Authority, n.d.). The project plans to extend rapid transit down to Chicago's southern border by 2030, adding four new transit stops in neighborhoods greatly underserved by transit. However, if the subjective impedances in the area found by this study are not addressed alongside the transit extension project, crucial barriers to achieving transit equity may remain.

However, the use of an equity lens has several problematic consequences. Though equity does account for differences in need among historically marginalized populations, outcomes are still relational; a distribution is considered equitable if a marginalized group receives the resources needed to ostensibly "catch up" to other groups, but such a distribution does not necessarily indicate whether their actual needs, which may be greater or entirely different, are being met. For instance, if access to a resource among a marginalized group is 1.25 times higher than average, though researchers and planners may consider this ratio to be equitable by virtue of it being greater than 1, the group may in fact need 1.5 times more access than average in order to achieve equal access in resources, or may require other resources entirely. Similarly, gaps between the metrics, even if on par with the city as a whole, may indeed leave critical deficiencies in transit access unaddressed, which could affect populations that are highly reliant on transit more severely. Furthermore, equitable transit access and metrics may be impossible to achieve in food and resource deserts, where grocery stores or other important destinations are not available anywhere nearby, an issue particularly pertinent on Chicago's South Side (Lowe et al., 2023), and thus improvements to transit alone would be insufficient to achieve transit equity. Therefore, though one could infer from the results of this study that equity has been achieved in the distribution of the ratio variable among Latine populations in Chicago overall (see Figure 12), process-based metrics alone may still be insufficient for addressing transit access among Latine populations. More research is needed to determine what an equitable distribution of transit access, or the ability of metrics to measure it equitably, should look like.

Another problematic conclusion one could draw is that equity is achieved if low-income and nonwhite populations have greater access to transit than wealthy, white populations. While this might make sense from an equity standpoint, it fails to question whether it is just for modes of transportation to be segregated by race or class in the first place. Furthermore, low transit access in wealthy, car-dependent areas can in fact pose barriers to mobility for lower-income, transit-dependent individuals who may want to visit, work in, or move to wealthier neighborhoods, requiring them to either purchase a car or pay for expensive alternatives to be granted entry. This disparity simply reinforces segregation and inequalities in physical and economic mobility, even if public transit resources are plentiful in areas with higher marginalized populations. Moreover, the lack of availability of public transit in wealthy, suburban areas also encourages suburbanites to drive more on the numerous highways routed through majority-Black neighborhoods in the mid-20th century in the name of "urban renewal," disproportionately polluting those neighborhoods with car exhaust and road dust in the process (Rothstein, 2018). Without consideration for the historical and contemporary injustices perpetuated by suburbanization, white flight, and urban renewal, such a system may indeed be ostensibly viewed as equitable. Therefore, the framework of justice may perhaps be more apt for evaluating transit access and its metrics, due to its more broad and historically contextualized scope.

Thus, in order to achieve transportation justice, methods that are more reflective of human experiences like the one demonstrated by this study are needed, though not sufficient alone. Transit improvement projects and policies should not rely solely on the findings of large-scale quantitative studies but should ensure that their proposals are grounded in historical and local context as well. Further study of personal needs, preferences, and experiences that studies like this cannot account for, in a manner similar to Lowe et al. (2023), is needed as well.

V. Conclusion

This is not the first study to demonstrate that transit access in the Chicago region, or another city, is unequally distributed (e.g., Ermagun & Tilahun, 2020). However, by including data on subjective impedances, including walkability, perceptions of safety, wait times, and number of transfers, this study has demonstrated how current methods of evaluating transit access can be improved upon and better grounded in human experience. These subjective impedances are directly based on literature on transit outcomes, such as Lowe et al. (2023), who find that factors like safety and walkability weigh heavily on people's willingness to take transit.

This study demonstrates that incorporating lived experience into transit metrics has several benefits. First, it bridges the divide between process-based and outcome-based studies by incorporating many of the findings of the latter into the former. This follows through with many of the recommendations for future research presented, but not operationalized systematically, by outcome-based studies. Second, it illustrates the large and unequal gaps that can emerge between the two methods. These gaps not only reveal a major limitation of process-based studies but also reveal geographic inequalities in their ability to accurately measure transit access. Transit access on Chicago's Far South Side and nearby suburbs, areas already deficient in transit access, is particularly overestimated if subjective impedances are not taken into account. This also indicates that subjective impedances play a relatively large role in inhibiting transit access in such areas, and therefore that future transit improvement initiatives in those localities should focus not only on decreasing travel times but on improving factors like walkability and wait times as well. By comparing the distribution of this gap with distributions of Black, Latine, and populations living in poverty, it is further revealed that historically marginalized groups are particularly susceptible to this overestimation of access. This indicates that traditional, process-based metrics are unable to fully account for the history of segregation and transit disinvestment that has impacted their neighborhoods. Finally, by shifting the focus of analysis away from equity and towards justice, it is shown that higher levels of transit access (and ability to measure access) in neighborhoods with high marginalized populations, and lower levels in other neighborhoods, may not always be a favorable outcome, especially if residents' actual needs are not being met or if segregation between neighborhoods is reinforced as a result.

However, this study has some notable limitations that should not be overlooked. The subjective impedance data used, while based heavily on human subject research that point to their significance, are not sourced directly from actual transit users but from data characterizing the transit system itself and its environment. Though the selected data sources are grounded strongly in the literature and have been demonstrated to greatly impact transit access, they still cannot fully encapsulate the entirety of human experience. Data on additional subjective impedances should be incorporated in future iterations, as well as other factors impacting access left unaccounted for by process-based metrics, such as delays and system unreliability. Future studies that relate transit access metrics to human experience could also benefit from systematically surveying transit users (and nonusers who would take transit if it were more accessible) to create a more grounded measure of subjective impedance. This way, the measured transit outcomes would be better accounted for and more relevant to actual people's needs.

Furthermore, needs and abilities can vary greatly among transit users. Future iterations of this study should analyze how impedances to access differ for transit users who cannot climb stairs or cannot walk as far or as fast to reach transit, as well as for women and gender minorities for whom safety on public transit can be of heightened concern. Rather than combining all jobs and points of interest into monolithic groups, future iterations should also measure access to varying categories of destinations that users may want or need to reach, such manufacturing jobs or mental health clinics, each of which could have greatly different spatial distributions and levels of access. Competition for access to resources like jobs is one factor of access that could not be addressed in this study due to time and data constraints but has been shown to greatly impact transit access (eg. Tiznado-Aitken et al., 2021) and should thus be considered for further study.

A further simplification is the exclusion of Metra and Pace, bus and commuter rail services that primarily serve the suburbs of Chicago, from the analysis in order to avoid overwhelming complexity. For instance, it would be particularly difficult to account for transfers between the three systems, or to combine schedule data, as each have separate reporting schemes. Nevertheless, an important consideration for future studies is the inclusion of multiple transit networks in an area, especially if they can serve as alternative routing options when transit access with another service is poor. Furthermore, the inclusion of other transit networks could be used to better identify gaps in transit and transit access methodology in suburban areas, and how these gaps differ between suburbs of different socioeconomic status.

Finally, one limitation pertaining to transit access research in general is that issues of accessibility to destinations may not be a matter of insufficient transit alone, but of the distributions of destinations themselves. In Chicago's many food deserts, for instance, the primary concern for improving accessibility of grocery stores should be bringing stores into the area, rather than increasing transit capacity to stores on the outside (Lowe et al., 2023). As transit access is inherently tied to the accessibility of destinations, this limitation is unavoidable. However, measures of transit access are still useful for identifying areas most in need of transit improvements, which can be completed in tandem with programs that bring grocery stores or other resources into an area.

This study alone cannot perfectly encapsulate the full potential of combined transit access measures. The methodology it puts forth is not immutable but rather provides a framework to be improved upon and contextually adapted as necessary. The author's aim is to provide a cogent demonstration of this framework, with the hope that more transit accessibility researchers consider the implications of the methods they deploy, and further, that the rigid barrier in the literature between process- and outcome-based transit access studies begins to fall.

VI. References

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VII. Appendix

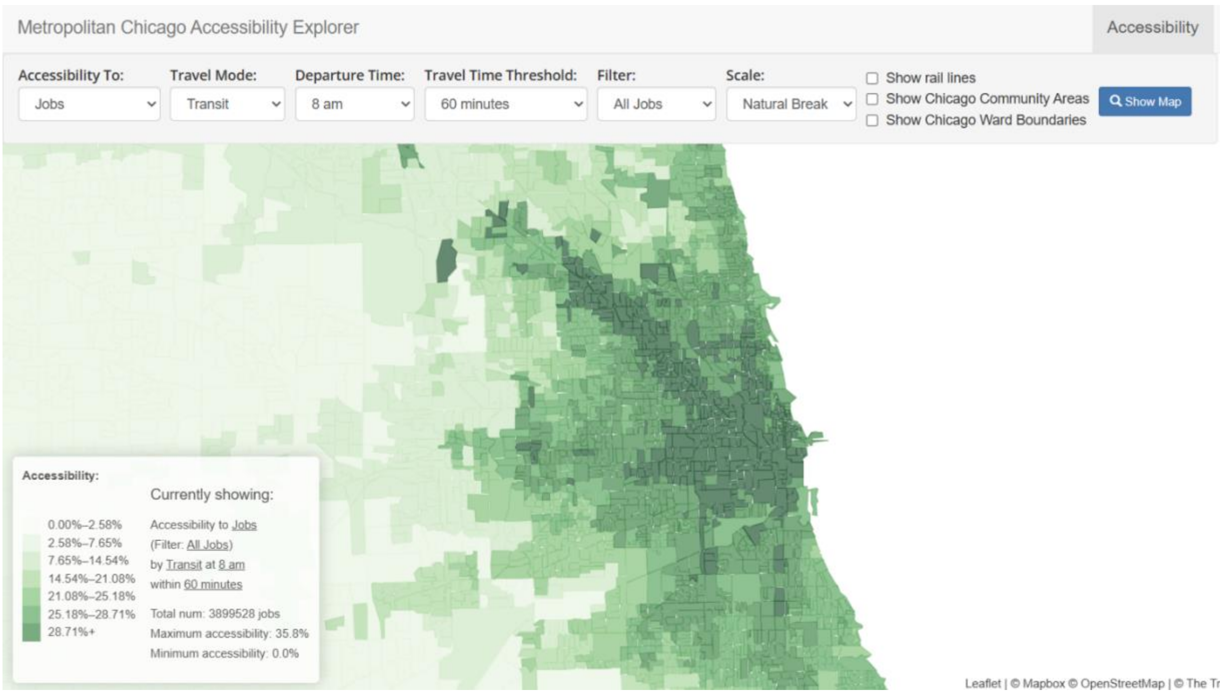

Figure A1: A screenshot of the Metropolitan Chicago Accessibility Explorer (MCAE) from before it was taken down (Tilahun et al., 2016b). Accessibility scores are determined by the percentage of jobs in the study area that can be reached by transit within a given time band, in this case 60 minutes. Drop-down menus near the top of the page can be used to calculate accessibility based on different parameters such as departure time or type of destination (including grocery stores, libraries, and other points of interest). As of May 5th, 2025, information on the tool can still be accessed at https://udv.lab.uic.edu/our-work/collaborations/metropolitan-chicago-accessibility-explorer/.