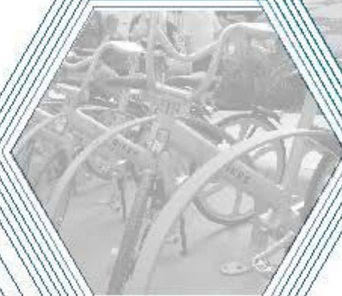

Integrating Transportation Management Companies (TMCs) and Public Transportation

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FINAL REPORT

Center for Transportation Equity, Decisions & Dollars

Integrating Transportation Management Companies (TMCs) and Public Transportation

FINAL PROJECT REPORT

by

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16. Abstract

Emerging technologies have given rise to Transportation Management Companies (TMCs), which deliver on-demand services via a customer-facing smartphone app. The expansion of wireless communication technology promises continued growth for ride-sourcing, and presents both challenges and opportunities in integrating these services into the transportation system (Middleton, 2010). Currently, the primary work linking on-demand service to public transportation focuses on the provision of both first- and last-mile trips (Clifton and Muhs, 2012). This study analyzes an expanded role for integrating TMCs into public transit linking the public and private sectors and providing greater accessibility through increased connectivity and coordinated service delivery. This integration requires a framework that facilitates and supports a public-private partnership. We examine the potential impact of this integration on transit services in an American context. Selected benefits include enhanced transit ridership, expanded access to employment, cost savings, and new revenue opportunities for transit agencies and private TMCs. This project examines the benefits of on-demand ride service from three aspects: 1) The extent that on-demand TMC services influence job access, 2) How this job accessibility varies spatially across different populations, and 3) How the cost-effectiveness of TMC services compares to traditional transit and what funding mechanisms might improve synergies between the two. This study focuses on the City of Chicago, and explores the impact of TMCs on accessibility to jobs and other amenities. With assumptions about average wait time of TMCs ranging from 1 to 12 minutes, the results of different scenarios suggest that TMC availability and trip lengths that TMCs can be used are the two more dominating factors influencing the extent to which accessibility can be improved. The accessibility improvement is most significant for areas with lowest existing accessibility and has no obvious difference across different population subgroups. Lastly, policy implications and potential funding and financing strategies of realizing the accessibility and equity benefits of integrating TMCs with transit are discussed.

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Abstract

Emerging technologies have given rise to Transportation Management Companies (TMCs) which are frequently referenced as Transport Network Companies (TNCs) that deliver on-demand services (for e.g. Uber and Lyft). These companies provide app-based services that link passengers and drivers and charge passengers automatically. The expansion of broadband services promises continuing growth for ride sourcing and presents both challenges and opportunities in integrating these services into the transportation system. This research analyzes an expanded role for integrating TMC's into public transportation, linking the public and the private sector, providing greater mobility through increased connectivity and coordinated service delivery. This integration requires consideration of the role of the Federal Transit Administration (FTA) and a framework that facilitates and supports a public private partnership (PPP). We examine the potential impact of this integration on the provision of transit services. Selected opportunities include enhanced transit ridership, expanded access to employment opportunities, cost savings, expanded accessibility for transit -dependent and riders with disabilities, new revenue streams and business models, enhanced ridesharing and service improvement across multiple sectors through shared mobility because of the greater integration of TMCs in transit services. The research project examines the potential of dynamic on-demand ride service from three primary aspects: (1) to what extent can the integration of TMCs with transit influence accessibility to employment centers and urban amenities; (2) how does the influence of accessibility vary spatially across different population groups, especially for transport-disadvantaged population; and (3) how does the cost-effectiveness of such integration compare to the existing transit system and what funding and financing mechanisms might be considered to improve the supportive role of dynamic on-demand ride service. The results suggest that using TMCs to serve short trips either connecting to/from transit or single modal trips can substantially elevate the existing level of job accessibility and accessibility to various types of urban amenities in the City of Chicago. With assumptions about average wait time of TMCs ranging from 1 to 12 minutes, the results of different scenarios suggest that TMC availability and trip lengths that TMCs can be used are the two more dominating factors influencing the extent to which accessibility can be improved. The accessibility improvement is most significant for areas with lowest existing accessibility and has no obvious difference across different population subgroups. Lastly, policy implications and potential funding and financing strategies of realizing the accessibility and equity benefits of integrating TMCs with transit are discussed.

Introduction

Background

For decades, people have relied on driving for mobility in most American cities. The vast difference between the mode shares of driving and alternative transportation modes has not only resulted in the lack of capacity on most American roads and highways, it has spawned the lack of funding for constructing infrastructure of all other modes. Subway, bus, paratransit, bike infrastructure, and sidewalk, have suffered from lack of funding and investment, many of which should have become the main travel options in cities, especially for the ones who cannot drive. Urban accessibility and mobility are impaired, on one hand, by the increasing level of traffic congestion, and on the other hand, by the lack of travel options especially for the physically or economically disadvantaged groups of people.

Innovations in information and vehicle technologies have given birth to transportation management companies (TMCs) and shared autonomous vehicles that marry the shared economy and autonomous cars is around the corner. These dynamic TMCs share similarities with both private and public mobility options but also differ from both (TRB Special Report 319, 2016). On one hand, these dynamic TMCs can serve point-to-point and flexible time schedules so they are able to mimic the convenience of driving. On the other hand, they are publicly available and do not require automobile ownership, so they also provide the merit of fixed-route public transportation. Also, the dynamic TMC differs from existing modes of driving and fixed-route public transportation, as it is request-based and the wait time and cost may vary given different real-time condition, information, and geographic locations. Wang & Ross, (2017) found that the taxi in New York City has been playing a paratransit role by disproportionately serving low-income, disabled, and retired/elderly population and it has a multifaceted relationship with fixed-route public transportation: the taxi may replace transit trips, complement transit trips by serving the route or time that transit does not serve, or serve the first/last miles of transit trips. TMCs may have the potential to further enlarge supportive role of taxis and it is critical to understand the benefits and challenges of integrating TMCs into transit services and our normal transportation planning processes.

Although accessibility to employment and amenities has long been a focus of transportation planning literature, there are few studies that examined the potential impact of TMCs on accessibility. The recent work by (Boarnet, Giuliano, Hou, & Shin, 2017) found that changing mode of access and egress to and from stations is more effective at improving transit access to low-wage jobs than policies that reduce transit wait time or improve service headway. Though the understanding of the potential impact of TMCs on accessibility is limited, computation methods of accessibility and equity have been improved substantially in recent years. The accuracy and time-sensitivity of accessibility computation has been substantially improved with the availability of detailed transit operations data such as the General Transit Feed Specification

(GTFS) and fine-grained work/residence data such as the Longitudinal Employer-Household Dynamics (LEHD) (Farber, Morang, & Widener, 2014; Karner, 2018). Also, the advancement of computational power such as easy application of parallel running has facilitated faster calculation of travel time between fine-grained origin-destination pairs. This research uses publicly available datasets and new accessibility calculation methods to forecast the potential impact of TMCs on accessibility and transit service equity. By estimating the potential accessibility and equity benefits of TMCs in the City of Chicago, the research also identifies potential funding and financing mechanism to facilitate the integration of TMCs with public transportation to realize those benefits. Policy and practical implications about how to leverage this rapidly growing travel mode to improve transportation benefits and reduce the conflicts between shared mobility and mass transit are examined.

Existing Literature and Gaps

Accessibility, a core concept of city and transportation planning, has been widely studied theoretically and empirically. The definition of accessibility takes assorted forms with consideration from different perspectives that date back to the 80's (Ben-Akiva & Lerman, 1979; Dalvi & Martin, 1976; Geurs & Wee, 2004). Accessibility is one of the most effective indicators that captures transport benefits and can be effectively measured. Previous literature focuses on accessibility by car, but the recent literature has paid more attention on accessibility across all travel modes and the closely related equity implications.

Compared to accessibility that is a holistic and more objective measurement of the performance of transportation systems, transport equity measures how accessibility is distributed across different population groups. In recent years, there have been increasingly more studies on examining if transit accessibility is equitably distributed across different population groups (Foth, Manaugh, & El-Geneidy, 2013). The most important merit of public transport is its role in providing mobility and accessibility to the population without other travel mode options. It also serves as a key component in addressing issues like poverty, unemployment, and equal opportunity goals (Blumenberg & Manville, 2004; Fan, Guthrie, & Levinson, 2010; Rast, 2004; Sanchez, 1998).

TMCs can have substantial impact on transit accessibility but the influence of TMCs on accessibility is rarely studied. On the one hand, TMCs can serve the first/last mile of fixed-route transit. Though there is concern that the growth of TMCs may take away transit usage, TMCs can also serve as an access/egress mode of public transportation. Wang & Ross, (2017) found that about eight percent of the taxi trips in New York City are taken to access/egress subway stations. Though both accessibility and the first/last mile transit access have been widely studied, there is limited research that integrates both. Boarnet et al., (2017) developed a seminal study on estimating how transit station access can influence low-wage job accessibility and showed that changing the mode of access and egress to/from stations is effective at improving transit access. On the other hand, if the expense is acceptable, TMCs can be used to serve origin-to-destination trips with flexible routing. Accessibility by driving is often times better than accessibility by transit, due to the limited transit network and low level of service that make travel time by transit much longer than driving travel time in most American cities. Boarnet et al., (2017) found that low-wage job accessibility by car is almost 30 times larger than low-wage job accessibility by public transportation in the San Diego region. Since TMCs are publicly available, using TMCs provide an opportunity to integrate accessibility by car into improving transit accessibility.

There are few studies on the potential impact of TMCs on accessibility, but the literature on measuring accessibility of different modes and the influence of transportation improvement on accessibility provide evidence and examples of how this question may be approached. Geurs & Wee (2004) provides a thorough review of accessibility measures and **Table 0-1** summarizes different factors that will influence the transportation and individual components of accessibility. Thus, the influence of TMCs on accessibility could be measured by estimating its influence on these factors, such as travel speed, congestion level, travel time/cost of different modes, utility of travel by individuals etc.

Table 0-1: Factors that Influence Transport Accessibility

Measures	Transport component	Individual component
Infrastructure-based measures	Travel speed; vehicle-hours lost in congestion	Trip-based stratification, e.g. home-to-work, business
Location-based measures	Travel time and/or costs between locations and activities	Stratification of the population (e.g. by income, educational level)
Person-based measures	Travel time between locations of activities	Accessibility is analyzed at individual level
Utility-based measures	Travel costs between locations of activities	Utility is derived at the individual or homogeneous population group level

(*Source*: Revised from Geurs & Wee (2004))

Regarding measuring and quantifying accessibility, earlier studies have focused on identifying the factors and metrics. Geurs & Wee (2004) provides a thorough review of accessibility measures and summarize different factors that will influence the transportation and individual components of accessibility, such as travel speed, congestion level, travel time/cost of different modes, utility of travel by individuals etc. Nassir, Hickman, Malekzadeh, & Irannezhad, (2016) develop a thorough literature review about quantifying accessibility and particularly transit accessibility. As Nassir et al. (2016) summarized, transit accessibility is defined in a similar fashion as accessibility, with the only difference that the mode of travel is restricted to public transportation and the impedance is thus calculated based on the transit network. Estimating transit travel time is an important step in transit accessibility, and most previous studies used regional travel model to estimate travel time by transit (Welch, Gehrke, & Wang, 2016). However, these travel models' result may not be easy to obtain, which makes it a challenge for estimating transit accessibility. The recent advancement of estimating transit travel time, facilitated by the availability of General Transit Feed Specification (GTFS) data, has enabled a lot easier estimation of transit travel time (Farber et al., 2014; Karner, 2018). Karner, (2018) developed time-sensitive fine-level transit accessibility and equity analysis using only publicly available data sources, including GTFS data and the US Census Bureau's Longitudinal Employer-Household Dynamics dataset.

Recent literature focuses more often on defining and measuring transport equity, which can be taken as a related concept to accessibility. Compared to accessibility that is a holistic and more objective measurement of the performance of transportation systems, transport equity measures how accessibility is distributed across different population groups. In recent years, there have been increasingly more studies on examining if transit accessibility is equitably distributed across different population groups (Foth et al., 2013). The most important merit of public transport is its role in providing mobility and accessibility to the population without other travel mode options. It also serves as a key component in addressing issues like poverty, unemployment, and equal opportunity goals (Blumenberg & Manville, 2004; Fan et al., 2010; Rast, 2004; Sanchez, 1998). Using data from Statistics Canada in 1996 and 2006, Foth et al. (2013) examined the transit accessibility and equity in Toronto comparing the socially disadvantaged group and the rest of the population. They found that Toronto has a generally equitable transit system as the most socially disadvantaged census tracts have statistically significantly better accessibility and lower transit travel times relative to the rest of the region in both 1996 and 2006. Fan et al., (2010) examined the level of job accessibility by categories before and after several transit improvement projects in the Twin Cities, using the LEHD dataset. By examining the change of low-wage, medium-wage, and high-wage jobs within 30 minutes travel time by transit before and after the projects, they concluded that the Hiawatha light-rail line has generated significant job accessibility benefits for all types of workers.

There are numerous studies on defining and measuring transport accessibility and equity, since both are complicated concepts that are associated with different transportation, land-use, temporal, and individual factors. As an emerging and increasingly popular travel mode, TMCs will inevitably influence accessibility and transport equity. Although existing literature has provided numerous approaches concerning how accessibility and transport equity can be measured, little is known about the potential impact of TMCs and its magnitude. The potential influence of TMCs is an important to better understand to shed light on future policy and regulations concerning this new travel mode.

Research Objectives

This proposed research project examines the potential of TMCs, from three aspects: (1) to what extent TMCs can influence accessibility to employment centers and amenities; (2) how the influence on accessibility may vary spatially and across different population groups, especially for transportation disadvantaged population; and (3) how the cost-effectiveness of dynamic TMCs compare to existing transit system and what funding and financing mechanisms should be considered to improve the supportive role of dynamic TMCs. This research project takes the City of Chicago as a case study and examines the operation of taxis and TMCs compared to transit and how TMCs may influence mobility, accessibility, equity, and cost-effectiveness under different operating scenarios. The project points to important implications on funding and financing mechanism that can enhance the TMCs service and improving the integration of TMCs into transit services.

Corresponding to three research objectives, the methodology also has three components. In the first component, we evaluate the existing level of accessibility to employment centers and other public amenities provided by the transit system in the City of Chicago and then estimate how the TMCs may change the accessibility level across different spatial locations. Accessibility is defined by Geurs & Wee, (2004) as "the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)". We will focus on evaluating transit accessibility in this project, which will be measured as the number of jobs or amenities one can reach within certain time thresholds by transit. The TMC service is expected to influence transit accessibility in two ways. On one hand, TMCs may serve as a connection mode to existing fixed-route public transportation, which will enlarge the catchment areas of the current transit system. On the other, being publicly available, TMCs can serve any route or time as request-based public transit and thus the magnitude of its influence on transit accessibility will largely depend on the availability and operation of TMCs.

Thus, the first component of the methodology consists of two steps. In the first step, we employ the General Transit Feed Specification (GTFS) data, Longitudinal Employer-Household Dynamics (LEHD) data, and other GIS data sources that provides the location of public amenities, such as schools, parks, hospitals, and so on, to evaluate the existing level of accessibility to employment centers and amenities provided by the transit system in Chicago. In the second step, we estimate how TMCs can change the accessibility level at different locations. The accessibility by TMCs will be calculated as the number of destinations (employment or amenities) that can be reached within certain time of travel, so estimation of the travel time by TMCs is critical. We develop twelve scenarios that reflect different future possibilities of using TMCs and estimate how accessibility will be changed under each of the scenarios. More details about how the scenarios are constructed are illustrated in the second chapter of this report.

The second methodological component addresses the equity effects of the TMCs' influence on accessibility. Public transportation has a critical role in providing mobility and accessibility to transportation disadvantaged population. Wang & Ross, (2017) found that about 59.5% of the taxi trips in the New York metropolitan area are made by people who are either disabled, low-income, elderly, retired or unemployed, indicating the significant role that taxis play in providing mobility to the physically and economically disadvantaged population. Given the ability to serve flexible origin-destination pairs, TMCs can effectively enlarge the service area of paratransit and probably at lower cost. Therefore, in the second component, we further the accessibility analysis to develop transit service equity analysis by examining how the TMCs' influence on accessibility vary across different population groups. More specifically, we are going to use the LEHD data to locate people of different age groups and income levels and examine how the accessibility to employment centers and other amenities will be changed under different operation scenarios of TMCs.

The third research objective focuses on policy, funding, and financing strategies to better integrate TMCs into transit services and requires in-depth examination of the cost-effectiveness of TMCs and the potential funding and financing strategies. The capital and operation cost of TMCs are not publicly available and the cost may vary significantly given different fleet sizes. The cost-effectiveness of TMCs are examined based on some fundamental assumptions about vehicle operation cost and drivers' compensation expenses by reviewing existing information and data. The capital and operation cost of public transit is available from the National Transit Database (NTD) of Bureau of Transportation Statistics. Relying on estimating the cost of TMCs and transit and analyzing the mode shares at the census tract level using the American Community Survey (ACS) data, the cost-effectiveness of TMCs and transit are compared by calculating their average cost per passenger trip miles. This comparison facilitates better understanding about which areas are TMC-effective vs. transit-effective, to inform transit-related investment and decision-making in future.

The last objective of this research reviews the existing funding and financing mechanisms at the federal, regional, and local level and develops a policy framework that can be applied to incorporating TMCs into future transit funding and financing considerations. Having realized the merit of TMCs of providing access to transit, some transit agencies have already been working with TMCs and providing fare discounts to encourage multimodal transit trips. For example, in Atlanta, Uber offers discounted UberPOOL rides to MARTA stations and Lyft offers 50 percent off on Lyft Line rides to or from MARTA locations during commuting hours (Vejnoska, 2017). While serving the first/last mile of transit trips is only part of the merit that TMCs can provide regarding improving accessibility and equity, subsidizing TMCs trips connecting to transit stations is the first step to incorporating this new travel mode into transit services. We review the existing funding and financing criteria and policies to summarize the strategies that can be applied to future considerations of incentivizing TMCs operations. Policy implications are derived based on the analytical results of how TMCs may influence accessibility, equity, and cost-effectiveness of the transit system in Chicago. Nevertheless, the policy implications can be generalized to be easily applied to other regions to support the integration of TMCs with public transportation to elevate the mobility and accessibility that the transport systems can provide.

Report Outline

The report has eight chapters including this first Introduction chapter. Detailed methodology and data sources are illustrated in Chapter 2. In the third chapter, the current transit accessibility to employment and urban amenities in the study area is evaluated and visualized. Chapter 4 presents the results of estimating accessibility change in the twelve scenarios. Chapter 5 presents the analytical results of how the accessibility impact varies across different population groups. In Chapter 6, the cost-effectiveness of integrating TMCs to public transit is evaluated and compared with the cost-effectiveness of using shuttle bus as feeder service to mass public transit (trains). Chapter 7 summarizes the potential funding and financing strategies to facilitate the integration of TMCs to public transit. The report concludes with Chapter 8 that highlights the findings and policy implications of this research.

Methodology and Data

This chapter provides detailed information about the data sources and processing in the analysis steps. The methodology is composed of two primary sections. The first section estimates accessibility to employment and amenities for Chicago residents strictly using the existing transit network. It also describes equity-related variations. The second section estimates accessibility to employment and amenities for Chicago residents using an TMCs system to extend the existing networks. TMC-supplemented estimates are based on scenarios for an TMCs regime that the research team created.

The data supporting the analysis comes from a variety of local, national, and private sources, which are discussed after the methodology. All analyses are conducted for land within the boundaries of the City of Chicago, IL. The spatial unit of analysis is the census tract.

Data

Transit Data

The transit network for the City of Chicago is composed of three networks: trains and buses operated by the Chicago Transit Authority, Metra commuter rail, and Pace Suburban Bus service. Routes and schedules for each are provided for 2017 using the General Transit Feed Specification (GTFS) protocol from the sources described in **Table 0-1**.

Table 0-1: Data Sources of Transit Systems Routes and Schedules

System	URL
Chicago Transit Authority	http://www.transitchicago.com/developers/gtfs.aspx
Metra	https://metrarail.com/developers
Pace Suburban Bus	https://www.pacebus.com/sub/about/data_services.asp

Residential Data

Resident characteristics are used to segment the population into age and income subgroups for the equity analysis. Residential data is provided by the U.S. Census Bureau's 2015 Longitudinal Employer-Household Dynamics (LEHD) database. Commute origins and destinations are paired using the LEHD Origin-Destination Employment Statistics (LODES) dataset version 7 (LODES 7). The LODES 7 dataset provides Residential Area Characteristics (RAC) for each block which can be aggregated to the census tract level for our analysis.

Employment Data

Employment data for each census tract is provided by the LODES 7 dataset, which provides Workplace Area Characteristics (WAC) for each block which can be aggregated to the census tract level for our analysis. In this research, we follow the definition in LODES 7 to define low-wage, medium-wage, and high-wage jobs as well as low-, medium-, and high-income workers. The definitions are shown in **Table 0-2**.

Table 0-2: Job and Worker Categories by Wage/Income

Job Categories	Definition	Workers Categories	Definition
Low-wage jobs	Jobs with earnings $1,250/month or less	Low-income workers	Workers with earnings $1,250/month or less
Mid-wage jobs	Jobs with earnings $1,251/month to $3,333/month	Mid-income workers	Workers with earnings $1,251/month to $3,333/month
High-wage jobs	Jobs with earnings greater than $3,333/month	High-income workers	Workers with earnings greater than $3,333/month

Urban Amenities

In addition to employment, urban amenities are another type of destinations that travelers need to reach. Understanding the impact of TMCs on accessibility to urban amenities is important. Residents may need or desire different urban amenity features. They make seek out some of these amenities regularly (e.g., grocery stores), while others such as hospital may elicit infrequent visits. Yet, residents who have closer access to better urban amenities can live with a higher quality of life than they otherwise would. Chicago residents' access to these amenities is estimated to detect disparities in service provision and quality of life in the city.

Table 0-3 describes the data sources of urban amenities. Locations and characteristics of most urban amenities are collected from the City of Chicago's GIS database, either in shapefile form or as addresses that were geocoded. Locations of colleges and universities are also collected from the

U.S. Geological Survey. Amenities were reviewed for reasonableness and in some cases slightly modified. For example, the grocery store database included convenience and liquor stores in addition to grocery stores with fresh foods. A build floor area threshold of 4,000 square feet was determined through trial and error to eliminate most convenience stores and alcohol vendors while retaining most vendors of fresh food. Therefore, any stores below 4,000 square feet were removed from the database.

Table 0-3: Data Sources of Urban Amenities

Amenity	Organization	Year	URL	Units
Colleges and Universities	United States Geological Survey	2010	https://www.sciencebase.gov/catalog/item/4f4e4acee4b07f02db67fb39	Count
Grocery Stores (over 4,000 sq. ft.)	City of Chicago	2013	https://data.cityofchicago.org/Community-Economic-Development/Map-of-Grocery-Stores-2013/ce29-twzt/data	Count
Hospitals	City of Chicago	2011	https://data.cityofchicago.org/Health-Human-Services/Hospitals-Chicago/ucpz-2r55	Count
Libraries	City of Chicago		https://data.cityofchicago.org/Education/Libraries-Locations-Hours-and-Contact-Information-/wa2i-tm5d	Count
Parks	City of Chicago	2017	https://data.cityofchicago.org/Parks-Recreation/Parks-Shapefiles/6wd3-bgii/data	Park area

TMCs Data

Taxi trips from the City of Chicago were collected at the Census Tract level from a 2015 and 2016 dataset released by city government (City of Chicago, 2016) and available at GitHub (Schneider, 2017). Uber fares were estimated from base, per mile, per minute, service fees, and minimum fares for Uber X service as reported by UberEstimate.com for the City of Chicago (Uber Estimate, 2017).

Calculation Steps

The following calculations were performed for the existing transit system and for scenarios with transit-supplementing TMCs service.

Employment Accessibility

Accessibility to employment is calculated using Equation 1, which is a hybrid of a cumulative opportunity and gravity measure of accessibility, suggested by the literature (Karner, 2018). When the accessibility index is higher, it means that Chicago residents in a given census tract can reach more jobs within a shorter commute time by transit. All opportunities within the 50 minutes are weighted equally but those further away have smaller weights. The best travel time by transit and/or TMC T_{ij} is calculated for each pair of census tracts located in the study area.

$$A_i^w = \sum_j E_j^w * e^{-\beta * T_{ij}} \qquad \text{(Equation 1)}$$

Where,

A_i^w = Accessibility at census tract *i* for employed residents (workers) with wage level *w*;

E_j^w = Jobs in census tract j with wage level *w*;

T_{ij}= Travel time (minutes) by transit and/or TMC between census tract *i* and census tract *j*;

β = Empirically derived impedance term: β = 0.021 if $T_{ij} > 50$; β = 0 otherwise.

Travel time T_{ij} by transit between all Chicago census tract pairs is calculated in three steps.

Step 1) Service areas of all the transit stops are developed. A service area of a transit stop represents the area that transit stop serves, so service areas are developed differently for each scenario. In the base scenario, the service areas are developed as 0.5-mile (network distance) area from a transit stop while in Scenario 1, the service areas are developed as 1-mile (network distance) area from transit stops. Details about how the scenarios are constructed are illustrated in Section 0.

Step 2) In each of the scenarios, transit stop pairwise travel times are calculated using the ArcGIS Network Analyst with the GTFS data. The transit network dataset is constructed using GTFS data and the tool "Add GTFS to a Network Dataset" (Morang, 2014) in ArcGIS. The GTFS data allows estimation of transit travel time between any origin-destination pair for specified trip departure time. We randomly select 10 departure time points between 7am to 9 am on a normal Tuesday and calculate travel time by transit for each transit stop pair. Then we use the average of the 10 travel times as the travel time for transit stop pairs.

Step 3) For each pair of census tracts, we used a searching script to find travel times between all possible pairs of transit stops whose service areas intersect with the census tracts; then we estimated the travel time by walking or by TMCs to access the corresponding transit stops on both ends of the trip; then we calculated the final travel time between census tract pairs as the sum of travel time between transit stop pairs and the corresponding accessing/egressing time; finally we searched for the minimum of the travel time between a census tract pair as the best travel time used for calculating accessibility.

Subsequently, the accessibility indexes are calculated for four job categories: all jobs, low-wage jobs, mid-wage jobs, and high-wage jobs. Equation 1 describes the calculation of the accessibility index, which uses the number of jobs by income category from the LEHD data and the empirically derived β. The impedance term is derived using the Chicago Regional Household Travel Inventory 2007 (CRHTI) data by fitting an exponential line against the trip frequency by transit travel time for commuting trips and is estimated as 0.021. The average commuting travel time by transit in the Chicago metropolitan region is 50 minutes, so it is assumed that propensity to travel by transit decreases only when the travel time exceeds 50 minutes. This explains why β equals to zero in Equation 1 for travel times at or below 50 minutes. The accessibility indexes are computed for all scenarios to estimate the influence of using TMCs to serve first/last mile of transit on accessibility and equity.

Urban Amenities Accessibility

Accessibility to urban amenities is estimated similarly to employment accessibility and the index is calculated as shown in Equation 2. When the accessibility index is higher, it means that Chicago residents in a given census tract can reach more of certain type of amenities within a shorter commute time by transit. All opportunities within the 45 minutes are weighted equally but those further away have smaller weights.

$$A_i = \sum_j U_k * e^{-\beta * T_{ij}} \qquad \text{(Equation 2)}$$

Where—

A_i = Urban amenity accessibility at census tract *i;*

U_k = The quantity of a specific type of urban amenity k (**Table 0-3**);

T_{ij}= Travel time (minutes) by transit and/or TMC between census tract *i* and census tract *j*;

β = Empirically derived impedance term: β = 0.024 if $T_{ij} > 40$; β = 0 otherwise.

Similarly, for estimating accessibility to urban amenities, the travel time T_{ij} by transit between all Chicago census tract pairs is calculated in three steps.

Step 1) Service areas of all the transit stops are developed. A service area of a transit stop represents the area that transit stop serves, so service areas are developed differently for each scenario. In the base scenario, the service areas are developed as 0.5-mile (network distance) area from a transit stop while in Scenario 1, the service areas are developed as 1-mile (network distance) area from transit stops. Details about how the scenarios are constructed are illustrated in Section 0.

Step 2) In each of the scenario, transit stop pairwise travel time are calculated using the ArcGIS Network Analyst with the GTFS data. The transit network dataset is constructed using GTFS data and the tool "Add GTFS to a Network Dataset" (Morang, 2014) in ArcGIS. The GTFS data allows estimation of transit travel time between any origin-destination pair for specified trip departure time. We randomly select 10 departure time points between 7am to 9 pm on a normal Tuesday and calculate travel time by transit for each transit stop pair. Then we use the average of the 10 travel times as the travel time for transit stop pairs.

Step 3) For each pair of census tracts, we used a searching script to find travel times between all possible pairs of transit stops whose service areas intersect with the census tracts; then we estimated the travel time by walking or by TMCs to access the corresponding transit stops on both ends of the trip; then we calculated the final travel time between census tract pairs as the sum of travel time between transit stop pairs and the corresponding accessing/egressing time; finally we searched for the minimum of the travel time between a census tract pair as the best travel time used for calculating accessibility.

Subsequently, the accessibility indexes are calculated for five types of urban amenities: (1) colleges and universities, (2) grocery stores, (3) hospitals, (4) libraries, and (5) parks. Equation 2 describes the calculation of the accessibility index, which uses the quantity of certain type of urban amenities and the empirically derived β. The impedance term is derived using the Chicago Regional Household Travel Inventory 2007 (CRHTI) data by fitting an exponential line against the trip frequency by transit travel time for non-commuting trips and is estimated as 0.024. The average non-commuting travel time by transit in the Chicago metropolitan region is 40 minutes, so it is assumed that propensity to travel by transit decreases only when the travel time exceeds 40 minutes. This explains why β equals zero in Equation 2 for travel times at or below 40 minutes. The accessibility indexes are computed for all scenarios to estimate the influence of using TMCs to serve first/last mile of transit on accessibility and equity.

Equity-Related Variations in Access

Accessibility is calculated for age and income subgroups. Population subgroups are formed based on income and age as they are the two important factors associated with different travel needs. There are three income-based subgroups corresponding with low, medium, and high income. Age is divided into two subgroups for seniors and non-seniors. Income levels are defined using the definition in the LODES 7 data as shown in **Table 0-2**. Senior residents are defined as those who are 65 years old or elderly.

Scenarios

It is not known exactly what form a TMCs regime will take in the future. Therefore, several reasonable scenarios are created that vary along travel distance and wait-time dimensions. There are 12 scenarios in all as a function of three possible wait time futures and four possible monetary cost futures. The scenarios are described in **Table 0-4** and detailed in the following subsections. The scenarios are developed mainly based on two parameters, wait time and travel distance of TMCs. TMCs are different from fixed-route public transportation, mainly because of three reasons: it serves point-to-point, has varying wait time rather than fixed headway, and has fluctuating cost based on travel distance, travel time, and other factors. Wait time and travel distance (rather than cost) are used to construct the scenarios mainly for two reasons. First, the cost of TMCs is still fluctuating and may see significant changes in the future if automated vehicles become available. Second, accessibility is intrinsically associated with how many destinations can be reached, so travel distance directly influences accessibility given fixed land use patterns and using different travel distance assumptions to construct the scenarios captures the impact of TMCs more fundamentally. For trips by TMCs, the travel time can be decomposed into in-vehicle travel time and wait time. In-vehicle travel time is simply the same as travel time by driving, so wait time is the major factor that influence the level of service of TMCs.

Table 0-4. Twelve Scenarios of TMCs

Wait Time Varies →

Travel Distance Varies ↓

	Even wait time (mean = 6 min)	Wait time varies by demand (mean =6 min)	Even & shorter wait time (mean = 3 min)
Access to transit <= 2 miles; Single mode trip <= 4 miles.	Scenario 1	Scenario 5	Scenario 9
Access to transit <= 1.5 miles; Single mode trip <= 3 miles.	Scenario 2	Scenario 6	Scenario 10
Access to transit <= 1.25 miles; Single mode trip <= 2.5 miles.	Scenario 3	Scenario 7	Scenario 11
Access to transit <= 1 mile; Single mode trip <= 2 miles.	Scenario 4	Scenario 8	Scenario 12

TMC Distance Thresholds

Distance thresholds are used to approximate monetary cost because it is unknown both how much TMCs service will cost and how much an average rider will be willing to pay. Using distance thresholds allows for a standard unit to serve as a stand-in for monetary costs. Two different thresholds are provided for each cost scenario: access mode and single mode trip. The access mode threshold provides the number of miles that a traveler is willing to take TMCs to access transit, while the single mode trip threshold provides the distance that a traveler is willing to take TMCs to access a destination (without transit).

Existing TMCs service by Uber serves as a model for relative user costs. Uber is an appropriate model because it accounts for non-mile-based variations that are likely to exist in any TMCs system, such as pick-up fees or service charges. The four distance thresholds correspond with potential cost scenarios including low-cost (50% of normal), normal cost, higher-cost (150%

of normal), and much higher surge cost (200% of normal). Calculation for the normal cost threshold is described below, and other thresholds are derived multiplicatively.

For Scenarios 1, 5, and 9, it is assumed that TMCs can be used for a trip up to 2 miles when it is used as an access/egress mode to transit, while it can be used for a trip up to 4 miles when it is serving origin to destination directly. Similarly, for Scenarios 2, 6, and 10, it is assumed that the maximum distance of transit-accessing/egressing trip is 1.5 mile while the maximum of a single modal trip is 3 miles. For Scenarios 3, 7, and 11, the maximum distance of an accessing/egressing trip is 1.25 mile while the maximum for a single modal trip is 2.5 miles. For Scenarios 4, 8, and 12, it is assumed that the maximum distance of transit-accessing/egressing trip is 1 mile while the maximum of a single modal trip is 2 miles. These two types of assumptions, including (1) the travel distance that TMCs can be used for accessing transit and (2) the travel distance that TMCs can be used for single modal trips, correspond to the two ways that TMCs can affect accessibility as mentioned before: (1) TMCs may serve as a connection mode to existing fixed-route public transportation, which will enlarge the catchment areas of the current transit system; and (2) being publicly available, TMCs can serve any route or time as request-based public transit. Developing these different assumptions about the travel distances that TMCs can be used for can reflect the potential cost constraints of using TMCs.

Wait Time

Wait time assumes three forms. The first form is a **standard, uniform** wait time for pick-ups in all census tracts. The wait time by taxis and the currently existing TMCs operators (Uber and Lyft) was used as a model for the likely wait times under a future TMCs service. Although there is no official release of current TMCs wait times, six minutes is a reasonable wait time based on several sources (Fang He & Shen, 2015; Jung, Jayakrishnan, & Park, 2013; Lambert, 2016). Therefore, scenarios 1 through 4 assume a uniform six-minute wait time.

The second wait time form is **demand-based**. Wait time could vary as a function of the density of demand for TMCs service. Accordingly, census tracts with greater demand density have shorter wait times than census tracts with lower demand density. Taxi pick-up data for the City of Chicago was used to estimate the TMCs demand density. Census tracts are divided into three categories based on demand. Over a third of census tracts have no taxi pick-ups in the Chicago taxi data, and they are assigned to the group with the longest wait time. The remaining census tracts are divided into two evenly sized groups for low wait time (most pick-ups) and medium wait time (fewer pick-ups) as a function of demand. Groups are used rather than assigning wait times directly as a function of pick-up numbers because the pick-up numbers are strongly skewed towards lower pick-up numbers. Within each group, census tracts are randomly assigned wait times between given boundaries, described in

Table 0-5. Wait times are randomly assigned to account for real-life variability. The wait times are set to maintain a citywide average wait time of 6 minutes. Demand-based wait times are applied to scenarios 5 through 8.

Table 0-5: Wait Time Definitions

Group	Number of Census Tracts	Lower Wait Boundary	Upper Wait Boundary
Short Wait Time	146	1 minute	4 minutes
Medium Wait Time	147	4 minutes	6.5 minutes
Long Wait Time	508	6.5 minutes	8 minutes

The final form is **short, uniform** wait times of 3 minutes, which are applied to scenarios 9 through 12. This form assumes an increase in the number of vehicles serving TMCs compared with taxis and/or technological improvements that allow the TMCs operator to more quickly serve customers.

Evaluating Existing Accessibility in Chicago

Chicago has three transit operators. Chicago Transit Agency (CTA) operates 129 bus routes with 1,536 route miles, while CTA train cars operate 8 routes on 224 miles of track (CTA, 2017). Metra operates 10 routes radiating from the downtown Loop area (Regional Transportation Authority, 2018). As visible in Figure 0-1, Pace stops are mostly limited to areas outside of the city limits, with a few in the cities' core. While the CTA bus and rail routes terminate at or near the city limits, Metra routes extend much farther.

Using the General Transit Feed Specification (GTFS) data allows us to estimate precise stop-to-stop time-sensitive travel time by transit. As described in Chapter 2, for estimating accessibility to employment, we randomly generated 10 departure time within the morning peak hour (7am – 9am) and compute the average peak-hour stop-to-stop travel time by transit. Similarly, for estimating accessibility to urban amenities, we randomly generated 10 departure time in between 9am – 9pm to compute the average stop-to-stop travel time. Although some of the stops are located outside the City of Chicago's boundary, all the transit stops of CTA, Metra, and Pace stops are considered in this analysis to avoid incorrect travel time estimation because of the exact boundary delineation. For example, even if a transit stop is located outside the city boundary, the transit stop may still be the one that provides the fasted travel time to some area within the city. Therefore, over 34 thousand transit stops of all lines run by CTA, Metra, and Pace are included in the analysis.

In the base scenario that considers the existing transit accessibility level, we assume that people are willing to walk for up to 0.5 mile to access or egress a transit stop. The travel time by walking is estimated by dividing the network pedestrian travel distance by an average walking speed of 3 miles per hour. With this assumption, the travel time by transit between any census tract pairs in the City of Chicago can be estimated. There are 801 census tracts in Chicago and thus there are 641,601 census tract pairs. For some of the census tract pairs, their travel time by transit are extremely long, as there are no transit lines that directly connect those census tracts. Therefore, in this research, we focus on census tract pairs with travel time less than 200 minutes and any pairs with travel time longer than 200 minutes are considered as 'inaccessible'. Among the 641,601 census tract pairs, 43,411 pairs' average travel time by transit are less than 200 minutes. Figure 0-2 presents the histograms of the number of census tract pairs by five-minute bins of average transit travel time in peak hours and non-peak hours in the City of Chicago. Among the 43,411 census tract pairs, the average peak-hour transit travel time is 33.4 minutes while the average non-peak hour transit travel time is 33.6 minutes. The maximum travel time by transit is about 70 minutes.

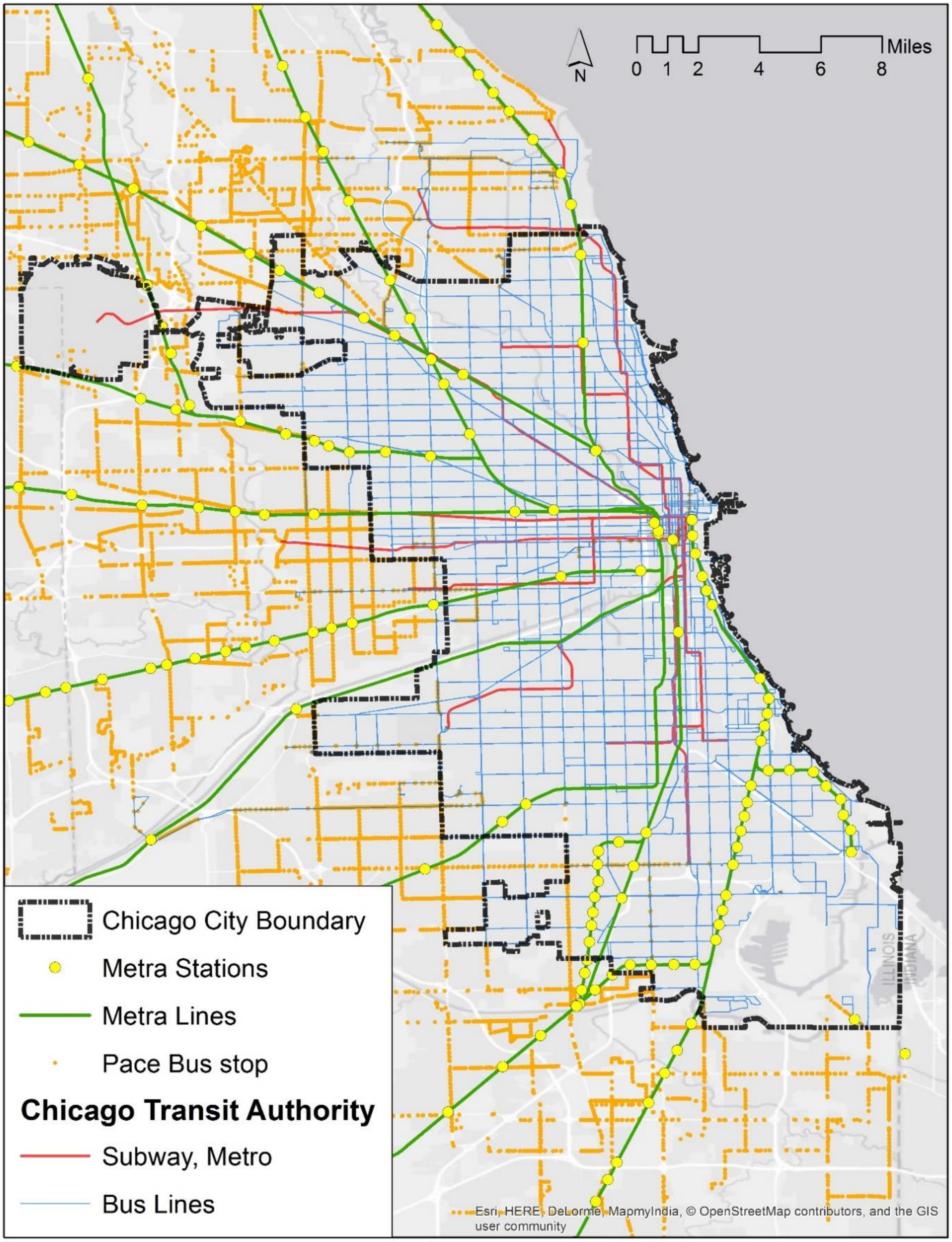

Figure 0-1: Transit in and Around the City of Chicago

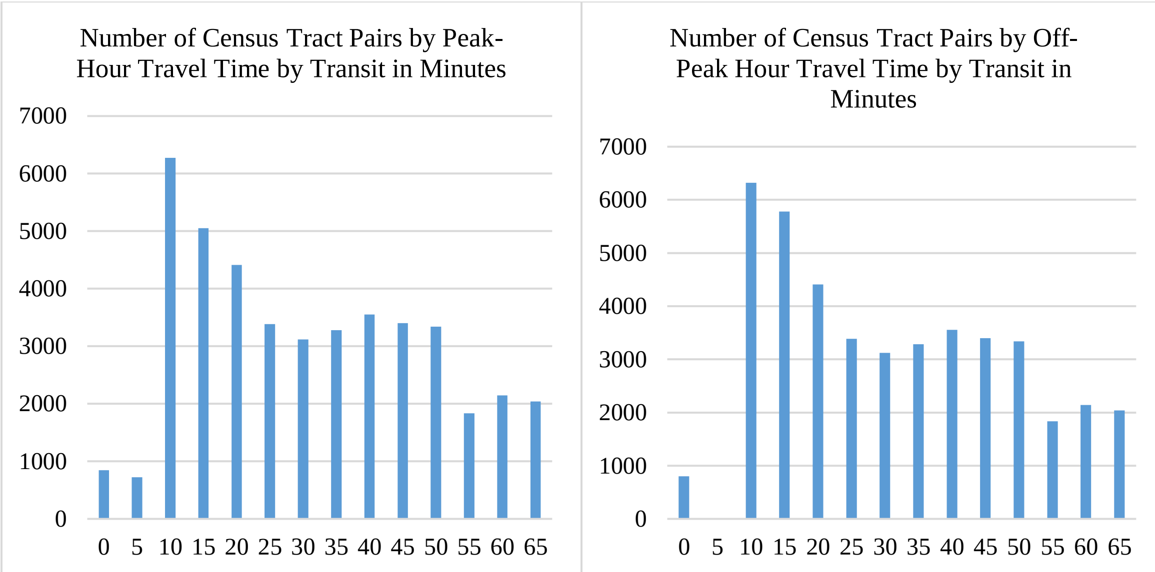

Figure 0-2: Histogram of Census Tract Pairs by Average Transit Travel Time. Left: Peak-hour; Right: Off-peak Hour

Table 0-1: Statistics of Current Transit Travel Time between Census Tract Pairs

	Peak Hour Travel Time	**Off-Peak Hour Travel Time**
Count (Census Tract Pairs with Travel Time < 200 Minutes)	43,411	43,411
Min	0	0
1st Quantile	18.0	18.4
Median	32.1	32.1
3rd Quantile	47.5	47.5
Max	70.0	70.0
Average	33.4	33.6

Current Accessibility to Employment

The detailed information of employment by category is available from the LEHD data. The spatial distribution of all jobs, low-wage, mid-wage, and high-wage jobs are mapped in **Figure 0-3**. Downtown Chicago has a high concentration of all types of jobs. The eight-census tract in darkest shade in downtown Chicago in the first map of **Figure 0-3** alone account for about 40% of all employment in the city. The O'Hare International Airport also has high concentration of all types of jobs and other sub job centers include areas like South Deering and Chicago Midway International Airport. Comparing the spatial distribution of employment in **Figure 0-3** with transit lines in **Figure 0-1** reveals that most of the peripheral job centers fall along with transit lines.

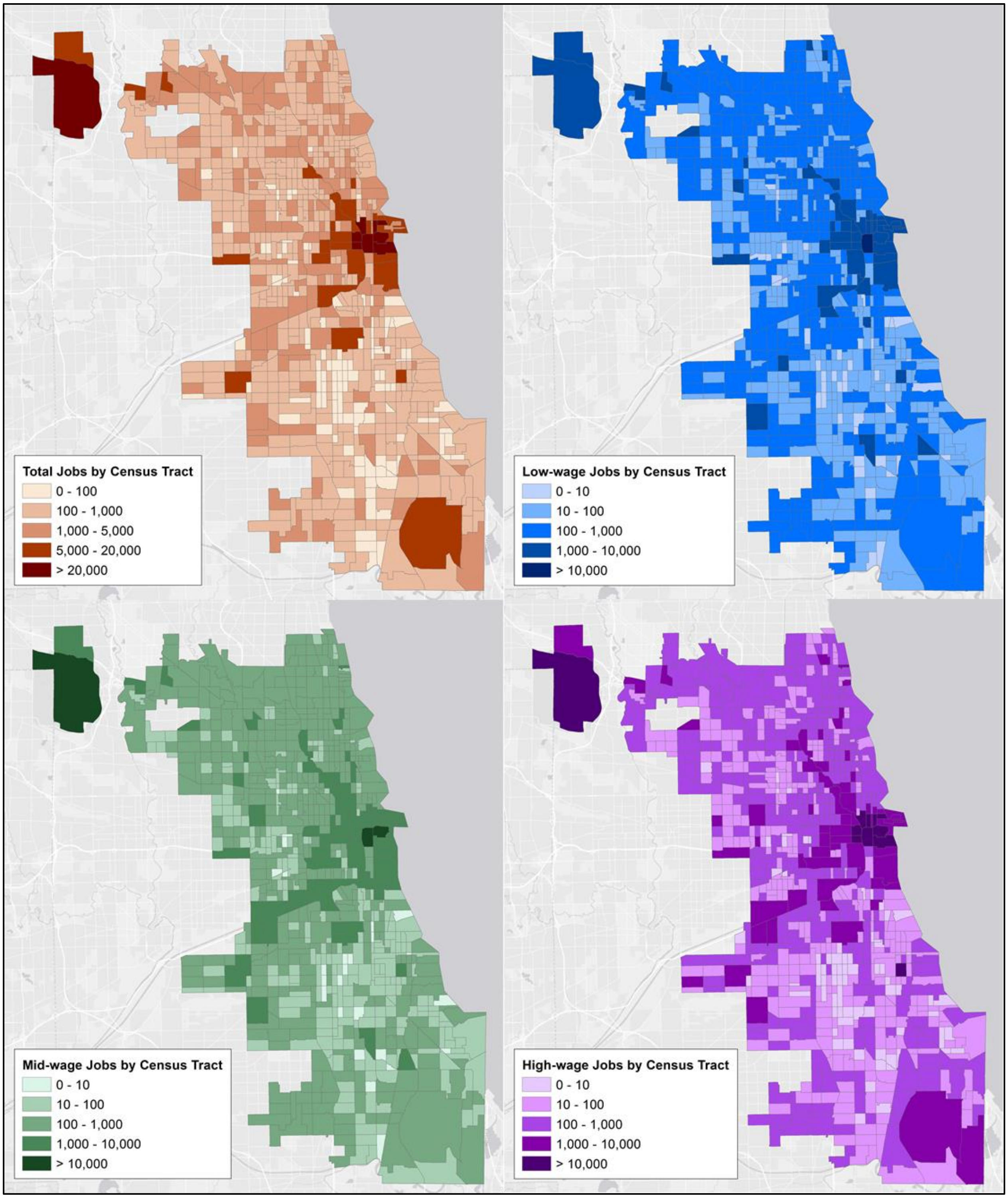

Figure 0-3: Spatial Distribution of Employment by Census Tract in the City of Chicago

The current census-tract level accessibility to all jobs, low-wage jobs, mid-wage jobs, and high-wage jobs are mapped in **Figure 0-4**. The current accessibility is evaluated by only considering using the current transit network and travelers can access transit stops within 0.5 miles for the census tract they reside in. As shown in the four maps in **Figure 0-4**, the current accessibility to jobs of different wage categories follow pretty similar spatial patterns: the center area and the peripheral areas with transit stops have higher level of accessibility. This is a result of how the transit stops in the study area are distributed. Most of the transit stops concentrate in Center Chicago and the areas near the outer boundary of the city, so the relatively inner areas outside the core of the city are the areas with lowest existing accessibility levels.

Some descriptive statistics of the existing accessibility to employment in the City of Chicago are presented in **Table 0-2**. As can be seen from the table, there is a huge variation in the existing accessibility to employment across different census tracts in the city. The first quantile of census-tract level all-job accessibility is only 649, while the median is 3,074, which is almost five times of the first quantile, and the third quantile is 120,994 which is about 186 times of the first quantile. The maximum of census tract all-job accessibility is 730,147, which is more than a thousand times of the first quantile value. The huge accessibility variation in census tracts reveals some extent of inequity in the spatial distribution of transport benefits. The areas in lighter colors in **Figure 0-4** are experiencing only marginal benefits that the transit system can provide while the areas in darker colors accrue most of the accessibility benefits of the existing transit network in Chicago.

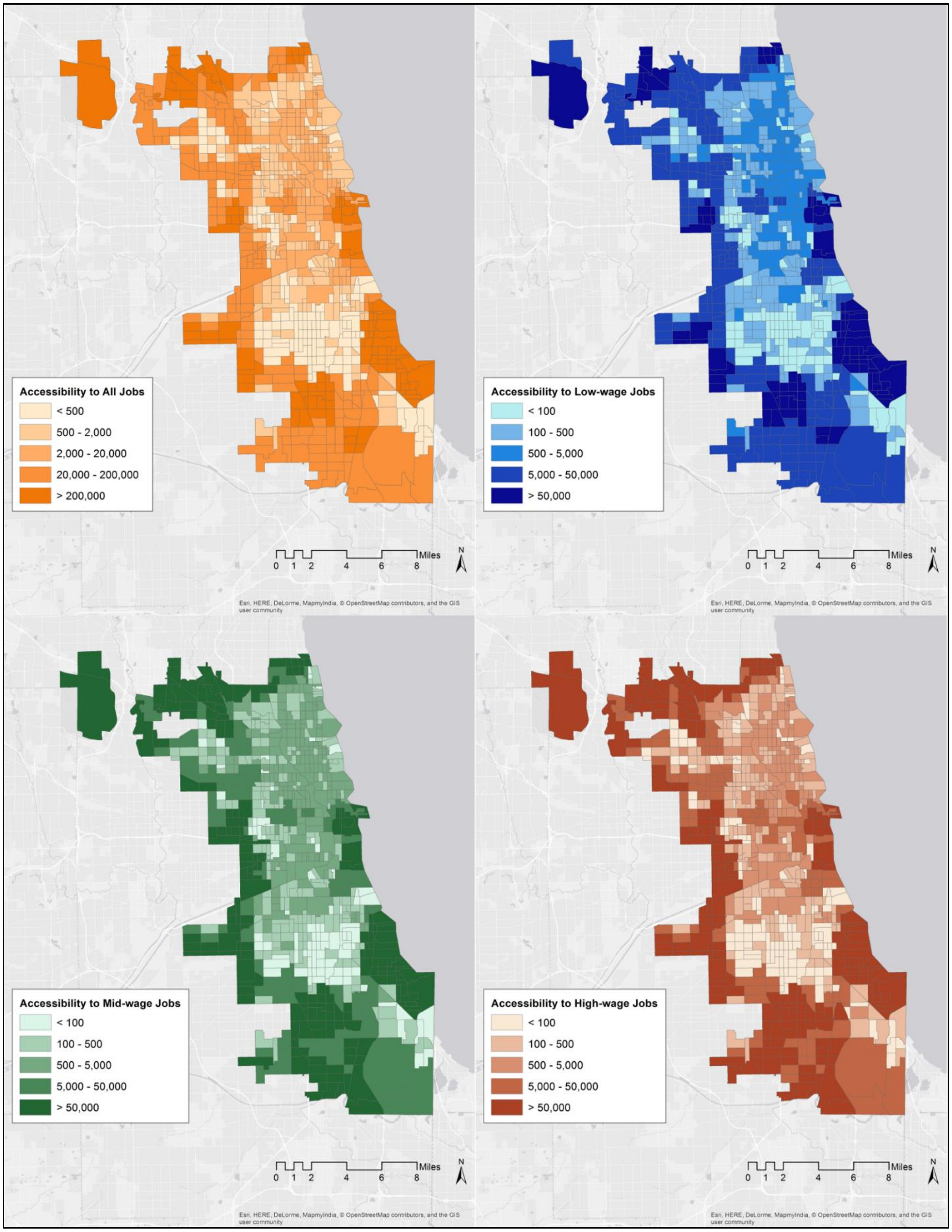

Figure 0-4: Current Accessibility to Jobs by Wage Categories

Table 0-2: Statistics of Census Tract Level Accessibility to Employment: Base Scenario

	Accessibility to All Jobs	Accessibility to Low-income Jobs	Accessibility to Mid-income Jobs	Accessibility to High-income Jobs
Min	2	0	2	0
1st Quantile	649	184	270	159
Median	3,074	916	1,218	917
3rd Quantile	120,994	27,080	45,315	48,414
Max	730,147	111,627	181,185	437,335
Average	105,246	17,712	28,398	59,137

Current Accessibility to Urban Amenities

Five types of urban amenities are considered in this research, including libraries, colleges, grocery stores (larger than 4,000 square feet), hospitals, and parks. **Figure 0-5** maps all the urban amenities in the City of Chicago. In sum, 80 libraries, 82 colleges and universities, 323 grocery stores that are larger than 4,000 square feet, 42 hospitals, and about 6795.9 acres of parks, shown in **Figure 0-5**, are considered in the analysis. The urban amenities in Chicago have a relatively even spatial distribution.

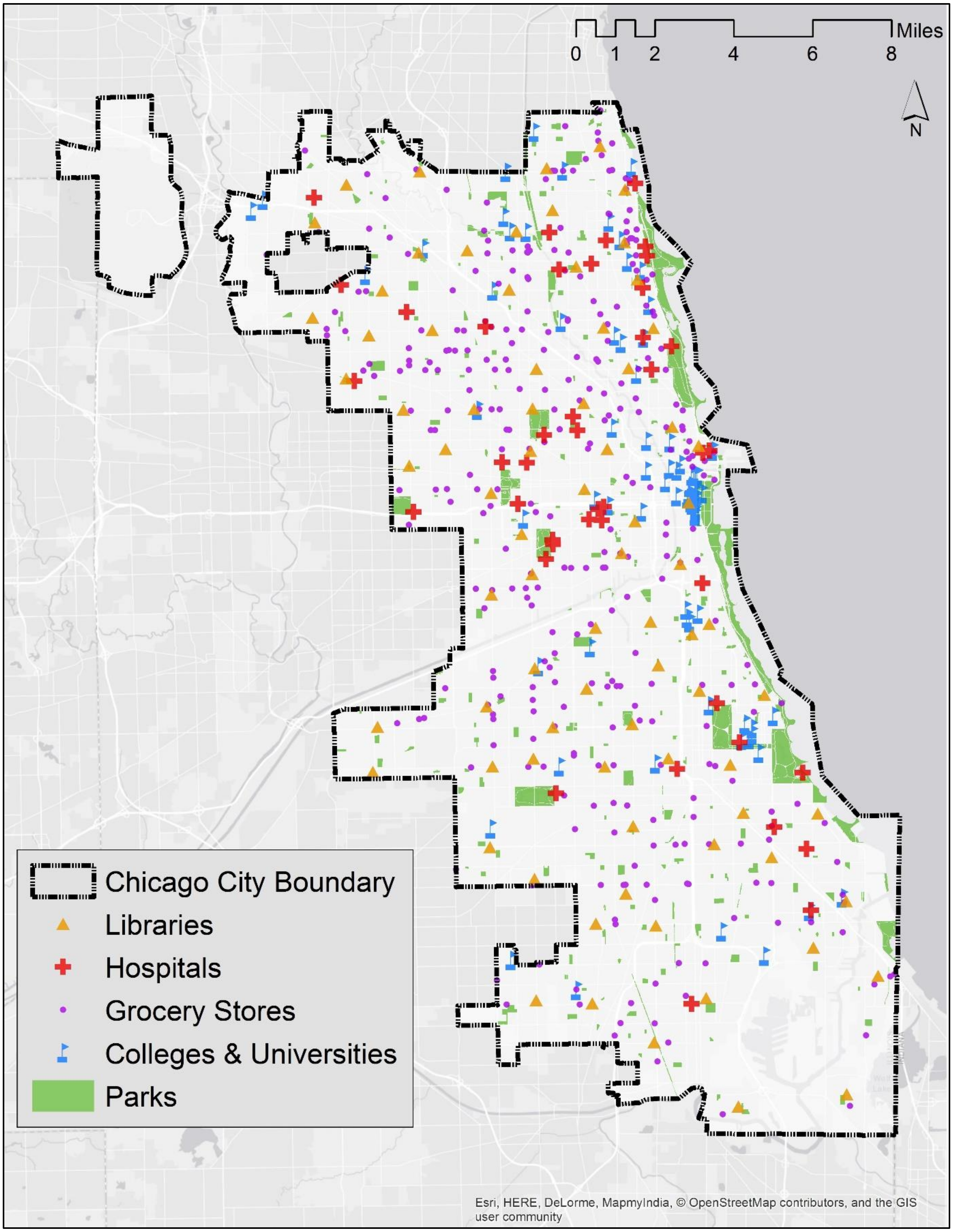

Figure 0-5: Urban Amenities in the City of Chicago

The current accessibility to the five types of urban amenities including libraries, colleges/universities, grocery stores, hospitals, and parks, are mapped in **Figure 0-6**, **Figure 0-7**, **Figure 0-8**, **Figure 0-9**, and **Figure 0-10** respectively. The current accessibility to urban amenities in Chicago City seems to be very unequal spatially. The core area of the city and areas at the outer boundary of the city have much higher accessibility levels to amenities compared to the inner part of the city.

Even though there is severe variation in the spatial distribution of accessibility to amenities, it is worth mentioning that accessibility to amenities probably should not be evaluated in the same way that employment accessibility is evaluated. The way that employment accessibility is evaluated emphasizes the magnitude of the accessibility that reflects the number of jobs can be reached from an area, as more jobs means more potential choices that a worker has. Accessibility to urban amenities is different to the extent that the magnitude is emphasized, as normal if a certain number of amenity destinations are accessible, the increase in magnitude does not bring much utility. For example, if residents living in each census tract find ten grocery stores are accessible, it may reflect that the accessibility to grocery store is good enough and even if another area can access a hundred grocery stores, the difference does not really result in difference in quality of life etc. Accessibility to college and university is another example, as normally a student lives near the college or university that he/she attends and does not need to access other colleges and universities. Consequently, the evaluation of accessibility to urban amenities should focus more on identifying areas with extremely low level of accessibility versus other areas that have middle-level or high-level accessibility.

As the map in **Figure 0-6** shows, there are some census tracts in the inner part but outside the core area of the city that have zero access to libraries. Of course, libraries may not be perceived as necessity compared to other urban amenities such as grocery stores, parks, and hospitals, the areas that cannot reach any library using the current transit system need to be paid attention. As **Figure 0-7** shows, all census tracts in Chicago City can at least access one college or university using the current transit system, though the spatial variation is very significant, as some areas can access almost all the colleges and universities in the city while some other can only access one. As **Figure 0-8** shows, all census tracts in the city can access at least one grocery stores, but the variation across areas is still very significant. Some census tracts can only access one grocery store using the current transit system, which may constrain the food choice and life quality of the residents that are transit-dependent. As **Figure 0-9** shows, all census tracts in the city can at least access one hospital relying on the transit system, but for the census tracts that can only reach one hospital, it is likely that the medical needs of some transit-dependent residents are not met because of the different specialty of hospitals. As **Figure 0-10** shows, there is also a huge variation in the census tracts regarding the accessibility to parks. Accessibility to parks is closely related to residents' health outcomes and quality of life and the areas with low level of park accessibility need to be considered for future park improvement or construction.

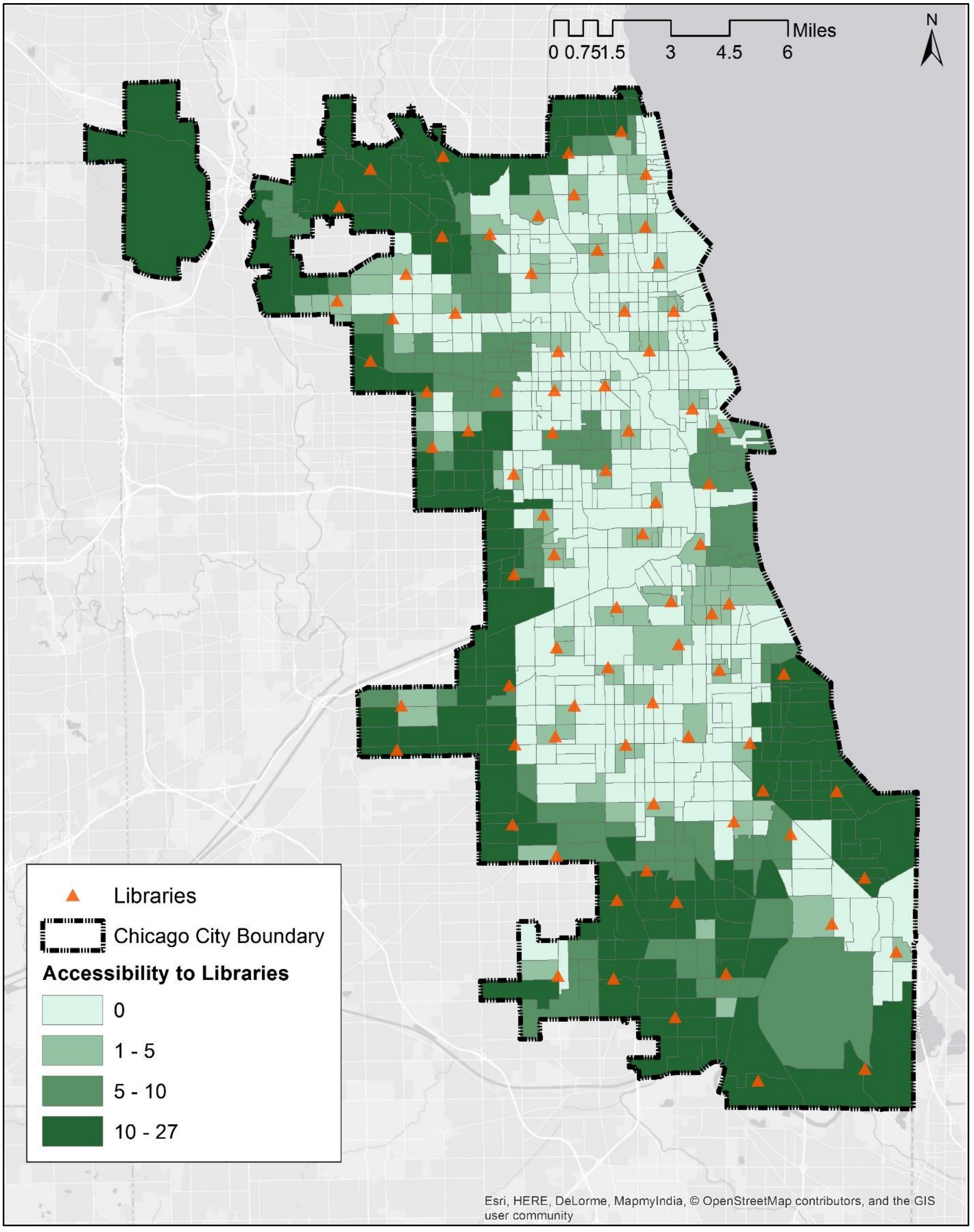

Figure 0-6: Current Accessibility to Libraries

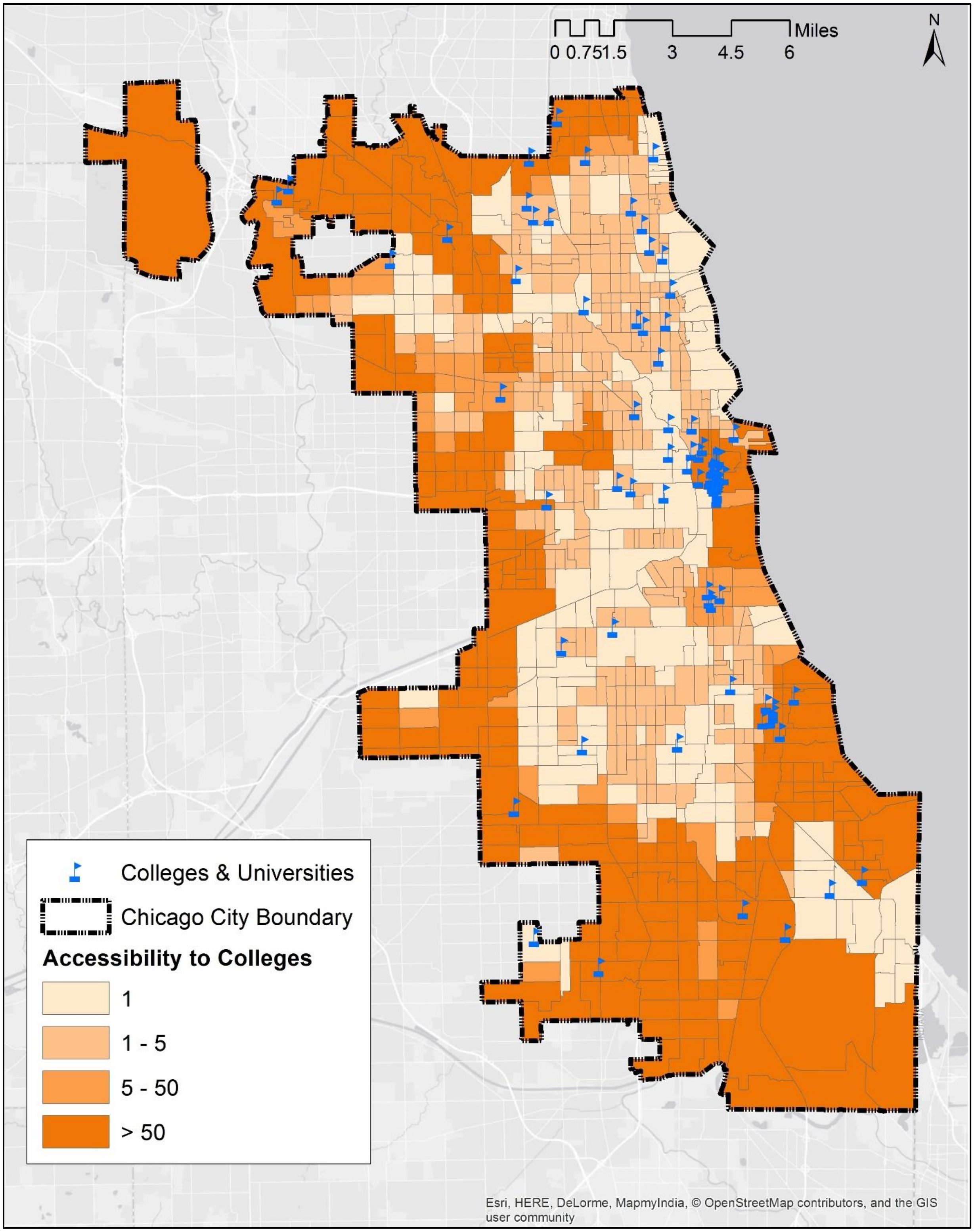

Figure 0-7: Current Accessibility to Colleges / Universities

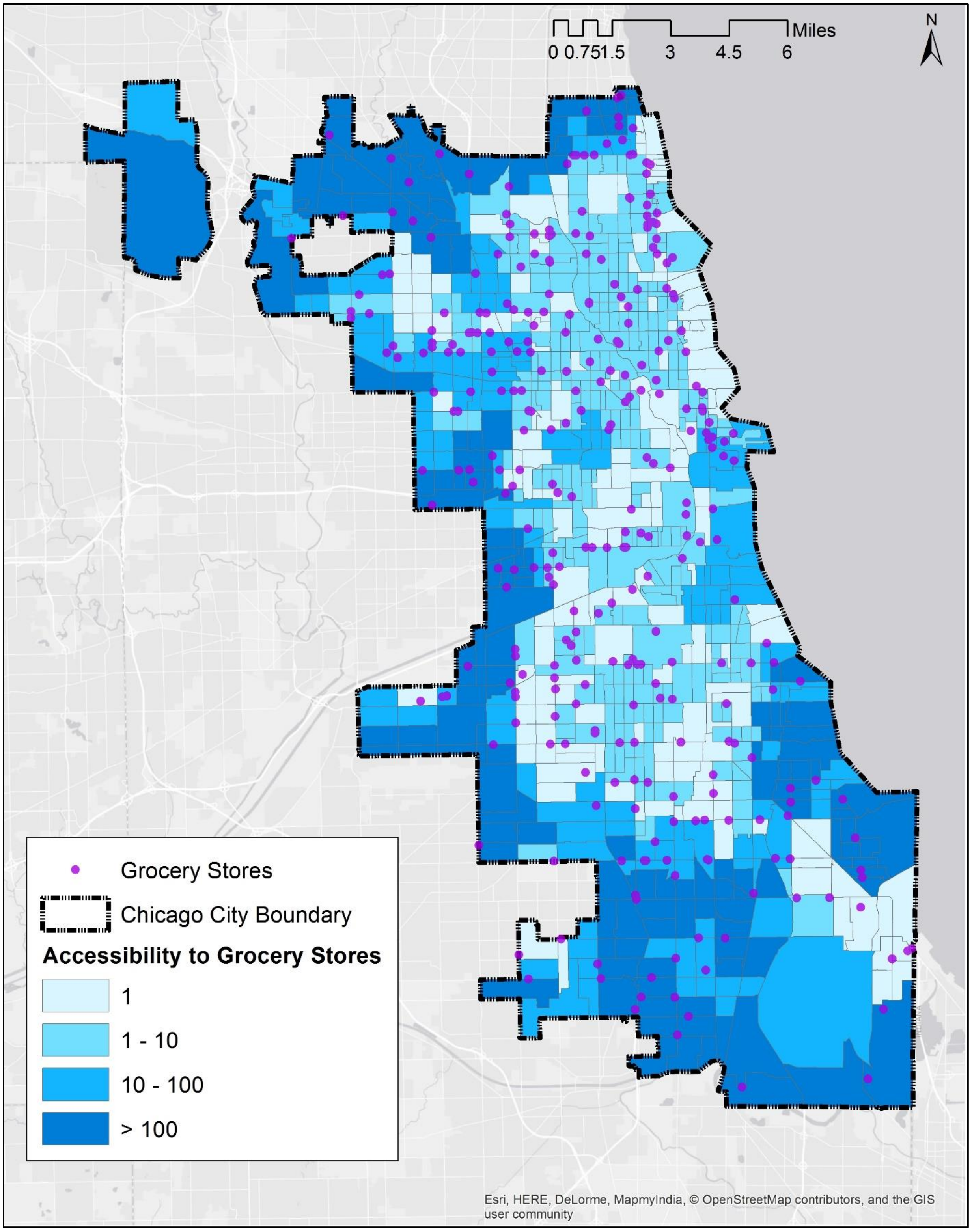

Figure 0-8: Current Accessibility to Grocery Stores (Larger than 4,000 sq. ft.)

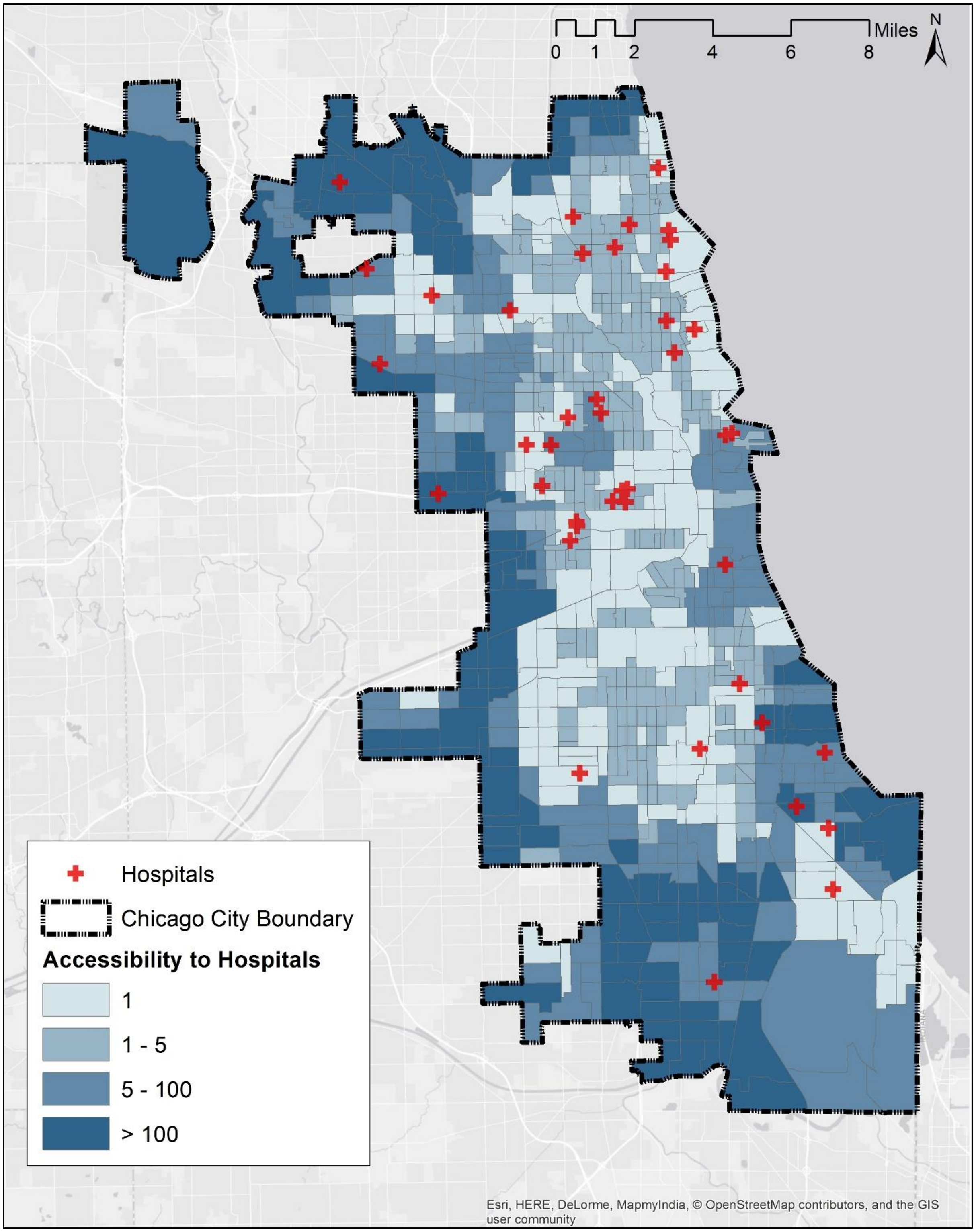

Figure 0-9: Current Accessibility to Hospitals

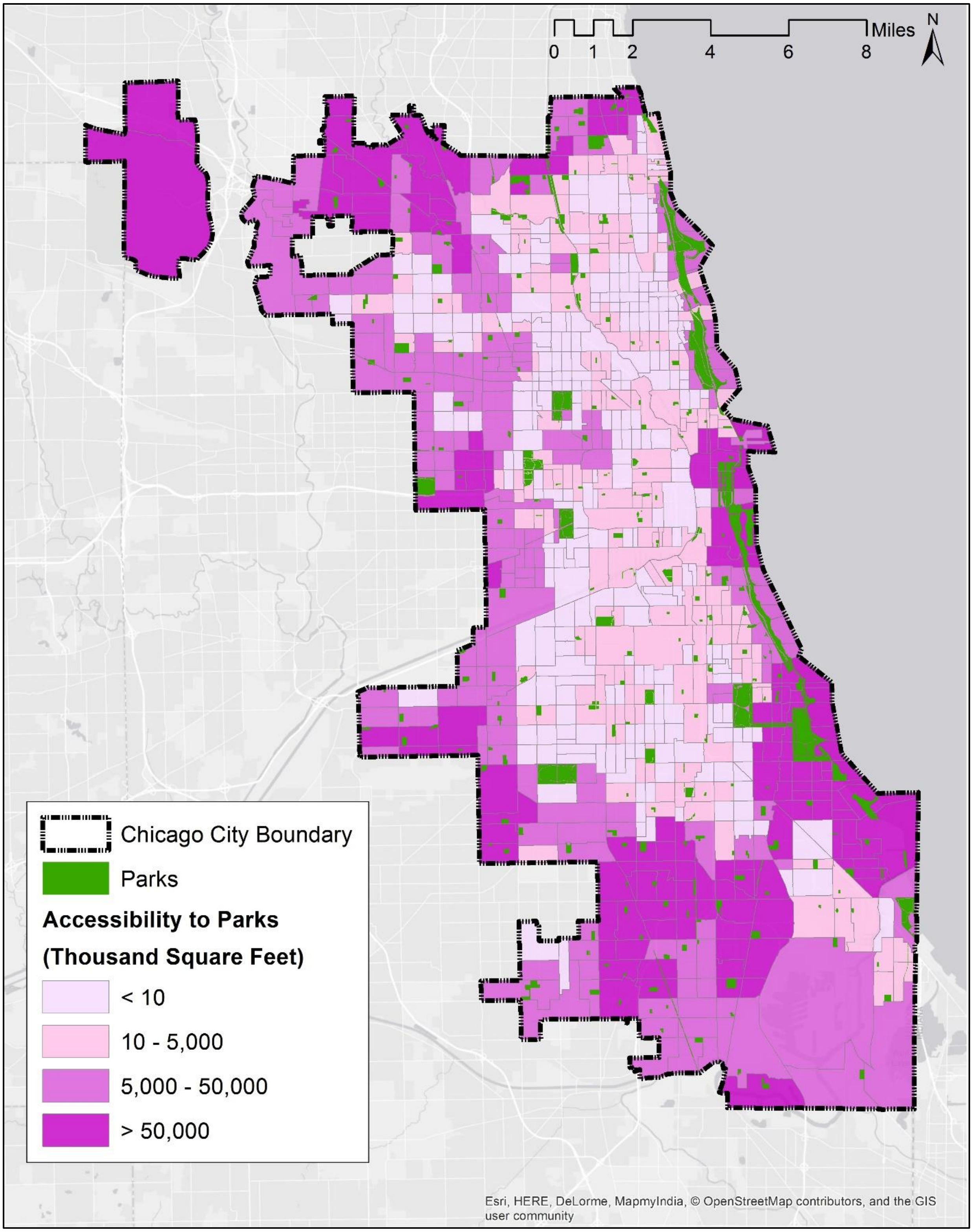

Figure 0-10: Current Accessibility to Parks

The current accessibility to urban amenities in the City of Chicago has significant spatial variation across different census tracts. Some descriptive statistics of the accessibility to amenities are summarized in **Table 0-3**. It can be seen from the table, that the median census tract in the city can access 2 grocery stores, 1 hospital, 1 library, 1 universities/colleges, and about 9.1 acre of parks. It seems that the accessibility to urban amenity level in the median census tract is acceptable considering residents' daily needs. However, the census tract in the first quantile can only access 1 grocery store, 1 hospital, 0 library, 1 universities/colleges and 972 square feet (0.02 acre) of parks. There are also some census tracts that cannot access any of the urban amenities with the current fixed-route transit system. It is very likely that residents in these areas that fall under the first quantile are constrained in meeting their daily needs because of the low accessibility level.

Table 0-3: Census Tract Level Accessibility to Urban Amenities: Base Scenario

Accessibility to Urban Amenities in the Base Scenario					
	Grocery Stores (Larger than 4,000sqft) (Count)	**Hospitals (Count)**	**Libraries (Count)**	**Colleges & Universities (Count)**	**Park (Acres)**
Min	0	0	0	0	0.0
1st Quantile	1	1	0	1	0.02
Median	2	1	1	1	9.1
3rd Quantile	30	3	9	5	582.3
Max	100	10	28	40	2,666.5
Average	15	2	5	4	374.4

Target Areas for Transit Service Improvement

The pattern of current accessibility to the four types of employment and the five types of urban amenities reveal that there is a great variation in accessibility levels across census tracts in the City of Chicago. In general, most of the highly accessible areas are areas with good access to transit stations, especially those near Metra Stations. Examining the current accessibility patterns can contribute to targeting the areas for potential transit service improvement and whether existing resources are distributed across different population groups. Following the categorization method shown in **Figure 0-11**, four types of areas are defined according to their different census-tract level accessibility. The areas shown in red and yellow in **Figure 0-11** are areas that should be paid more attention in future transit service improvement programs.

Overlaying the four types of area with the median household income by census tract gives the map shown in **Figure 0-13**. As can be seen from the map, most of the low-accessibility census tracts are also census tracts with low household income (less than $35,000) in the city. There is a high consistency between census tracts with low accessibility (especially accessibility to jobs) and census tracts that have low median household income. This consistency reflects a commonly found equity issue in American cities. Areas with better transportation access normally have higher housing values, as land value always captures transportation benefits. It is an important equity challenge, as even though transit-dependent population have limited options for affordable and convenient mobility options, many of them are low-income families who might not be able to afford living in the close adjacency to transit infrastructure. Improving the access to transit especially for low-income and transit-dependent populations is critical for making our transportation systems more inclusive and equitable.

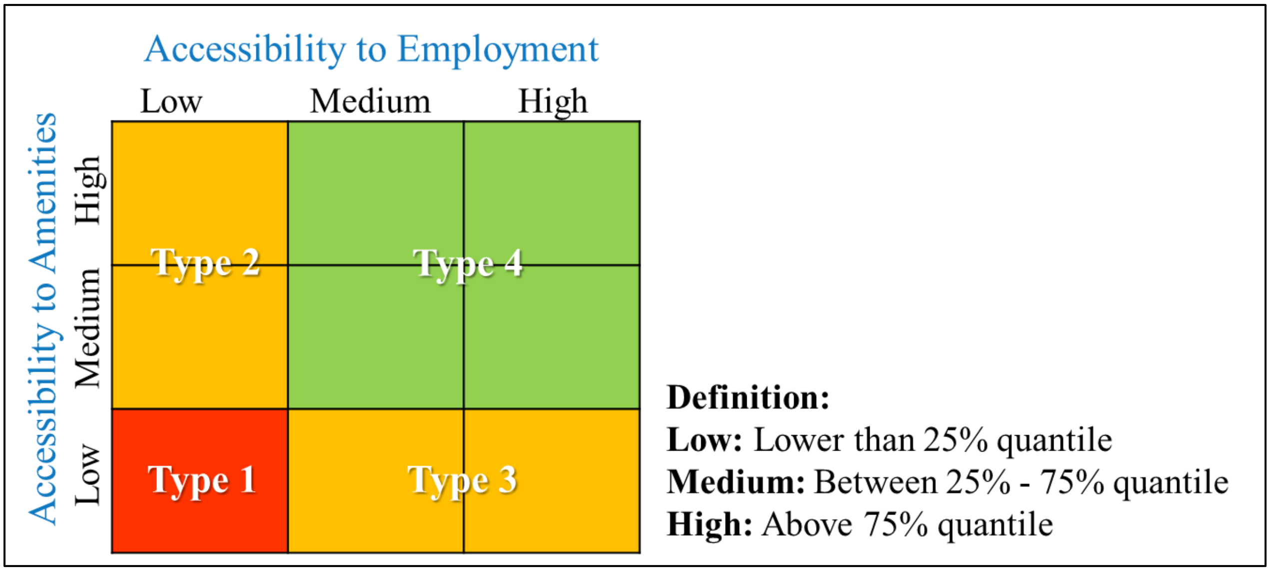

Figure 0-11: Defining areas with low, medium, high accessibility

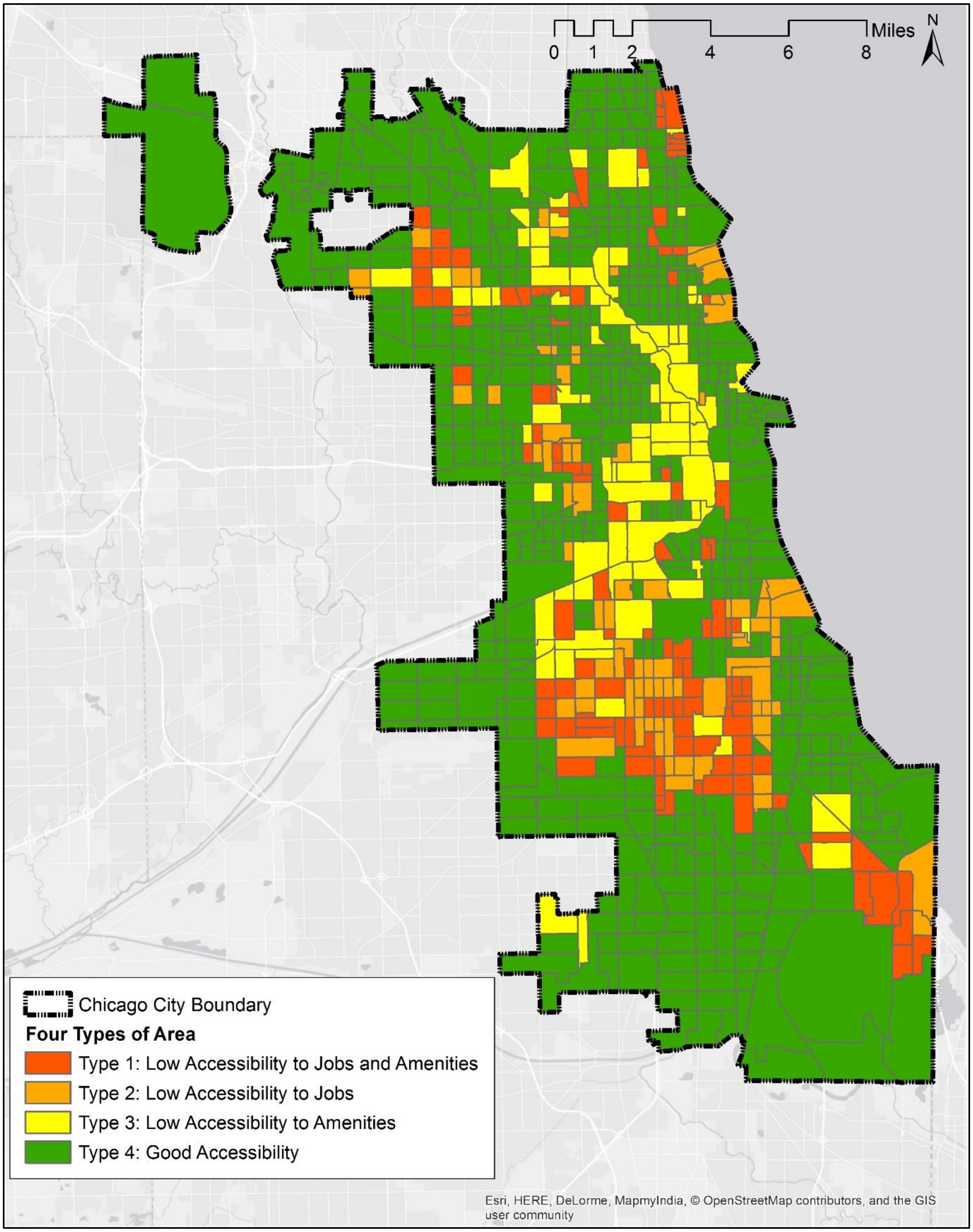

Figure 0-12: Four Types of Area in Chicago by Accessibility Levels

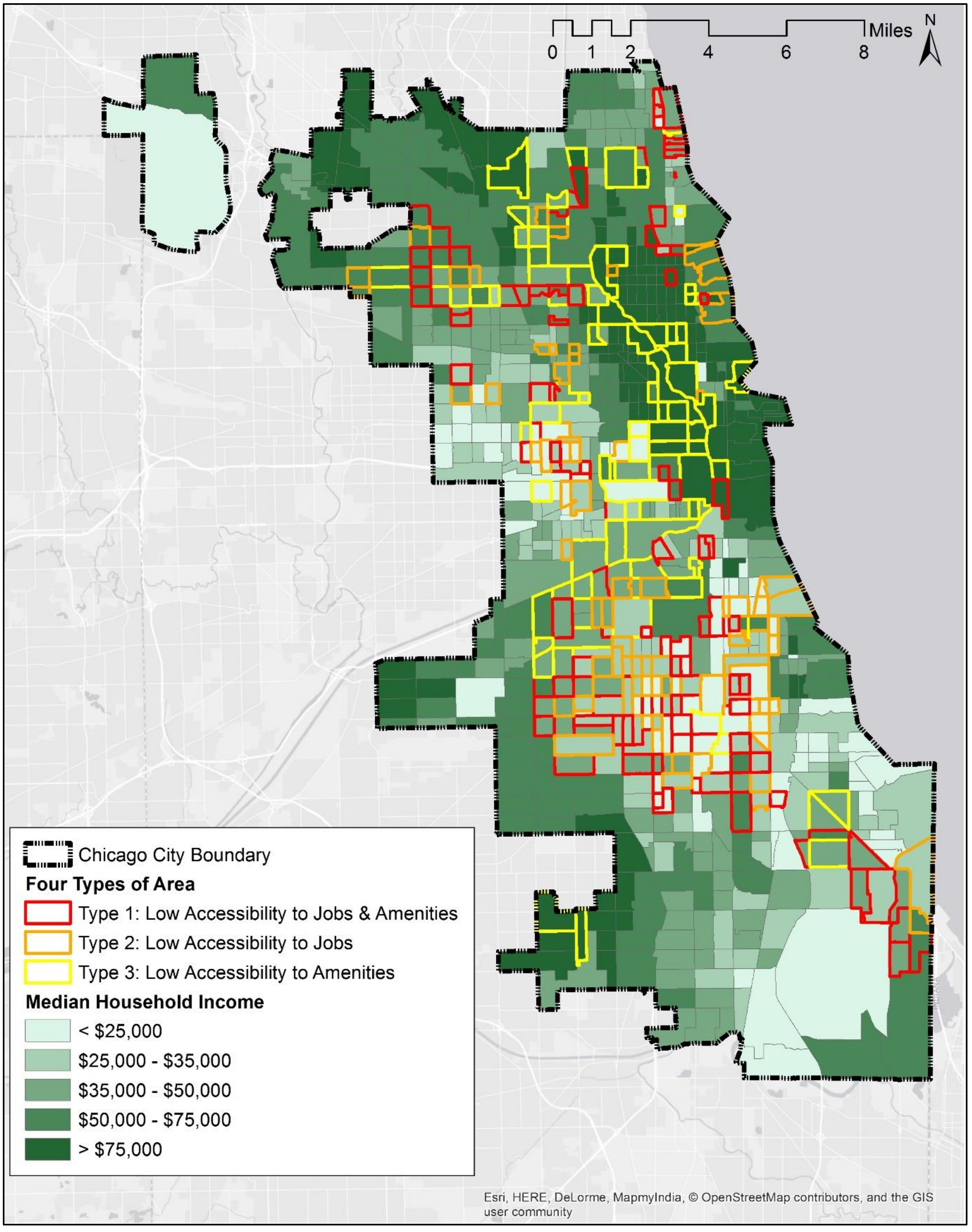

Figure 0-13: Four Area Types and Median Household Income by Census Tract
Data Source: American Community Survey, 2012-2016

Estimating the Accessibility Impact of TMCs

Change in Travel Time

Twelve scenarios are developed to reflect different levels of service of TMCs in the City of Chicago. The scenarios are developed mainly based on two parameters, TMCs wait time and travel distance that TMCs can be used for (see **Table 0-4**). In each of the twelve scenarios, accessibility to employment and urban amenities is estimated and compared with the base scenario that does not consider TMCs are available.

With assumptions in the 12 scenarios changing, the number of census tract pairs that have travel time less than 200 minutes ($T_{ij} \leq 200\ minutes$) also changes (see **Table 0-1** and

Table 0-2). In the base scenario, there are 43,411 census tract pairs that have travel time by transit less than 200 minutes (see **Table 0-1**). The number of census tract pairs with less than 200-minute travel time significantly increase in the 12 scenarios. The travel time starting and ending in the same census tract is zero in all scenarios, so the minimum of census-tract-pair travel time is always zero. As the statistics show, the 12 scenarios have significant influence on the shortest travel time between census tracts. The number of census tract pairs that have travel time of less than 200 minutes almost increases by three times in Scenarios 4, 8, 12; increases by four times in Scenarios 3, 7, 11; increases by five times in Scenarios 2, 6, 10; and increases almost by eight times in Scenarios 1, 5, 9. The average census-tract-pair travel time out of all census-tract pairs with less than 200-minute travel times in the twelve scenarios is even shorter than that in the base scenario. The average travel time between census tracts in the 12 scenarios ranges from 27.5 minutes to 34.6 minutes, while in the base scenario, the average travel time is 33.4. One thing to remember is that the average travel time is calculated for all the census-tract pairs with travel time less than 200 minutes, so in the 12 scenarios, the total number of census tract pairs considered is much larger than that in the base scenario, but the average travel time is still similar. This indicates the substantial potential of shortening travel time between census tracts by integrating TMCs with transit.

Table 0-1: Peak Hour Travel Time between Census Tract Pairs in Future Scenarios

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Count (Census-tract Pairs with Travel Time < 200 Minutes)	338,191	223,427	174,883	121,203	338,191	223,427
Min (Minutes)	0	0	0	0	0	0
1st Quantile (Minutes)	16.1	16.7	16.9	16.0	18.3	17.8
Median (Minutes)	26.2	26.8	27.1	28.0	30.3	30.5

3rd Quantile (Minutes)	44.1	46.0	46.6	46.9	47.0	48.1
Max (Minutes)	82.0	80.0	78.0	76.0	89.9	87.3
Average (Minutes)	32.0	32.1	32.0	32.1	34.6	34.5
	Scenario 7	**Scenario 8**	**Scenario 9**	**Scenario 10**	**Scenario 11**	**Scenario 12**
Count (Census-tract Pairs with Travel Time < 200 Minutes)	174,883	121,203	338,191	223,427	174,883	121,203
Min (Minutes)	0	0	0	0	0	0
1st Quantile (Minutes)	17.9	17.5	12.6	12.0	12.0	13.1
Median (Minutes)	30.5	30.9	21.1	22.2	22.7	24.1
3rd Quantile (Minutes)	48.4	48.6	38.5	41.7	42.5	43.2
Max (Minutes)	85.8	83.7	76.0	74.0	72.0	70.0
Average (Minutes)	34.4	34.1	27.5	27.9	28.1	28.7

Table 0-2: Off-Peak Hour Travel Time between Census Tract Pairs in Future Scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Count (Census-tract Pairs with Travel Time < 200 Minutes)	338,191	223,427	174,883	121,203	338,191	223,427
Min (Minutes)	0	0	0	0	0	0
1st Quantile (Minutes)	16.1	16.7	16.9	16.0	18.3	17.8
Median (Minutes)	26.2	26.8	27.1	28.0	30.3	30.5
3rd Quantile (Minutes)	44.1	46.0	46.6	46.9	47.0	48.1
Max (Minutes)	82.0	80.0	78.0	76.0	89.9	87.3
Average (Minutes)	32.0	32.1	32.0	32.1	34.6	34.5
	Scenario 7	**Scenario 8**	**Scenario 9**	**Scenario 10**	**Scenario 11**	**Scenario 12**
Count (Census-tract Pairs with Travel Time < 200 Minutes)	174,883	121,203	338,191	223,427	174,883	121,203
Min (Minutes)	0	0	0	0	0	0
1st Quantile (Minutes)	17.9	17.5	12.6	12.0	12.0	13.1
Median (Minutes)	30.5	30.9	21.1	22.2	22.7	24.1
3rd Quantile (Minutes)	48.4	48.6	38.5	41.7	42.5	43.2
Max (Minutes)	85.8	83.7	76.0	74.0	72.0	70.0
Average (Minutes)	34.4	34.1	27.5	27.9	28.1	28.7

Change in Employment Accessibility

The change in accessibility to employment are estimated in each of the 12 scenarios that considers the integration of TMCs with public transportation. Overall, accessibility to employment is significantly augmented in the 12 scenarios, as shown in **Figure 0-1**. Percent change of job accessibility in the 12 scenarios and some descriptive statistics are summarized in **Table 0-3**. In Scenarios 1, 5, and 9, which assume that TMCs can be used for up to 2 miles around transit stops and up to 4 miles for single modal trips, job accessibility is improved most significantly, and the average census-tract level accessibility increased by more than 400%. For Scenarios 2, 6 and 10, which assume that TMCs can be used for up to 1.5 miles for multimodal trips and 3 miles for single modal trips, the average accessibility increases by more than 250%. For Scenarios 3, 7, and 11, which assume that TMCs can be used for 1.25 miles for multimodal trips and 2.5 miles for single modal trips, the average accessibility increases by about 200%. For Scenarios 4, 8, and 12, which assume that TMCs can only be used for 1 mile for multimodal trips and 2 miles for single modal trips, the average accessibility increases by more than 110%. Comparing different rows in **Table 0-3** reveals the impact of changing wait time of TMCs on job accessibility. Scenarios 1 through 4 assume a uniform 6-minute wait time of TMCs; Scenarios 5 through 8 assume demand-based variation in wait times but still maintain a citywide average wait time of 6 minutes; Scenarios 9 through 12 assume a uniform 3-minute wait time. As the table shows, there is not a significant difference between the first row of scenarios (Scenarios 1 through 4) and the second row of scenarios (Scenarios 5 through 8) in **Table 0-3**, while the third row of scenarios (Scenarios 9 through 12) shows moderate increase in job accessibility compared to the first two rows. This indicates that the spatial variation in wait times within a moderate range may not influence the change in job accessibility significantly, while an average shortening in wait time can increase job accessibility regionwide. Nevertheless, the influence of shortening wait time is not as significant as the influence of lengthening the distance that TMCs can be used. Overall, the availability of TMCs and the distance that TMCs can be used for are the two predominant factors for influencing the extent to which job accessibility can be improved.

An interesting finding is that across the 12 scenarios as shown in **Table 0-3**, the first quantile of census tracts has the most significant accessibility increase the percent increase is far more than that of the higher quantiles. This is not hard to understand, as census tracts with lower current accessibility will see higher percentage growth when nearby jobs become accessible because of TMCs. Moreover, the accessibility increase for the first quantile of census tracts is also very substantial in terms of its absolute quantity. This implies that enlarging the catchment areas of transit stops by TMCs and using TMCs for short-distance trips can significantly improve accessibility levels citywide and the increase is especially substantial in areas with low current accessibility.

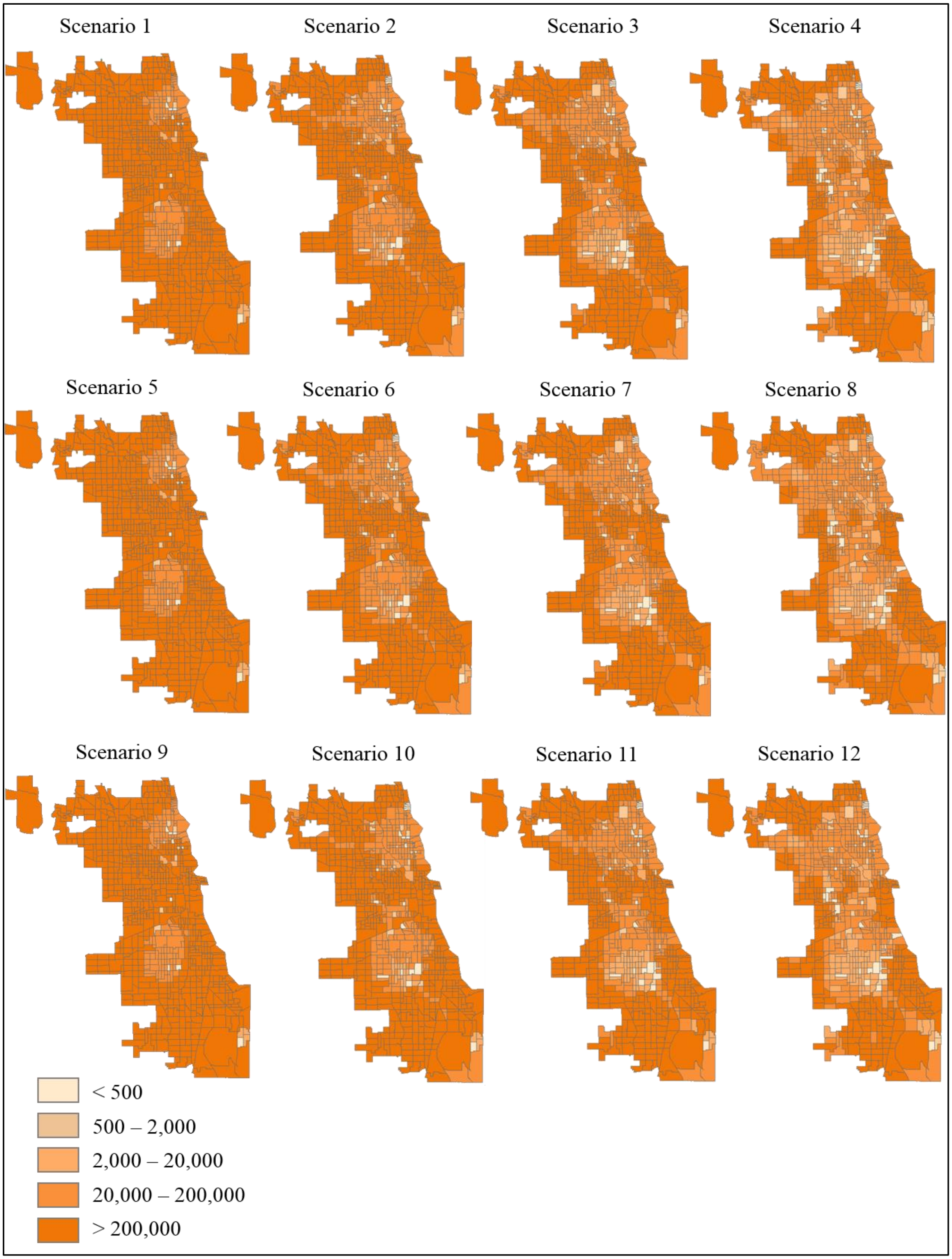

Figure 0-1: Accessibility to All Jobs in the 12 Scenarios

Table 0-3: Accessibility to All Jobs and Changes in the 12 Scenarios

Accessibility to All Jobs								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	96	4700%	52	2500%	52	2500%	2	0%
1st Quantile	295,453	45424%	97,150	14869%	54,806	8345%	26,925	4049%
Median	466,959	15091%	273,763	8806%	208,291	6676%	120,562	3822%
3rd Quantile	951,488	686%	804,242	565%	518,933	329%	271,648	125%
Max	1,206,228	65%	1,117,686	53%	1,077,421	48%	963,175	32%
Average	568,207	440%	395,918	276%	326,525	210%	235,773	124%
	Scenario 5		**Scenario 6**		**Scenario 7**		**Scenario 8**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	96	4700%	52	2500%	52	2500%	2	0%
1st Quantile	290,791	44706%	97,150	14869%	54,806	8345%	26,925	4049%
Median	455,892	14731%	269,699	8674%	202,506	6488%	116,810	3700%
3rd Quantile	887,698	634%	593,055	390%	484,227	300%	261,958	117%
Max	1,201,180	65%	1,119,745	53%	1,076,166	47%	954,691	31%
Average	541,242	414%	379,119	260%	314,086	198%	228,085	117%
	Scenario 9		**Scenario 10**		**Scenario 11**		**Scenario 12**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	96	4700%	52	2500%	52	2500%	2	0%
1st Quantile	301,110	46296%	97,150	14869%	54,806	8345%	26,925	4049%
Median	493,250	15946%	284,324	9149%	219,755	7049%	130,464	4144%
3rd Quantile	1,014,498	738%	872,234	621%	595,690	392%	281,229	132%
Max	1,223,527	68%	1,124,899	54%	1,078,638	48%	964,535	32%
Average	605,927	476%	425,596	304%	348,318	231%	248,644	136%

Change in Accessibility to Urban Amenities

Like the significant influence on job accessibility, integrating TMCs with public transit also has significant impact on accessibility to urban amenities in the City of Chicago. **Table 0-4**,

Table 0-5, **Table 0-6**, **Table 0-7**, and **Error! Reference source not found.** present the changes in accessibility to grocery stores, hospitals, libraries, universities/colleges, and parks respectively in the 12 scenarios. The improvement variation across the 12 scenarios are consistent with patterns of job accessibility changes: In Scenarios 1, 5 and 9, which assume that TMCs can be used for longest distance, accessibility to urban amenities have been increased most significantly. The average census tract in Scenarios 1, 5, and 9 see more than eight times increase in accessibility to grocery stores, more than ten times increase in accessibility to hospitals, more than six times increase in accessibility to libraries, more than six times increase in accessibility to universities or colleges, and more than seven times increase in accessibility to parks. In Scenarios 2, 6, and 10, the accessibility increase to these five types of amenities is less substantial compared to Scenarios 1, 5, and 9, but on average, the accessibility increase exceeds five times in these three scenarios. For Scenarios 3, 7, and 11, the accessibility improvement is smaller, but on average the increase exceeds three times. Scenarios 4, 8, and 12 assume the most modest use of TMCs, so the accessibility improvement is also most modest, but on average, the accessibility to the five types of urban amenities increase by more than twice.

Like the influence on job accessibilities, it can be seen that the distance thresholds that TMCs can be used are an important factor influencing the extent to which amenity accessibility can be improved. The longer distance that TMCs can be used, the larger the improvement it can make regarding accessibility to urban amenities. Since generally there are much fewer urban amenities than jobs, so the base scenario of accessibility to urban amenities is much smaller compared to job accessibility, which explains why the percentage increase in amenity accessibility is more significant than the percentage increase in job accessibility. Also, like job accessibility changes, the percentage increase to the amenity accessibility in the first quantile of census tracts is much more substantial compared to other quantiles. This implies that for the areas with low current accessibility levels, the potential improvement of accessibility by integrating TMCs with public transit is most significant.

Table 0-4: Accessibility to Grocery Stores and Changes

Accessibility to Grocery Stores that are Larger than 4,000 sq. ft. (Count)

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	109	21798%	36	7100%	23	4500%	13	2500%
Median	147	7269%	101	4955%	81	3967%	43	2045%
3rd Quantile	190	542%	140	371%	115	290%	86	189%
Max	258	157%	212	111%	192	91%	168	67%
Average	143	872%	95	543%	75	410%	53	258%
	Scenario 5		**Scenario 6**		**Scenario 7**		**Scenario 8**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	106	21105%	36	7100%	23	4500%	13	2500%
Median	146	7182%	101	4935%	80	3908%	40	1902%
3rd Quantile	188	533%	134	352%	113	281%	83	179%
Max	259	158%	214	113%	191	90%	166	65%
Average	141	855%	93	530%	73	398%	51	248%
	Scenario 9		**Scenario 10**		**Scenario 11**		**Scenario 12**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	117	23279%	36	7100%	23	4500%	13	2500%
Median	154	7621%	107	5249%	90	4381%	44	2114%
3rd Quantile	200	574%	147	395%	121	310%	89	199%
Max	267	166%	215	114%	195	94%	168	68%
Average	149	912%	99	571%	78	432%	55	272%

Table 0-5: Accessibility to Hospitals and Changes

Accessibility to Hospitals (Count)								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	13	2445%	6	1100%	4	700%	2	300%
Median	18	3584%	11	2100%	8	1526%	4	700%
3rd Quantile	23	767%	15	478%	12	366%	9	240%
Max	36	265%	27	172%	24	141%	17	71%
Average	18	1065%	11	616%	8	459%	5	250%
	Scenario 5		**Scenario 6**		**Scenario 7**		**Scenario 8**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	13	2442%	6	1057%	4	700%	2	300%
Median	18	3558%	11	2024%	8	1500%	4	700%
3rd Quantile	22	742%	15	460%	12	353%	9	228%
Max	36	265%	28	177%	24	141%	16	64%
Average	17	1038%	10	594%	8	440%	5	241%
	Scenario 9		**Scenario 10**		**Scenario 11**		**Scenario 12**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	13	2507%	6	1100%	4	700%	2	300%
Median	20	3847%	11	2170%	9	1664%	4	727%
3rd Quantile	24	816%	16	513%	14	412%	9	253%
Max	37	275%	28	181%	24	141%	17	71%
Average	19	1127%	11	653%	9	489%	5	263%

Table 0-6: Accessibility to Libraries and Changes

Accessibility to Libraries (Count)								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	27	5387%	7	1300%	4	700%	2	300%
Median	41	3970%	27	2567%	22	2076%	14	1277%
3rd Quantile	51	456%	40	339%	34	272%	23	158%
Max	65	133%	57	105%	54	95%	46	64%
Average	37	692%	26	449%	21	341%	14	204%
	Scenario 5		**Scenario 6**		**Scenario 7**		**Scenario 8**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	27	5397%	7	1300%	4	700%	2	300%
Median	40	3857%	27	2566%	22	2057%	13	1209%
3rd Quantile	50	448%	39	327%	33	259%	23	150%
Max	64	130%	57	103%	53	90%	44	59%
Average	37	681%	25	439%	20	332%	14	196%
	Scenario 9		**Scenario 10**		**Scenario 11**		**Scenario 12**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	30	5921%	7	1300%	4	700%	2	300%
Median	42	4128%	29	2781%	23	2213%	15	1379%
3rd Quantile	53	480%	41	352%	35	283%	25	173%
Max	66	138%	57	106%	54	95%	46	64%
Average	39	725%	27	473%	22	361%	15	215%

Table 0-7: Accessibility to University or College and Changes

Accessibility to Colleges & Universities (Count)								
	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	18	3545%	8	1500%	5	900%	2	300%
Median	30	5959%	17	3366%	14	2788%	6	1100%
3rd Quantile	56	1040%	42	757%	35	616%	17	251%
Max	69	71%	66	63%	66	63%	53	32%
Average	35	705%	25	465%	21	374%	13	206%
	Scenario 5		Scenario 6		Scenario 7		Scenario 8	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	18	3451%	8	1500%	5	900%	2	300%
Median	30	5832%	17	3318%	14	2693%	6	1100%
3rd Quantile	52	964%	39	699%	34	584%	17	240%
Max	69	71%	66	63%	66	63%	53	32%
Average	34	676%	24	447%	20	360%	13	197%
	Scenario 9		Scenario 10		Scenario 11		Scenario 12	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	20	3823%	8	1500%	5	900%	2	300%
Median	32	6300%	18	3549%	16	3027%	6	1147%
3rd Quantile	61	1146%	49	907%	38	677%	18	258%
Max	70	73%	66	63%	66	63%	53	32%
Average	37	754%	26	502%	22	403%	14	221%

Table 0-8: Accessibility to Parks and Changes

Accessibility to Park (Acres)								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	1,983	396564%	770	153945%	410	81928%	164	32617%
Median	3,060	33616%	2,020	22150%	1,375	15052%	755	8212%
3rd Quantile	4,299	638%	3,577	514%	3,090	431%	2,141	268%
Max	5,554	108%	5,137	93%	4,910	84%	4,144	55%
Average	3,083	723%	2,199	487%	1,746	366%	1,198	220%
	Scenario 5		**Scenario 6**		**Scenario 7**		**Scenario 8**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	1,887	377306%	749	149644%	410	81928%	164	32617%
Median	2,992	32861%	1,895	20776%	1,346	14733%	707	7693%
3rd Quantile	4,263	632%	3,556	511%	3,102	433%	2,093	259%
Max	5,539	108%	5,079	90%	4,909	84%	4,141	55%
Average	3,046	714%	2,166	479%	1,711	357%	1,175	214%
	Scenario 9		**Scenario 10**		**Scenario 11**		**Scenario 12**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	0	0%	0	0%	0	0%	0	0%
1st Quantile	2,104	420768%	770	153945%	410	81928%	164	32617%
Median	3,238	35575%	2,100	23038%	1,491	16331%	849	9250%
3rd Quantile	4,550	681%	3,663	529%	3,183	447%	2,267	289%
Max	5,806	118%	5,146	93%	4,913	84%	4,148	56%
Average	3,217	759%	2,305	516%	1,828	388%	1,243	232%

Estimating the Equity Impact of TMCs

Change in Low-, Mid-, High- Accessibility Areas

In Chapter 3, four types of areas regarding the current level of accessibility are identified (see **Figure 0-11**) and comparing the change to accessibility across these four types of areas can contribute to understanding the equity implication of integrating TMCs with transit. The four areas are: Area Type 1 which have low accessibility to jobs and amenities; Area Type 2 which are only low in job accessibility; Area Type 3 which are areas only low in amenity accessibility; and Area Type 4 which have good accessibility to jobs and amenities. Areas falling into Type 1 are the areas that have most limited accessibility and should be identified as target areas for future transportation improvement. **Table 0-1** summarizes the average change to accessibility by the four types of areas in the twelve scenarios and **Figure 0-1** presents an intuitive comparison across area types and scenarios. As shown in the table and the figure, accessibility improvement is most significant in Type 1 areas and the average percent increase of Area Type 1 is much more significant than for other area types. It is also shown that accessibility increase is also very significant for Type 2 areas, which are the areas that have low current job accessibility, and the percent increase is also many times more than the increase for Area Type 3 and 4. This is consistent with previous finding that the census tracts with low current accessibility will see most significant increase in accessibility because of TMCs. The results of changes to accessibility to urban amenities across the four area types are similar: Type 1 areas have the most significant increase in accessibility to amenities and Type 3 areas have the second to most significant increase. The areas with low amenity accessibility will have most significant percentage increase because of TMCs. Since the results are similar, detailed tables are not presented here but are included in the Appendix.

Table 0-1: Percent Change of Average Employment Accessibility by Four Area Types

	Area Type 1 (Low in Job & Amenity Accessibility)		Area Type 2 (Only Low in Job Accessibility)		Area Type 3 (Only Low in Amenity Accessibility)		Area Type 4 (Good Job & Amenity Accessibility)	
	Average Value	% Change	Average Value	% Change	Average Value	% Change	Average Value	% Change
Base Scenario	263	na	348	na	3,836	na	162,322	na
Scenario 1	453,974	172514%	449,638	129235%	478,975	12387%	627,600	287%
Scenario 2	244,164	92738%	274,467	78848%	292,797	7533%	466,456	187%
Scenario 3	163,330	62003%	179,949	51661%	222,672	5705%	403,830	149%
Scenario 4	91,440	34668%	88,111	25244%	123,879	3130%	310,329	91%
Scenario 5	411,525	156373%	394,611	113407%	468,391	12111%	606,007	273%
Scenario 6	223,225	84776%	238,468	68493%	292,971	7538%	450,947	178%
Scenario 7	153,483	58258%	152,773	43844%	220,097	5638%	391,601	141%
Scenario 8	86,973	32970%	78,032	22345%	120,890	3052%	301,544	86%
Scenario 9	500,195	190088%	499,893	143690%	511,865	13245%	662,161	308%
Scenario 10	273,241	103794%	316,686	90992%	304,299	7833%	497,183	206%
Scenario 11	179,329	68086%	209,567	60180%	230,516	5910%	427,918	164%
Scenario 12	100,771	38216%	104,712	30019%	128,148	3241%	324,786	100%

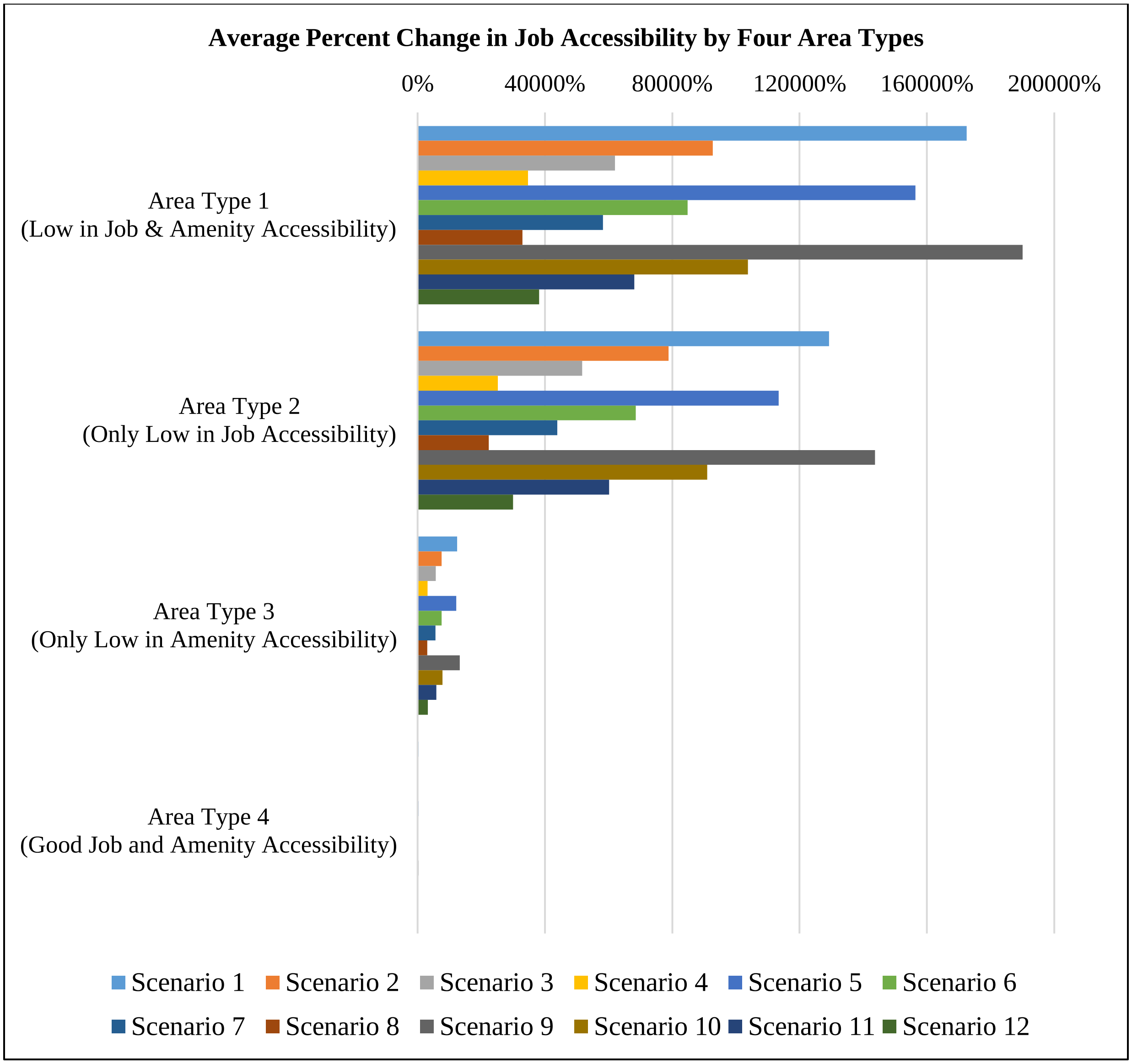

Figure 0-1: Percent Change in Employment Accessibility by Four Area Types

Employment Accessibility Change by Income Subgroups

In addition to understanding the impact of TMCs on overall job accessibility, it is also important to understand the potential change to accessibility across different job wage levels. The jobs wage levels are defined according to the LEHD data as shown in **Table 0-2** in Chapter 2. It is important to understand the wage-level-specific influence simply because transit-dependent population are more likely to be low-income population. Also, as the previous analysis shows, there is a high consistency between the areas with low current accessibility and low-income population in the City of Chicago. The spatial distributions of accessibility to low-wage jobs, mid-wage jobs, and high-wage jobs in all the 12 scenarios are all estimated and the results are mapped in **Figure 0-2**, **Figure 0-3**, and **Figure 0-4** respectively. More detailed statistics are summarized in

Table 0-2, **Table 0-3**, and **Table 0-4** respectively for accessibility to low-wage, mid-wage, and high-wage jobs.

Generally, the growths of accessibility to wage-specific jobs in different scenarios follow a similar pattern of the overall accessibility change. As the statistics show, the average census tracts in the city have similar percent growth regarding low-wage, mid-wage, and high-wage jobs, which is also like the percent growth of accessibility to all jobs. Even in Scenarios 5, 6, 7, and 8 which assume TMC wait time varies according to potential demand (low-income areas have longer wait time of TMCs), the increase of accessibility to low-wage jobs are also very substantial. The significant accessibility improvement to low-wage jobs indicates that the accessibility benefit of TMCs is evenly distributed across wage levels.

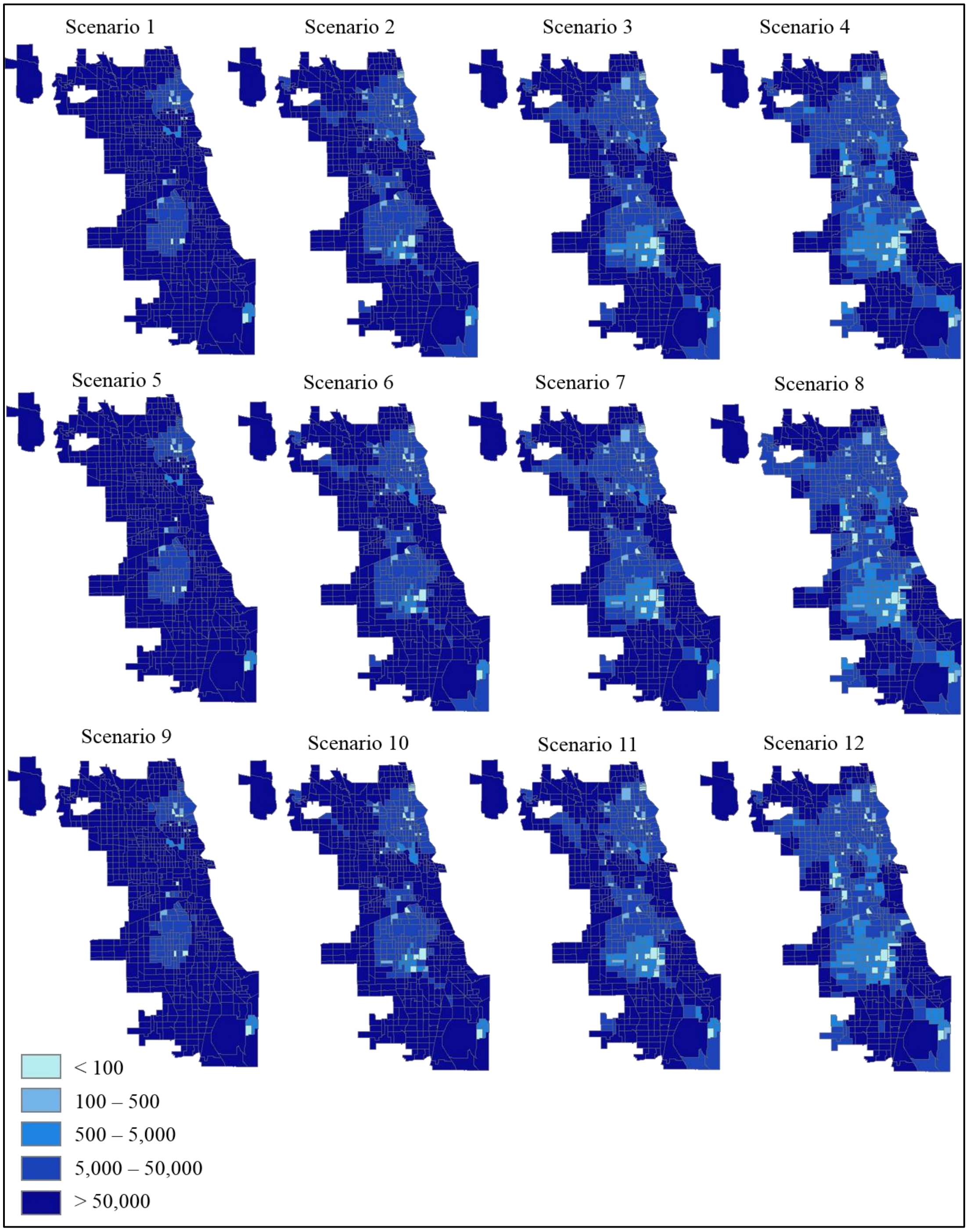

Figure 0-2: Accessibility to Low-income Jobs in the 12 Scenarios

Table 0-2: Accessibility to Low-income Jobs and Changes in the 12 Scenarios

Accessibility to Low-income Jobs								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	22	21900%	22	21900%	22	21900%	0	0%
1st Quantile	73,952	40091%	26,992	14570%	14,899	7997%	6,963	3684%
Median	113,071	12244%	65,273	7026%	49,779	5334%	29,696	3142%
3rd Quantile	160,190	492%	127,156	370%	100,970	273%	64,854	139%
Max	221,004	98%	198,830	78%	188,660	69%	158,936	42%
Average	112,335	534%	76,237	330%	61,978	250%	43,206	144%
	Scenario 5		**Scenario 6**		**Scenario 7**		**Scenario 8**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	22	21900%	22	21900%	22	21900%	0	0%
1st Quantile	72,899	39519%	26,992	14570%	14,899	7997%	6,963	3684%
Median	106,992	11580%	63,522	6835%	47,733	5111%	28,434	3004%
3rd Quantile	150,974	458%	118,250	337%	95,076	251%	63,148	133%
Max	220,273	97%	198,991	78%	188,318	69%	156,916	41%
Average	108,280	511%	73,509	315%	59,748	237%	41,851	136%
	Scenario 9		**Scenario 10**		**Scenario 11**		**Scenario 12**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	22	21900%	22	21900%	22	21900%	0	0%
1st Quantile	75,676	41028%	26,992	14570%	14,899	7997%	6,963	3684%
Median	119,881	12987%	68,568	7386%	52,657	5649%	31,664	3357%
3rd Quantile	173,037	539%	137,179	407%	116,287	329%	66,772	147%
Max	225,935	102%	200,090	79%	189,149	69%	159,207	43%
Average	119,393	574%	81,660	361%	65,953	272%	45,321	156%

Figure 0-3: Accessibility to Mid-Income Jobs in the 12 Scenarios

Table 0-3: Accessibility to Mid-Income Jobs and Changes in the 12 Scenarios

Accessibility to Mid-Income Jobs								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	43	2050%	15	650%	15	650%	2	0%
1st Quantile	103,406	38199%	36,336	13358%	20,644	7546%	10,515	3794%
Median	166,749	13590%	100,537	8154%	73,996	5975%	43,371	3461%
3rd Quantile	243,190	437%	194,927	330%	155,231	243%	100,353	121%
Max	339,237	87%	306,228	69%	290,753	60%	254,154	40%
Average	169,554	497%	115,969	308%	94,695	233%	67,397	137%
	Scenario 5		**Scenario 6**		**Scenario 7**		**Scenario 8**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	43	2050%	15	650%	15	650%	2	0%
1st Quantile	102,103	37716%	36,108	13273%	20,644	7546%	10,515	3794%
Median	159,386	12986%	98,256	7967%	71,931	5806%	42,708	3406%
3rd Quantile	232,946	414%	181,727	301%	143,934	218%	95,884	112%
Max	337,776	86%	307,327	70%	290,146	60%	250,912	38%
Average	163,048	474%	111,686	293%	91,287	221%	65,210	130%
	Scenario 9		**Scenario 10**		**Scenario 11**		**Scenario 12**	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	43	2050%	15	650%	15	650%	2	0%
1st Quantile	105,668	39036%	36,336	13358%	20,644	7546%	10,515	3794%
Median	178,519	14557%	103,578	8404%	79,137	6397%	47,378	3790%
3rd Quantile	264,110	483%	214,663	374%	181,217	300%	103,409	128%
Max	345,804	91%	308,467	70%	291,210	61%	254,544	40%
Average	180,296	535%	124,190	337%	100,698	255%	70,832	149%

Figure 0-4: Accessibility to High-income Jobs in the 12 Scenarios

Table 0-4: Accessibility to High-income Jobs and Changes in the 12 Scenarios

Accessibility to High-income Jobs								
	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	9	8900%	9	8900%	9	8900%	0	0%
1st Quantile	112,154	70437%	33,015	20664%	18,974	11833%	9,425	5827%
Median	188,805	20489%	108,600	11743%	87,002	9388%	41,734	4451%
3rd Quantile	542,197	1020%	475,034	881%	262,655	443%	104,818	117%
Max	646,711	48%	612,628	40%	598,008	37%	550,085	26%
Average	286,318	384%	203,712	244%	169,852	187%	125,170	112%
	Scenario 5		Scenario 6		Scenario 7		Scenario 8	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	9	8900%	9	8900%	9	8900%	0	0%
1st Quantile	109,720	68906%	33,015	20664%	18,974	11833%	9,425	5827%
Median	182,118	19760%	107,779	11653%	83,339	8988%	40,432	4309%
3rd Quantile	518,244	970%	289,082	497%	247,510	411%	99,872	106%
Max	643,993	47%	613,428	40%	597,703	37%	546,864	25%
Average	269,913	356%	193,925	228%	163,051	176%	121,025	105%
	Scenario 9		Scenario 10		Scenario 11		Scenario 12	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Min	9	8900%	9	8900%	9	8900%	0	0%
1st Quantile	115,301	72416%	33,015	20664%	18,974	11833%	9,425	5827%
Median	193,828	21037%	112,534	12172%	91,620	9891%	45,483	4860%
3rd Quantile	578,217	1094%	519,589	973%	292,748	505%	108,537	124%
Max	651,788	49%	616,342	41%	598,278	37%	550,784	26%
Average	306,239	418%	219,745	272%	181,667	207%	132,492	124%

Urban Amenity Accessibility Change by Age Subgroups

Comparing the change in accessibility to five types of urban amenities for age subgroups allows further understanding of the equity implications of this analysis. Therefore, to estimate the change in accessibility to urban amenities in the twelve scenarios, the changes are further examined by comparing the areas with higher concentration of elderly population, younger population, to the overall population. Census tracts that have more than one standard deviation above the average percentage of juveniles/senior people are designated as areas with higher concentration of juveniles/senior residents. Table 0-5, Table 0-6, Table 0-7, Table 0-8, and Table 0-9 present the comparison between all census tracts, and census tracts with higher concentration of juveniles/senior residents regarding accessibility to grocery stores, hospitals, libraries, colleges, and park acres respectively. Figure 0-5, Figure 0-6, Figure 0-7, Figure 0-8, and Figure 0-1 show the comparison between age subgroups correspondingly.

As the statistics and figures show, there is not a remarkable difference across areas with higher concentration of juveniles/senior residents compared to the average. This result is associated with the fact that juveniles/senior residents in the city is quite evenly distributed. It also indicates that the potential improvement in accessibility to urban amenities because of TMCs follow an even spatial distribution because the way TMCs improves accessibility is largely expanding the service areas of transit stops and the serving areas of destinations (urban amenities). Therefore, if the transit stations and urban amenities are evenly distributed, the potential improvement in accessibility by TMCs is likely to be evenly distributed spatially.

Table 0-5: Change in Accessibility to Grocery Stores by Age Subgroups

	Total Population		Census Tracts with More Juveniles (Under 18 Years Old)		Census Tracts with More Senior Residents (Above 65 Years Old)	
	Average Accessibility	% Change	Average Accessibility	% Change	Average Accessibility	% Change
Base Scenario	14.7	na	20	na	20.6	na
Scenario 1	143.3	872%	162.3	713%	163.5	694%
Scenario 2	94.8	543%	111.8	460%	114.3	455%
Scenario 3	75.2	410%	90.2	352%	92.1	348%
Scenario 4	52.7	258%	64.6	224%	66.5	223%
Scenario 5	140.8	855%	158.3	693%	160.9	681%
Scenario 6	92.9	530%	108.6	444%	111.8	443%
Scenario 7	73.4	398%	87.3	337%	89.9	337%
Scenario 8	51.3	248%	62.4	213%	64.5	213%
Scenario 9	149.3	912%	168	742%	170.3	727%
Scenario 10	99	571%	115.8	480%	119.3	480%
Scenario 11	78.4	432%	93.3	368%	95.9	366%
Scenario 12	54.9	272%	66.8	234%	69	235%

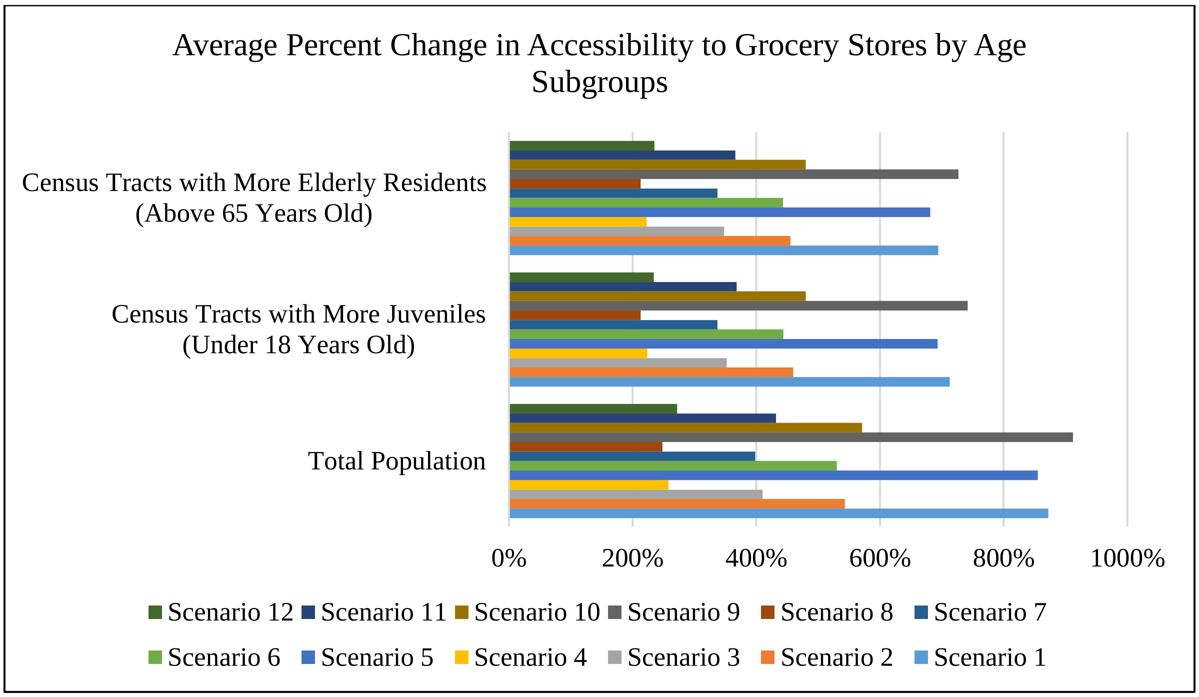

Figure 0-5: Average Change in Accessibility to Grocery Stores by Age Subgroups

Table 0-6: Change in Accessibility to Hospitals by Age Subgroups

	Total Population		Census Tracts with More Juveniles (Under 18 Years Old)		Census Tracts with More Senior Residents (Above 65 Years Old)	
	Average Accessibility	% Change	Average Accessibility	% Change	Average Accessibility	% Change
Base Scenario	1.5	na	1.9	na	2	na
Scenario 1	17.6	1065%	19.3	895%	19.9	878%
Scenario 2	10.8	616%	12.2	529%	12.8	527%
Scenario 3	8.4	459%	9.5	391%	10	391%
Scenario 4	5.3	250%	5.8	197%	6.2	206%
Scenario 5	17.2	1038%	18.6	861%	19.3	849%
Scenario 6	10.5	594%	11.7	502%	12.2	501%
Scenario 7	8.1	440%	9.1	368%	9.6	370%
Scenario 8	5.2	241%	5.6	187%	6.1	197%
Scenario 9	18.5	1127%	20.3	944%	21.1	937%
Scenario 10	11.4	653%	12.8	562%	13.6	568%
Scenario 11	8.9	489%	10	417%	10.7	424%
Scenario 12	5.5	263%	6	208%	6.5	219%

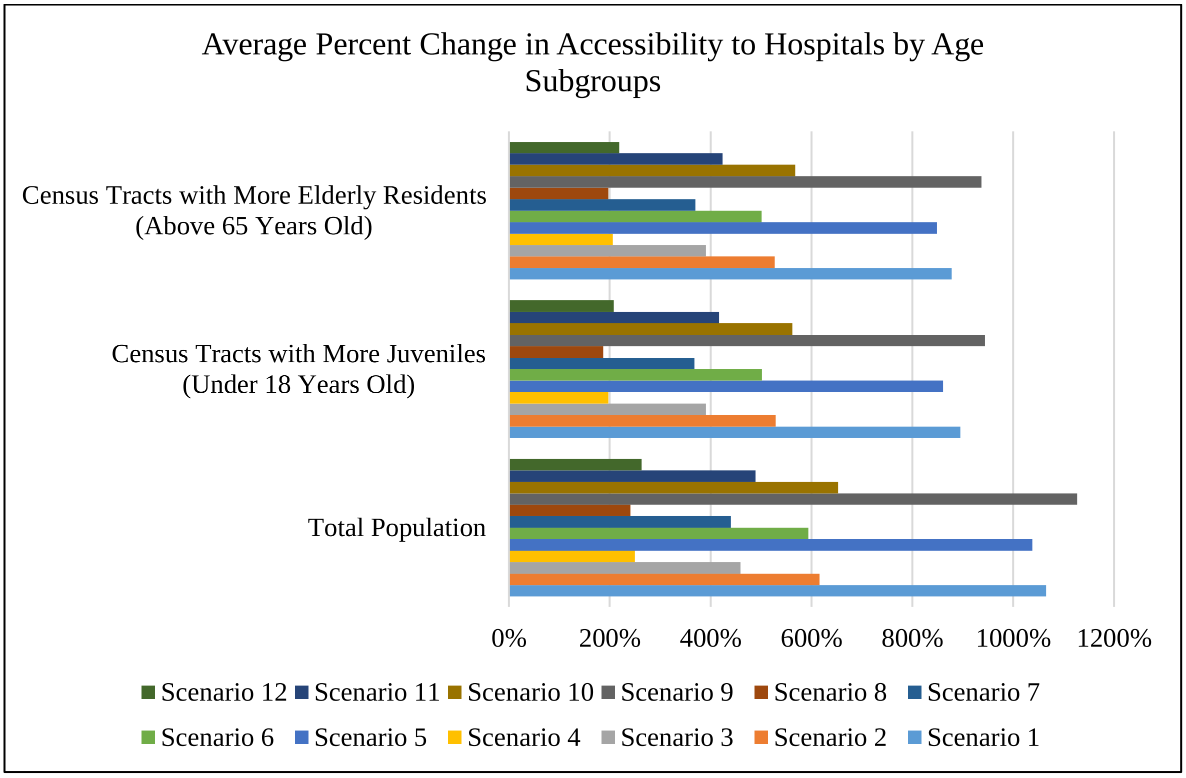

Figure 0-6: Average Change in Accessibility to Hospitals by Age Subgroups

Table 0-7: Change in Accessibility to Libraries by Age Subgroups

	Total Population		Census Tracts with More Juveniles (Under 18 Years Old)		Census Tracts with More Senior Residents (Above 65 Years Old)	
	Average Accessibility	% Change	Average Accessibility	% Change	Average Accessibility	% Change
Base Scenario	4.7	na	6.5	na	6.6	na
Scenario 1	37	692%	42.7	562%	42.5	544%
Scenario 2	25.7	449%	30.9	379%	31.3	375%
Scenario 3	20.6	341%	25.5	294%	25.8	291%
Scenario 4	14.2	204%	18.1	180%	18.2	176%
Scenario 5	36.5	681%	41.8	547%	41.9	536%
Scenario 6	25.2	439%	30.1	366%	30.8	366%
Scenario 7	20.2	332%	24.7	282%	25.2	282%
Scenario 8	13.8	196%	17.5	171%	17.7	168%
Scenario 9	38.5	725%	44.1	583%	44.2	569%
Scenario 10	26.7	473%	31.9	394%	32.6	395%
Scenario 11	21.5	361%	26.4	309%	27	308%
Scenario 12	14.7	215%	18.7	189%	18.9	186%

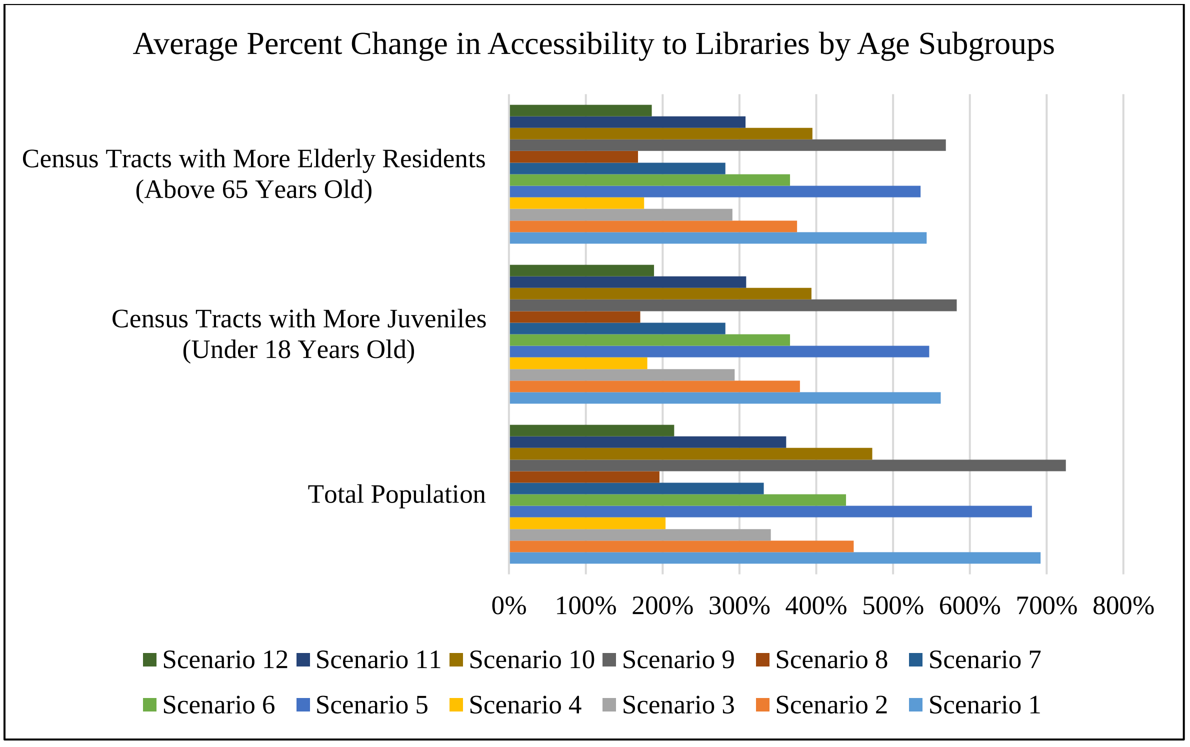

Figure 0-7: Average Change in Accessibility to Libraries by Age Subgroups

Table 0-8: Change in Accessibility to Colleges & Universities by Age Subgroups

	Total Population		Census Tracts with More Juveniles (Under 18 Years Old)		Census Tracts with More Senior Residents (Above 65 Years Old)	
	Average Accessibility	% Change	Average Accessibility	% Change	Average Accessibility	% Change
Base Scenario	4.4	na	5.2	na	6.1	na
Scenario 1	35.1	705%	36.2	595%	40.8	575%
Scenario 2	24.6	465%	26.2	403%	30.4	403%
Scenario 3	20.7	374%	22.6	334%	26.1	331%
Scenario 4	13.3	206%	14.5	178%	17.1	183%
Scenario 5	33.9	676%	34.2	557%	39.4	552%
Scenario 6	23.9	447%	24.8	377%	29.6	389%
Scenario 7	20.1	360%	21.5	313%	25.3	319%
Scenario 8	13	197%	13.8	165%	16.6	174%
Scenario 9	37.3	754%	38.2	634%	43.3	615%
Scenario 10	26.2	502%	27.7	432%	32.5	437%
Scenario 11	21.9	403%	23.7	355%	27.4	353%
Scenario 12	14	221%	15	189%	17.8	194%

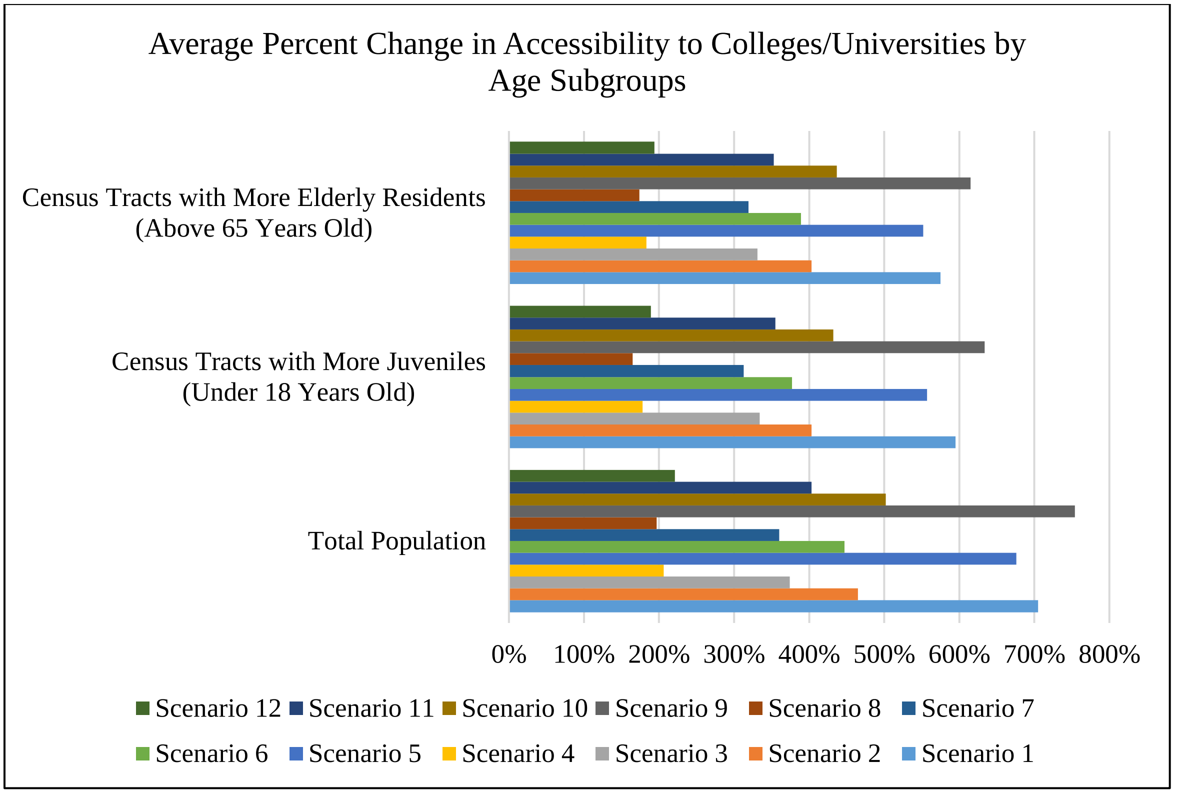

Figure 0-8: Average Change in Accessibility to Colleges / Univ. by Age Subgroups

Table 0-9: Change in Accessibility to Park (Acres) by Age Subgroups

	Total Population		Census Tracts with More Juveniles (Under 18 Years Old)		Census Tracts with More Senior Residents (Above 65 Years Old)	
	Average Accessibility	% Change	Average Accessibility	% Change	Average Accessibility	% Change
Base Scenario	374.4	na	486.6	na	526.5	na
Scenario 1	3,083.00	723%	3,388.70	596%	3,590.20	582%
Scenario 2	2,199.50	487%	2,513.60	417%	2,730.40	419%
Scenario 3	1,746.10	366%	2,026.90	317%	2,220.70	322%
Scenario 4	1,198.00	220%	1,389.40	186%	1,552.00	195%
Scenario 5	3,046.30	714%	3,308.90	580%	3,554.80	575%
Scenario 6	2,166.30	479%	2,440.60	402%	2,692.20	411%
Scenario 7	1,711.20	357%	1,955.30	302%	2,180.80	314%
Scenario 8	1,174.70	214%	1,347.80	177%	1,519.00	189%
Scenario 9	3,216.90	759%	3,507.20	621%	3,747.30	612%
Scenario 10	2,304.90	516%	2,612.70	437%	2,865.00	444%
Scenario 11	1,828.30	388%	2,104.70	333%	2,325.20	342%
Scenario 12	1,243.30	232%	1,436.80	195%	1,612.50	206%

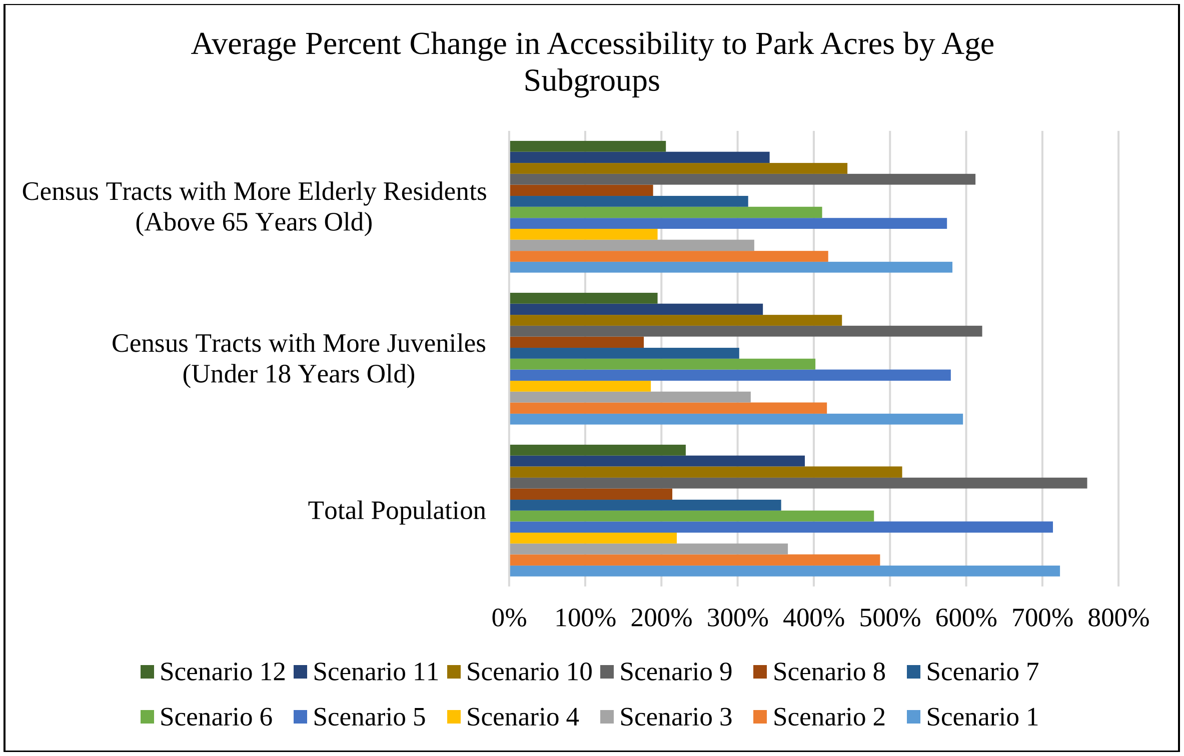

Figure 0-1: Average Percent Change in Accessibility to Park (Acres) by Age Subgroups

Estimating the Cost-Effectiveness of TMCs

Background

This chapter is devoted to the analysis of cost-effectiveness of TMCs service acting as the connecting link between trip origin/destination and train stations. The cost-effectiveness of integrating TMCs to mass public transit (trains) is evaluated and compared with the cost-effectiveness of using shuttle bus as feeder service to mass public transit (trains).

Estimating the Average Cost-effectiveness of TMC

This section aims at estimating the cost-effectiveness of TMC in terms of average cost per vehicle mile. Here it is important to understand two important aspects related to TMC operation. First, potential of savings in vehicle operating cost (VOC) by TMC due to targeted riders and second, components of VOC itself. We first focus on the cost savings part and then proceed to VOC estimation calculations.

Savings in VOC Due to Targeted Riders

The vehicles operated by TMC typically must wait in parking lots or travel empty (here empty implies no rider discounting the fact that driver is always present) in the road network until it finds and meets a ride request. Let's label distance driven by TMC vehicle without any rider till the TMC vehicle driver finds and accepts ride request as Empty Haul 1 (or EH-1). TMC vehicle will also need to incur some empty haul while it drives from the point of receiving (and accepting) ride request to the location of rider. Let's label it as Empty Haul 2 (or EH-2). These two components (EH-1 and EH-2) do not earn revenue and just involve the operation cost. In addition, these two components can vary significantly based on location, time (peak versus off-peak) and network condition (congested versus uncongested) and can be significant in many situations. Therefore, TMC vehicles strive to decrease these two components (EH-1 and EH-2).

Figure 0-1 demonstrates a complete trip cycle of typical TMC vehicle operation using time-space diagram. To simplify the representation, we have not represented acceleration and deceleration components in this figure as they are not the focus here. The representation in this figure uses four types of virtual nodes namely, free node, request receiving node, trip origin node and trip destination node. Let's define the trip as the distance traveled by TMC vehicle from rider's location (trip origin node) to his/her destination node. In general, time spent in EH-1 will be higher than that in EH-2 and EH-2 will be preceded by EH-1 making a triplet sequence of EH-1, EH-2, and trip. Therefore, a trip will be sandwiched between two sequences of EH-1, EH-2 as shown in Figure 0-1. However, if the TMC vehicle is located in the high demand area then it may receive the ride request as soon as it completes current trip or even is about to complete it. In that case, the next (subsequent) request receiving node will coincide with the current trip destination node and EH'-1 will be circumvented. This will lead to gain in efficiency of TMC operation. Similarly, TMC vehicle operation can have improved efficiency through measures that can minimize the EH-2.

Let's now analyze the situation when a TMC vehicle is serving the transit passengers. When the TMC vehicle reaches the destination of current trip which is transit station, it has a good likelihood of receiving another trip request from a potential rider very close to that point (at transit station). In this case, the trip origin node of the next trip will approximately coincide with the trip destination of the current trip, thereby either eliminating both EH'-1 and EH'-2 or reducing one or both at one leg of trip (at transit stop). The elimination and or reduction of EH'-1 and EH'-2 will lead to significant gain in efficiency of TMC operation. This indicates that due to targeted riders at transit stops, on average, the operating cost of TMC vehicles serving transit passengers is likely to be lower than those serving non-transit riders.

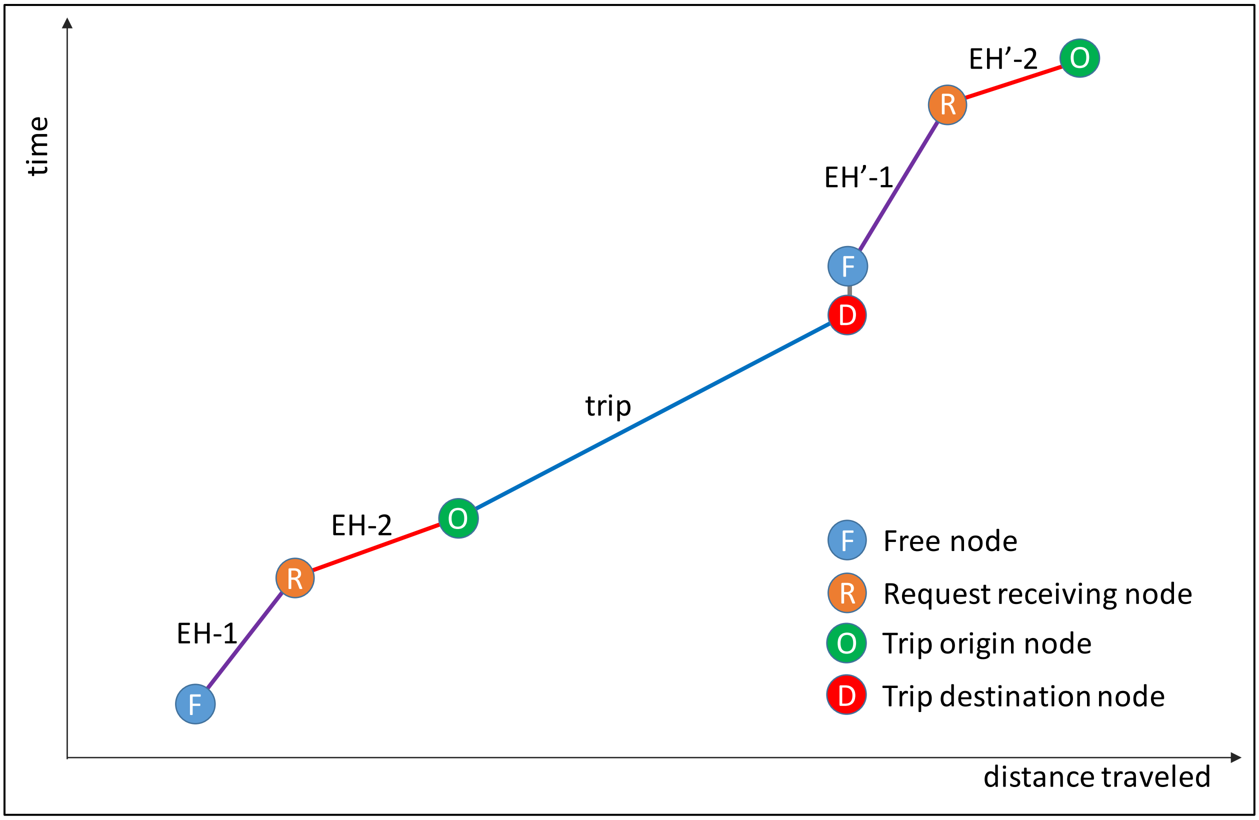

Figure 0-1: Time-space Diagram of a Typical TMC Vehicle Operation

Computation of Full Cost of Taxi

The operation cost of TMC vehicle can vary significantly based on the vehicle type (gasoline, electric, or hybrid), operating condition (congested urban, rural, and suburban), and price of gas/electricity. Literature shows multiple approaches for estimating the VOC of taxi. According to CTS Report (Christie et al., 2010) the full cost of a taxi has four components as below:

1. Capital cost
   a) Used sedan cost
   b) New taxi capital cost
   c) Used van capital cost
   d) Retrofit cost
2. Insurance cost: varies with vehicles type and geographic area
3. Operating cost: varies with vehicles type and age of vehicles. Other than fuel consumption, operating cost includes general maintenance and upkeep like oil, tires, and parts for the vehicle as needed.

4. Depreciation cost: three methods are used in USA

a) Straight Line depreciation,
b) Double Declining Balance depreciation
c) Sum-of-Years depreciation method

Following table shows the typical values for various vehicle costs.

Table 0-1: Vehicle Cost Categories

Category	Description	Typical Values
Vehicle operating cost	Fuel, oil and tire wear	**15-20¢** per vehicle-mile. Higher under congested conditions
Other distance-based costs	Distance-based maintenance and depreciation, mileage lease fees, additional crash and citation risk costs	**10-20¢** per vehicle-mile
Special fees	Parking fees and road tolls	Varies based on location
Vehicle ownership costs	Time-based depreciation, financing, insurance, registration fees and taxes	$3,000-5,000 per vehicle-year

(*Source*: VTPI, "Transportation Cost and Benefit Analysis II – Vehicle Costs", VTPI report)

Table 0-1 provides ready-to-use information for the operating cost of a typical TMC vehicle. For example, a conservative estimate will be 20+20= 40 cents per vehicle mile excluding the ownership costs. The operating costs can also be computed by accounting for individual components of operation cost. According to (Litman, 2009)the motor vehicle cost can be classified into two types: Internal costs and external costs. Internal costs are generally those that are paid by the owner or operator of vehicle. External costs are those that are typically not paid by the owner/operator but borne by others. The examples of internal costs include: vehicle ownership costs, vehicle operating costs, parking fees, toll, vehicle maintenance, cost of time (based on value of time of driver) and cost resulting from crashes. The examples of external cost include land use impacts, congestion delays, and environmental impacts. However, in this study we are mainly interested in the estimation of vehicle operating cost (part of internal cost) and is explained next.

Estimation of VOC of TMC Vehicles

In general, vehicles operated by TMC will likely have operating cost very similar to that of private vehicles except the insurance cost which is likely to be higher than privately owned cars. The operating cost of a typical TMC vehicle can be classified into: (1) fixed costs (2) variable cost. Fixed costs are those cost components that do not vary with distance traveled and variable cost are the cost components that varies with the distance travelled (Litman, 2009). The above two types of costs can further be classified as explicit costs and implicit costs (Porter, 1999). The explicit cots (e.g. gas, registration) are those that are paid directly in money and implicit costs (e.g. depreciation, value of time of driver) are those that are paid in other ways. The components of fixed cost as per the AAA cost of driving estimates for three vehicle types (small sedan, SUV, minivan) are summarized in Table 0-2. According to the AAA cost of driving estimates the components of variable cost of the three vehicle types are summarized in

Table **0-3**. Assuming a TMC vehicle is driven 20000 miles per year, the total fixed costs per vehicle mile for three vehicle types comes out to be 22.74 cents, 36.9 cents and 32.1 cents respectively. Therefore, using above values and values from

Table **0-3** the sum of fixed and variable costs for the three vehicle types are estimated as 37.34, 58.5 and 51.8 cents per vehicle mile respectively.

In the above calculation we have not considered two important components namely value of time of drivers and value of life (as well as cost of personal injury) due to likelihood of falling in an accident. Assuming the accident costs covered by insurance, we are left with one uncovered component of cost, namely value of time (VOT). The VOT can be computed as follows:

$$VOT = \frac{Average\ hourly\ wage}{Average\ operating\ speed} = \frac{W}{V}$$

The operating speed in urban conditions can typically vary between 10 miles/hour to 40 miles/hour for congested and uncongested condition. Let's assume the average wage $8/hour. Then, VOT of driver will vary between 20 and 80 cents per mile. Assuming an average speed of 20 miles per hour, the VOT of TMC driver is estimated as 40 cents per mile. Adding this component, the operating cost of TMC vehicle is estimated for three vehicle types (small sedan, SUV, minivan) is estimated as 77.34, 98.5 and 91.8 cents per vehicle mile.

Table 0-2: The Components of Fixed Vehicle Costs

	Fixed cost in $ per year		
Cost component	Small Sedan	SUV	Minivan
Insurance	1071	1058	999
License, registration	489	827	688
Depreciation	2515	4646	4039
Interest	473	848	694
Total	4548	7379	6420

(*Source*: AAA Costs of Driving (2015))

Table 0-3: The Components of Variable Vehicle Costs

Cost component	Variable cost in cents per mile		
	Small Sedan	SUV	Minivan
Gasoline	9.2	14.6	13.7
Maintenance	4.7	5.6	5.2
Tires	0.7	1.4	0.8
Total	14.6	21.6	19.7

(*Source*: AAA Costs of Driving (2015))

The introduction of automated taxi has the potential to reduce the operating cost although Litman, (2017) points out that self-driving taxis and self-parking cars may increase empty vehicle travel. Litman, (2017) also points out that self-driving taxis will incur additional costs such as cost related to cleaning and vandalism. As automated taxi is not the focus of this study, therefore we do not consider these costs.

Cost-Effectiveness of Bus as Feeder Service in Comparison to TMC Vehicles

The TMC vehicles as well as transit buses both can typically act as the feeder services for mass transit system (trains). To understand the cost-effectiveness of transit feeder services in comparison to TMC vehicles we need to first understand the operating cost of buses and TMC vehicles under urban conditions. In this study we use two different approaches to understand the cost effectiveness of buses and TMC vehicles. These approaches are based on two separate data sources for estimating the cost of operation of buses. The first approach is based on the energy efficiency, the energy required for the operation of vehicle per mile. Table 0-4 provides energy use by different modes of passenger transport based on end uses data for the year 2015.

Table 0-4: The Energy Use by Different Modes of Transportation for the Year 2015[a]

	Number of vehicles (thousands)	Vehicle-miles (millions)	Passenger - miles (millions)	Load factor (persons/ vehicle)	Energy intensities (Btu per vehicle-mile)	Energy use (trillion Btu)
Cars	112,864.0	1,445,400	2,240,370	1.60	**4,702**	6,796.5
Personal trucks	113,054.6	1,123,226	2,066,736	1.80	6,156	6,870.1
Motorcycles	8,601.0	19,606	22,743	1.20	2,855	56.0
Demand response[b]	71.4	1,595	2,267	1.4	20,047	32.0
Buses	c	c	c	c	c	202.7
Transit	64.2	2,216	20,239	9.1	**36,760**	81.5
Intercity[d]	c	c	c	c	c	35.1
School[d]	628.1	c	c	c	c	86.1
Air	c	c	c	c	c	1,684.3
Certificated route[e]	c	5,589	632,648	113.2	263,971	1,475.4
General aviation	210.0	c	c	c	c	208.9
Recreational boats	13,915.6	c	c	c	c	246.0
Rail	20.5	1,496	39,050	26.1	30,972	46.3
Intercity (Amtrak)	0.4	319	6,536	20.5	34,034	10.9
Transit	12.8	803	20,710	25.8	20.022	16.1
Commuter	7.3	374	11,804	31.6	51,888	19.4

[a] Only end-use energy was counted for electricity. Previous editions included primary energy use for electricity which included generation and distribution losses.

[b] Demand response data are for 2014. Includes passenger cars, vans, and small buses operating in response to calls from passengers to the transit operator who dispatches the vehicles.

[c] Data are not available.

[d] Energy use is estimated.

[e] Only domestic service and domestic energy use are shown on this table. (Previous editions included half of international energy.) These energy intensities may be inflated because all energy use is attributed to passengers– cargo energy use is not taken into account.

(*Source*: Transportation Energy Data Book, Edition 36, Oak Ridge National Laboratory, 2017.)

As evident from

Table **0-5**, the energy required (in terms of Btu) for one-mile operation of transit buses is 36,760 units. On the other hand, one-mile operation of cars (considered for TMC vehicles) on average require 4,702 unit of energy (in terms of Btu per mile). So, typically a bus requires 8 times more energy (7.818 times more precisely) for operating equivalent distances. Considering single occupancy of TMC vehicle (excluding driver) the energy required for passenger transportation (for single mile) using TMC vehicle will be 4,702 Btu per passenger-mile. Therefore, based on this calculation, if the demand for feeder bus service is greater than 8 passengers then, feeder bus services will be the winner against TMC vehicles. As indicated in

Table **0-5** the average occupancy of transit buses in USA is 9.1, indicating that the present ridership is sufficient to provide an edge to transit buses over TMC vehicles (assuming most TMC vehicles are serving single person). However, if we assume the average occupancy of TMC vehicles to be 1.6, same as the average occupancy of private cars, then the energy required for passenger transportation (for single mile) using TMC vehicle will be 2,939 Btu per passenger-mile. Therefore, based on this new calculation, if the demand for feeder bus service is greater than 12 passengers then, feeder bus services will be the winner against TMC vehicles. However, the average occupancy of transit buses in the USA is 9.1, indicating that the present ridership is not enough to provide an edge to transit buses over TMC vehicles (assuming TMC vehicle rideshare with occupancy 1.6). However, if the ridership of feeder buses can be increased even by one third of exiting ridership then they will become more efficient than TMC vehicles.

Our second approach is based upon the cost of operation in terms of US Dollars ($) per mile of operation of vehicle. There are three major components of bus operating cost (BOC); the biggest cost is the driver, typically paid by the hour. The other major costs components are fuel consumption and maintenance. As per the recent study by Levy, (2018) there is significant variation in bus operating cost (See

Table **0-5**). As per Levy, (2018), based on 2018 Dollars the BOC per mile varies between $7.4 for Charlotte Area Transit System to highest value $30.4 for New York City Transit. There are multiple factors that can impact the BOC, for example, wage, average operating speed, spacing of intersections and number of bus stops. For this study we use BOC for Chicago Transit Authority (CTA) as reference.

Table 0-5: The Operating Costs of Bus for Various Bus Systems in USA

Bus network	Cost per mile ($)	Cost per hour ($)
New York City Transit	30.40	215
San Francisco Muni	24.60	195
Boston MBTA	18.50	180
WMATA (Washington D.C.)	16.20	160
SEPTA (Philadelphia)	15.60	160
Chicago Transit Authority	**15.20**	**140**
Pittsburgh Port Authority	14.10	185
Seattle Metro Transit	13.90	160
Los Angeles MTA	13.20	145
Minneapolis Metro Transit	12.30	145
Miami-Dade Transit	12.00	140
Portland Tri-Met	11.70	135
New Jersey Transit	10.90	150
MARTA (Atlanta)	9.40	115
Houston Metro	9.20	120
Phoenix Valley Metro	8.80	115
Denver RTD	8.70	115
Dallas Area Rapid Transit	8.50	110
San Diego MTS	8.00	90
Charlotte Area Transit System	7.40	$100

(*Source*: Levy, (2018))

Using the CTA BOC data, operating a bus for a single mile costs $15.20 on average. Based on our computations in previous section, a TMC vehicle's operation cost (for small sedan) is 77.34 cents per vehicle mile. Even with a conservative estimate assuming single occupancy (excluding TMC driver) demand for transit buses will need to surpass 19 passengers on average to become as cost efficient as TMC vehicle operation, a scenario that seems difficult to achieve given the current state of transit bus system operations in the USA. This indicates that for using transit bus as the feeder service, either an innovative funding mechanism is required that can cover a significant portion of its operation cost or the bus system operating cost needs to be reduced significantly.

Summary

This chapter focused on estimating the operational efficiency of TMC vehicles in comparison to feeder bus service to Transit Rail. Based on the available data, our analysis indicates that TMC operation in improving the accessibility to transit rail will be more efficient than feeder bus service given the current average occupancy of bus systems in the USA. Our analysis also indicates that due to targeted riders at transit stops, on average, the operating cost of TMC vehicles serving transit passengers is likely to be lower than those serving non-transit riders.

Funding and Financing Options of Integrating TMCs with Transit

The rise of Transportation Network Companies (TMCs) like Uber and Lyft has disrupted and transformed the field of urban transportation. With near-ubiquitous access to a largely safe, comfortable, and reliable mode of transport, commuters and travelers are altering their transportation habits in unprecedented ways. By complementing each other's services, public entities and private companies may be able to partner to provide the best possible solution to urban transportation needs.

Multiple papers have addressed the relationship between TMCs and transit agencies. A study by Hall, Palsson, & Price, (2018) used data from Uber and the National Transit Database (NTD) to show that Uber is largely a complement to transit, particularly in larger cities and for rail systems. Wang & Ross, (2017) found that a significant proportion of the taxi trips, which share important similarities with TMCs, are serving areas with low transit service or the first/last mile of transit in New York City. A large study on transit ridership by Boisjoly et al., (2018) used data from 25 agencies in North America and found that the presence of Uber correlated with increases in ridership, but that most of the variation in ridership comes from the amount of service provided by each agency. Clewlow & Mishra, (2017) used an internet survey in seven major metropolitan areas and found that adopters of TMCs reduced their bus usage by 6% but increased their commuter rail usage by 3% on average. Polzin, (2016) outlines policies for public transportation regarding TMCs. The paper suggests that agencies monitor the impact of technology on travel behavior, redefine transit's role as mobility options change, and position transit to address emerging issues. A Transit Center report published in early 2016 suggested that transit agencies partner with TMCs to create efficiencies in how service is provided by replacing inefficient markets and reallocating services (Feigon & Murphy, 2016). They also suggested that transit agencies prompt TMCs to exchange data to understand rider needs better.

Feigon & Murphy, (2016) draw on interviews with transportation agencies; a survey of shared mobility users; travel time, demand, and capacity analysis; an assessment of paratransit practices and regulations; and documentation of business models. The report presents five key findings: (1) Among survey respondents, greater use of shared modes is associated with greater likelihood to use transit frequently, own fewer cars, and have reduced transportation spending; (2) Shared modes largely complement public transit, enhancing urban mobility; (3) Because shared modes are expected to continue growing in significance, public entities should identify opportunities to engage with them to ensure that benefits are widely and equitably shared; (4) The public sector and private mobility operators are eager to collaborate to improve paratransit using emerging approaches and technology; and (5) A number of business models are emerging that include new forms of public-private partnership for provision of mobility and related information services.

Taking this advice to heart, in the last few years, these public transit-TMC partnerships have proliferated. Multiple transit agencies across the country are implementing programs that subsidize the activities of these companies to provide people in their service areas with more reliable transportation. **Table 0-1** shows a preliminary, selective list of existing partnership programs to demonstrate their popularity.

Table 0-1: Agencies with Partnership Programs

Agency	City	TMC	Description	Effective Date
Pinellas Suncoast Transit Authority (PSTA)	St. Petersburg, FL	Uber/ United Taxi	Offers discounted rides to bus stops within designated zone, up to $3/ride	February 2016
SEPTA	Philadelphia, PA	Uber	Discounted rides (40% up to $10) to busiest Regional Rail stations	May 2016
Altamonte Springs	Altamonte Springs, FL	Uber	Discounted rides (20% within city limits, 25% to SunRail station)	March 2016
Centennial	Centennial, CO	Lyft	Subsidized all Lyft Line rides to Dry Creek Light Rail Station	August 2016
City of Phoenix/Valley Metro	Phoenix, AZ	Lyft	Discounted rides (20%) from select transit stops	October 2017
Arlington, TX	Arlington, TX	Via	Replaced Arlington Xpress commuter bus service	December 2017
Richmond, VA	Richmond, VA	UZURV	Up to $15 discount on paratransit rides	August 2017
MBTA	Boston, MA	Uber/Lyft	Up to $13 discount on paratransit	March 2017
Dallas Area Rapid Transit (DART)	Dallas, TX	Lyft	Free Paratransit Rides	October 2017
Cap Metro	Austin, TX	Via Transit	Free rides within service zone and to MetroRail Station	June 2017

Regional Transportation Commission of Southern Nevada	Las Vegas, NV	Lyft	Up to $15-dollar discount on paratransit	Feb 2018
LA Metro	Los Angeles, CA	Via Transit	Discounted rides to and from transit stop	N/A
Marin Transit	Marin County, CA	Via Transit	$4 on-demand rides within service area	June 2018
Greater Dayton RTA	Dayton, OH	Lyft	Cost limited to standard one-way fare for on-demand ride	June 2017

Sources: APTA (https://www.apta.com/resources/mobility/Pages/Transit-and-TMC-Partnerships-.aspx) and The Transit Wire (http://www.thetransitwire.com/category/new-mobility/)

Generally, these programs act as a solution to the difficult first-mile last-mile problem, offering a discounted trip through a TMC to or from a transit stop. As many more transit agencies seek to implement their own forms of partnerships, it is important to consider the mechanisms by which agencies can and have funded their partnership programs.

This paper seeks to better understand the advantages and disadvantages of those funding mechanisms through conversations with employees at public transit agencies that have implemented these programs. By engaging people involved with running these programs, the study explores the challenges and opportunities involved.

Sample Selection

The study selected a sample of public transit agencies to participate in semi-structured interviews. To build as complete a picture as possible, the researchers contacted public transit agencies that varied in size, operational procedures, and geography. Agencies were selected based on a) having a partnership program in place and running for at least one month, and b) not limiting the program to paratransit. Transit agencies that had established a partnership program with a major TMC within the last two years were attributed special attention. These agencies were selected through an internet keyword search for agencies with partnership programs. Six agencies were originally contacted, and four transit agencies were included in this preliminary study.

Table 0-2 summarizes the agencies included and their operational characteristics.

Table 0-2: Agencies Included in this Study

Transit Agency	City/Region	Modes	Annual Unlinked Trips (2016)
Pinellas Suncoast Transit Authority	Pinellas County, FL	Bus	13 million
Charlotte Area Transit System	Charlotte, NC	Bus+Light Rail	26.2 million
City of Phoenix/Valley Metro	Phoenix, AZ	Bus+Light Rail	34.2 million
Pierce Transit	Pierce County, WA	Bus	9.8 million

Each of these transit agencies operates a partnership with either Uber, Lyft, or a taxi service to provide First-Mile/Last-Mile service to or from transit stops, or zones centered around transit stops. Cities without transit agencies that have implemented partnerships, such as Altamonte Springs, FL, were excluded from this study.

Semi-Structured Interview Questions

The semi-structured interview with each agency followed the same basic list of six questions but allowed for the collection of additional information that has been processed and included in this paper. The questions included:

1. Why was the partnership program implemented?
2. How was the partnership program implemented?
3. What funding mechanisms were used to implement the program?
4. What were the advantages/disadvantages to this type of funding?
5. What, if any, other options were considered?
6. What have the TMCs contributed to this partnership?

Results

The following section describes the interviews with each of the four agencies, breaking the discussion that resulted into three categories, program implementation, funding, and TMC contributions.

Pinellas Suncoast Transit Authority (PSTA)

PSTA is a regional transit agency serving Pinellas County, Florida, a bus-only agency with close to 13 million annual unlinked trips. It serves the peninsula west of Tampa Bay, which includes the major municipalities of St. Petersburg, Clearwater, and Palm Harbor.

Program Implementation

During a regular service adjustment, as PSTA considered potentially eliminating a low-ridership route along the coast, the agency confronted fierce resistance from a small number of riders, as well as elected officials on the board of directors for the agency. Facing pressure to provide service to an area where it would have been cost-inefficient, PSTA began looking for solutions to provide reliable service to areas that were not transit-heavy. Borrowing a strategy from the University of Florida, which had already implemented a system to subsidize Uber rides for students on Friday and Saturday nights, PSTA established Direct Connect, now one of the longest-running and best-established programs of its kind.

Direct Connect offers a flat $5 discount on Uber, Lyft, and United Taxi rides around two dozen Direct Connect zones spread throughout PSTA's Service Area. Each of these zones is centered around major transit stops that serve high-frequency, high-ridership routes throughout the county. The design and selection of these zones encourages people located in low-service areas to use transit, by eliminating the obstacle of connecting to transit from the origin or destination. **Figure 0-1** shows the Zones for which Direct Connect is active.

In examining how PSTA funds the Direct Connect program, it is important to understand the other major partnership program the agency offers. TD LateShift is a program for the Transit Disadvantaged that seeks to minimize the adverse impact of transit schedules on those who work outside of service hours. The program offers 25 free trips a month on a service of choice (Uber, Lyft, or United Taxi) to those that work between 10pm and 6am and fall at or below 150 percent of the poverty line. The program is funded through a State Mobility Enhancement Grant, through the Commission for the Transportation Disadvantaged, and has proven to be extremely popular. Not only do the employees benefit from the program, but many businesses that depend on these workers are also benefitting.

Figure 0-1: Map of Direct Connect Zones in Pinellas County
Image Source: https://www.psta.net/riding-psta/direct-connect/

Funding

Because the Direct Connect program emerged from cost-efficiency measures, PSTA's sales tax revenue provides 100 percent of the funding. Since the program offers a flat, and financially predictable discount, and since each expenditure presumably increases transit ridership, PSTA has been able to self-fund the program entirely. The clear benefit to this method for both users and the agency is that an internally developed program is operationally streamlined: there are no requirements or authority the agency is beholden to in the decisions it makes, and the methods used to operate the program. Because many federal grant programs involve substantial federal oversight, developing a program through grant funds can lead to substantial time, effort, and money involved in collecting, analyzing, processing, and presenting the data required. In this case, PSTA felt that potential grants would not provide enough funding to justify the time involved in the required analysis and oversight. Eliminating the reporting burdens by developing an in-house partnership program has, in their opinion, resulted in a more efficient system. While the negative implication of this structure is that the agency must pay for the program itself, the creative model is nonetheless financially feasible.

The introduction of private, profit-seeking companies into the public transit system has presented another challenge to PSTA regarding the data requirements of traditional grant programs. The private agencies PSTA is working with are concerned about their customers' privacy and the competitive nature of their services, and therefore many of these transportation companies are, in the first place, unwilling to provide the data that public transit agencies have traditionally had at their disposal regarding service provided and consumed. Though these companies are obligated to provide a broad level of data including bucketed time of day and census-tract location, the private operators have been unwilling to share trip-level data to PSTA, even though PSTA could use such data to provide more effective service to their customers. As these partnerships develop further, and private companies and public agencies become more familiar with each other's operations and data requirements, PSTA hopes that the situation will improve.

In the long run, funding for new transit services must prove to be cost efficient for transit agencies. One of the most promising funding mechanisms PSTA is considering, is having participating municipalities or businesses that are interested in collaborating with the program offer funding in exchange for a Direct Connect zone nearby. With the potential benefits of reducing congestion and increasing tourism, municipalities currently not served by Direct Connect might be willing to contribute to implementing the program, around whichever PSTA routes run through their jurisdiction. Similarly, large employers seeking to reduce employee driving-hours or increase the reliability of getting their employees to work, might be interested in providing this program to their employees by paying for a zone. This latter solution is especially relevant to a program like TD LateShift, where the intended consumer is working individuals. Having a party pay completely or in part for a new Zone also ensures that the benefits of the program are directed to where the money is coming from. Exploring these funding possibilities could significantly increase the reach of the program, while offering a multitude of benefits to the municipalities and/or businesses involved.

TMC Contributions

Since PSTA's program depends on Uber and Lyft's digital infrastructure, it is important to acknowledge that these companies have largely shouldered the costs and burdens associated with modifying their applications, taking on the responsibilities of testing and troubleshooting to ensure that the program and the service work well together. For example, Uber has integrated the geofencing involved with ensuring users are inside one of the Direct Connect zones, as well as the relevant in-app messages and information necessary to provide this service, at no cost to PSTA. Additionally, when the program first launched, Uber independently conducted a significant marketing campaign to raise awareness of the program. The in-app component of the marketing campaign, through the dialog boxes familiar to any Uber user, advertised the availability and details of the program. Beyond this feature, Uber deployed a more involved strategy by employing their drivers to speak in-person with commuters and other transit users at major transit stations in the area. The drivers walked interested parties through the details of the program and offered rides to those willing to participate. In addition, Uber also waived the Uber-for-Business fee usually charged to organizations seeking to employ Uber's services.

Though clearly Uber and companies like it stand to benefit from these partnerships, both in terms of an expanded customer base and good public relations, it is also important to acknowledge the services and costs Uber assumed to implement the program.

Charlotte Area Transit System (CATS)

CATS operates a transit system in and around Charlotte, North Carolina, consisting of both bus and light rail components. Its daily unlinked trips, as of Q4 2017, were close to 90,000, with 16,000 riding on the LYNX Blue Line. The Blue Line serves 15 stations on a north-south axis through Charlotte, with two of these stations, JW Clay Blvd/UNC Charlotte and Parkwood, having opened earlier this year in March 2018. **Figure 0-2** shows a map of the LYNX Blue Line extension.

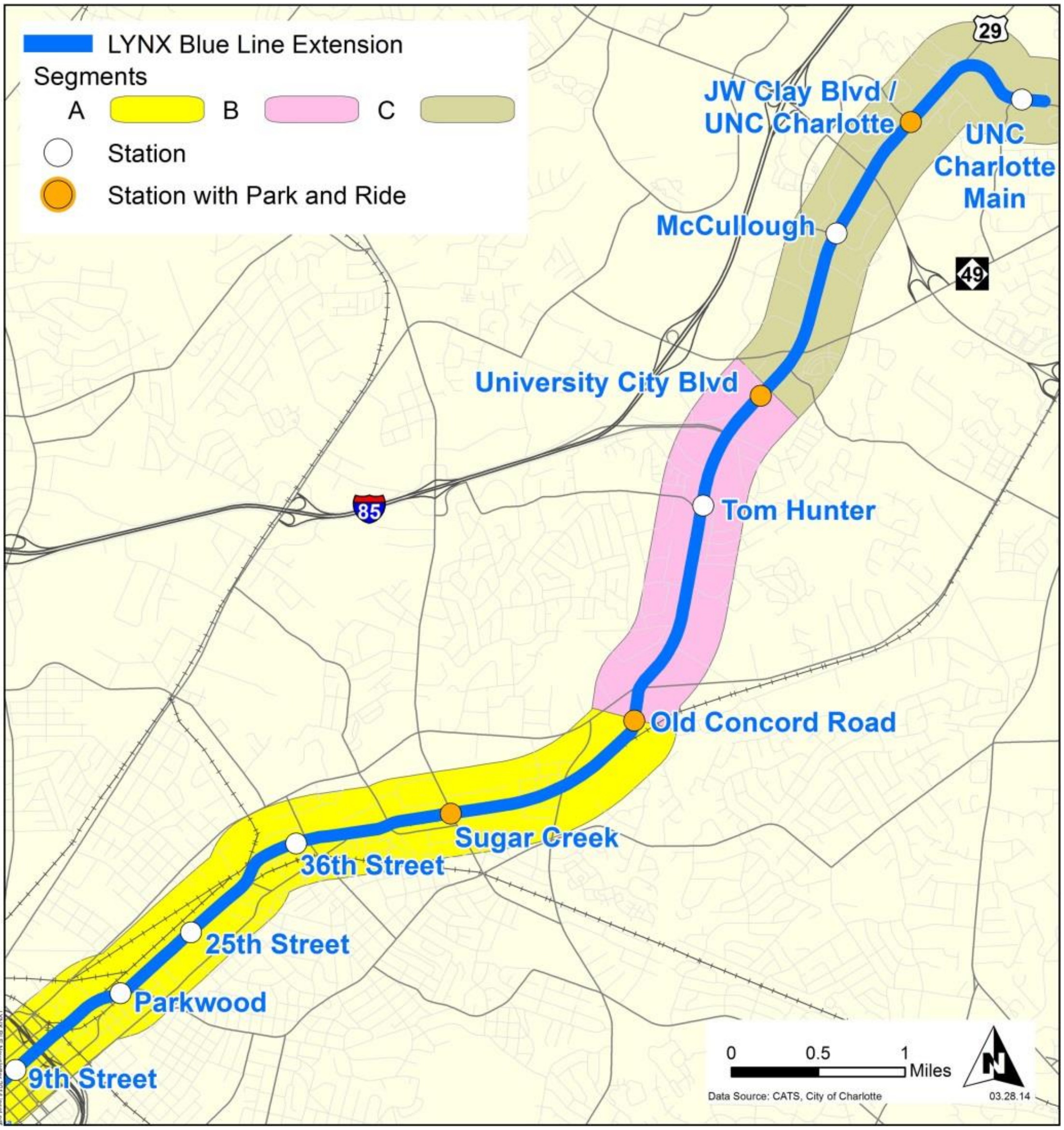

Figure 0-2: Map of the LYNX Blue Line Extension

Image Source: https://www.transportation.gov/tifia/financed-projects/cats-lynx-blue-line-extension

Program Implementation

Bundled with the opening of these two stations was the launch of a partnership program with Lyft. The purpose of the partnership is to subsidize rides to and from either of these two stations to encourage ridership of the Blue Line. Previously, CATS had determined that bus service to these areas was not cost-effective. However, there were still a large number of commuters that needed to get to work. For example, the JW Clay Blvd. Station services the University Research Park, a large center of employment. Because of the inconsistent and irregular demand for service in this area, the agency determined that a flexible partnership would have been more cost-effective than the bus line.

To meet these needs, CATS partnered with Lyft to offer a $4 discount on Lyft rides taken to or from either of the light rail stations within a geofenced area. This program is offered both through standard promotional codes through the Lyft app, as well as through the CATSPass app which facilitates transit use for monthly pass holders. While the shuttle and bus services that had served these areas were eliminated years ago, the introduction of a partnership program fulfills CATS' obligation to provide service while simultaneously offering users more flexibility: those working later, or irregular hours no longer find themselves stuck to transit schedules unaccommodating to unusual working hours, instead using the program to get to the regular all-day service of LYNX Light Rail.

Funding

CATS opted to fund this partnership entirely through its own general revenue stream, comprised mainly of sales tax dollars. After initial conversations with Lyft about the partnership, the agency wanted to move as quickly as possible to have the program up and running soon after the opening of the blue line. Since the expansion of light rail also provided an opportunity for the total revamp of bus service, CATS worked to eliminate inefficiencies in the bus service in a way that could also potentially provide extra money for the partnership program. It is considering a similar approach in areas where the LYNX Red Line commuter rail might be extended north from Charlotte. A similar program offering first-mile/last-mile service to commuters and other rail riders may be an effective supplement to standard bus service to and from commuter rail stations.

Despite the potential benefits and cost-savings to transit agencies, additional analysis and data collection is necessary to determine whether the alternative rideshare partnership is successful in improving service and reducing time and cost burdens for consumers. An important area of future research is to examine whether replacing cost-inefficient bus services with subsidized ride-share services improve transit services and costs in an equitable manner.

TMC Contributions

As a company experienced in public private partnerships, Lyft has guided the development of the partnership with CATS. For example, Lyft provided advice regarding the recommended level of subsidy, seeking to balance the benefits delivered to user, agency, and company. Like in the PSTA partnership, Lyft assumed the responsibility of integrating the program with their app, building in the geofencing and promo code infrastructure necessary for the program to work. The parties agreed that a $4 subsidy was enough to ensure that users were not paying more than a few dollars for their rides; with the average Lyft totaling no more than $8, the subsidy guarantees that a user is paying less for the combination of Lyft and light rail or bus, than by Lyft alone.

City of Phoenix/Valley Metro

Though the region around Phoenix, AZ is served by the Valley Metro Regional Public Transportation Authority, the primary responsibility for the operation of bus and rail routes falls to the municipalities. Featuring both bus and rail service, Valley Metro serves nearly a quarter million people daily along 102 bus lines and 32 light rail stations. The City of Phoenix, responsible for the operation of the clear majority of bus lines, passed an initiative in 2015 called Transportation 2050, a comprehensive transportation measure seeking to build light rail and improve multimodal accessibility.

Program Implementation

With a mayor who was eager to adopt innovative transit solutions, the City of Phoenix launched a six-month pilot program with Lyft in October of 2017 to provide a 20 percent subsidy on rides to and from transit stops in select parts of the city. The northeastern part of the city is served by commuter lines but did not have enough demand to sustain regular bus service. Similar to the Charlotte example, the pilot TMC-agency program launched to provide customers with a more flexible service beyond the capabilities of commuter bus service. The City of Phoenix also needed a quick solution to provide transit service to newly annexed land in its southwest region. While the city is adding routes in this area, project completion is still several years away. In the meantime, the pilot program offers accommodates those wanting to use transit, while simultaneously providing a means to gauge demand for this type of service. **Figure 0-3** and **Error! Reference source not found.** show the areas in which the program is active.

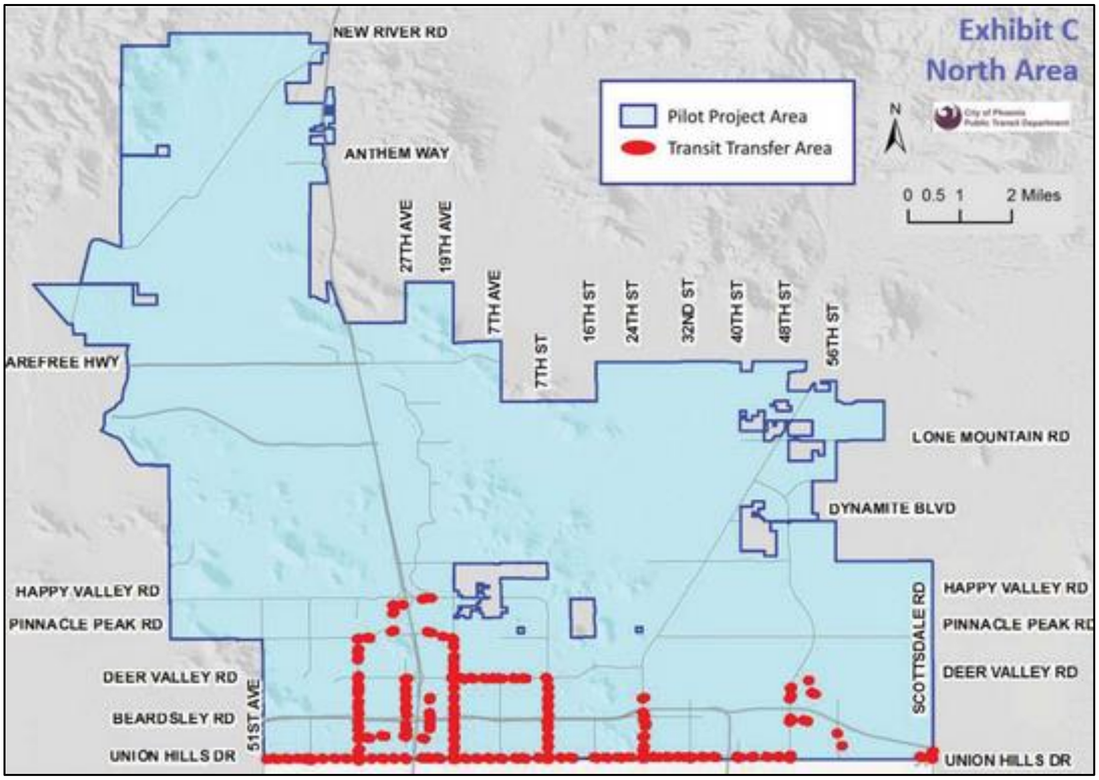

Figure 0-3: Phoenix Partnership Area (North)
Image Source: https://www.azcentral.com/story/news/local/phoenix/2017/10/18/lyft-give-discounts-riders-traveling-to-phoenix-bus-stops/774239001/

Funding

Lyft began operating in the Phoenix region at the same time that the city passed Transportation 2050. In the pursuit of market share, this partnership was borne as much out of the city's desire to provide service as Lyft's desire to gain customers in the region. As a result, the two entities established a creative agreement whereby Lyft would assume the cost of the discount itself, in exchange for free advertising space on the side of bus shelters throughout the city.

By leveraging its assets in a mutually beneficial way, the City has begun a transportation experiment and service at no cost to itself, while simultaneously providing its customers with a reliable and flexible service. The data obtained from this experiment is important in enabling the city to judge the location of transit hotspots and spot opportunities for service changes. Neighborhood circulators that serve certain areas of the city could potentially be eliminated based on the performance of this program, a clear opportunity for cost-cutting without sacrificing service. Of course, it is unlikely that Lyft would continue to sacrifice revenue in the long-term, but this arrangement provides the opportunity to prove that the model is feasible. In the future, beyond the six-month pilot program, the city is considering using general funds from the Transportation 2050 initiative for a similar program, though likely larger in scale. A federal grant for Valley Metro's mobility app, which features Uber as a part of the standard trip planner, is also a potential source of funding for such a partnership. The City of Phoenix feels that cities have numerous assets that they can use as initial buy-ins for deals to run a pilot program, which may indicate the efficacy of these partnerships.

Pierce Transit

Pierce Transit, the agency serving Pierce County in Central Western Washington State, is a bus-only agency that often complements the commuter and light rail and bus services operated by the larger, regional agency, Sound Transit. Pierce Transit has a large service area, and though it includes the metropolitan region of Tacoma, there are large portions of the service area that have very limited service.

Program Implementation

In an attempt to increase the accessibility of transit in less dense, transit-demanding but underserved neighborhoods, Pierce Transit implemented their Limited Access Connections program. This TMC-agency program involves several zones, centered around Sounder commuter rail stations, the local community college, and high-ridership routes that connect to rural areas. Additionally, the zone in the more urban area of northeast Tacoma facilitates connections to every major transit route that Pierce Transit administers. **Figure 0-4** shows the location of these zones.

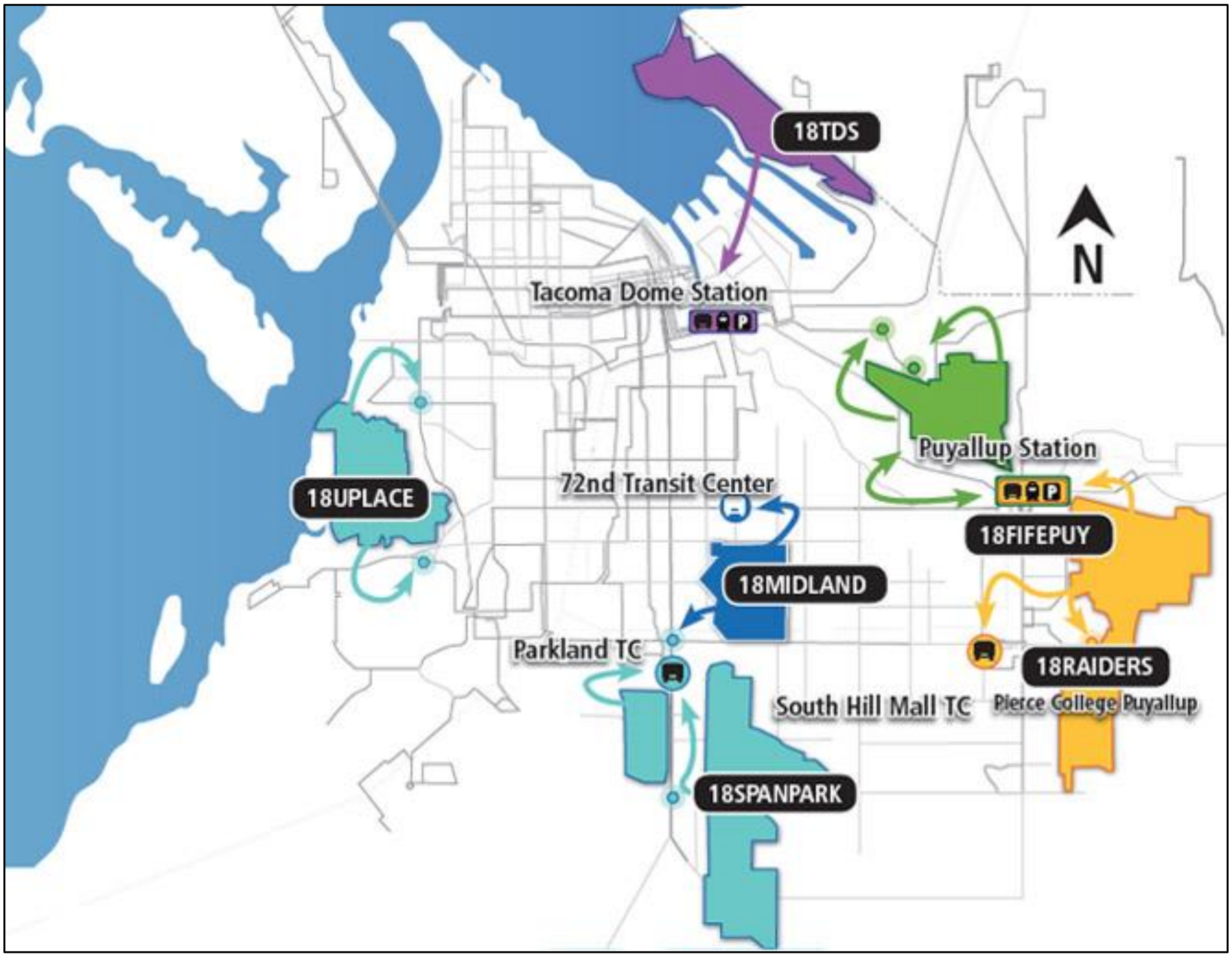

Figure 0-4: Limited Access Connection Zones

Image Source: https://www.piercetransit.org/limited-access-connections/

Within these zones, Limited Access Connections offers completely free Lyft rides to and from transit stops inside each zone, as well as certain major transit stations, establishing easy connection possibilities between major destinations and transit routes. For example, the zone around Pierce College Puyallup has many cul-de-sacs and major hills that make accessing transit stops difficult. Despite the reliability and frequency of the service, the primary obstacle to transit ridership is physical access, which the program eliminates. Similarly, the zone centered around the major transit station in Tacoma enables regional connection regardless of where the customer is in the zone.

Funding

Pierce Transit has funded Limited Access Connections through the Federal Transit Association's Sandbox Grant, a research-oriented grant that encourages experimentation with transportation, placing far fewer restrictions on agencies than traditional grant programs. The purpose of the grant is to allow agencies to more freely implement progressive programs. Limited Access Connections will enable Pierce Transit to gauge where transit demand exceeds service, and to determine the viability of a similar (if less expensive) program to supplement transit service. The program, subject to limited funding of $257,403, is set to wrap up at the end of one year beginning May 2018, or when the funding runs out.

Pierce Transit is currently working to re-establish their pre-recession level of operations and cannot sustain the program beyond the initial grant with its own funds. If Pierce chooses to continue the program or a version of it, the agency will likely move to traditional grant structures or attempt to fund the program internally with a much lower subsidy. However, like the possibilities of PSTA's Direct Connect, Pierce Transit thinks Limited Access Connections has a strong likelihood of attracting institutional investors to expand and develop the program. For example, SoundTransit is facing incredible congestion at a Sounder station Park & Ride, and so it may be willing to pay to implement a LAC zone around the station. Similarly, after the program ends, Pierce College Puyallup could offer money to keep the zone intact.

TMC Contributions

An important consideration for Pierce Transit is the issue of equity. As public entities receiving state and federal dollars, public transit agencies are obligated to ensure that their services are accessible to everyone, including the disabled and the poorer populations. Because Lyft (and Uber) do not provide accessible vehicles in many regions on the west coast, Pierce Transit's paratransit arm must work in conjunction with Limited Access Connections, subject to the same rules. To provide service to those without credit cards or smartphones, Lyft provided Pierce Transit a service called Concierge, originally designed for hotels, so that customers could call a phone line and have Pierce Transit representatives order a Lyft for them.

Like the other programs mentioned, Pierce Transit has been disappointed in the quality of the data received from the private companies. As a concrete example, Lyft provides census tract-level data whereas the agency would prefer block-level data and Lyft provides ranges of time (afternoon, evening) whereas the agency could prefer a specific time. Once again, however, Lyft independently generated the digital infrastructure necessary to get the program started. The geofencing and timeboxing necessary to prevent abuse of the program, as well as the Concierge service, were implemented entirely by Lyft.

Additional Possible Grant Funding

Many of these interviews mentioned the possibility of grant funding to supplement or replace their current sources. While the Mobility on Demand Sandbox Grant, and its potential successor, have funded and will continue to fund several innovative partnership programs across the country, the FTA offers a few other grant programs that could be used to continue this type of work as it becomes more mainstream. The Urbanized Area Formula Grants – 5307 are eligible to be used for technical transportation-related studies, as well as for certain expenses associated with mobility management, programs associated with offering a diversity of transportation options to customers, unlike traditional transit service. As these programs are largely designed as first-mile/last-mile solutions, they have less applicability in more rural areas without heavy transit service. Consequently, the Rural Transportation Assistance Program – 5311(b)(3), which offers funds for transportation research to providers of public transportation in rural areas, could be used to fund pilot programs in a greater number of regions. The eligibility of shared mobility services for FTA grants is dependent on several factors, but job access, reverse commute, and paratransit service are key possibilities. Additionally, the implementation of technology systems in support of shared mobility is also a likely candidate for funding.

Summary and Conclusions

The role of public transportation is very crucial in not only achieving an environmentally friendly transportation system but also in achieving a more equitable society where those who cannot own, or drive car are not deprived of mobility and has good access to jobs and various destinations based on their life style aspirations. Unfortunately, the transit system in most cities of USA do not have full coverage, meaning there is a significant population that cannot access the public transportation system especially mass public transportation (e.g. suburban train, subway, metro train etc.). This is due to the fact that either the train stations are too far from their residences or the destinations of their choice/needs. Emerging technologies have given rise to Transportation Management Companies (TMCs) which are frequently referenced as Transport Network Companies (TNCs) that deliver on-demand services (for e.g. Uber and LYFT). These companies typically provide an app-based service that links passengers and drivers and charges passengers automatically. The innovative ride matching system operated by TMC has the potential to improve the accessibility of transportation system through proper integration.

This study analyzes an expanded role for integrating TMC's into public transportation linking the public and the private sector providing greater accessibility through increased connectivity and coordinated service delivery. The study considers a number of scenarios and provides both aggregated and disaggregated analysis of accessibility in the presence and absence of this integration.

The results of the accessibility analysis of this project indicate that using TMCs to serve short distances either for multimodal trips connecting to transit or single modal trips can significantly improve accessibility to jobs and urban amenities in the City of Chicago. The average increase in job accessibility exceeds 200% even when it is assumed that TMCs can only be used for one mile around transit stations and two miles for single modal trips. Moreover, the potential accessibility elevation for the areas with lowest accessibility is most significant. For the target areas that have most limited accessibility currently, integrating TMCs with transit can significantly improve the accessibility level in those areas. Such considerable accessibility increase because of TMCs is associated with the huge gap between car and transit accessibility. On one hand, currently transit can only serve travelers within 0.5 mile from a transit station but using TMCs can enlarge the catchment area of transit which can significantly increase the number of travelers that transit can serve and make more jobs more accessible by using transit. On the other hand, in the scenarios, we assume that TMCs can be used to serve trips shorter than 2 miles, 3 miles, and 4 miles respectively, similar as paratransit, which is able to reduce the gap between car and transit accessibility for short distance trips. This means that assuming TMCs is available everywhere, any jobs or urban amenities that are located within 2, 3, or 4 miles will be considered as easily accessible, meaning that the catchment areas of employment are enlarged significantly.

The results reveal the huge accessibility benefits of leveraging TMCs to provide better access to transit and to provide point-to-point mobility service. The accessibility benefits that are quantified can be easily monetized and used to compare the cost-effectiveness of using TMCs to provide certain level of accessibility versus using other modes. Therefore, it provides a base for implementing strategies to integrate TMCs with transit by providing incentives or subsidies to TMCs for targeted areas. Moreover, the analysis also suggests a way to identify target areas of leveraging TMCs to improve accessibility. For areas that have low accessibility currently and higher concentration of transit-dependent populations, subsidizing TMC trips to/from a transit station for short distances can be very cost effective to improve mobility and accessibility for captive transit users. Especially for areas with low-density and cannot support mass transit, TMCs provide new opportunity of enhancing transit accessibility and equity.

Another important finding from the analysis is that the potential accessibility increase is very evenly distributed across wage/income categories and across areas with different demographic traits. This is related to the fact that the spatial distribution of different types of jobs and urban amenities are quite even in the city. Though there is several heavy clusters of jobs and urban amenities, the mix of low-, mid-, and high-wage jobs is consistent spatially and different types of urban amenities are distributed evenly. Using TMCs for short multimodal and single modal trips simply enlarges the catchment areas of transit stops and the serving areas of those destinations, so the potential accessibility improvement is likely to follow the current spatial pattern. This means that if the destinations are evenly distributed, the potential impact of TMCs is also likely to be spatially equitable.

Implementing strategies such as enhancing equal access to TMCs and subsidizing TMCs trips for low-income transit-dependent travelers must rely on a more active role of planners, government agencies, and transit operators to initiate building partnership with private TMCs providers. The current social, economic, perceptual barriers to using TMCs is a main challenge for providing equal access to TMCs and will continue to be the main challenge when TMCs are provided by automated vehicles, and thus should be researched more.

This study analyses both qualitatively and quantitatively the operational efficiency of TMC vehicles for providing the connectivity to/from train stations. Study also provided comparative analysis of operating efficiency of TMC vehicles and bus service acting as feeder service to trains. Based on the available data about vehicle operating costs (for cars and buses), our analysis indicates that TMC operation in improving the accessibility to transit rail will be more efficient than feeder bus service in areas with low demand. Our analysis also indicates that due to targeted riders at transit stops, on average, the operating cost of TMC vehicles serving transit passengers is likely to be lower than those serving non-transit riders. This can be a motivating factor for both TMCs and transit operators to come together to provide an integrated transportation solution to public.

As transportation moves into a new age of innovation, the involved parties must reach compromises and foster co-operation to provide the best service possible. As TMCs proliferate throughout the country and across the world, transit agencies will need to continue engaging and building partnerships with them. Already, many agencies have embraced and implemented collaborative programs with TMCs.

That said, as this phenomenon continues to expand, it is important to examine the best way to implement these programs, including how agencies will fund them. Through conversations with employees at several different transit agencies, this project also sought to determine the advantages and disadvantages of various funding methods for these partnerships. Though self-funding may be limited to bigger agencies with larger revenue streams, this method provides the easiest pathway to implementation, with fewer reporting requirements and oversight than grant-based programs. Consequently, it is important to examine the substitution of cost-inefficient routes with TMC-complemented service, using the relevant cost savings to fund the program. While multiple grant programs also exist to help agencies fund their programs, their requirements can oftentimes be too burdensome to work with these partnerships. As private entities, TMCs are naturally guarded about sharing their data; traditional requirements of free data-sharing of grants may not facilitate this type of collaboration. The establishment of grant programs like the FTA's Sandbox grant may be necessary to increase the efficacy of these partnerships. Additionally, agencies can leverage their assets to, at least temporarily, work out non-monetary arrangements with TMCs. The provision of advertisement space is a clear example of a mutually beneficial arrangement, provided the lost advertising revenue does not exceed the advantages. Finally, the flexible nature of these programs means that they are eligible for buy-in from parties interested in the service. Municipalities wanting first-mile/last-mile connectivity, or employers and institutions wanting greater flexibility for their members, can easily be incorporated into these partnership programs.

As these programs mature and the need for stable, long-term funding rises, agencies must carefully examine the multitude of funding options. Though grant programs can also be a useful source of funds, until they are adapted to accommodate this new generation of transportation technology, they will be of limited usefulness. By leveraging their assets and partnering with interested entities, agencies can self-fund operationally streamlined TMC partnerships to best serve their customers. The small sample size of the funding analysis in the project necessitates further study. The inclusion of paratransit-based partnership programs, or the programs of cities without transit agencies that have partnered with TMCs may also yield valuable information. Equity analysis, in ensuring that these programs continue to serve transit-dependent individuals, was also not a significant consideration in the analysis. Further research on this topic must take those equity issues into account.

References

Ben-Akiva, M., & Lerman, S. R. (1979). Disaggregate travel and mobility choice models and measures of accessibility. *Behavioural Travel Modelling*, 654–679.

Blumenberg, E., & Manville, M. (2004). Beyond the spatial mismatch: welfare recipients and transportation policy. *Journal of Planning Literature*, *19*(2), 182–205.

Boarnet, M. G., Giuliano, G., Hou, Y., & Shin, E. J. (2017). First/last mile transit access as an equity planning issue. *Transportation Research Part A: Policy and Practice*, *103*(Supplement C), 296–310. https://doi.org/10.1016/j.tra.2017.06.011

Boisjoly, G., Grisé, E., Maguire, M., Veillette, M.-P., Deboosere, R., Berrebi, E., & El-Geneidy, A. (2018). Invest in the ride: A 14 year longitudinal analysis of the determinants of public transport ridership in 25 North American cities. *Transportation Research Part A: Policy and Practice*, *116*, 434–445.

Christie, E., Koparan, A., Long, D., Perrot, R., Quach, M., Wolfram, T., & North, J. (2010). Assessing the Full Cost of Implementing an Accessible Taxicab Program.

City of Chicago. (2016, November 16). Chicago taxi data released. Retrieved from http://digital.cityofchicago.org/index.php/chicago-taxi-data-released/

Clewlow, R. R., & Mishra, G. S. (2017). *Disruptive transportation: The adoption, utilization, and impacts of ride-hailing in the United States* (No. UCD-ITS-RR-17-07). University of California, Davis. Retrieved from http://usa.streetsblog.org/wp-content/uploads/sites/5/2017/10/2017_UCD-ITS-RR-17-07.pdf

CTA. (2017). CTA facts at a glance. Retrieved from http://www.transitchicago.com/about/facts.aspx

Dalvi, M. Q., & Martin, K. M. (1976). The measurement of accessibility: some preliminary results. *Transportation*, *5*(1), 17–42.

Fan, Y., Guthrie, A., & Levinson, D. M. (2010). Impact of light rail implementation on labor market accessibility: A transportation equity perspective. *Journal of Transport and Land Use*, *5*(3). Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1736206

Fang He, & Shen, Z.-J. M. (2015). Modeling taxi services with smartphone-based e-hailing applications. *Transportation Research Part C: Emerging Technologies*, *58*, 93–106. https://doi.org/10.1016/j.trc.2015.06.023

Farber, S., Morang, M. Z., & Widener, M. J. (2014). Temporal variability in transit-based accessibility to supermarkets. *Applied Geography*, *53*, 149–159.

Feigon, S., & Murphy, C. (2016). *Shared Mobility and the Transformation of Public Transit* (TCRP Report). Retrieved from http://www.trb.org/Main/Blurbs/174653.aspx

Foth, N., Manaugh, K., & El-Geneidy, A. M. (2013). Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006. *Journal of Transport Geography*, *29*, 1–10.

Geurs, K. T., & Wee, B. van. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, *12*(2), 127–140. https://doi.org/10.1016/j.jtrangeo.2003.10.005

Hall, J. D., Palsson, C., & Price, J. (2018). *Is Uber a substitute or complement for public transit?* (Working Paper). Retrieved from http://www.palssonresearch.org/Uber_and_Public_Transit.pdf

Jung, J., Jayakrishnan, R., & Park, J. Y. (2013). Design and modeling of real-time shared-taxi dispatch algorithms. Presented at the 92nd Annual Meeting Transportation Research Board. Retrieved from https://academic.microsoft.com/#/detail/305515526

Karner, A. (2018). Assessing public transit service equity using route-level accessibility measures and public data. *Journal of Transport Geography*, *67*, 24–32.

Lambert, O. (2016, February 1). A new report explores the benefits of Uber. Retrieved from http://www.news.com.au/finance/business/travel/a-new-report-explores-the-benefits-of-uber/news-story/5e41687c9bc2614f07015f85eb784f7f

Levy, A. (2018, January 30). Why are New York's bus operating costs so high? Retrieved August 8, 2018, from https://ny.curbed.com/2018/1/30/16946476/mta-new-york-city-bus-operating-costs-analysis

Litman, T. (2009). *Transportation cost and benefit analysis: Techniques, Estimates and Implications (Second Edition)*. Retrieved from https://www.researchgate.net/profile/Todd_Litman/publication/235360398_Transportation_Cost_and_Benefit_Analysis_Techniques_Estimates_and_Implications/links/544a94ca0cf2d6347f401152.pdf

Litman, T. (2017). *Autonomous vehicle implementation predictions*. Victoria Transport Policy Institute Victoria, Canada.

Morang, M. Z. (2014). Add GTFS to a Network Dataset | GTFS in ArcGIS. Retrieved June 2, 2018, from https://esri.github.io/public-transit-tools/AddGTFStoaNetworkDataset.html

Nassir, N., Hickman, M., Malekzadeh, A., & Irannezhad, E. (2016). A utility-based travel impedance measure for public transit network accessibility. *Transportation Research Part A: Policy and Practice*, *88*, 26–39.

Polzin, S. E. (2016). *Implications to public transportation of emerging technologies* (NCTR). National Center for Transit Research. Retrieved from https://www.nctr.usf.edu/wp-content/uploads/2016/11/Implications-for-Public-Transit-of-Emerging-Technologies-11-1-16.pdf

Porter, R. C. (1999). *Economics at the Wheel: The Costs of Cars and Drivers.* San Diego, CA, Academic Press.

Rast, J. (2004). Transportation equity and access to jobs in Metropolitan Milwaukee. *Milwaukee, The University of Wisconsin-Milwaukee Center for Economic Development*.

Regional Transportation Authority. (2018). Maps and schedules. Retrieved from https://metrarail.com/maps-schedules/system-map

Sanchez, T. W. (1998). The connection between public transit and employment. *Portland. Portland: Portland State University Center for Urban Studies*. Retrieved from https://www.researchgate.net/profile/Thomas_Sanchez/publication/230820719_The_Connection_Between_Public_Transit_and_Employment_The_Cases_of_Portland_and_Atlanta/links/00463528be5c319afa000000.pdf

Schneider, T. (2017). Chicago taxi data. Retrieved from https://github.com/toddwschneider/chicago-taxi-data

TRB Special Report 319. (2016). *Between Public and Private Mobility: Examining the Rise of Technology-Enabled Transportation Services*. Washington, D.C.: National Academies Press. https://doi.org/10.17226/21875

Uber Estimate. (2017). Chicago Uber prices. Retrieved from http://uberestimate.com/prices/Chicago/

Vejnoska, J. (2017). Atlanta I-85 collapse: Lyft discounts rides to MARTA now, too. Retrieved May 11, 2017, from http://www.ajc.com/news/traffic/atlanta-collapse-lyft-discounts-rides-marta-now-too/I1cwYUij29ilzvdGVsz8XN/

Wang, F., & Ross, C. L. (2017). New potential for multimodal connection: exploring the relationship between taxi and transit in New York City (NYC). *Transportation*, 1–22.

Welch, T. F., Gehrke, S. R., & Wang, F. (2016). Long-term impact of network access to bike facilities and public transit stations on housing sales prices in Portland, Oregon. *Journal of Transport Geography*, *54*, 264–272.

Appendix

Table A-1: Percent Change in Accessibility to Grocery Stores by Four Area Types

	Area Type 1 (Low in Job & Amenity Accessibility)		Area Type 2 (Only Low in Job Accessibility)		Area Type 3 (Only Low in Amenity Accessibility)		Area Type 4 (Good Job & Amenity Accessibility)	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Base Scenario	0.4	na	0.6	na	0.8	na	22.5	na
Scenario 1	119.2	28697%	118.3	19766%	127.2	16854%	155.4	589%
Scenario 2	61.6	14785%	70.6	11764%	69.3	9146%	110.3	389%
Scenario 3	40.1	9601%	45.6	7554%	51.8	6809%	91.7	307%
Scenario 4	22.3	5288%	24.4	3991%	28.7	3726%	68.1	202%
Scenario 5	114.6	27594%	113.7	19003%	128.7	17055%	153.1	579%
Scenario 6	58.7	14097%	67.4	11231%	70.7	9326%	108.4	381%
Scenario 7	38.2	9137%	43.2	7166%	52.3	6871%	89.7	298%
Scenario 8	21.1	5006%	23.2	3798%	28.6	3707%	66.3	194%
Scenario 9	124.7	30032%	123.8	20692%	134.8	17868%	161.3	616%
Scenario 10	65	15616%	74.8	12470%	74.9	9893%	114.5	408%
Scenario 11	42.5	10162%	48.1	7988%	55.9	7356%	95	322%
Scenario 12	23.6	5613%	25.7	4215%	31.1	4047%	70.5	213%

Table A-2: Percent Change in Accessibility to Hospitals by Four Area Types

	Area Type 1 (Low in Job & Amenity Accessibility)		Area Type 2 (Only Low in Job Accessibility)		Area Type 3 (Only Low in Amenity Accessibility)		Area Type 4 (Good Job & Amenity Accessibility)	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Base Scenario	0	na	0	na	0.1	na	2.3	na
Scenario 1	12.9	74452%	13.6	38110%	16	13332%	19.6	746%
Scenario 2	6.5	37500%	7.7	21341%	8.2	6823%	12.7	451%
Scenario 3	4.3	24916%	5	13796%	6.1	4984%	10.3	347%
Scenario 4	2.2	12933%	2.7	7439%	3	2421%	6.8	192%
Scenario 5	12.4	71828%	13.1	36639%	16.1	13395%	19.1	727%
Scenario 6	6.2	36059%	7.4	20624%	8.1	6728%	12.3	433%
Scenario 7	4.1	23941%	4.8	13222%	5.9	4891%	10	331%
Scenario 8	2.2	12404%	2.6	7189%	2.9	2372%	6.6	185%
Scenario 9	13.7	79631%	14.3	39971%	16.9	14096%	20.6	790%
Scenario 10	6.9	39942%	8.2	22738%	8.6	7150%	13.4	478%
Scenario 11	4.7	26964%	5.2	14583%	6.3	5226%	10.9	369%
Scenario 12	2.4	13904%	2.8	7758%	3.2	2612%	7	202%

Table A-3: Percent Change in Accessibility to Libraries by Four Area Types

	Area Type 1 (Low in Job & Amenity Accessibility)		Area Type 2 (Only Low in Job Accessibility)		Area Type 3 (Only Low in Amenity Accessibility)		Area Type 4 (Good Job & Amenity Accessibility)	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Base Scenario	0	na	0.4	na	0	na	7.2	na
Scenario 1	31.4	6289%	31.3	8392%	32.2	6434%	39.9	457%
Scenario 2	17.1	3412%	19.6	5216%	18	3595%	29.8	315%
Scenario 3	10.9	2185%	12.5	3296%	13.5	2702%	25.3	252%
Scenario 4	6.1	1228%	6.6	1678%	7.3	1468%	18.4	156%
Scenario 5	30.3	6063%	30.4	8138%	32.8	6559%	39.5	450%
Scenario 6	16.4	3272%	18.8	4993%	18.5	3705%	29.3	308%
Scenario 7	10.5	2093%	12.1	3170%	13.7	2742%	24.7	245%
Scenario 8	5.9	1179%	6.3	1598%	7.2	1450%	17.9	150%
Scenario 9	32.8	6562%	32.6	8744%	34.3	6860%	41.5	477%
Scenario 10	18	3593%	20.6	5494%	19.7	3935%	30.9	330%
Scenario 11	11.6	2326%	13.1	3455%	14.8	2961%	26.2	265%
Scenario 12	6.5	1304%	6.9	1764%	8	1599%	19	164%

Table A-4: Percent Change in Accessibility to Universities by Four Area Types

	Area Type 1 (Low in Job & Amenity Accessibility)		Area Type 2 (Only Low in Job Accessibility)		Area Type 3 (Only Low in Amenity Accessibility)		Area Type 4 (Good Job & Amenity Accessibility)	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Base Scenario	0	na	0	na	0.2	na	6.7	na
Scenario 1	28.6	166022%	28.8	121039%	29.3	13551%	38.6	474%
Scenario 2	15.4	89095%	18.1	75916%	17.4	8027%	29	331%
Scenario 3	10.6	61127%	12.6	52659%	13.3	6097%	25.5	279%
Scenario 4	5.5	31619%	5.7	23682%	6.8	3093%	17.4	159%
Scenario 5	26.4	152949%	25.9	108591%	29.4	13624%	37.6	459%
Scenario 6	14.3	82917%	16.2	67914%	17.8	8211%	28.2	320%
Scenario 7	10	57829%	11.2	46769%	13.5	6204%	24.8	270%
Scenario 8	5.2	30289%	5.2	21542%	6.8	3076%	17	153%
Scenario 9	31	179616%	31.3	131291%	31.7	14686%	40.6	504%
Scenario 10	16.9	97958%	20.2	84536%	18.5	8554%	30.6	355%
Scenario 11	11.5	66548%	14	58596%	14.2	6504%	26.8	299%
Scenario 12	5.9	34383%	6.5	27103%	7.2	3251%	18.2	170%

Table A-5: Percent Change in Accessibility to Parks by Four Area Types

	Area Type 1		**Area Type 2**		**Area Type 3**		**Area Type 4**	
	(Low in Job & Amenity Accessibility)		(Only Low in Job Accessibility)		(Only Low in Amenity Accessibility)		(Good Job & Amenity Accessibility)	
	Value	% Change	Value	% Change	Value	% Change	Value	% Change
Base Scenario	2	na	24	na	3	na	575	na
Scenario 1	2585	107159%	2673	11013%	2540	82956%	3350	482%
Scenario 2	1439	59617%	1732	7101%	1414	46114%	2574	348%
Scenario 3	926	38313%	1110	4512%	1006	32772%	2154	275%
Scenario 4	499	20601%	574	2286%	547	17794%	1562	172%
Scenario 5	2499	103627%	2587	10654%	2610	85214%	3315	476%
Scenario 6	1369	56730%	1656	6785%	1482	48361%	2539	342%
Scenario 7	874	36154%	1060	4307%	1048	34161%	2113	267%
Scenario 8	473	19508%	552	2196%	560	18200%	1533	167%
Scenario 9	2722	112869%	2785	11478%	2729	89126%	3477	505%
Scenario 10	1522	63078%	1830	7506%	1566	51100%	2678	366%
Scenario 11	986	40808%	1171	4770%	1122	36576%	2239	289%
Scenario 12	534	22052%	597	2383%	596	19398%	1613	180%

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