DEPARTMENT OF TRANSPORTATION

Accessibility and Behavior Impacts of Bus-Highway System Interactions

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This research presents a series of accessibility methodologies developed for bus-highway system interactions. Accessibility is defined as the collective number of jobs that can be reached by a particular mode of transportation within a given travel time period. The effects of managed lanes (ML), park-and-ride (PNR), and travel costs on walk-up transit accessibility are measured for the Minneapolis–Saint Paul (Twin Cities) region. Each methodology is introduced, supported by a literature review, and described in detail before scenario results are presented. The final analysis uses the ML and PNR methodologies to establish a comprehensive transit accessibility profile for the Twin Cities, which accounts for the dual impact of auxiliary transportation facilities.

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FINAL REPORT

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EXECUTIVE SUMMARY

The following multi-stage research effort explores how managed lanes (ML) and park-and-ride (PNR) facilities individually and together influence the walk-up transit accessibility profile of Minneapolis–Saint Paul, Minnesota (Twin Cities). Here, accessibility refers to the number of jobs that can be reached by a particular mode of transportation within a given travel time period. We use the term "walk-up transit" to distinguish the mode connection type to transit service throughout each analysis. In the first stage of work, the current and future ML network is assessed for its contribution to walk-up transit accessibility. Buses operating on highways experience different travel times depending on the type of lane or highway facility they use; these travel time differences translate to changes in users' ability to reach destinations by walk-up transit. This stage demonstrates the development and use of the StopTimesEditor computer program, which is used to edit transit schedule datasets to reflect bus operation in different types of highway environments. The modified schedules are used to calculate walk-up transit accessibility to jobs—providing an opportunity to evaluate the system-wide accessibility impacts of MLs.

The second stage of work presents a methodology for calculating PNR (drive-to-transit) accessibility and provides case study results for the Twin Cities region. PNR is a form of mixed-mode travel, which is studied here for its impacts on access to opportunities. Regional PNR systems offer a longstanding and widespread example of the collective benefit of mixed-mode travel. The Twin Cities metropolitan region has over one hundred PNR facilities that are primarily connected to business districts through express and limited-stop transit service. Access to jobs by PNR trip type is measured for individual comparison with walk-up transit and automobile accessibility results. The third stage of this research develops a mixed-mode accessibility profile that is understood through time and money components. The costs associated with automobile and transit travel are incorporated with a value of time (VOT) quantity to give a "time + money" accessibility metric used to interpret accessibility results.

The following sections summarize the methodologies used to evaluate the impact MLs and PNR facilities have on accessibility. In each section, the results for several scenarios are given. First, the ML and non-ML transit scenarios are provided. These are followed by modal comparisons between the PNR accessibility profile and walk-up transit and automobile. The PNR scenarios are also converted to a monetary accessibility metric for two travel cost plans. Finally, the ML and PNR methodologies are combined to measure the regional transit benefit provided by PNR facility connections and express bus use of MLs on I-35W South, I-35E North, and I-394. Each scenario comparison highlights the value of including ML network attributes and PNR trip types in future accessibility analyses.

There are several key takeaways from this research. The analysis of bus access to MLs indicates two levels of impact on the Twin Cities walk-up transit accessibility landscape. At the regional scale, walk-up transit accessibility gains are modest when express bus utilizes the existing ML system. At the local level, walk-up transit accessibility impacts are much larger. The average worker living within a half mile (800

m) of a transit stop may experience a 12.96% increase in walk-up transit accessibility within 30-minutes when the existing ML system is utilized. Travel time savings compound over the number and frequency of routes and amount to more destinations accessible by transit in the same amount of time. The development of the StopTimesEditor tool paves the way for similar analyses, which involve simulating link speed changes. The cost to build and operate MLs comes at a premium but these costs may be justified by the increased walk-up transit accessibility for those living in the impact zone.

The PNR accessibility study improves our understanding of regional transit accessibility. By incorporating access to transit service via automobile, suburban and exurban areas are found to have higher levels of transit accessibility where they had previously been considered low. PNR accessibility is three times greater than walk-up transit accessibility for the average Twin Cities worker. The mixed-mode form of travel by PNR is challenging to study yet important to understand. The growing prevalence of transportation network companies and their potential to help or hinder transit ridership makes the topic of “drive to transit” fitting for additional study. This research creates a method for computing mixed-mode travel time matrices and returning cumulative accessibility. The associated computer tools can be extended to other forms of mixed-mode travel. Given the investments made to the PNR system, the quantifiable impact of PNR trip types on regional transit accessibility is important to understand for planning and evaluation purposes.

Cost-based accessibility measures provide an alternative way to determine where modes are competitive across a metropolitan region. The two monetary scenarios explored in this research highlight how excluding the cost of externalities favors automobile accessibility over other transit modes. The assignment of VOT further penalizes transit for having longer travel times on average compared to automobile. By including the VOT, the travel time disparity between automobile and transit travel is shown through accessibility levels. A broader understanding of accessibility may be achieved by establishing complimentary monetary measures. Not only can cost-based accessibility provide additional understanding of regional accessibility trends, but the measure may interest new stakeholders or academic bodies that more commonly work in terms of monetary units. There is room for considerable research in this direction and the benefit lies with broadening the reach and interpretability of accessibility to decision makers and the public.

CHAPTER 1: INTRODUCTION

The operational environment of transit service in the Twin Cities has changed dramatically in the past 25 years with the build-out of the ML and PNR networks. One quantifiable measure of impact is the change in job accessibility experienced by users of transit services. MLs improve the speed and reliability of travel for those moving through the corridor. PNRs enable suburban and exurban commuters to connect with transit service—which mainly moves passengers to central business districts (CBD). These initiatives improve regional transportation performance metrics; however, the network effects are not readily incorporated into the accessibility context. For planning and engineering purposes, a better understanding of the impacts these systems have on transit accessibility is needed.

At the crossroads of transportation and land use comes the performance measure of accessibility. Accessibility measures the ease of reaching valued destinations [**1**]. It is a function of both land use and the transportation network, and accessibility is greatest when land use and transportation are coordinated. For example, an accessibility metric might indicate that 25,000 jobs can be reached in a given travel time budget from a particular origin. By focusing on access to destinations, accessibility metrics provide a good indication of the usefulness of a transportation system. Numerous forms of accessibility have been explored in the literature. Several themes remain consistent across definitions. In general, an accessibility measure includes an analysis zone, an access mode, and a measure of impedance along the transportation network. Each mode, such as walk, bike, transit, and automobile, provide a unique network for accessing the surrounding land uses. The Metropolitan Council of the Twin Cities has placed new emphasis on accessibility. The 2040 long-range transportation policy plan cites accessibility measures as the program for making “lower-cost/high-return investments” in improving the connection between people and “employment, commerce, education, and cultural activity” [**2**].

Both the 2040 long-range plan and the Minnesota Department of Transportation recommend expanding the current ML system known as MnPASS. MLs provide an additional mobility option for those willing to carpool, pay a toll, or use transit. The construction of the priced ML system MnPASS, has resulted in many noteworthy benefits for the Twin Cities region. Segments I-394, I-35W South, and I-35E have experienced increased transit ridership, greater travel time reliability, and increased throughput along the selected corridors [**2**]. Express bus service is especially suitable for utilizing the MnPASS system due to the station placement and ML alignment. Express bus stops are typically located at either end of the route, which makes long distance, minimal access MLs feasible for use with heavy bus vehicles [**3**]. The Federal Highway Administration classifies ML operation strategies by pricing scheme, vehicle eligibility, and method of access control. The MnPASS system incorporates all three of these elements. Priced lanes are further broken down into high-occupancy, express, truck-only, and bus. In addition to the MnPASS dynamic pricing scheme, the network incorporates the high-occupancy, express, and bus portions of the priced lane definition [**4**].

While a majority of commute trips are completed by automobile, commuters continue to adopt new methods to reach the workplace that avoid congestion [**5**]. Mixed-mode travel involves two or more transportation modes to access a destination. Mixed-mode travel may include walking to ride share, biking to a transit stop, or driving to a PNR facility before completing the trip on the primary mode. These transport options are more nuanced than their singular mode counterparts. The added flexibility of mixed-mode travel creates new opportunities for users of the transportation system.

PNR systems are an example of mixed-mode travel. These systems exist across the nation, but they are frequently overlooked in transportation analyses. For example, popular trip planning applications, such as Apple Maps and Google Maps, do not identify PNR trip types when routing users on their platforms [**6**] [**7**]. Regional PNR systems have enabled mixed-mode travel for decades. These facilities allow suburban and exurban commuters to use transit where population density typically would not support such service if it were reachable only by walking. The setup enables peak-hour commuters to be transported between the suburbs and CBD regions. The utility PNR systems provide to users is difficult to capture in a single metric. The computational challenge of linking automobile and transit trips in a space and time sensitive manner may be one reason mixed-mode travel is not readily studied. The fixed transit connection points at PNR facilities present an approachable starting point for establishing a mixed-mode accessibility methodology.

Each investment made to the transportation system has the potential to improve travel times across the network. Time savings means more destinations may be reached for the same travel budget. A travel budget can be enumerated by time or money components. A combined “time + money” accessibility measure captures the full cost to access valuable destinations. The internal costs of travel such as fuel, vehicle repair, parking, and transit fare are influencing factors in transportation mode choice. For accessibility measures to be readily incorporated into transportation forecasting models and planning practices, methods for defining full-cost accessibility must be refined. This research uses information about the cost of parking and transit along with information from a full-cost automobile travel analysis conducted by Cui, Owen, and Levinson [**8**]. The distance-based costs and value of time benchmark are used to translate a purely time-based measure of accessibility to a cost-based indicator.

CHAPTER 2: LITERATURE REVIEW

2.1 CUMULATIVE ACCESSIBILITY

Many different formulations of accessibility metrics exist [**9**]. Accessibility can be measured using fixed buffer regions, Euclidean distances, or network distances to determine spatial and temporal travel distance (or cost) to the user. This research uses the cumulative opportunities accessibility metric, which indicates the total number of opportunities that can be reached from a given location within a particular travel time threshold. This metric provides a straightforward, easy-to-interpret indicator of accessibility [**1**]. Here, accessibility is quantified as the cumulative number of jobs that can be reached in a given travel time threshold.

Cumulative accessibility, given by Equation **1**, is the summation of interaction terms of a binary cost function $f(C_{ij})$ and the number of opportunities *a* at destination *j* [**10, 11**].

$$A_i = \sum_{j=1}^{J} a_j \, \mathrm{f}\big(C_{ij}\big) \tag{1}$$

Where

A_i Access measure of origin *i* to jobs in destination zone *j*

a_j Job opportunities in destination zone *j*

C_{ij} The time cost of travel from *i* to *j*

$$f(C_{ij} = \begin{cases} 1, & \text{if } C_{ij} <= t \\ 0, & \text{if } C_{ij} > t \end{cases}$$

Where

t=Travel time threshold

The decay function shown by Equation **2**, provides a way to measure accessibility across all travel time thresholds. A negative exponential function where *β* equals -0.08 gives more weight to accessibility values at low travel time thresholds *t* than at high thresholds.

$$A_w = \sum_t (A_t - A_{t-10}) \times e^{\beta t} \tag{2}$$

A_w = Accessibility value weighted by travel time
A_t = Accessibility value for threshold *t*

β = -0.08

2.2 BUS-HIGHWAY OPERATIONS

2.2.1 General Purpose Lanes

The first stage of this project assesses the differences in operational characteristics of general purpose (GP) lanes and MLs. Distinctions between these two operating environments are drawn from federal design standards and academic research findings. It is necessary to understand the characteristics of GP lanes as they offer a baseline for transit travel times. The difference in travel time between GP and ML lane types translate to differences in accessibility. The prevailing travel conditions along a transit route impact transit schedule development. The interaction between congestion on GP lanes and MLs has been shown to affect the speed to volume relationship on MLs. The depth of this interaction can vary depending on the separation type, ML operational strategy, and the number of parallel MLs [**12**].

2.2.2 Managed Lanes

To understand the main ML operational characteristics and observed outcomes, it is necessary to consider findings on lane use restrictions, impacts on surrounding traffic, access design, and land use changes. Each of these components contribute to a holistic picture of the operating environment for buses and personal vehicles traversing special use lanes. To date, little research has been completed to understand the schedule impacts of ML use by buses. However, a broad range of documentation covers the key implementation and operational aspects of MLs across the United States. A number of recent publications by the Federal Highway Administration (FHWA), National Cooperative Highway Research Program (NCHRP), Federal Transit Administration (FTA), American Association of State Highway and Transportation Officials (AASHTO), and local agencies such as the Minnesota Department of Transportation (MnDOT) offer a summary of the best practices [**13**] [**14**] [**15**] [**16**] [**4**].

The assessment of transit operation along MLs requires additional scrutiny as the function and form changes considerably across the Twin Cities transportation network. Within this region, one-lane high occupancy vehicle (HOV), high occupancy toll (HOT), two-lane HOV/HOT, and bus-on-shoulder (BOS) lanes are all in use. It has been found that one-lane and/or soft buffered ML facilities experience a sharper decline in their speed to volume relationship as compared with two-lane and/or hard buffered facilities [**12**]. Soft buffers between ML and GP lanes creates friction for faster moving traffic in the ML lane thereby decreasing speeds. This finding shows the benefit of considering separation type in the modifications made to bus-highway transit schedules. General Transit Feed Specification data published by Metro Transit and Minnesota Valley Transit Authority (MVTA) give the actual conditions of bus-highway operations specific to the Twin Cities region [**17**][**18**]. Speed and congestion data collected from loop detector stations and automatic vehicle location (AVL) devices provide the most accurate trajectory for transit vehicles operating in the GP lane [**19**] [**20**].

Operating a bus in exclusive right-of-way improves speed, reliability, and safety; however, buses that operate in mixed traffic are common and more easily implemented [**16**]. Express bus and bus rapid transit (BRT) routes are flexible in where they are placed within the transportation network and come with modest implementation and operating costs. Studies have found that these bus lines offer many economic benefits to the transit agency and improve route configuration [**16**]. Switching a transit route to a ML reduces the congestion that each transit vehicle experiences thereby making trip times shorter and more reliable. The impact such travel changes have on transit accessibility to opportunities is the objective of this research.

The review of literature on bus-highway lanes demonstrates the variety of configurations these facilities can take on as a result of the existing roadway features. The mix of traffic, direction of flow, traffic control, and access/egress points are all elements that determine the operational domain of a highway bus lane [**21**]. One facility suggestion noted in the literature is that for an express or BRT line operating on an HOV/HOT facility, separate access/egress ramps should be included to limit weaving through traffic [**21**]. There are only two such facilities in the Twin Cities that provide separate access for MLs, both along I-394: at I-94 and highway 100, dedicated ramps provide direct access to and from the center MLs. For this research, the access type to MLs will be considered by accounting for the exclusive access versus access via GP lanes. To inform the modeling procedure for ML use by buses, we refer to documentation about the best practices for bus lanes on highways, the Minnesota statutes in relation to bus shoulders, and other key governing documents [**22**] [**23**] [**24**] [**13**] [**25**] [**26**] [**27**].

2.3 MIXED-MODE TRAVEL

The combination of automobile and transit modes to complete a trip falls under the category of mixed-mode travel. PNR facilities enable this mode transfer by offering ample parking spaces and optimized transit service for peak hour travel to-and-from the CBD. Mixed-mode travel is not frequently studied, and the literature is sparse on the topic of linked automobile and transit travel. More common are studies of mixed-mode trips that use active modes of transport to access and egress from transit services, i.e. walking, biking, etc.

The incorporation of mixed-mode trips for network assessment purposes focus on the travel demand forecasting aspects such as mode choice [**28**], route assignment [**29**], or their combination [**30**]. Tangential topics that are studied include, parking charges, congestion, transit fare, and total trip time associated with mixed-mode trips. These elements inform the logic that underpins optimal mixed-mode paths across the network. In many studies, the VOT and network travel time metrics are applied to transportation analyses using an aggregate path characteristics approach.

Other research has considered how to properly site new PNR facilities given existing infrastructure. Key factors in such analyses include proximity to major roadways and user catchment and demand areas [**31**]. Such studies tend to solve for the optimal PNR location scheme, which may involve relocating a percentage of existing facilities.

The initial step in understanding mixed-mode travel comes through the interpretation of cumulative accessibility. Cumulative accessibility counts the number of potential opportunities available within a time or distance threshold. That number will vary depending on the mode of transportation and the selected threshold. Cumulative accessibility relies on fewer inputs compared to other accessibility models thus reducing the barrier for interpretation [**32**]. While it is common to find singular mode accessibility analyses, it is uncommon to find mixed-mode accessibility measures that account for two modes of transportation to complete a single trip. The coordination of automobile and transit systems into a single accessibility metric has not been explored in previous research [**33**].

2.3.1 Park-and-Ride Facilities

Metro Transit operates 114 PNR lots for metropolitan residents [**34**]. The utilization rate of these facilities is closely linked with the frequency of express bus services and the congestion on Twin Cities' roadways [**35**]. The transit advantage offered to commuters through ML use and PNR facilities sets the Twin Cities strategy apart from other transit agencies. Two case studies originating on the West Coast shed light on the increased transit efficiency (measured in ridership per service hour) by providing suburban parking lots for commuters to use as a transfer point to transit. The same study found that reasonable parking costs at a PNR facility outweighs the cost of driving and parking in a more expensive CBD area [**36**].

PNR facilities create artificial density hubs in otherwise sprawling suburban communities. The density created by giving transit customers the option to drive and park allows higher occupancy modes to be employed. The size of a PNR lot is generally indicative of the use, i.e. local, express, shared use [**37**]. In terms of access to PNR facilities, users tend to park in the first lot encountered on the path to their destination. If there are too many lots available, they may become underutilized [**38**]. Several studies have plotted the market shed of PNR facilities to gather information on the optimal placement of these lots. In general, the market area for an individual PNR lot extends upstream about 10 miles (16 km) in a parabolic shape. Potential users rarely backtrack to access a lot and they typically do not drive more than 2.5 miles (4 km) out of their way—regardless of direction [**37**]. Many research projects have developed methods of optimally locating PNR facilities [**39**] [**40**] [**41**]. A number of proposed and planned facilities along with connecting transit lines are cited within the 2030 Park-and-Ride plan and the 2040 Transportation Policy Plan [**42**] [**2**].

The site location criteria recorded in the 2030 Park-and-Ride Plan is used in the development of the PNR accessibility methodology. Two pieces of information that support the methodology and the interpretation of results are the following: Demand for a PNR facility is influenced by the proximity of other PNR facilities and the frequency of transit serving them. Within a PNR corridor, facilities located closest to the CBD should be expected to have the highest demand, all else equal. The most comprehensive documentation on PNR implementation guidelines is *Park-and-Ride Planning and Design Guideline* [**43**]. Additional material on parking facilities and costs is outlined in [**44**].

2.4 MONETARY ACCESSIBILITY

Cost-benefit analysis on transportation investment attempts to capture the social and economic impact of better mobility across a region. Measures of accessibility are less frequently incorporated to such analyses. The following literature develop methods for assigning monetary value to accessibility and interpreting the equity implications of the cost of travel.

Forslund and Johansson [**45**] evaluates the economic production value of various transportation investments brought to Sweden that impact mobility. The additional production potential brought about by transportation investment is evaluated by a standard cost-benefit analysis. It was found that "improved accessibility implies an increase of the production potential". The monetary value of changes to accessibility are explored in greater detail by [**46**]. The value placed on accessibility is found to vary by mode, destination type, and income group. The results are presented as tradeoffs between accessibility and money. Improvements to transit accessibility are found to be worth twice as much to low income groups (<$35,000) compared to those making above $35,000. This effect is dependent on the business district destination under consideration.

The social equity rami cations of the cost of travel are explored by [**47**]. The job accessibility landscape for those of different socio-economic backgrounds is assessed using a travel time and transit fare accessibility measure. Socially disadvantaged neighborhoods in Montreal, Canada are found to have more equitable access to jobs by transit compared to other groups in the region. The inclusion of transit fare price to time-based accessibility provides new insight to transportation planners and policy makers. This is one example of the benefit of understanding accessibility through multiple units of measurement.

2.4.1 Parking Costs

A number of studies and literature reviews have found that proximity to transit stations plays a role in property value. Improved accessibility increases land value. There are different classifications of PNR facilities. Peripheral PNR facilities are located just outside of the CBD and function as automobile interceptors to reduce the number of parking spaces needed in the CBD region. The facilities typically are fare-free or reduced fare zones that are served by bus or rail lines into the urban core [**37**]. Suburban and remote PNR lots typically do not charge a fee for parking. See [**37**] page 5 for PNR pricing strategies. Substantial parking costs in the CBD are cited as one of the main ways suburban traffic may shift to using transit services as opposed to driving. This research collects parking cost data using OpenStreetMap and online documentation. Parking cost profiles for Minneapolis, Saint Paul, and the University of Minnesota-Twin Cities campuses are developed and used in the monetary accessibility measure.

2.4.2 Parking Location vs. Walking Distance

In the Twin Cities region, a majority of Census blocks do not contain a priced parking ramp or lot. These facilities primarily reside in the CBD of Minneapolis and Saint Paul, as well as the University of

Minnesota campuses. The destinations that reside in each zone may be associated with a different parking cost. The vehicle occupant's willingness to walk, combined with the parking facility spatial distribution, can affect the average parking price for a given destination. A review of literature on average commuter walking distance, willingness to pay, and the effect parking placement has on these choices is summarized below.

A survey study conducted in Calgary, Alberta, Canada measured respondents mean and median distance to walk from work origins to a variety of destinations including parking and transit stops [**48**]. About 90% of respondents that walked from work to parking said their path is less than 1,970 feet (600 meters) in length. The data for Calgary is compared to Washington D.C, Chicago, and Toronto and the values are similar for some trip purposes and different for others. "This confirms that walking distances are not strictly a function of city size or the density of development but are related to the transit and road network as well, and the overall transportation policies of a city." The Gamma distribution is found to fit the cumulative frequency distribution of walking distance. The distribution is used to derive a "critical walking distance" for each trip purpose. In conclusion, trip type, trip purpose, and time of day are all determining factors of acceptable walking distance [**48**].

Research into the mode choice and parking behavior of visitors to CBD regions has been studied since the 1960's when suburban residents no longer lived within walking distance of transit lines to the downtown region. Demand studies that measure choice between mode and parking location offer insight to commuters' propensity to park on the fringe of the CBD, near their destination, or somewhere in-between. A survey and statistical analysis conducted by [**49**] finds that price per hour of ramp use is the biggest factor affecting parking location choice. The models indicate that time restrictions on parking facilities cause a redistribution of parking across the CBD while increases in pricing "divert travel to public transport and parking beyond the CBD." The researchers also found differences in parking behavior based on the reason of travel. Regular commuters tend to be more willing to park beyond the CBD while visitors on business travel are more likely to park close to their destination in the CBD. A range of 15 to 25 minutes was used for average walking time from parking to destination. Ultimately it was found that despite raising the price of parking, no trips to the CBD are lost, commuters merely find another mode or time to get to work.

There are two takeaways from the literature review on parking location choice and acceptable walking distance. The first being that a majority of commuters in metropolitan regions are willing to walk up to 1,970 feet (600 meters) to reach their workplace destination. This distance is used to capture parking costs associated with job centers given a maximum walking distance. The second takeaway is that commuters are more likely to park on the edge of the CBD where parking cost is lower and walking distance is higher. The relatively small size of the Minneapolis, Saint Paul, and University of Minnesota campus, and the even spread of parking facilities, are two reasons to lower the assigned maximum walking time from 15–25 minutes (as reported by [**49**]) down to 10-minutes. Given that the average human walking speed is 3.1 miles per hour (5 km/h), the time to walk 1,970 feet (600 meters) is 7.2

minutes. For this reason, a conservative value of 10-minutes is used as the traversal time between parking and the destination.

2.5 LITERATURE REVIEW CONCLUDING REMARKS

The literature review informs the methods developed by this research for assessing the impact of auxiliary transportation facilities on transit accessibility. The tools built to carry out the analysis are based on those developed by the Accessibility Observatory for assessing transit accessibility across the United States [**50**]. By aligning the methodologies and program inputs, we enable straightforward integration of the bus-highway research findings to the existing transit accessibility framework.

CHAPTER 3: ACCESSIBILITY IMPACTS OF BUS ACCESS TO MANAGED LANES

3.1 METHODOLOGY

3.1.1 StopTimesEditor Program Logic

The objective of this research is to demonstrate the accessibility impacts when ML facilities are used by transit vehicles. Compared to GP lanes, MLs are designed to offer higher operating speeds for vehicles and buses alike. GTFS data break down transit routes by trip and stop points in separate files that can be linked to one another through unique identification codes. The GTFS data supply information about the travel time between stops; however, the data do not include the distance between two stops. With the addition of distance information, the speed between bus stops can be estimated. For a route that uses MLs, only a portion of the distance between the abutting stops may be on the ML. The remaining distance may consist of on/off ramps, smaller arterial roads, or non-ML highway. Therefore, the ML must be isolated from the other roadway lengths. By implementing a speed change on only the ML portion of the route, the stop times downstream of the ML link must be updated. This is the framework of the StopTimesEditor program. MLs are the test case for this program. The program may be extended to BRT or BOS contexts to test link speed changes on accessibility. The following sections describe the inputs and logic necessary for the StopTimesEditor to make updates to GTFS data.

3.1.2 StopTimesEditor Inputs

Three inputs are needed for the StopTimesEditor program. A copy of the published GTFS data, a network input file, and a scenario configuration file. The design of the StopTimesEditor and associated input and configuration files is visualized in Figure **1**. Note that the “route info”, “road lengths”, and “loop detector data” inputs are necessary for the user to consider, however, they are not directly incorporated into the calculations performed by the StopTimesEditor. The original GTFS data, input file, and configuration file are the direct inputs to the StopTimesEditor program.

- Automatic Vehicle Location data - Metro Transit 2016 [**20**]
- Traffic data - MnDOT loop detector data extract program [**19**]
- Functional Class Roads - Minnesota Existing 2016 shape file [**51**]
- Transit routes & stops shape files - Minnesota Geospatial Commons 2016 [**52**]
- Metro Transit Interactive Map [**53**]
- General Transit Feed Specification (GTFS) - Metro Transit, Minnesota Valley Transit Authority - Fall 2016 [**17**] [**18**]
- U.S. Census TIGER 2010 Census Blocks - Minnesota Geospatial Commons 2016 [**54**]
- U.S. Census Longitudinal Employer-Household Dynamics (LEHD) 2014 Origin-Destination Employment Statistics (LODES) [**55**]

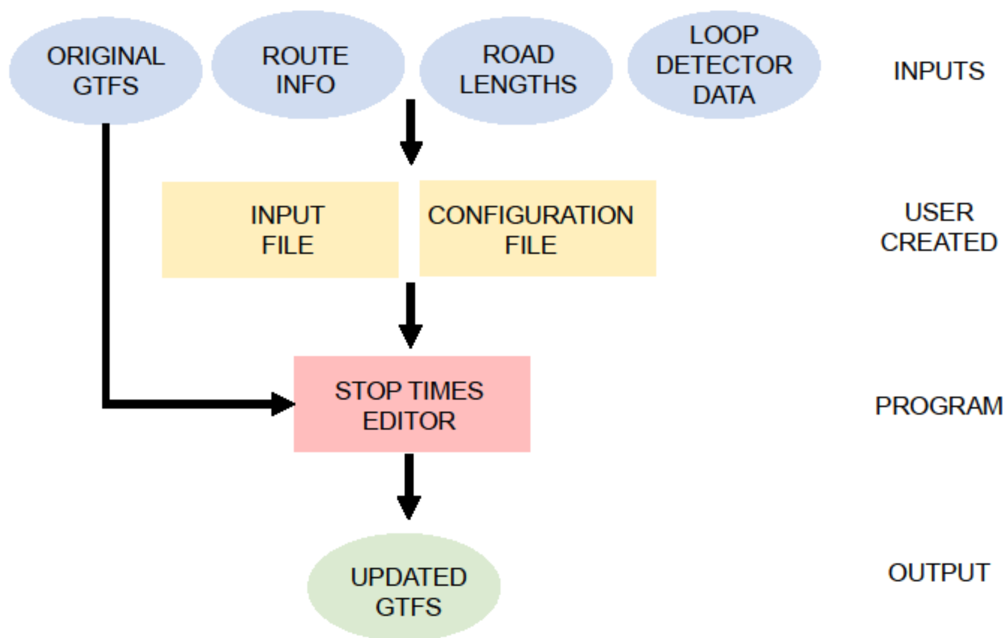


Figure 1 The workflow and inputs needed to use the StopTimesEditor program.

3.1.3 Identifying Highway Segments of Bus Routes

GTFS data is the primary information needed to compile network graphs for assessing transit accessibility. A change in speed along a portion of a trip can be reflected in the GTFS data through the stop times text file. If speed increases, the time between stops should decrease and vice versa. The StopTimesEditor interprets where to make changes in the stop times text file through the use of a user created input file. The input file documents each route that is subject to change. Figure 2 demonstrates the orientation of route information provided by the stop times text file for use with the input file. Four stops (A, B, E, F) and two points (C and D) are noted for spatial and temporal relation to the ML segment. Links A to B (lead leg) and E to F (lag leg) are documented in the input file to assist with estimating speed along links B to C (access to ML) and D to E (egress from ML), where travel time is unknown. The ML link is denoted from C to D. The distance logged for the ML link includes only the length where the ML level of service (LOS) requirements are maintained. Some routes may have multiple trips that share the same access (stop B) and egress (stop E) stops, but have different lead or lag stops. The user should document the route that has lead/lag links that best match the functional class of the adjacent access/egress links. It is up to the user to properly model the ML network in the input file through the enumeration of link distances. The input file should be updated when changes to a bus route or ML network are made. Refer to the Managed Lane Test Scenario section for an example of the input file format.

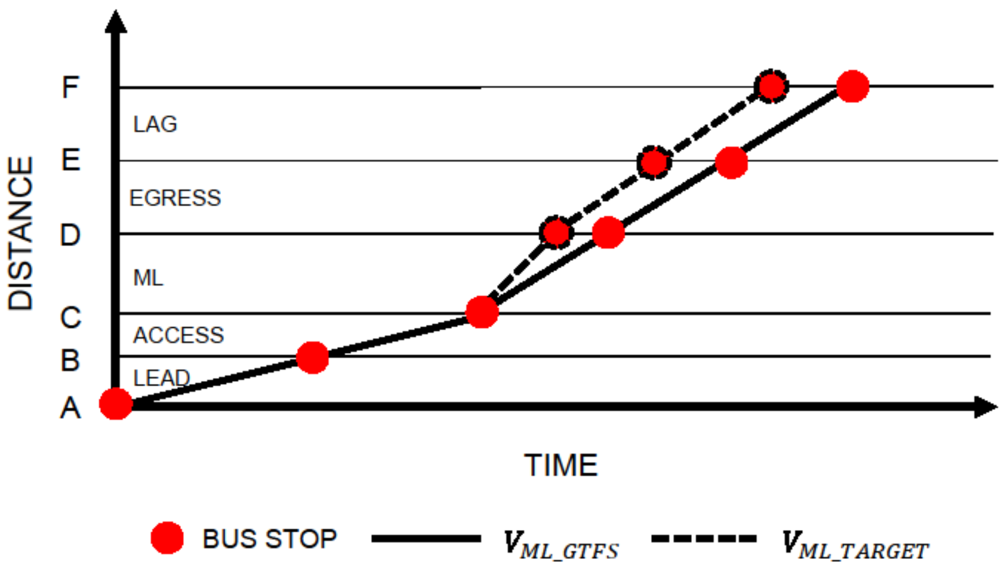


Figure 2 Space-time diagram depicting the difference in travel time due to a change in speed along the ML link (point C to point D).

3.2 MODIFYING BUS SPEEDS ON HIGHWAY SEGMENTS

To estimate speed along only the ML portion of the transit trip, the ML must be isolated from the access and egress sections of the B to E stop pair. Stops B and E are the first and last place where stop identification numbers are assigned along the length of the ML and noted in the GTFS stop times text file. The user defines the extents of the ML by recording distances from B to C, C to D, and D to E in the input file. For example, the test scenario described later uses the functional class roads shape file published by the Twin Cities Metropolitan Council in September 2016 to measure distance (meters) between points. Each of these points in space and time is needed to calculate an estimate of speed on the ML link. The StopTimesEditor computes the change in travel time needed to achieve the target speed using Equations **3**—**8** below. Please refer to Table **1** for the nomenclature used throughout the description of the StopTimesEditor calculations.

Table 1 Nomenclature for mathematically describing the travel time estimation process applied by the StopTimesEditor.

Symbol	Description
S	distance (m)
T	GTFS stop time (hh:mm:ss)
V	speed (m/sec)
t	travel time (sec)
ab	lead link—Stop A to Stop B (m)
bc	access link—Stop B to point C (m)
cd	ML link—point C to point D (m)
de	egress link—point D to Stop E (m)
ef	lag link—Stop E to Stop F (m)

The StopTimesEditor applies the information provided in the input file for the calculation of speed (V) between points A to B and E to F. The distance (S) in meters is divided by the difference in stop times (T) converted to seconds between the two stops.

$$V_{ab} = \frac{S_{ab}}{T_b - T_a} \tag{3}$$

$$V_{ef} = \frac{S_{ef}}{T_f - T_e} \tag{4}$$

The speeds calculated by Equations **3** and **4** are used as an estimate of the speed on the access and egress links in order to derive the travel time along these links.

$$t_{bc} = \frac{S_{bc}}{V_{ab}} \tag{5}$$

$$t_{de} = \frac{S_{de}}{V_{ef}} \quad (6)$$

An estimate of the GTFS speed along the ML link (C to D) is found by dividing the link distance by the difference in stop times less the access and egress times found in Equations **5** and **6**.

$$V_{cd} = \frac{S_{cd}}{T_e - T_b - t_{bc} - t_{de}} \quad (7)$$

Finally, the change in travel time needed for the ML link to run at the target speed is calculated. ML distance is divided by the GTFS estimated speed found in Equation **7** and subtracted from the ML distance divided by the target speed. The result is the change in travel time (Δt) in seconds needed to simulate the target speed on the ML link.

$$\Delta t_{cd} = \frac{S_{cd}}{V_{target}} - \frac{S_{cd}}{V_{cd}} \quad (8)$$

Once a ML link has been identified, the StopTimesEditor applies Equations **3** through **8** and edits the remaining stop times for that trip.

3.2.1 The Input and Configuration Files

Each line in the input file represents a route shape that contains a ML link. It should be noted that the user must enumerate all variations of a specified route (generally noted by the shape identification field in the stop times text file). Within the input file, a unique link ID is assigned for referencing to the configuration file. A comparison is made at every line in the stop times file back to the information stored in the input file.

A configuration file is built from a selection of links found within the input file. It is used for testing combinations of links and speed changes. The user is required to list the link IDs that are to be changed, a test window, and target speeds. Each new line in the configuration file proposes a specific change to a specific link and direction. The design makes it possible for users to apply a single change across the entire network or individual changes for each link. The StopTimesEditor is unique because it can quickly change all trips that match with the route details and time window provided by the user.

3.2.2 Calculating Transit Accessibility Using GTFS Data

Transit level accessibility is calculated using transit and pedestrian network datasets, origin and destination spatial files and a scenario configuration file. A graph file is created using network data. Transit information comes from GTFS data published by local transit agencies and pedestrian network data is extracted from OpenStreetMap.org [**56**] [**57**]. The Accessibility Observatory Batch Analyst links the graph file with the origin and destination (OD) spatial information les. Each Census block destination is labeled with the number of jobs in that area. OpenTripPlanner (OTP) software is used to find the travel time along each link in the graph file [**58**]. Dijkstra's shortest path algorithm is then applied between each OD pair. The access and egress time from origin to transit stop, and transit stop to destination by walk mode is accounted for in the shortest path calculation. A summation of jobs accumulated along each path is then assigned to the origin set and referred to as the "raw" accessibility. For a comprehensive description of the calculation of accessibility, see [**50**].

3.3 EXPRESS BUS ON EXISTING MANAGED LANE (ML) NETWORK SCENARIO

3.3.1 Setup

The StopTimesEditor and bus-highway interaction methodology is applied to the Twin Cities transit network. GTFS data for the local agencies Metro Transit and MVTA are used in the analysis [**17**] [**18**]. SouthWest Transit and Plymouth Metrolink routes are included in the Metro Transit GTFS data.

The methodology is applied to 60 express bus routes that use the existing ML network. The ML network under consideration contains the entirety of I-394, I-35W South, and I-35E ML links in both directions. A majority of these routes operate on the I-394 and I-35W links, while only three routes, namely routes 265, 275, and 860 use I-35E. A route is considered "express" if it is labeled so within the transit agency documentation and if stops are clustered at the ends of the route, indicating express bus configuration.

The existing ML—Express Bus scenario introduces a speed increase along the express bus links of routes shown in black in Figure **3**. The change in speed is applied solely to trips made by the 60 express bus routes that are identified to use segments of the existing ML network. The change in speed is applied to a representative week during the August 31st, 2016 through December 2, 2016 GTFS publication window. Only trips made between 7–9 AM experience a speed increase along the ML network. The target speeds for I-394 and I-35W are set using the average ML speeds collected in 2015 posted on the MnDOT "MnPASS Express Lanes" webpage. There is no aggregate speed information for the newly opened ML link on I-35E. A review of the speed limit signage along the I-35E link shows a range in speed between 55–60 mi/h (88.5 and 96.5 km/h), therefore a target speed of 65 mi/h (104.6 km/h) is applied to I-35E. The default access/egress link speeds for the existing ML—Express Bus scenario are set between 30–40 mi/h (48.2 and 64.4 km/h) in the input file based on the direction of travel. Trips running inbound to the Minneapolis or Saint Paul CBD use 40 mi/h (64.4 km/h) as the access speed and 30 mi/h (48.2 km/h) as the egress speed. Differences between suburban and urban lane widths, likelihood of congestion, and freeway speeds support the use of higher average link speeds in the suburbs and lower average link speeds in urban areas [**59**] [**60**]. Seven SouthWest Transit routes have significantly longer access links that require a higher average access speed. These routes are assigned an access speed between 50–55 mi/h (80.5 and 88.5 km/h).

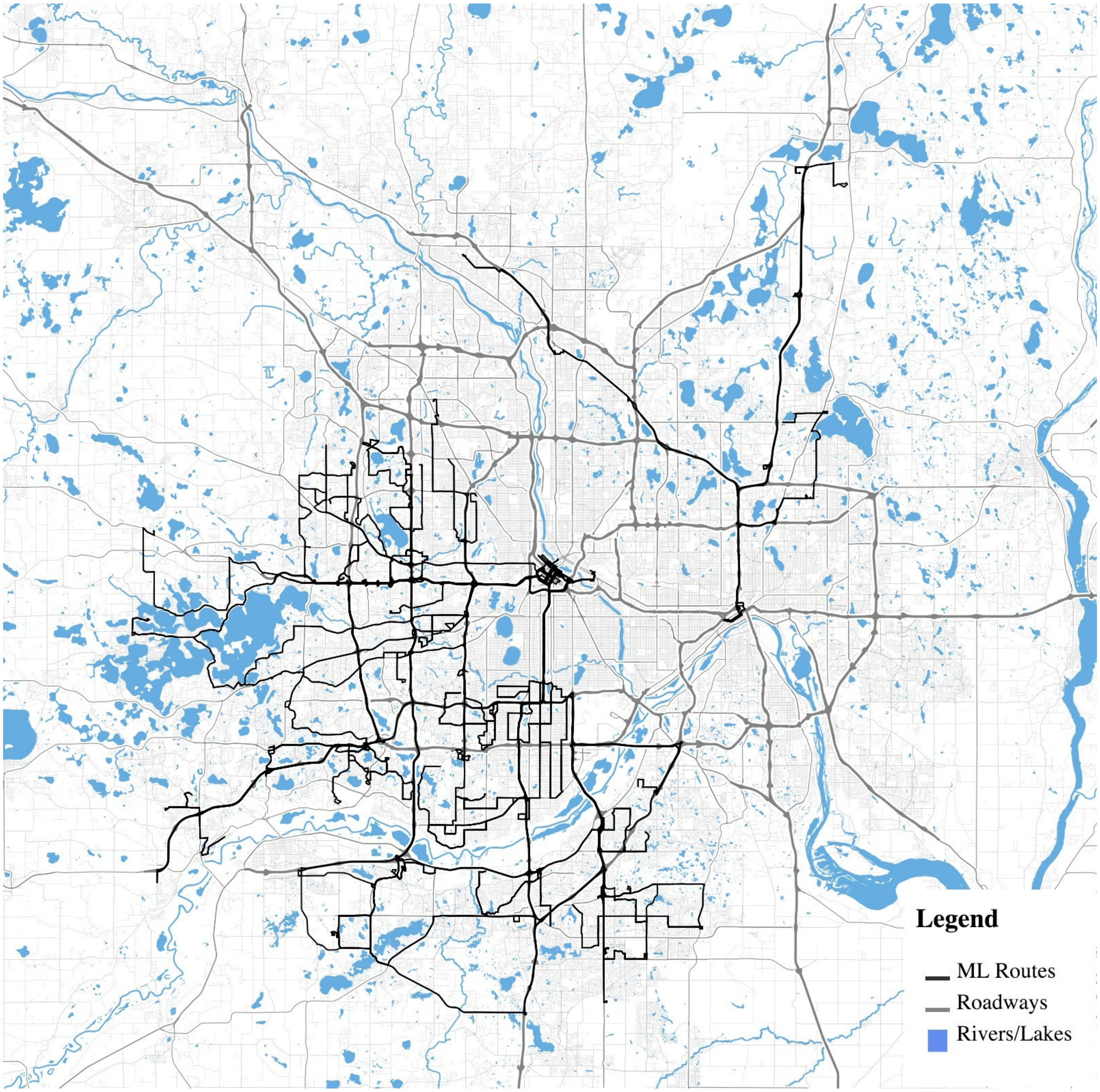


Figure 3 Transit routes that operate on portions of the existing ML network.

3.3.2 GTFS Changes

The changes to express bus routes described earlier are translated to GTFS data using the StopTimesEditor program. During the test time frame, the average end-to-end change in run time for each trip ranged between one and fourteen minutes. The estimated reduction in travel time for each trip is found by applying Equation **8** across the ML link (C to D), then carrying that time change through to the last stop in the trip. One-thousand and eleven trips experienced run time changes during the test time window. These trips are distributed across the variety of calendar dates published with the GTFS data. For example, some trips only occur during one week of the four-month schedule due to temporary service changes that are planned by the transit agency. The total run time savings for the existing ML—Express Bus scenario is 91.3 hours. On average, each express bus trip within the test time frame experienced a reduction in run time of 5.4 minutes. The changes are applied to each trip but do not account for the number of days in a week that that trip runs. For example, if all the modified trips run Monday–Friday, the potential time savings can be multiplied by five. These diagnostics are recorded in a log file produced by the StopTimesEditor. The potential time savings that may be accrued between in-service and dead heading trips provides a rational for increasing the frequency on these routes. The impacts of higher frequency service are not explored in this research but remain a plausible outcome of increased transit speeds.

3.3.3 Express Bus on Existing Managed Lane (ML) Network Scenario Results

Speed increases to the freeway portions of the express bus routes are translated to changes in accessibility for the Twin Cities region. These changes are best shown visually. Beginning with the Twin Cities baseline transit accessibility, Appendix A Figure 43 shows the state of transit accessibility during the Fall of 2016. Appendix A Figure **44** allows a comparison of the raw accessibility values for the 30-minute travel time thresholds before and after speed changes are made. Appendix A Figures **45** and **46** provide the same comparison at the 60-minute travel time threshold. After the speed increase on the ML network is simulated within the GTFS data, pockets of the Twin Cities experience notable changes to their levels of job accessibility. Appendix A Figures **47**, **48**, **49**, and **50** highlight the places in the Twin Cities where accessibility changed during the test time window.

Worker-weighted average accessibility values are computed for varying travel time thresholds and analysis zones. The first analysis zone is derived from all origins that are within 0.5 miles (800 meters) of the transit stops on the 60 express bus routes used in this analysis. These zones will be referred to as the "impact zone". The second zone average is calculated for the entire Twin Cities region. The caveat being that the metro-wide worker-weighted average accessibility value includes blocks unaffected by the transit service speed changes, thereby pulling down the average.

Accessibility values at higher travel time thresholds are affected more by the express route scenario changes but the values have less influence in the weighted percent change metric. A comparison between the 60-minute percent change map (Appendix A Figure **50**) and the weighted travel time map (Appendix A Figure **51**) shows a dampened color scale for the weighted map across the metro; however, it better reflects the value of accessibility changes for transit users.

3.3.4 Discussion

The existing ML—Express Bus scenario demonstrates the cascading effects that MLs may have on transit performance and efficiency. The greatest change in accessibility can be seen in the suburbs, especially in areas closest to the bus stops just before accessing the ML link (see Appendix A Figure **50**). The largest accessibility changes are found in the suburbs because the analysis took place during the morning peak hours when there are far more inbound trips to the CBD. If the analysis was carried out for the afternoon peak, much of the gains in accessibility would be seen in and around the CBD.

The existing ML—Express Bus scenario is bi-directionally applied to the highway links. Although the greatest accessibility increases can be seen surrounding the suburban transit stops, some accessibility is gained in the CBD due to several reverse commute trips during the morning peak hours. While most areas experience an increase in accessibility, several ex-urban blocks see a decrease in accessibility (shown in light brown). The decrease is presumably due to the misalignment of transfers that result from reduced travel time on the first transit trip. For these locations, the number of jobs lost while waiting additional time for a transfer bus is more than the number of jobs gained by reducing in-vehicle time.

The worker-weighted average accessibility for the Twin Cities can be seen in Table **2**. These values do not represent the raw summation of jobs, rather they express a level of jobs that can be reached relative to the spatial distribution of Twin Cites workers. For the origins located within the half mile (800 m) buffer shown in Figures **4** and **5**, the absolute change in worker-weighted average accessibility at the 30 and 60-minute travel time thresholds are 2,574 and 21,241 respectively. These values are translated to a percent change of 12.96% and 21.12%. And for the entire Twin Cities region, the absolute change values are 280 and 3,145 for the 30 and 60-minute travel time thresholds. Again, translated to a percent change of 1.44% and 3.79% for the respective travel time thresholds. The regional values are lower due to the large number of blocks that do not experience a change in accessibility as a result of the existing ML—Express Bus scenario. See Table **2** for a comparison between travel time thresholds and assessment zones.

Table 2 Worker-weighted average accessibility compared for the seven county Twin Cities region and the impact zone.

	Twin Cities	**Impact Area**
Baseline 30 min	10,563	31,053
Existing ML—Express Bus Scenario 30 min	10,843	33,627
Baseline 60 min	89,702	222,649
Existing ML—Express Bus Scenario 60 min	92,847	243,889
Abs. Change 30 min	+280	+2,574
Percent Change 30 min	1.44%	12.96%
Abs. Change 60 min	+3,145	+21,241
Percent Change 60 min	3.79%	21.12%

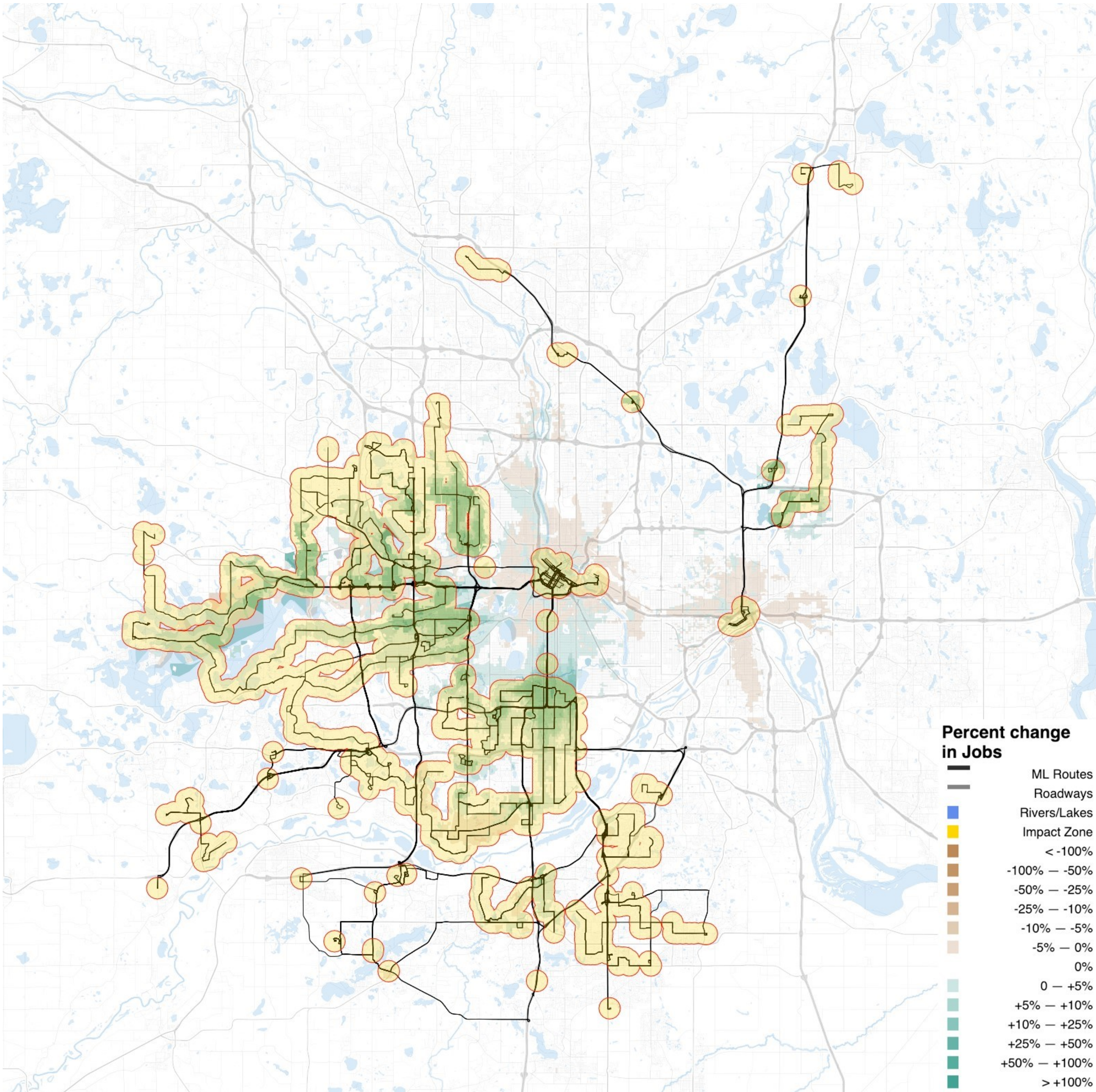


Figure 4 The percent change in accessibility for a 30-minute transit trip is overlaid by the half mile (800 m) impact zones that extend from transit stops located on express bus routes.

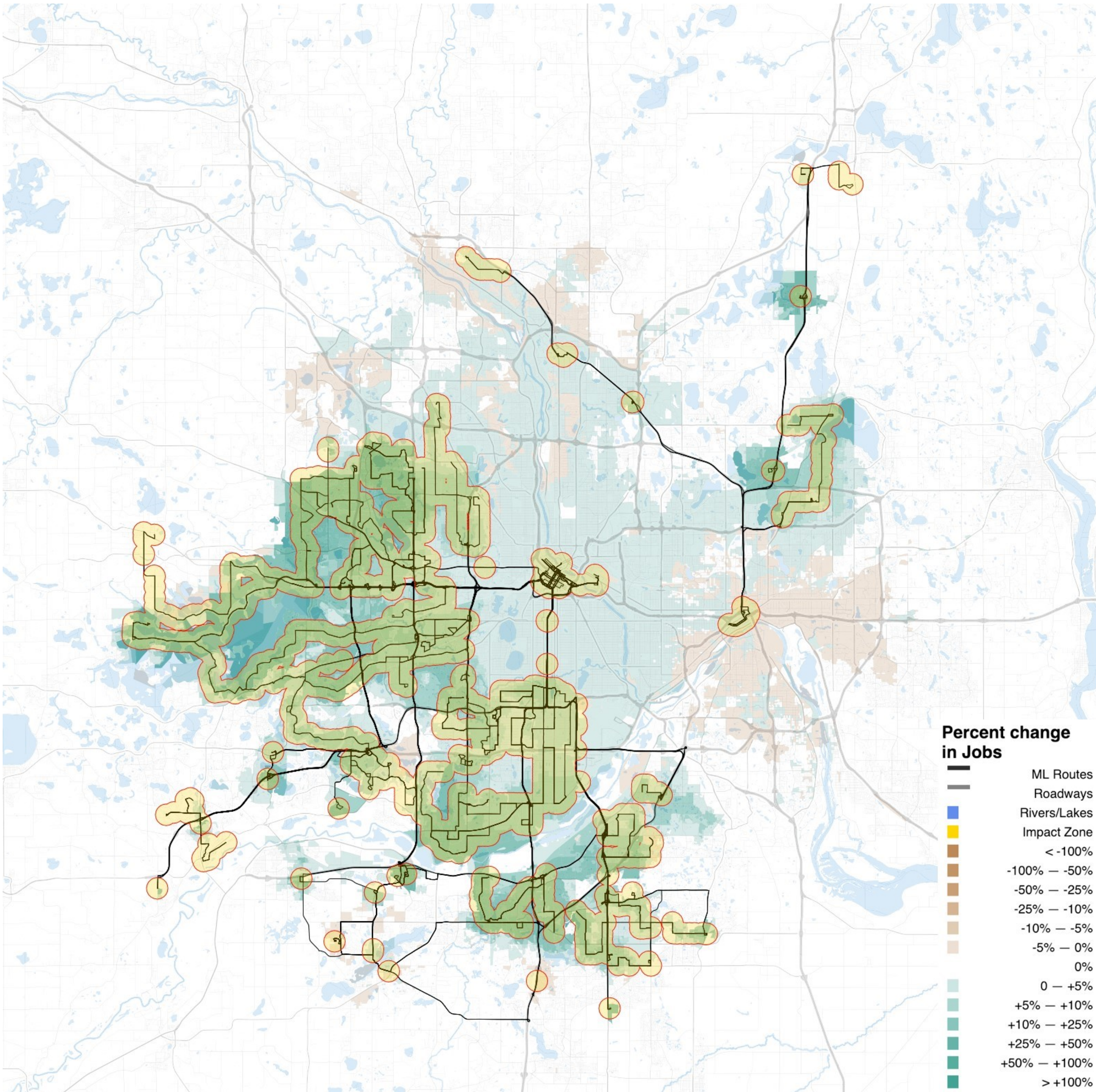


Figure 5 The percent change in accessibility for a 60-minute transit trip is overlaid by the half mile (800 m) impact zones that extend from transit stops located on express bus routes.

3.4 EXPRESS BUS ON FUTURE MANAGED LANE (ML) NETWORK SCENARIO

3.4.1 Setup

Sections I-35W North and I-94 between Minneapolis and Saint Paul are planned additions to the MnPASS network as reported in the MnPASS System Study Phase 2 report [**61**]. These two segments are used to test the effects of additional ML operation on job accessibility levels by transit in the Twin Cities. The simulated changes in express bus operation are implemented in isolation for each of the two freeway segments. The final scenario relays changes to both segments and explores the compound effect on the transit accessibility profile of the surrounding communities and metro region. In order to meet pre-defined ML performance objectives, the target speed for express buses is set to 55 mph on both segments. Transit schedule data from the Fall of 2016 is used for the following three scenarios.

3.4.1.1 I-35W North

Seven express bus routes were in operation during the Fall of 2016 along I-35W North. These routes include 250, 252, 261, 263, 264, 270, and 288. All routes run on a portion of I-35W North between Lake Drive Northeast in Columbus, Minnesota and downtown Minneapolis. The entirety of this segment is 26.2 miles (42.2 km). The StopTimesEditor is used to update route data to reflect operation on a MnPASS style ML. The analysis is carried out for the morning peak hour from 7–9 AM at one-minute intervals. The results are aggregated and plotted in Figures **6**, **7**, **8**, and Table **3**.

Table 3 Worker-weighted average accessibility compared for the seven county Twin Cities region and the I-35W North impact zone.

	Twin Cities	I-35W North Impact Area
Baseline 30 min	10,563	112,270
I-35W Scenario 30 min	10,567	112,436
Baseline 60 min	89,702	368,781
I-35W Scenario 60 min	90,112	375,436
Abs. Change 30 min	+4	+166
Percent Change 30 min	0.02%	1.10%
Abs. Change 60 min	+410	+6,655
Percent Change 60 min	0.57%	12.1%

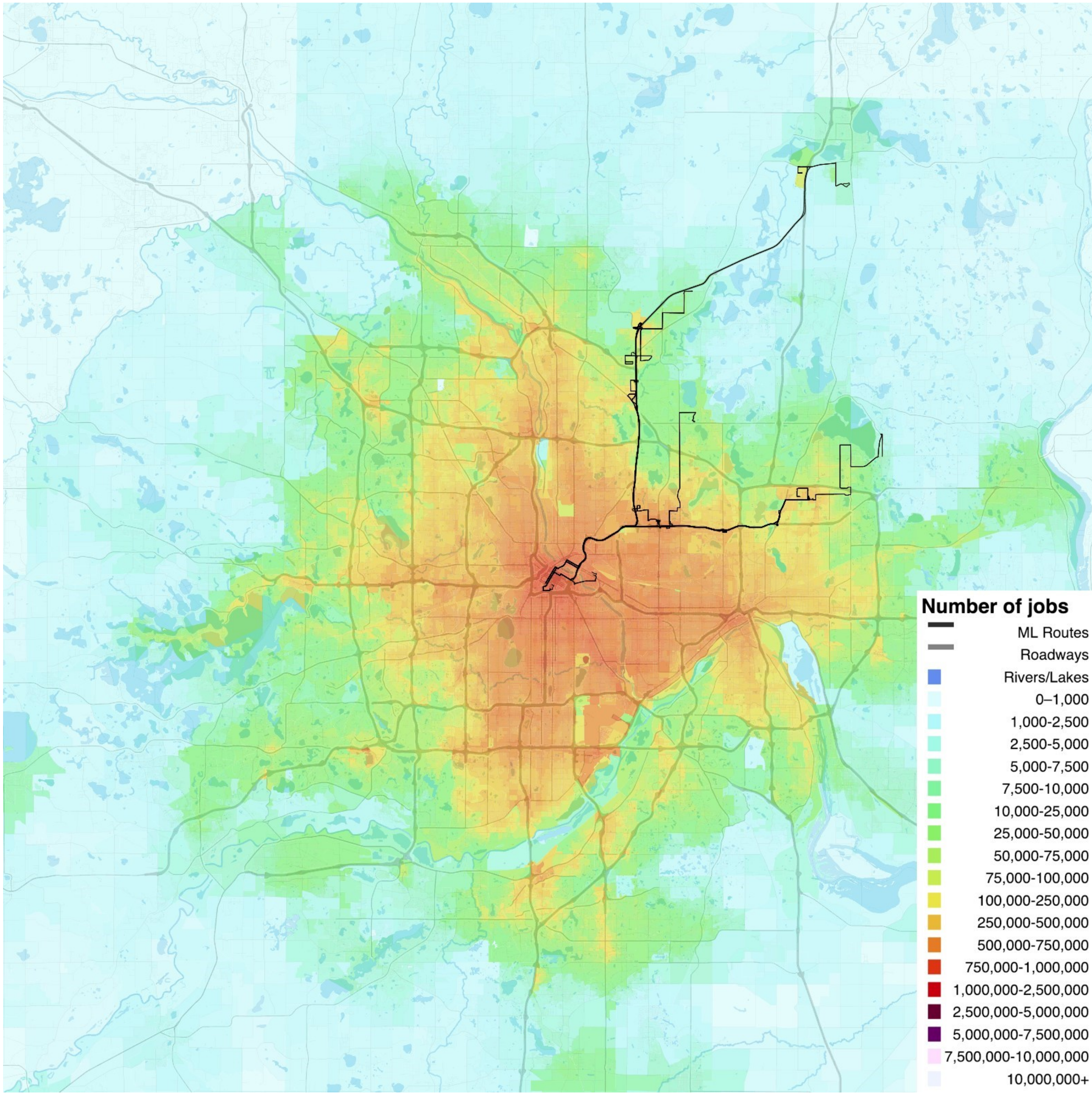


Figure 6 The I-35W North scenario average job accessibility within 60-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

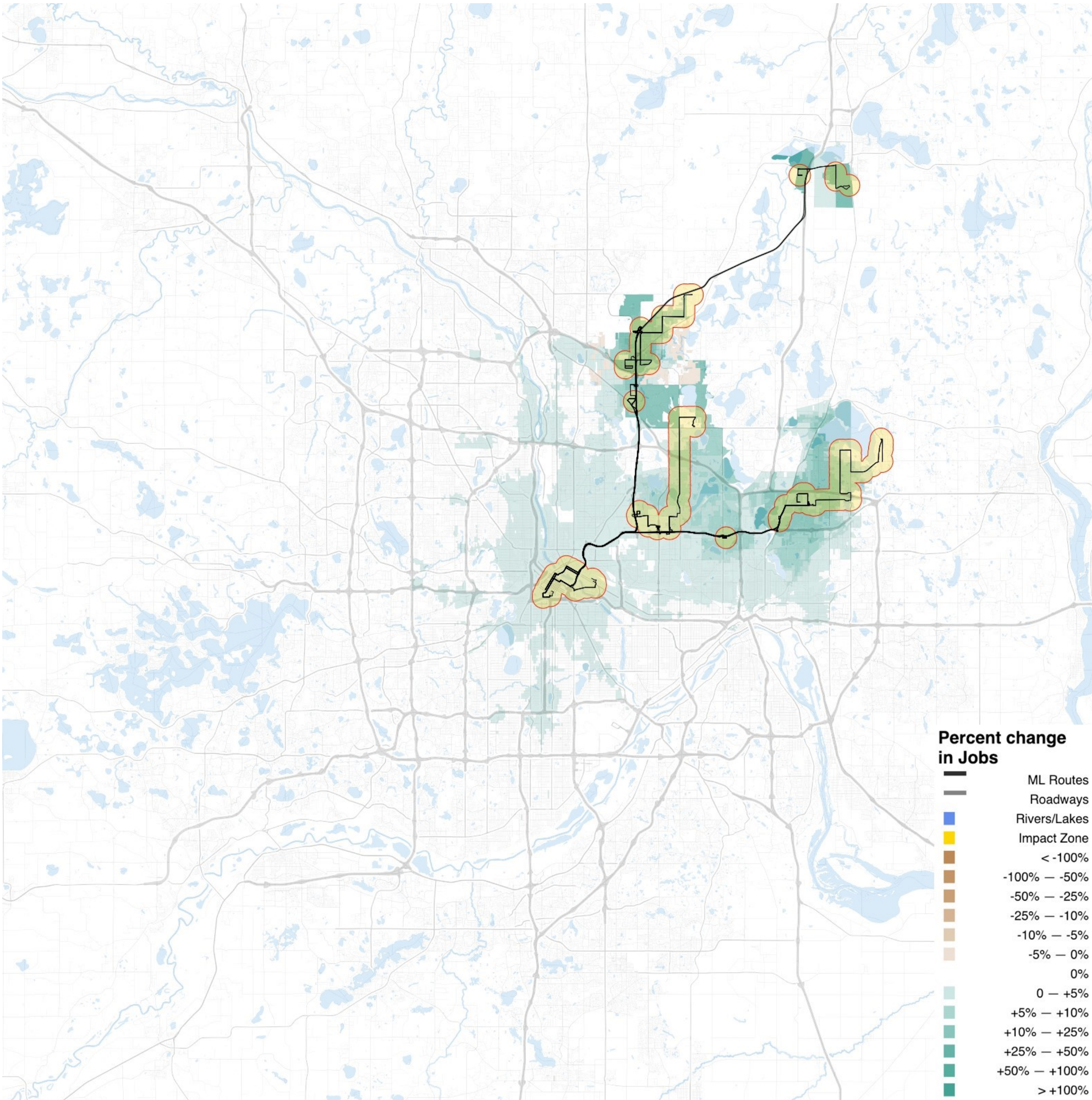


Figure 7 The percent change in accessibility for a 60-minute transit trip is overlaid by the half mile (800 m) impact zones that extend from transit stops located on I-35W North express bus routes.

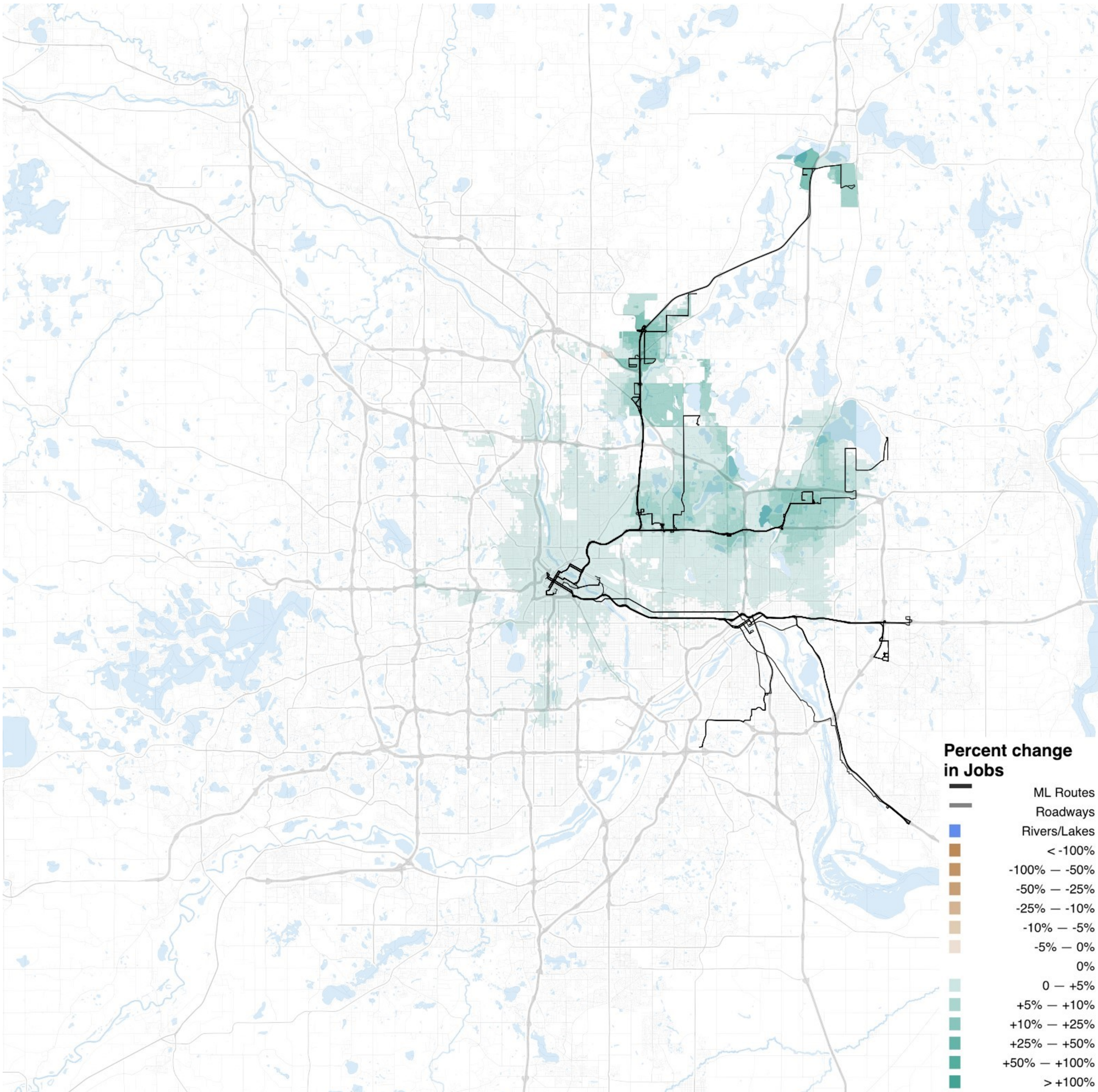


Figure 8 The percent change in average job accessibility between the I-35W North scenario and baseline using the travel time threshold decay function.

3.4.1.2 I-94 Minneapolis to Saint Paul

Six express bus routes were in operation during the Fall of 2016 along the segment of I-94 between downtown Minneapolis and downtown Saint Paul. These routes include 94, 353, 355, 365, 375, and 452. All routes run on the 7.6-mile (12.2 km) corridor between Minneapolis and Saint Paul where MnPASS is proposed to operate. The StopTimesEditor is used to update these route data to reflect operation on a

MnPASS style ML. The analysis is carried out for the morning peak hour from 7–9 AM at one-minute intervals. The results are aggregated and plotted in Figures **9**, **10**, **11**, and Table **4**.

Table 4 Worker-weighted average accessibility compared for the seven county Twin Cities region and the I-94 impact zone.

	Twin Cities	**I-94 Impact Area**
Baseline 30 min	10,563	167,246
I-94 Scenario 30 min	10,575	168,771
Baseline 60 min	89,702	558,089
I-94 Scenario 60 min	90,452	565,493
Abs. Change 30 min	+11	+1,525
Percent Change 30 min	0.008%	1.16%
Abs. Change 60 min	+750	+7,404
Percent Change 60 min	0.37%	3.92%

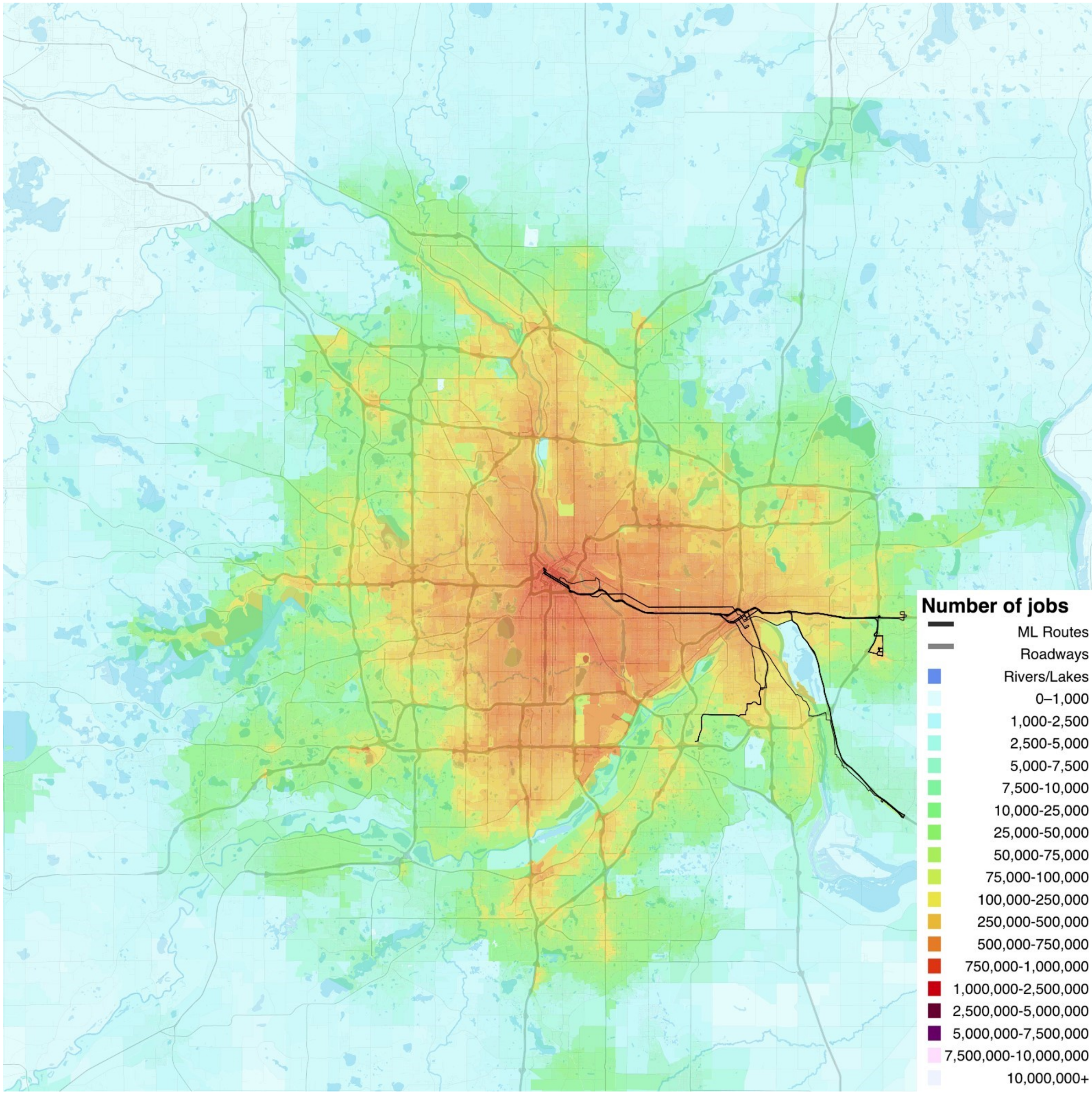


Figure 9 The I-94 scenario average job accessibility within 60-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

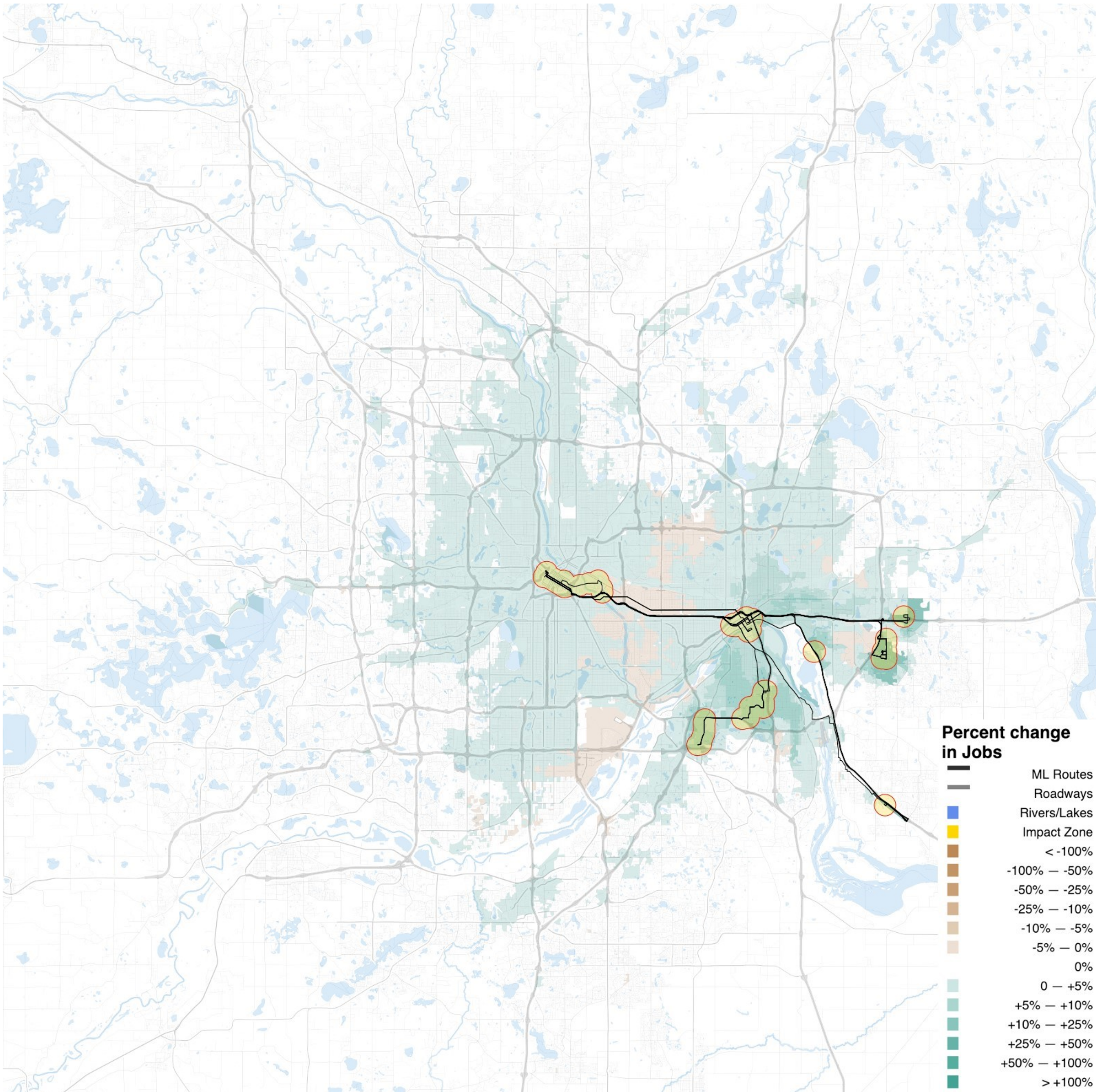


Figure 10 The percent change in accessibility for a 60-minute transit trip is overlaid by the half mile (800 m) impact zones that extend from transit stops located on I-94 express bus routes.

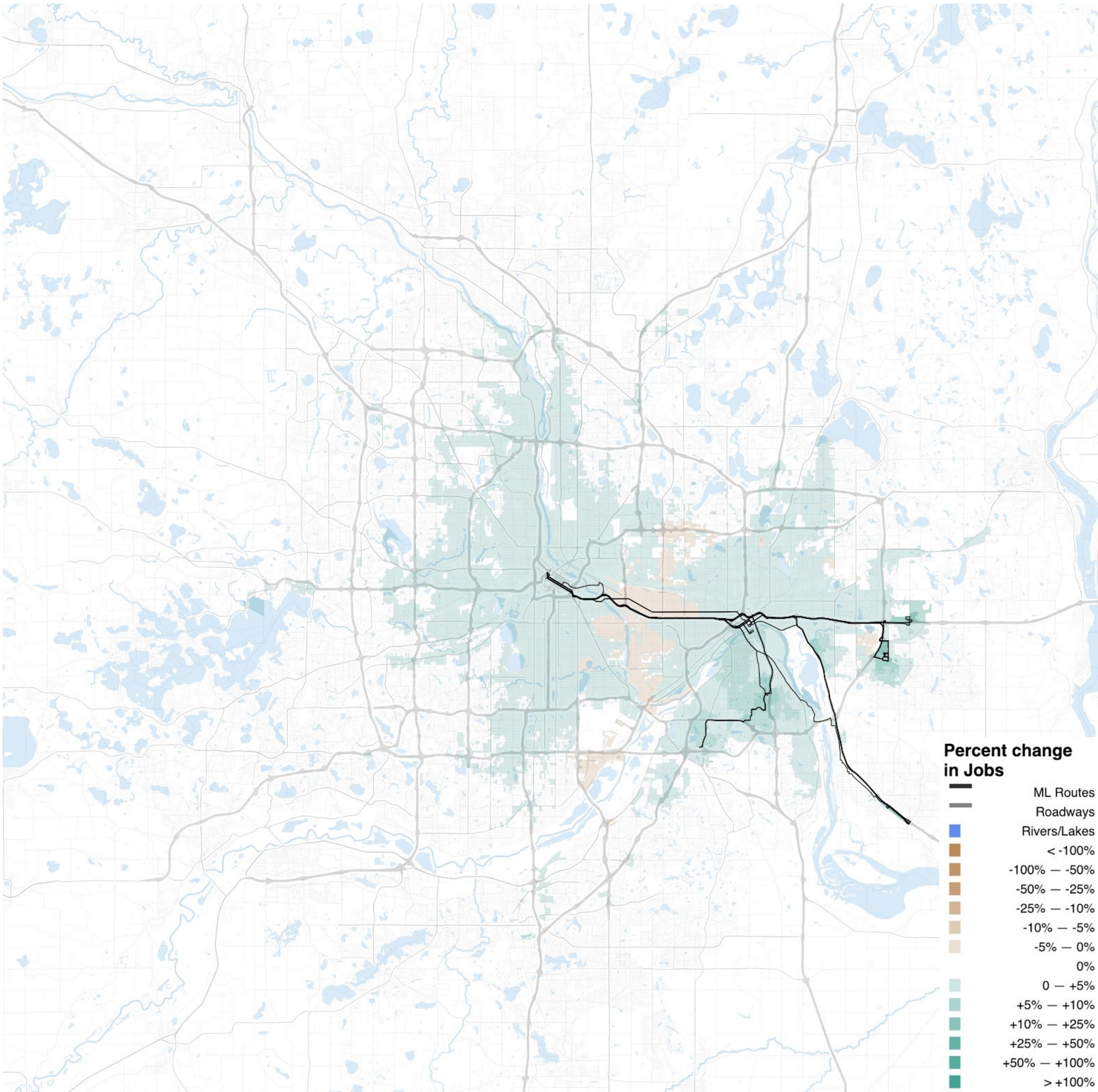


Figure 11 The percent change in average job accessibility between the I-94 scenario and baseline using the travel time threshold decay function.

3.4.1.3 I-35W North and I-94

The final scenario modifies all thirteen routes that operate on I-35W North and I-94 to simulate the addition of MnPASS style MLs on the freeway segments. The accessibility analysis is carried out for the morning peak hour from 7–9 AM at one-minute departure intervals. The results are aggregated and plotted in Figures **12**, **13**, **14**, and Table **5**.

Table 5 Worker-weighted average accessibility compared for the seven county Twin Cities region and the I-35W North and I-94 impact zone.

	Twin Cities	I-35W I-94 Impact Area
Baseline 30 min	10,563	109,354
I-35W I-94 Scenario 30 min	10,579	110,048
Baseline 60 min	89,702	379,874
I-35W I-94 Scenario 60 min	90,856	388,586
Abs. Change 30 min	+15	+694
Percent Change 30 min	0.03%	1.31%
Abs. Change 60 min	+1,154	+8,712
Percent Change 60 min	0.94%	11.2%

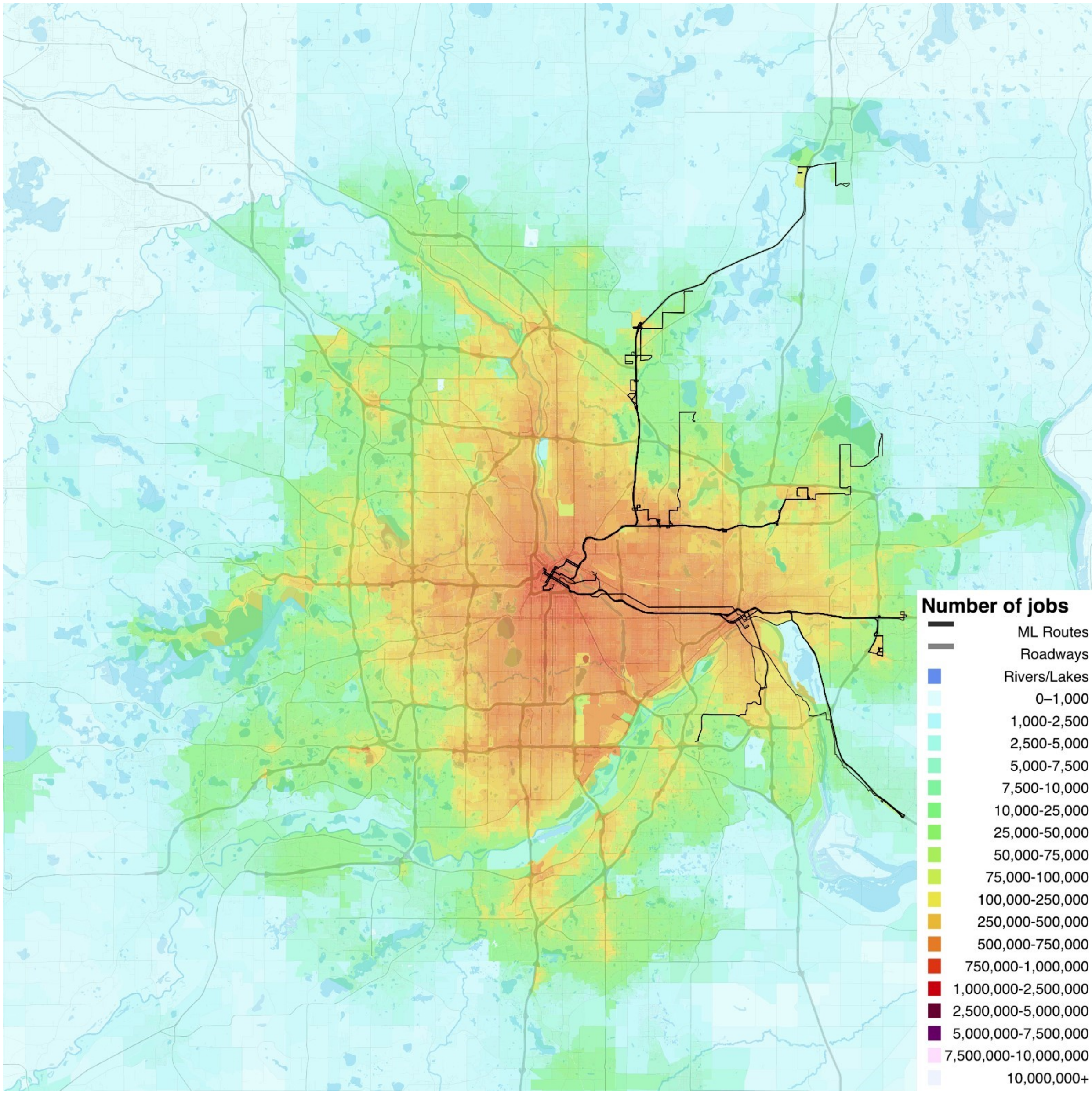


Figure 12 The I-35W and North I-94 scenario average job accessibility within 60-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

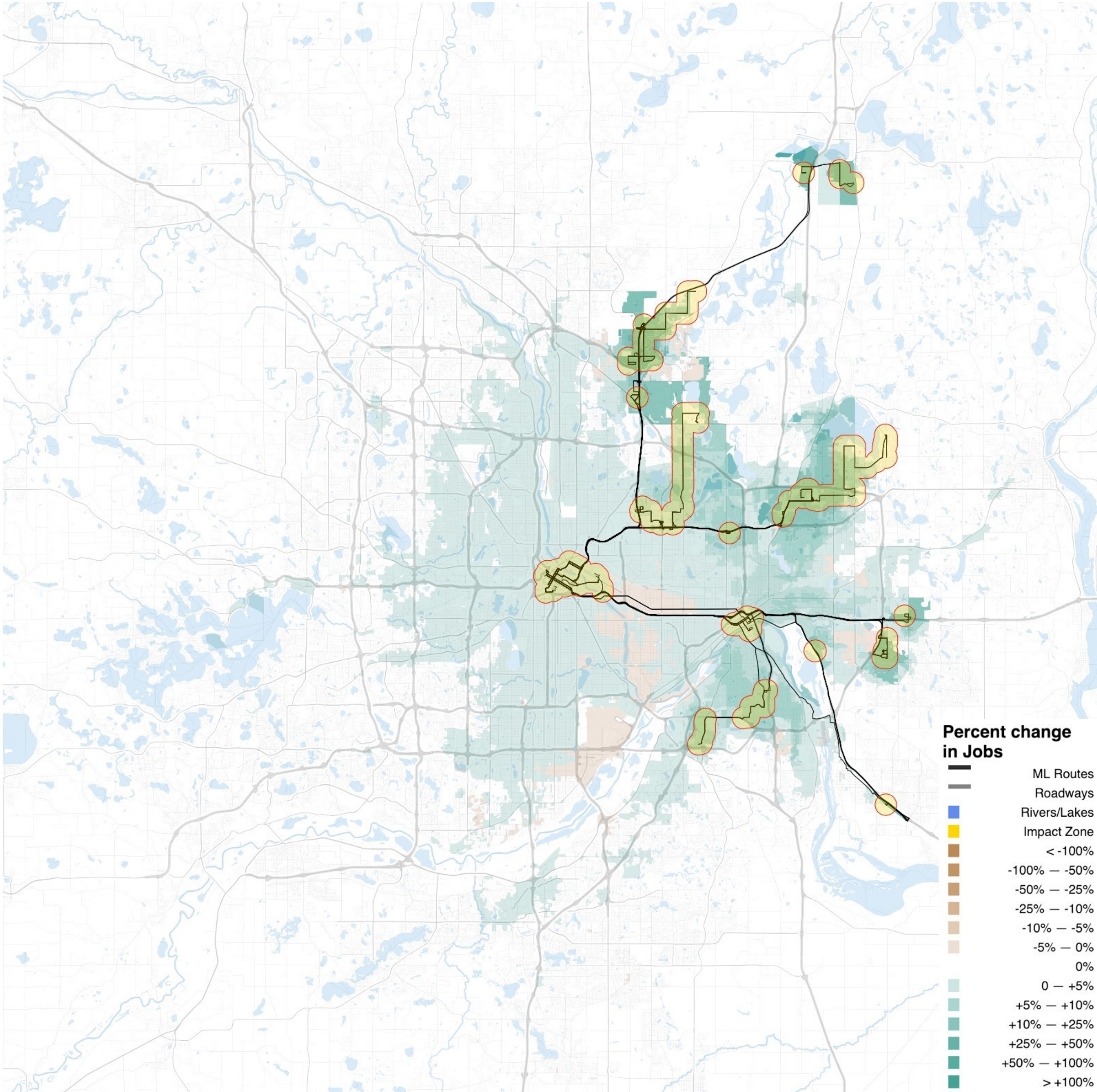


Figure 13 The percent change in accessibility for a 60-minute transit trip is overlaid by the half mile (800 m) impact zones that extend from transit stops located on I-35W North and I-94 express bus routes.

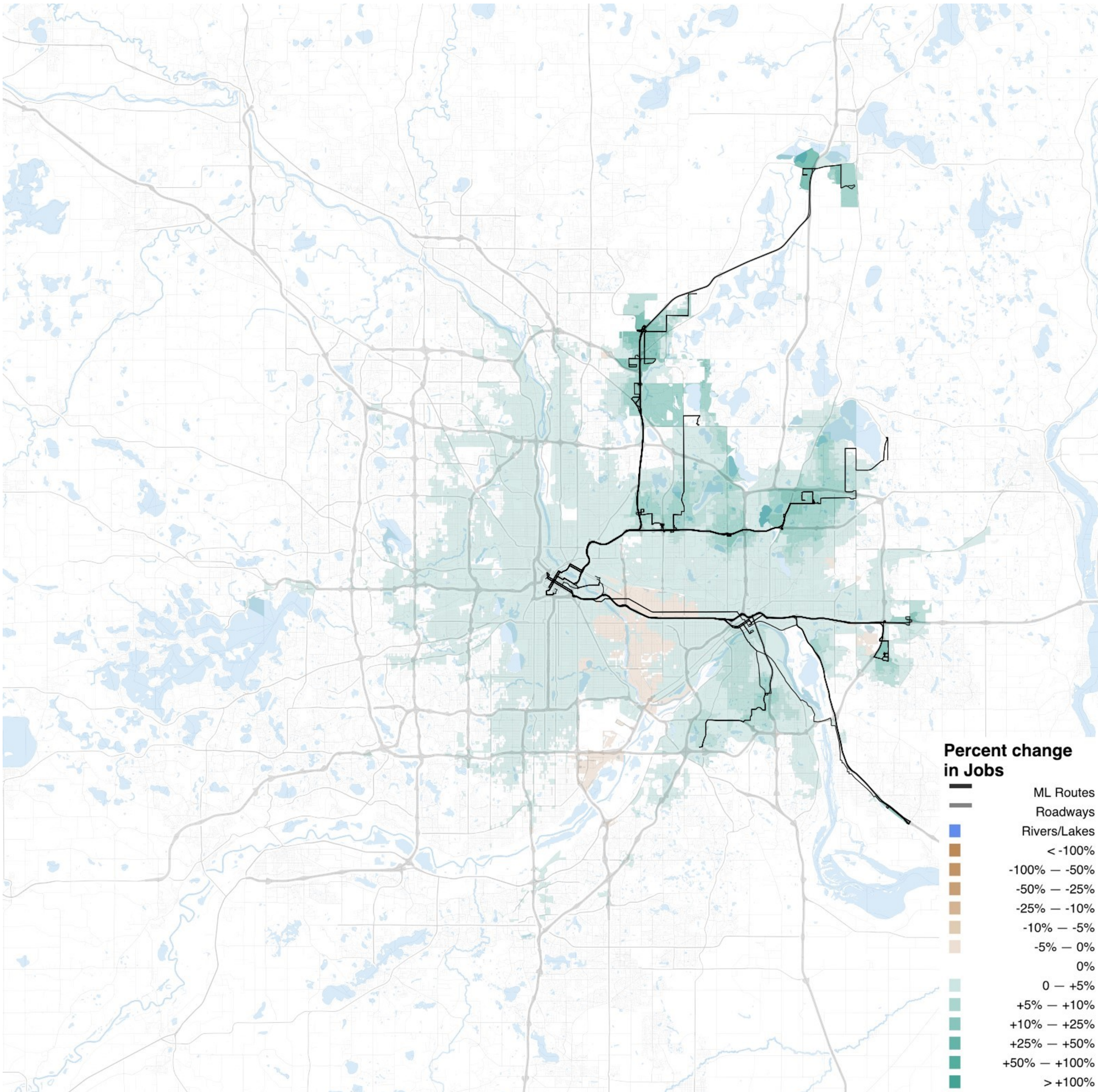


Figure 14 The percent change in average job accessibility between the I-35W and North I-94 scenario and baseline using the travel time threshold decay function.

3.4.2 Express Bus on Future Managed Lane (ML) Network Scenario Results

Changes to job accessibility for the isolated I-35W North and I-94 scenarios are shown in Tables **3** and **4**. The joint scenario imposes speed changes to thirteen express bus routes on segments I-35W North and I-94 between Minneapolis and Saint Paul. Given that these express bus trips operate at the target speed of 55 mph while on I-35W North and I-94, the joint effects on the 60-minute job accessibility profile for the Twin Cities region and impact zones are an increase of 0.94% and 11.2% respectively. Accessibility increases by a factor of ten between the 30 and 60-minute travel time thresholds, which indicates that many trips remain longer than a half hour—even after speed changes are made.

One notable difference between the existing ML network and the future ML network scenarios, is that the I-35W and I-94 segments effect one fifth of the routes as that of the current ML network, yet the accessibility benefits for the region and impact zone are a quarter of that of the entire existing network. This means that the transportation network and land use along I-35W North and I-94 is better coordinated for accessibility gains after the installation of a MnPASS facility. Many of the largest accessibility gains occur at the Census blocks closest to transit stops along the thirteen routes. This effect is highlighted in the travel time threshold decay function maps. If the MnPASS lane improves accessibility for short duration and long duration trips, the gains to accessibility at lower travel time thresholds is weighted heavier in the decay metric plotted in Figures **8**, **11**, and **14**.

3.5 BUS ACCESS TO MANAGED LANES CONCLUSION

This stage of the research introduces a methodology and computer program for relaying adjustments in bus-highway interactions to transit accessibility. MLs are increasingly a part of the national conversation about improving the level of service on U.S. highways. But improvements to the level of service manifest themselves in better access to destinations. By allowing transit vehicles to operate at higher speeds on MLs, the accessibility profile of transit users improves noticeably. The existing ML—Express Bus scenario demonstrates the gains in job accessibility that Twin Cities workers experience when express buses are simulated to operate at 55–65 mph on ML facilities. The percent increase in the 60-minute worker-weighted average accessibility for the Twin Cities and the impact zone surrounding the existing ML—Express Bus scenario routes is 3.79% and 21.12% respectively.

The I-35W North/I-94 future scenario imposes speed changes to thirteen express bus routes. The percent increase in the 60-minute worker-weighted average accessibility for the Twin Cities region and impact zones is 0.94% and 11.2% respectively. Of the three future scenarios, I-35W North offers the greatest gains in job accessibility for the Twin Cities region and the associated impact zone. Sixty percent of the regional gains in accessibility from the joint future scenario come from the I-35W North segment changes. If the per-mile construction costs are assumed to be equal for I-35W North and I-94 and the project lengths are considered, the I-94 segment becomes more worthwhile from an accessibility standpoint. The per-MnPASS-mile gain in average job accessibility for Twin Cities residents is 16 jobs per mile (10 jobs per km) for I-35W North and 98 jobs per mile (61 jobs per km) for I-94 at the 60-minute travel time threshold. Improvements to corridor speeds make it possible to increase transit frequency, which would further improve accessibility levels. These gains are important for employers, employees, transit agencies, and the broader economy.

CHAPTER 4: ACCESSIBILITY AT PARK-AND-RIDE FACILITIES

PNR facilities add a new function to an existing land use—that being, transit service. Not only does transit service become available to the area, but the service types tend to be faster, including express bus, limited-stop bus, or rail. Transit priority such as BRT, BOS and access to MLs further enhance the destinations that become available to origins that transfer through a PNR stop. In order for these services to be provided, PNR facilities must be constructed, maintained, and administratively managed, all of which come at a cost. The benefits of added transit service can be quantified by measuring the change in job accessibility and travel time at PNR stops.

4.1 METHODOLOGY

Each PNR stop acts as a junction between transportation modes. Transit service is extended to low density regions by allowing single occupancy vehicles to park and create the density needed to make transit service viable. Previous research has investigated the location and capacity optimization problems involved with planning a PNR network including [**62**], [**63**], and [**64**]. Here, the existing Twin Cities PNR network is assessed using the localized accessibility profiles of PNR stops. This section analyzes accessibility and travel time when express transit services are added to the existing placement of the Twin Cities PNR network.

4.1.1 Data Sources

The spatial and temporal variation of automobile and transit travel time and accessibility is quantified using two transportation network data sources along with origin-destination area characteristics. The transit network including route alignment and frequency is gathered through General Transit Feed Specification data for the Fall of 2016. The pedestrian network, which interfaces with transit stop information, is collected using a 2017 OpenStreetMap metro extract for the Twin Cities. Spatial information such as block origins, PNR stations, and destinations are taken from the U.S Census Bureau TIGER 2010 Census blocks, Metro Transit PNR lots dataset, and the Longitudinal Employer-Household Dynamics (LEHD) 2014 Origin-Destination employment statistics.

The Accessibility Observatory Java program BatchAnalyst V0.2.2 is used for calculating travel time matrices and accessibility. Computer programs developed in Python3 are used for post-processing of large datasets. All PNR locations that are connected to the transit network and listed as “open” in the Metro Transit dataset are included in the following analyses for a total of 114 PNR origins.

4.1.2 Measuring Park-and-Ride Facility Accessibility

The effects of express transit service on the travel time and accessibility from PNR locations are found by comparing the local transit network and the complete transit network. The local network is defined as; all scheduled routes in the Twin Cities less the express routes where ridership originating from a PNR stop is 10% or greater for an average trip. This means that express routes that primarily serve PNR stops are not included in the local network. The complete network fills in the local network by adding back these express routes. The complete network is equivalent to the transit schedule published by local transit agencies Metro Transit and MVTA for the Fall of 2016. Automated passenger count data is made available from Metro Transit and is used to create a rule-based determination of routes that primarily serve PNR stops. Comparable data from MVTA is unavailable, however, the determination between local and express routes is more distinct due to the nature of service MVTA provides. Express routes that are added to the local network are listed below in Table **6**.

Table 6 Express transit routes that primarily serve PNRs.

Express Routes			
250	252	261	263
264	265	270	272
275	288	294	351
353	355	361	364
365	375	452	460
464	465	467	470
472	475	476	477
478	479	480	484
490	491	492	493
495	RED	535	578
579	589	597	649
652	663	670	672
673	674	675	677
679	756	760	765
766	767	768	850
852	854	860	865

4.1.3 Local Transit Network Scenario

The travel time by local transit from each of the 114 PNR origins to three common Twin Cities destinations is computed. Downtown Minneapolis, downtown Saint Paul, and the University of Minnesota East Bank campus are used as final destinations because they are common end points for routes that serve PNR facilities. In the following section, the local scenario travel time matrix will be compared with the complete network scenario—where express routes are introduced to the network.

Accessibility by local transit from each PNR origin to a destination set comprised of approximately 108,000 Census blocks is computed. Accessibility is calculated for morning peak hours from 6–9 AM at one-minute intervals on Wednesday, October 5th, 2016. The cumulative accessibility metric is used to calculate the number of jobs accessible within travel time thresholds between 5–90-minutes. Minute-by-minute departure times are averaged for a single value of accessibility at each PNR origin and travel time threshold. Each of the eighteen travel threshold values is weighted to give more value to accessible destinations at low travel times and decaying value to accessible destinations at high travel times. The decay function simplifies the interpretation of the relative impact each network improvement has on the overall level of accessibility. In the following sections, the weighted accessibility level and the 60-minute accessibility level will be discussed when comparing the overall changes in accessibility and travel times. The baseline absolute value of local transit accessibility from each PNR origin to the surrounding metropolitan region at the 60-minute travel time threshold is shown in Figure **15**.

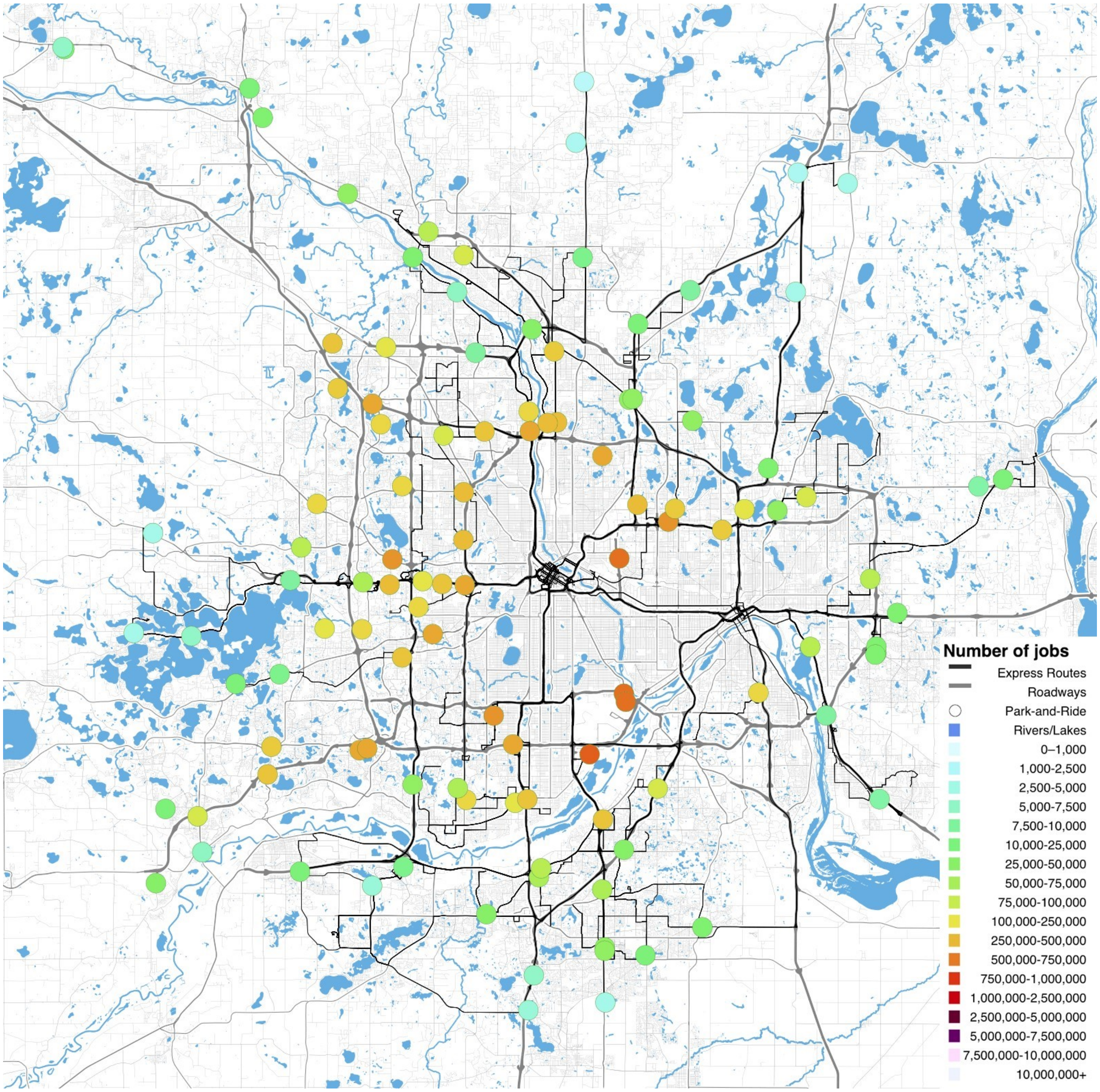


Figure 15 The average job accessibility for the local transit network at the 60-minute travel time threshold from 6–9 AM on Wednesday, October 5, 2016.

4.1.4 Complete Transit Network Scenario

The sixty-four routes listed in Table **6** are added to the local transit network to complete the Metro Transit and MVTA transit schedule as of the Fall of 2016 General Transit Feed Specification release. The pedestrian and automobile traversal networks are not affected by the modifications to the transit network because each mode uses different data inputs. Accessibility and travel time from the set of PNR origins is computed for the complete transit network. The analyses are carried out for the morning peak hours from 6–9 AM at one-minute intervals on Wednesday, October 5th, 2016. The calculation parameters are identical to the local network scenario. The setup enables a direct comparison of the results. The complete transit network accessibility from each PNR origin to the surrounding metropolitan region at the 60-minute travel time threshold is shown in Figure **16** and can be compared against the local results in Figure **15**.

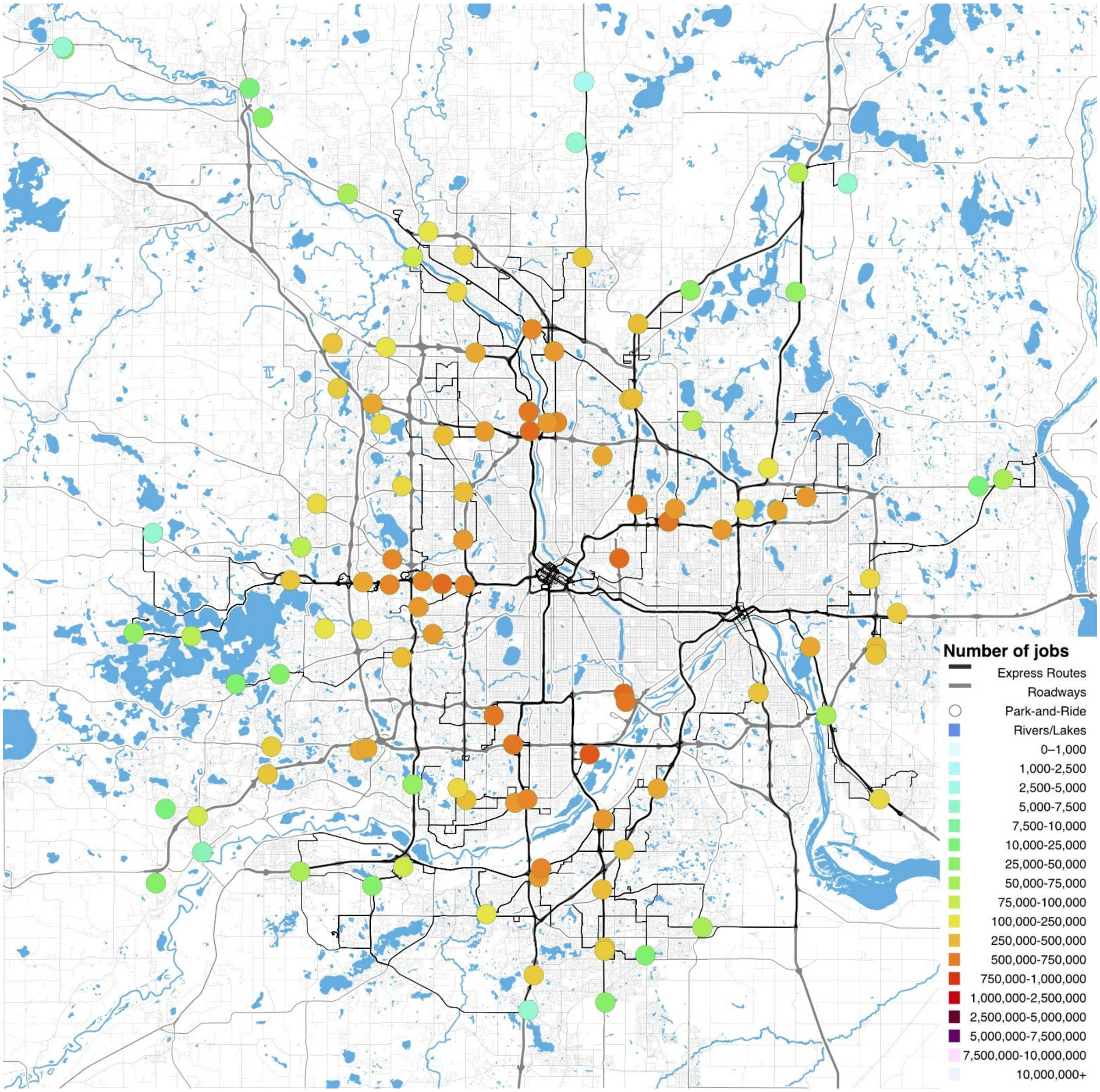


Figure 16 The average job accessibility for the complete transit network at the 60-minute travel time threshold from 6–9 AM on Wednesday, October 5, 2016.

4.2 RESULTS

The top twenty PNR origins with the greatest average percent change in travel time between destinations is shown in Table **7** and is expanded in Appendix Table **17**. The max travel time is limited to ninety minutes due to computation demands. PNRs that do not experience a change in travel time (indicated by a dash), lack transit links that can provide an average trip in ninety minutes or less.

Table 7 The top twenty PNR lots with the greatest average time savings when comparing the local to the complete transit network.

	UMN	MPLS	ST. PAUL	AVERAGE
PNR Name	Time Savings [min] (Percent Faster)	Time Savings [min] (Percent Faster)	Time Savings [min] (Percent Faster)	Time Savings [min] (Percent Faster)
General Mills Blvd & I-394	34.5 (41.9%)	33.4 (46.3%)	-	33.9 (44.1%)
Hwy 610 & Noble	30.6 (35.2%)	40.8 (50.1%)	-	35.7 (42.6%)
Church of Nazarene	27 (37.5%)	32.2 (51.3%)	22.8 (27.3%)	27.3 (38.7%)
Richardson Park	-	32.2 (36.4%)	-	32.2 (36.4%)
Christ Episcopal Church	28.8 (32.3%)	-	34 (40.1%)	31.4 (36.2%)
Saint Edward's Catholic Church	-	30.1 (35.4%)	-	30.1 (35.4%)
Woodbury Lutheran Church	29.3 (33.1%)	-	30.7 (36.3%)	30 (34.7%)
Hwy 61 & Co Rd C	39.3 (45%)	-	20 (23.4%)	29.6 (34.2%)
Burnsville Transit Station	33.6 (40.2%)	40.9 (49.7%)	8.4 (9.6%)	27.7 (33.2%)
Louisiana Ave Transit Center	28.9 (38.1%)	28.6 (44.6%)	13 (15%)	23.5 (32.6%)
Woodbury Theatre	-	-	28 (32.2%)	28 (32.2%)
Eagan Transit Station	16.8 (20.9%)	21.9 (27.6%)	38.6 (44.9%)	25.8 (31.1%)
Wayzata Blvd & Barry Ave	21.2 (24.2%)	29.6 (36.3%)	-	25.4 (30.2%)
Hwy 61 & Lower Afton Rd	27.9 (35.3%)	29.6 (34.5%)	13.2 (19%)	23.6 (29.6%)
I-35W & 95th Ave	37.8 (42.8%)	-	13.2 (15.5%)	25.5 (29.1%)
Plymouth Road Park & Ride	21.5 (25.9%)	23.1 (31.9%)	-	22.3 (28.9%)
Maplewood Mall Transit Center	26.5 (32.9%)	33.3 (38.7%)	11.3 (15.1%)	23.7 (28.9%)
Heart of the City	30.7 (35.9%)	34.3 (40.5%)	5.6 (6.2%)	23.5 (27.5%)
I-35W & Co Rd H	18 (22.2%)	23.3 (29.7%)	-	20.6 (25.9%)
Northtown Transit Center	14.6 (20.3%)	20.2 (30.5%)	22.5 (26.1%)	19.1 (25.6%)

The average travel times between the origin and destination set for the local transit network scenario are greater due to the lack of direct express routes connected to the network. The direction of comparison is local to complete, thus the time savings shown in Table **7** are the average difference in minutes between the local and complete network scenarios for each origin-destination pair. For example, the average reduction in travel time between the Highway 610 & Noble Parkway PNR and Minneapolis is 40.8 minutes meanwhile no change occurs between Noble Parkway PNR and Saint Paul.

The local scenario severely isolates many PNR stops from transit connections meaning the shortest path may involve significant waiting, walking, and transferring time to alternative local bus stops before arriving at the destination. This results in large travel time differences between the local and complete network scenarios. Of the 114 PNRs analyzed, 16 do not experience a change in travel time when express routes are added. The routes connecting to these particular PNR stops have less than 10% of riders originating from a PNR, meaning they remain a part of the complete network **and** local network. An additional 29 PNR stops are unable to reach all three destinations in 90-minutes in both the local and complete scenarios, thus no travel time change occurs. However, these same PNR stops do experience changes in accessibility. In fact, the addition of express routes improves accessibility at low travel time thresholds more than at high travel time thresholds, thereby inducing a larger weighted accessibility impact. This outcome highlights the need to assess transportation network changes through both level of service and land use accessibility methods.

4.2.1 Time-Weighted Accessibility at Park-and-Ride Facilities

A comparison of the local and complete transit network accessibility levels is presented using percent change figures along with the time decay function. The time decay function is discussed in greater detail in Chapter **2**. Accessibility is calculated for eighteen travel time thresholds. Accessibility gains in lower travel time thresholds are assigned a larger weight for the overall accessibility profile. The time weighted percent change in accessibility between the local and complete network scenarios is shown in Figure **17**. The travel time threshold that experiences the largest change between the local and complete network scenarios is plotted in Figure **18**. This figure uncovers the threshold that contributes the most to the weighted percent change value shown by Figure **17**.

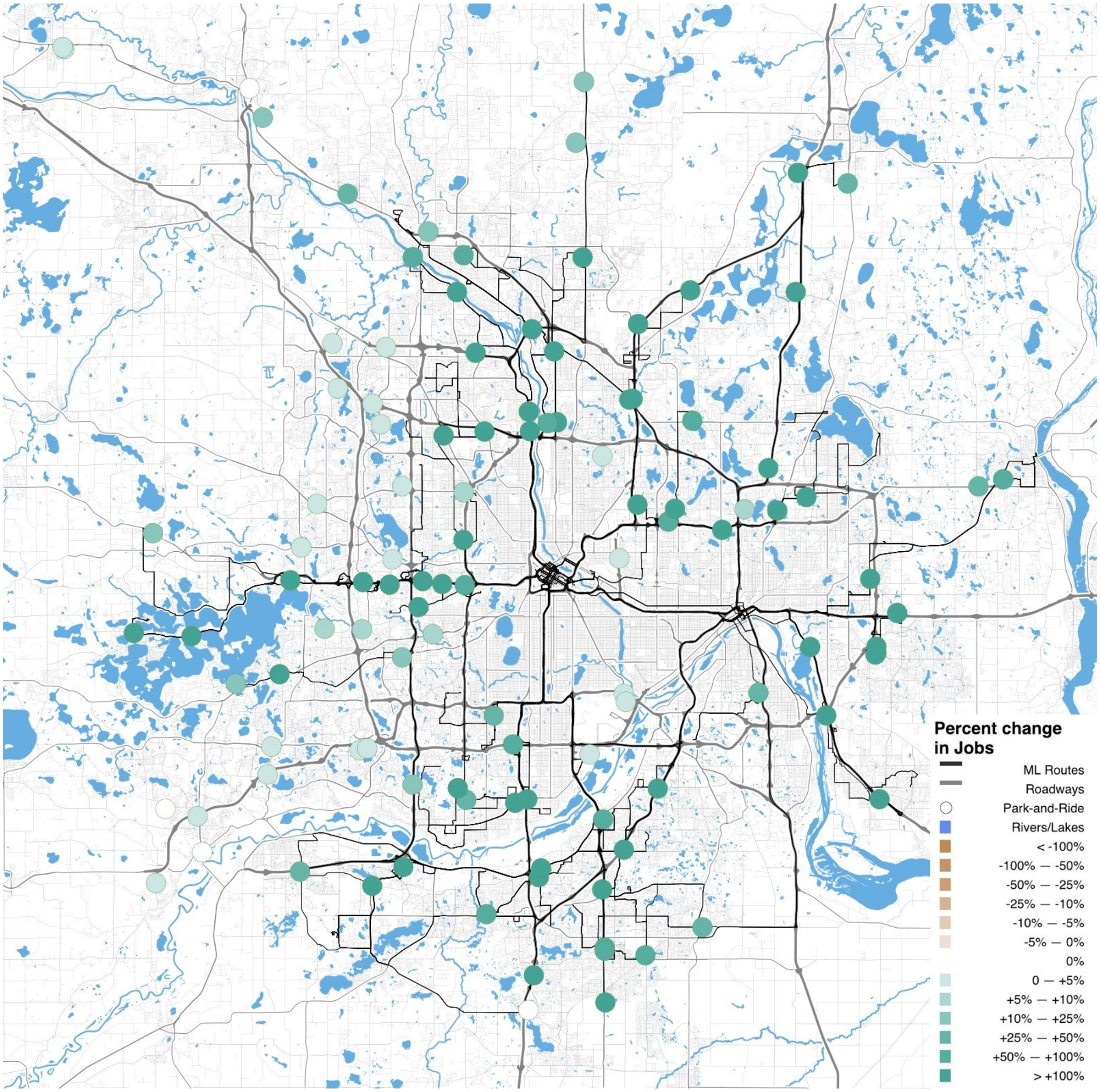


Figure 17 The weighted percent change in job accessibility when express transit service is added to the local network. Results are weighted using the travel time threshold decay function. Analysis time from 6–9 AM on Wednesday, October 5, 2016.

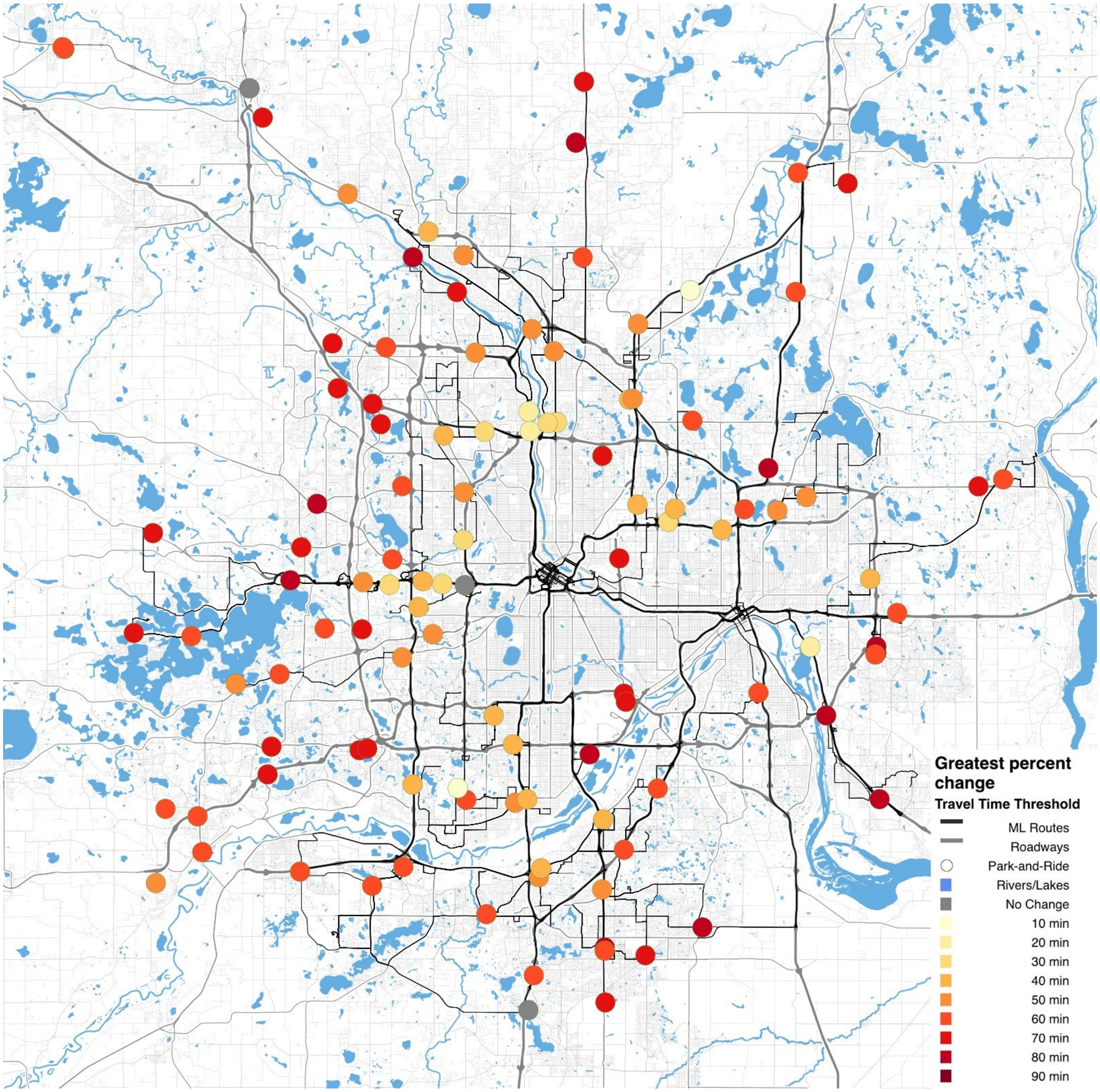


Figure 18 The travel time threshold (listed in minutes) that exhibits the largest change between the local and complete transit network scenarios. A supplement to Figure 17.

The twenty PNR stops that experience the greatest change in the number of jobs accessible during the morning peak hour are listed in Table **8**, values are sorted by absolute difference. Fifteen of the PNRs that experience large travel time savings when express transit is added, are found to experience large accessibility changes at the 60-minute threshold, i.e. there are fifteen overlapping PNR stops on Tables **7** and **8**. The weighted percent change listed in Table **8** shows the collective accessibility change at all travel time thresholds. Many PNRs that rank high for absolute difference in jobs at the 60-minute travel time threshold also have greater weighted percent change values meaning at **all** thresholds, these PNRs experience large job access changes when express transit service is added to the network. An expanded accessibility results table is listed in Appendix B Table **18**.

Table 8 The twenty PNR stops with the largest absolute difference in jobs accessible within 60-minutes of travel—comparing the local and complete network scenarios.

Name	Abs. Diff. 60 Min	Pct. Chg. 60 Min	Weight Pct. Chg.
Burnsville Transit Station	407,682	648%	326%
General Mills Blvd & I-394	390,201	423%	358%
Church of Nazarene	388,151	286%	814%
Foley Blvd	384,939	1764%	1115%
Louisiana Ave Transit Center	348,272	165%	261%
Heart of the City	305,176	570%	192%
Hwy 610 & Noble	302,840	4123%	2798%
Hwy 61 & Co Rd C	283,039	931%	587%
Maplewood Mall Transit Center	280,904	309%	155%
South Bloomington Transit Center	272,175	130%	138%
Plymouth Road Park & Ride	261,010	495%	299%
Hwy 61 & Lower Afton Rd	239,506	347%	486%
Saint Luke's Lutheran Church	239,460	258%	152%
Northtown Transit Center	234,830	144%	113%
I-35W & 95th Ave	231,140	1663%	755%
Regal Cinemas 20	226,716	67%	128%
Eagan Transit Station	221,695	278%	104%
Westwood Lutheran Church	221,388	171%	291%
Woodbury Theatre	214,344	1284%	194%
Mermaid Supper Club	211,260	542%	282%

4.3 CONCLUSION

The benefits of transit service to PNR locations across the metropolitan region can be seen visually and numerically in the figures above. When express transit service is added to the local network, morning peak hour accessibility increases fourfold or by approximately 100,000 jobs for trips originating from PNR stops. Travel times between PNR origins and the set of destinations decrease by 10.7 minutes on average, meaning more destinations can be reached within a given travel time threshold. Taking these figures into context, the complete scenario adds sixty-four routes to the local scenario, each of which directly link suburban PNR stations with downtown Minneapolis and Saint Paul. The connectivity of the transit network to high job density land use accounts for the substantial accessibility increase between scenarios. This analysis offers a look at the accessibility and travel time benefits brought to PNR facilities through the connection of express transit services. Later stages of this research explore the regional impacts of PNR facilities on transit accessibility.

CHAPTER 5: ACCESSIBILITY IMPACTS OF PARK-AND-RIDE SYSTEMS

The PNR section presents a methodology for linking automobile and transit travel time matrices across space and time. The resulting travel time matrices are used in a cumulative accessibility analysis where total jobs accessible within a given time and cost threshold are the variables of interest. We expect the accessibility profile of a metropolitan region where PNR trip types are explicitly included to reflect a blend of automobile and walk-up transit accessibility patterns. Given this reasoning, we expect suburban regions to show the greatest accessibility impact from PNR facilities compared to exurban and urban areas. By developing a methodology for incorporating PNR routes into accessibility measurements, the network level contribution of each PNR facility can be computed and assessed. Accounting for more elements of the transportation system allows a finer level of detail to be applied when tracking changes to accessibility across a region. This ultimately leads to an improvement in the usefulness of accessibility as an assessment tool for planners and engineers alike. In the following sections, the algorithm used to link travel time matrices is described and results for the Minneapolis–Saint Paul, Minnesota accessibility profile are presented.

5.1 MIXED-MODE METHODOLOGY OVERVIEW

Accessibility is typically found using travel time matrices that reflect an array of departure times. The travel time matrix captures the travel shed of each origin for a given departure time and travel time limit. The destinations that fall within each travel shed are accounted for in the accessibility metric. The inclusion of PNR facilities as an intermediate stop between the origin and destination set means two travel time matrices must be considered before accessibility can be calculated. The location of the PNR facility and the frequency of the transit routes that serve the facility affect the likelihood for a given PNR to be chosen for the optimal route between an origin-destination (OD) pair. Ultimately, each OD pair is connected through all PNR facilities—the facility that provides the lowest travel time between the OD pair is carried forward in the analysis (see Figure **19**).

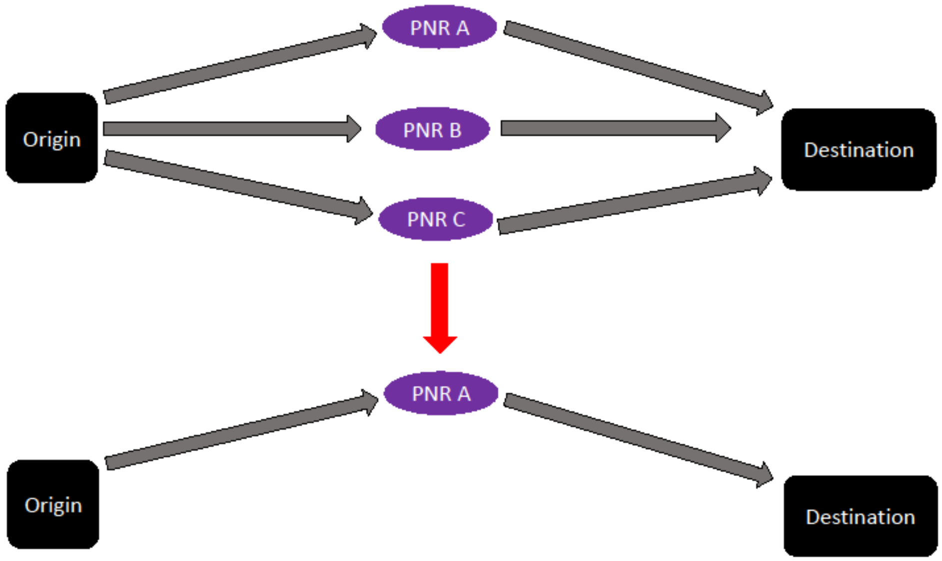


Figure 19 The selection process used to find the optimal PNR facility that minimizes OD travel time.

To demonstrate the mixed-mode accessibility methodology, the metropolitan region of Minneapolis–Saint Paul, Minnesota is selected. The region has 114 PNR facilities that are primarily connected to business districts through express and limited-stop transit service. Access to jobs is measured for comparison with previously reported, single-mode accessibility results [**65**]. The goal of this research is to develop a mixed-mode accessibility profile enabled by PNR transfer points. In order to do so, the procedure for connecting viable paths across modes is described in detail.

5.2 CASE STUDY DATA

Link-based and schedule-based travel time matrices are used to calculate automobile and transit accessibility respectively. The intersection of these matrices allows mixed-mode travel times to be computed for input to the PNR accessibility framework. The analysis is conducted for the morning peak hours from 6:00–9:00 AM. The origin set O is comprised of 3,030 transportation analysis zones (TAZ) for the Minneapolis–Saint Paul metropolitan region defined in 2018 [**66**]. The destination set D contains 108,000 Census blocks defined in 2016—taken at the geometric centroid [**54**]. The origin and destination sets vary in resolution to balance computational demand with accuracy in transit accessibility. The accessibility program uses the centroid of each analysis unit to connect transit stops with destination points, therefore a finer scale results in more accurate walking distances. Job and worker data are taken from the Longitudinal Employer-Household Dynamics (LEHD) 2016 Census data and joined with the destination set. The Twin Cities metropolitan region has 1.7 million jobs which provides the upper limit of job accessibility found in the region. The travel time matrices are computed using OpenTripPlanner routing software, which employs Dijkstra's Algorithm to identify the shortest time paths between the origin-PNR and PNR-destination sets [**58**].

The study area is served by over 200 transit routes operated by Metro Transit and Minnesota Valley Transit Authority, and several smaller agencies. Sixty-four of these routes are express service that primarily serve the 114 PNR facilities identified on the network. In order to capture local transit transfers, all routes are used in the mixed-mode accessibility analysis. The study area is shown in Figure **20** with transit routes and PNR facilities highlighted.

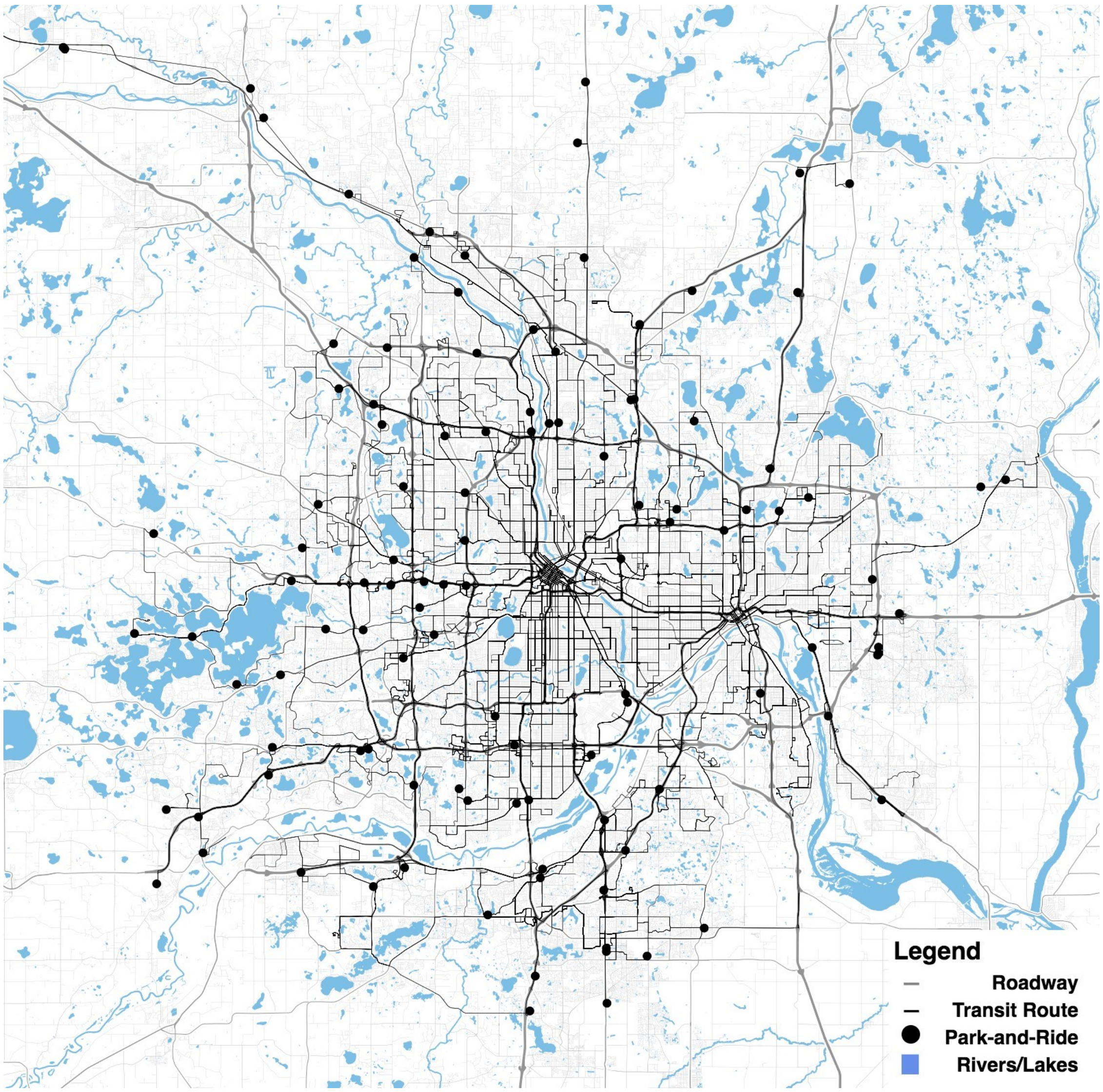


Figure 20 The transit and PNR network for the Minneapolis–Saint Paul metropolitan area.

5.3 MATRIX LINKING PROCEDURE

In this study, the morning commute is modeled by directing travel from home to workplace. The trip from home origin *i* to workplace destination *j* is completed in two legs—with a transfer at PNR *k*. Thus, two travel time matrices are required. Matrix $(M_{i,k})_A$ is travel from origin *i* to PNR *k* where *A* denotes automobile travel times derived using GPS-based link speed data licensed from TomTom, Inc. The transit matrix $(M_{k,j})_T$ is travel by transit from PNR *k* to destination *j* where *T* denotes transit travel times taken from the timetable data for local transit operators [**17**] [**18**].

With over 35 billion spatial pairs for every departure time d_t, the computational demand is high. The algorithm is written in Python3 and is executed on an macOS machine with 16 gigabytes of random-access memory, a 3.5 GHz Intel Core i7 processor, and running OS X Yosemite. The matrix linking process and cumulative accessibility calculations are completed in 3.25 hours.

5.3.1 Automobile Parameters

For this analysis, Matrix $(M_{i,k})_A$ is computed for departure time d_t where t = 7:00 AM. A single departure time is chosen to reduce the file size and computation time of the matrix linking procedure. The travel times found at 7:00 AM are within 2% of those found at departure times from 6:00–9:00 AM. For this reason, the travel times at 7:00 AM are used for modeling the auto portion of the PNR trip across the 6:00–9:00 AM departure window.

5.3.2 Transfers

The activities associated with accessing transit such as parking a car or buying a fare are not explicitly included in the transfer window. The transfer time is included implicitly by the gap of time between an auto trip arriving at a PNR facility and the next departing transit trip. Transfer time varies between one second and fifteen-minutes—depending on the coordination of each mode. Additionally, PNR lot capacity and its potential effects on transfer time or facility selection are not considered in the matrix-linking algorithm.

The minimum travel time path chosen for a given origin *i* and destination *j* is optimized by the transfer at PNR *k* and varies by departure time. For example, at 6:15 AM the optimal PNR between origin *i* and destination *j* may be different than the optimal PNR found at 6:00 AM or 6:30 AM. The accessibility derived from the minimum travel time path can be realized if the users are assumed to have complete information about the auto and transit networks and that they will take the shortest time path. These are two commonly applied route choice assumptions taken during travel demand forecasting.

5.3.3 Transit Parameters

Transit travel times, which include wait time, change substantially depending on the frequency of service. For this reason, matrix $(M_{k,j})_T$ is computed for minute-by-minute departure times from 6:00 AM to 9:00 AM. PNR facilities are commonly served by low-frequency express buses. Lower frequency service has been shown to influence rider departure time from the origin site [**67**]. Post-processing of matrix $(M_{k,j})_T$ is completed to reduce the computational demand of the matrix linking procedure and to account for the behavior of riders to minimize wait time at transit stops. The minute-by-minute transit data set is aggregated up to fifteen-minute bins using the minimum travel value. For example, travel time between pair *k,j* is computed for $d_{6:00}, d_{6:01},...,d_{6:14}$, the minimum travel time of this set is assigned to the 6:00 AM bin.

5.3.4 Algorithm Description

The matrix linking algorithm is structured in three looping procedures, which iteratively select the PNR *k* that produces the minimum travel time path for an origin *i* and destination *j* pair. The first loop selects origin *i* from set *O*.

$$O = \{i_1,i_2,...,i_n\} \text{ where } n = 3030$$

The network is comprised of 483,515 links where each link l_n is associated with a speed profile and traversal time based on TomTom, Inc. aggregated data from Thursday, January 14th, 2016.

$$L = \{l_1,l_2,...,l_n\} \text{ where } n = 483{,}515$$

The second loop is nested within the first operation and selects departure time d_t from set *T*.

$$T = \{d_{t=6:00}, d_{t=6:15},...,d_{t=9:00}\}$$

The innermost loop selects PNR *k* from set *K*.

$$K = \{k_1,k_2,...,k_n\} \text{ where } n = 114$$

Given the selected PNR *k*, the subset array of travel times for *k* to the set of destinations *D* is retained.

$$D = \{j_1,j_2,...,j_n\} \text{ where } n = 108{,}000$$

For each *i,k,j* pairing, the set of network links on the path is described by $h_{i,k,j}$, which belongs to the full path set *H*.

$$h_{i,k,j} = \{l_i,...,l_k,...,l_j\} \text{ where } h_{i,k,j} \in H$$

Given the location pairing i,k,j, the travel time $c_{i,k}$ is queried. Next, a subset of matrix $(M_{k,j})_T$ is queried for PNR k to the destination set D such that an array of destinations and corresponding travel times are returned, $v_{k,D}$.

$$v_{k,D} = \{c_{k,j1}, c_{k,j2}, \ldots, c_{k,jn}\} \forall j \in D$$

The path travel time for the first leg of the trip from i to k is added as a constant to array $v_{k,D}$ and stored as $v_{k,D}'$.

$$v_{k,D'} = \{(c_{i,k} + c_{k,j1}), (c_{i,k} + c_{k,j2}), \ldots, (c_{i,k} + c_{k,jn})\}$$

Each element in array $v_{k,D}'$ is the total path travel time $c_{i,k,j}$ as described by $h_{i,k,j}$. Let n be the number of links on path $h_{i,k,j}$ then the path travel time $c_{i,k,j}$ is equal to the sum of link travel times on path $h_{i,k,j}$ where all links are on the path.

$$c_{i,k,j} \underset{\forall c \in C}{=} \sum_{x=1}^{n} l_n$$

Array $v_{k,D}'$ gives the total path travel time for origin i to all destinations j in set D when connecting through PNR facility k. One iteration is complete and node k+1 is selected from the PNR set. While iterating through each PNR location k in set K, travel time arrays $v_{k,D}'$ and $v_{k}'_{+1,D}$ are compared and the minimum path travel time min($c_{i,j}$) is retained for each pair i,j.

$$\min (c) \forall h \in H$$

5.3.5 Algorithm Output

Once each PNR has been visited, the array $v_{k,D}'$ contains the minimum travel time for origin i to each destination j in set D and the corresponding PNR k that enables the minimal travel time. Flexible PNR assignment allows every path travel time $c_{i,j}$ to be minimized according to departure time, facility location, and transit service. Once each origin i has been visited at each departure time, the minimum path travel time arrays constitute the final mixed-mode travel time matrix M_C. Each entry in matrix M_C provides an origin i, destination j, departure time d_t, and mixed-mode travel time $c_{i,j}$.

5.4 POST-PROCESSING OF TRAVEL TIME MATRICES TO ACCESSIBILITY

Upon completion of the matrix linking procedure, a mixed-mode travel time matrix is found. The travel time between each PNR pair is minimized by selecting the PNR with transit service that best completes the path. The optimal path is determined for each departure time from 6:00–9:00 AM in 15-minute increments.

The mixed-mode travel time matrix M_C is used to determine the cumulative opportunities accessible from each origin *i*. For this analysis, the travel time thresholds of 5–90-minutes are computed. Each destination *j* is then joined with the LEHD total jobs figures. The sum of jobs provides the magnitude of accessibility at origin *i* for the selected threshold. The average accessibility over the 6:00–9:00 AM study window is used in the mixed-mode accessibility profile for the area.

5.5 JOB ACCESSIBILITY IN THE TWIN CITIES

PNR accessibility is a function of both the automobile and transit networks of a region. The individual accessibility profiles of each mode contribute to the hybrid pattern of mixed-mode accessibility. For this reason, the singular mode accessibility profiles for automobile and transit are presented alongside the PNR mixed-mode accessibility results. Table **9** gives the worker-weighted average accessibility found by mode and travel time threshold. The results for each mode are discussed below.

Table 9 Worker-weighted Average Job Accessibility.

	15 min.	**30 min.**	**45 min.**	**60 min.**	**75 min.**	**90 min.**
Automobile	216,322	865,337	1,355,814	1,627,419	1,777,501	1,845,715
Transit	1,524	15,868	61,975	140,086	149,585	149,615
PNR	1,389	51,902	263,173	459,408	561,122	609,864

5.5.1 Automobile

Access to jobs by automobile is measured for the Twin Cities using similar calculation parameters to the PNR scenario. Automobile accessibility is calculated in fifteen-minute intervals from 6:00–9:00 AM for travel time thresholds of 5–90-minutes. The OD matrix is composed of 3,030 TAZs. The level of job accessibility within 30-minutes by automobile for the Twin Cities analysis region is shown in Figure **21**. The average commuter can reach 976,018 jobs in 30-minutes of driving (see Table **9**). The 30-minute travel time threshold captures the average travel time (25.4 minutes) by Twin Cities drivers and transit customers in 2016 [**68**]. For this reason, the 30-minute threshold is used as the standard of measurement for discussion purposes; however, all accessibility thresholds are important to consider in the assessment of accessibility.

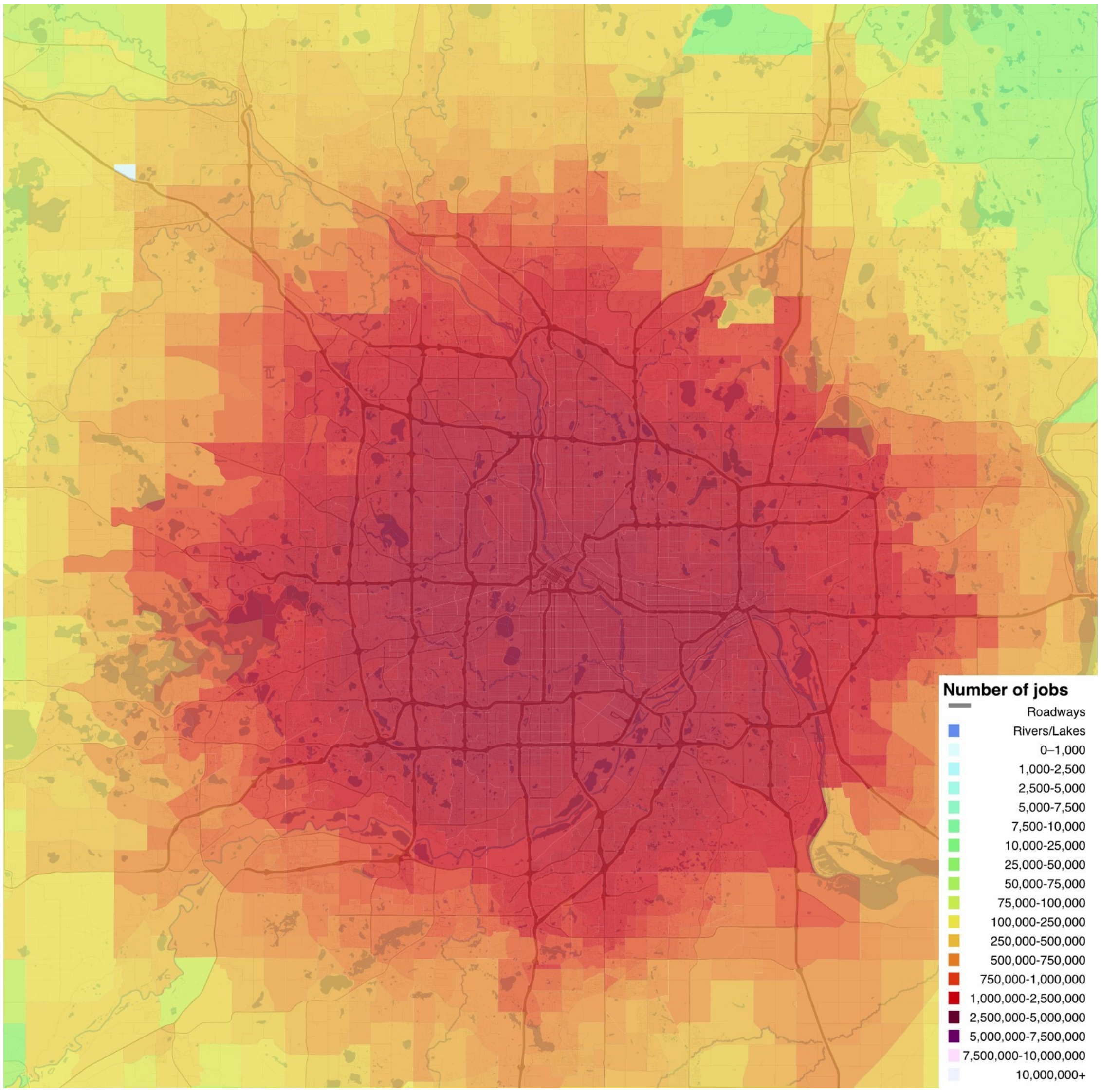


Figure 21 Automobile job accessibility within 30-minutes of travel in the Minneapolis–Saint Paul metropolitan area.

5.5.2 Walk-up Transit

The walk-up transit travel time matrix is computed for the Census Block PNR set using the same calculation parameters applied to the mixed-mode PNR scenario. The walk-up transit job accessibility profile is measured for the region by averaging block level results to the TAZ level for relation to auto and PNR scenario results. Walk-up transit accessibility is defined to include trips completed by walking or transit vehicles. More specifically, walk-up transit indicates that walking is the mode applied to the access and egress legs of the transit vehicle trip. Figure **22** shows the average job accessibility across the analysis time frame from 6:00–9:00 AM for a 30-minute walk-up transit trip. The average commuter can reach 16,697 jobs in 30-minutes of walk-up transit travel (see Table **9**). The highest accessibility levels occur in the CBD areas where transit routes are dense and frequent. In the suburbs, accessibility tends to be greatest on high frequency transit routes that terminate at the CBD. Service frequency emphasizes a pattern of high accessibility along transit corridors followed by low accessibility as the distance from the transit route increases. Like much of the nation, the transit network is far less connected than the road network, as evidenced by the automobile and walk-up transit job accessibility profiles.

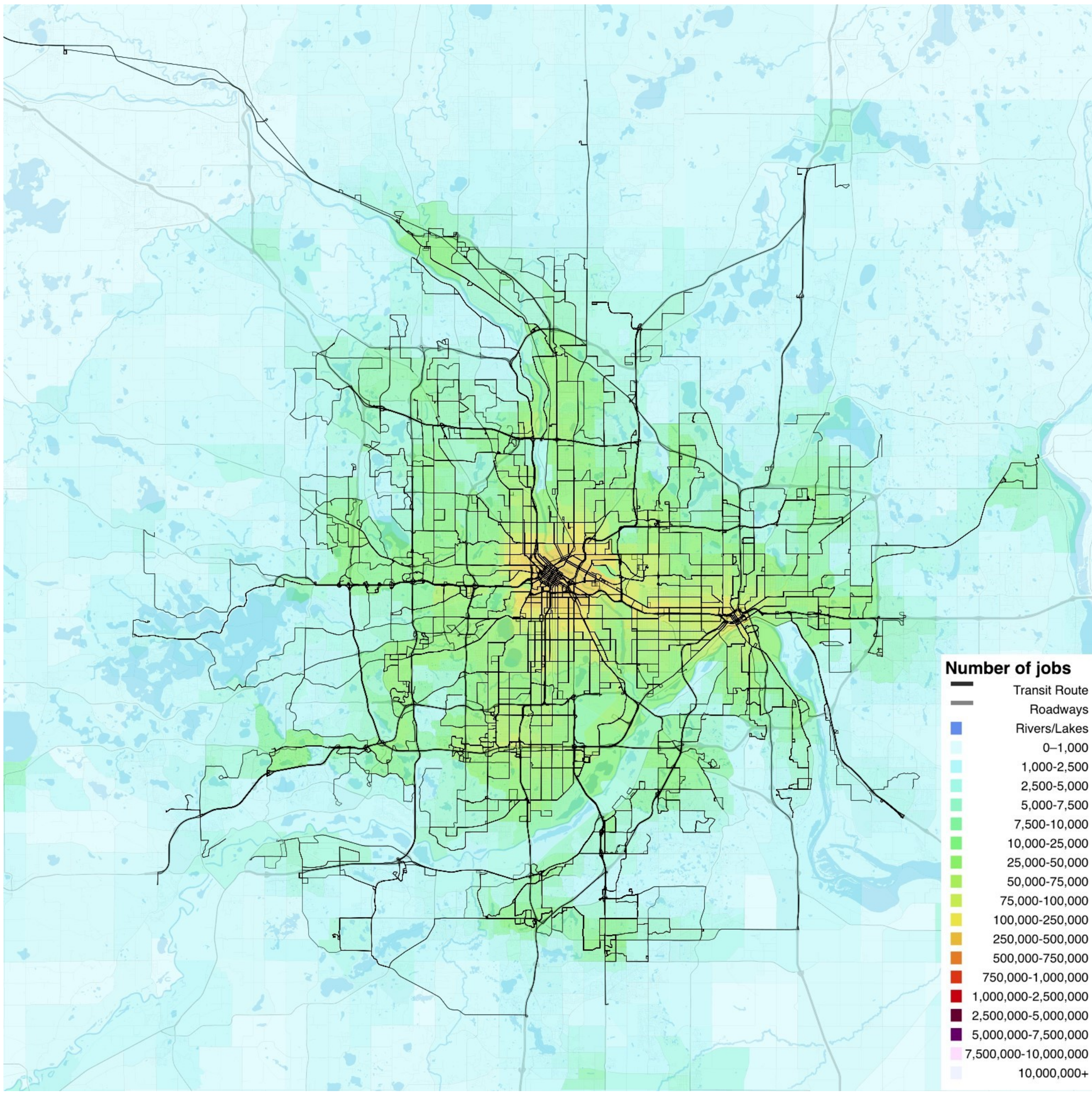


Figure 22 Walk-up transit job accessibility within 30-minutes of travel in the Minneapolis–Saint Paul metropolitan area.

5.5.3 Park-and-Ride

The baseline automobile and walk-up transit accessibility profiles support the interpretation of a PNR accessibility landscape. The PNR measure incorporates the speed of automobile travel to access PNR facilities, and the frequency and job-centric attributes of transit service. Figure **23** depicts the absolute value of jobs accessible within 30-minutes by PNR trip type. The results show moderate job accessibility levels dispersed across the metropolitan region. A 30-minute PNR trip allows the average commuter to reach 51,900 jobs (see Table **9**), a 210% increase over walk-up transit. PNR accessibility follows the breadth of automobile accessibility while exhibiting the reduced magnitude of walk-up transit accessibility that results from transit-only connections. A hybrid pattern of accessibility emerges across the analysis region. This finding supports the hypothesis that gaps in suburban and exurban job accessibility by walk-up transit are reduced when automobile travel is used to access transit service at PNR facilities.

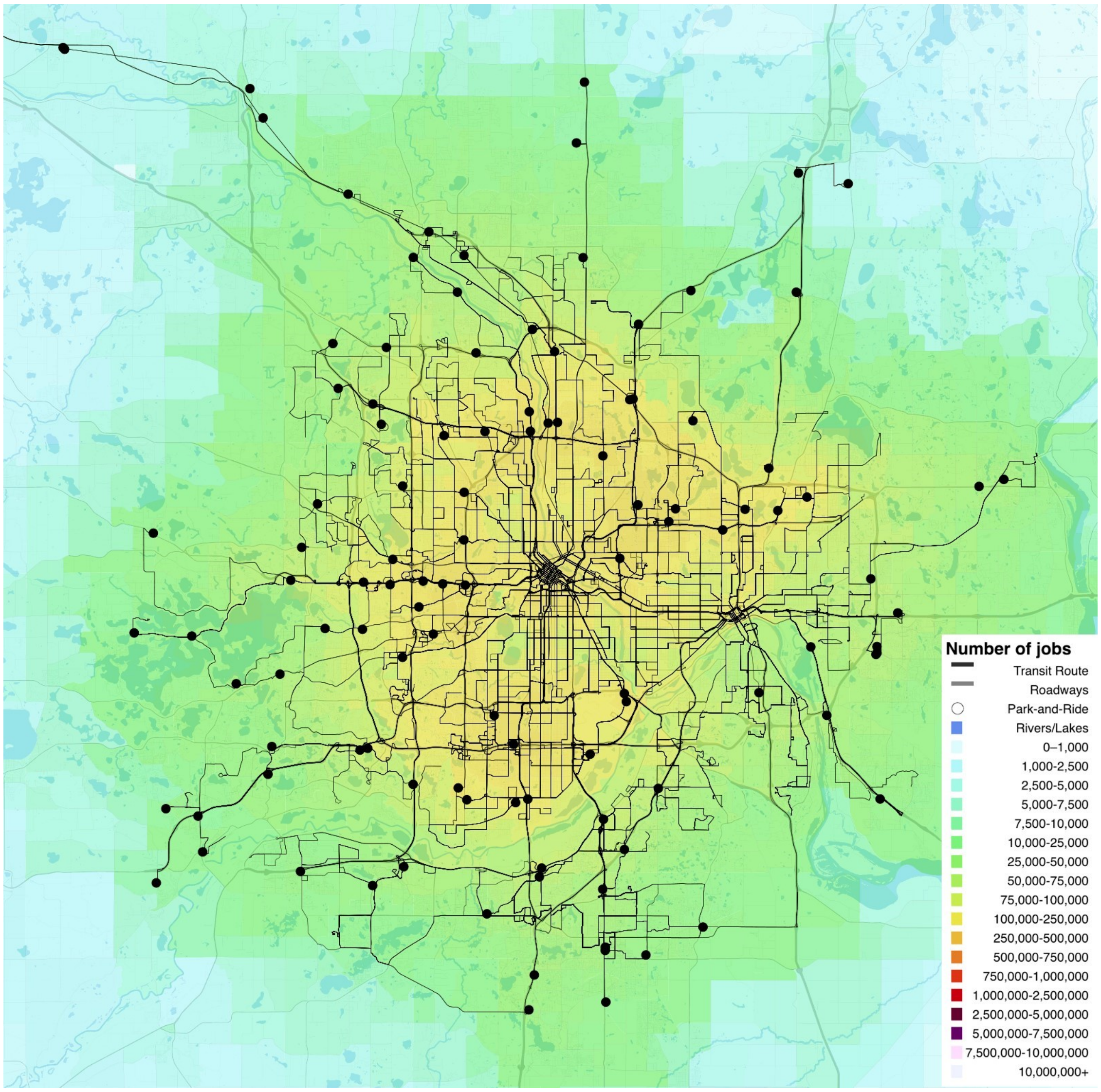


Figure 23 PNR job accessibility within 30-minutes of travel in the Minneapolis–Saint Paul metropolitan area.

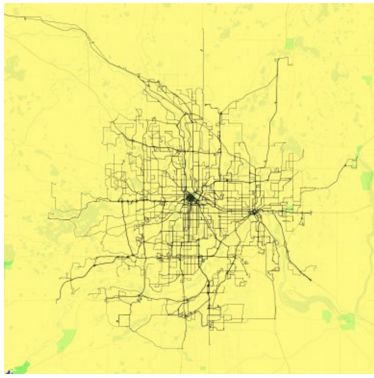
5.5.4 Mode Comparison

In order to compare job accessibility results for automobile, walk-up transit, and PNR, the ratio of each modes' accessibility to automobile accessibility is plotted. Automobile accessibility is chosen as the common denominator because it is generally one order of magnitude greater than competing modes, thus it provides the maximum range of accessibility that can be achieved on the network. In this way, walk-up transit and PNR modes can be compared using their respective ratio plots. Walk-up transit accessibility as a percent of automobile accessibility for each of six travel time thresholds from 15—90-minutes are plotted in Figure **24**.

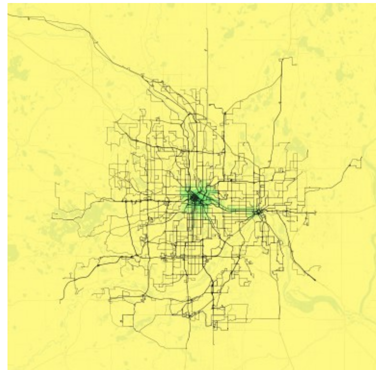
Table **10** lists the competitiveness ratio for walk-up transit and PNR modes. As travel time increases, both modes experience an improvement in competitiveness with automobile. For 75-minutes of walkup transit travel, the CBD of Minneapolis is most competitive to automobile. Eight zones in the CBD reach accessibility competitiveness values of 45% or greater. Each zone increases in competitiveness with automobile by 2.5% from 30 to 45-minutes of travel time. Each zone increases in competitiveness with automobile by 4.0% from 45 to 60-minutes. For travel times equal or greater than 60-minutes, the rate of improvement drops off to 0.20–0.27%—showing that gains in walk-up transit accessibility are nearly matched by automobile accessibility.

Table 10 Job Accessibility as a Percent of Automobile Accessibility Shown by Worker-weighted Averages.

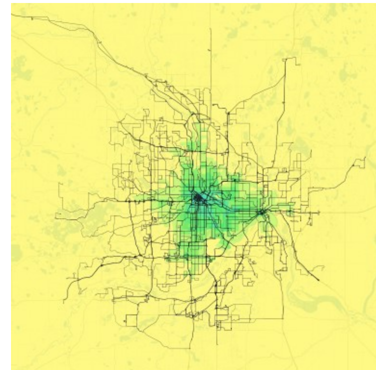
	15 min.	**30 min.**	**45 min.**	**60 min.**	**75 min.**	**90 min.**
Transit	0.58%	1.15%	3.65%	7.76%	8.06%	7.98%
PNR	0.71%	4.47%	16.15%	26.01%	30.67%	32.78%



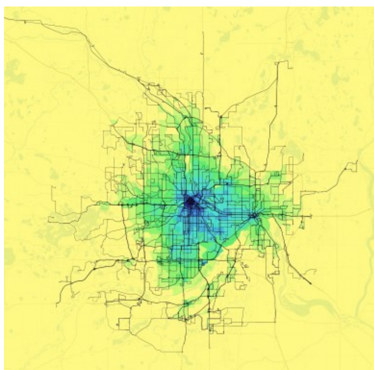
(a) 15-minutes



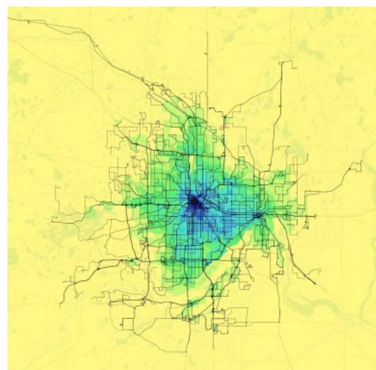
(b) 30-minutes



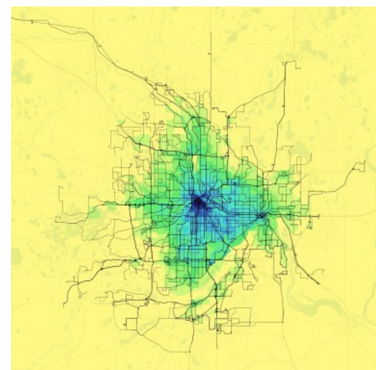
(c) 45-minutes



(d) 60-minutes



(e) 75-minutes



(f) 90-minutes

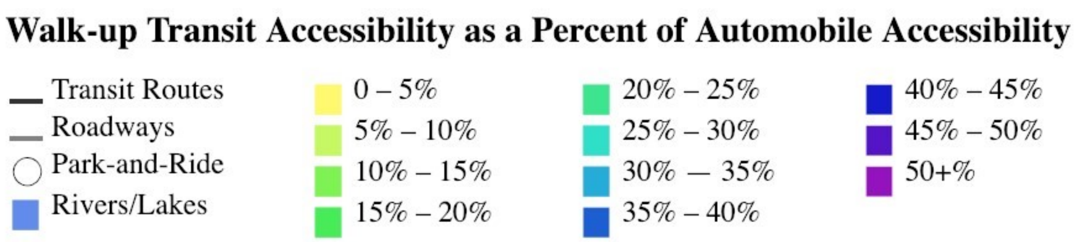
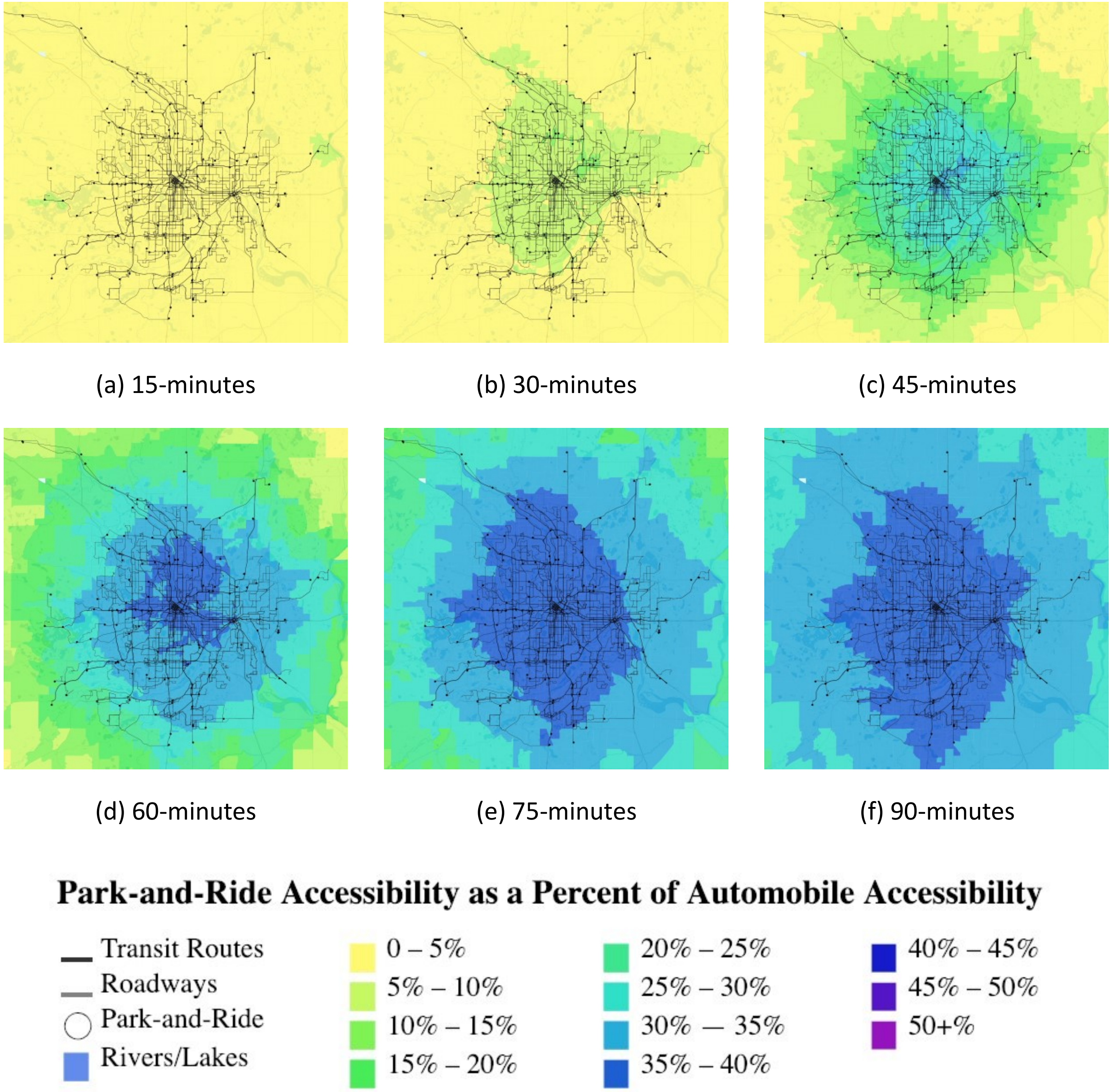


Figure 24 Walk-up transit accessibility as a percent of automobile accessibility at travel time thresholds of 15–90-minutes.

In a parallel comparison, PNR accessibility shows broad competitiveness with automobile accessibility. The level of competitiveness with automobile is approximately quadruple the value of walk-up transit (see Table **10**). In contrast to Figure **24** where walk-up transit is shown, the PNR competitive zones in Figure **26** extend beyond the core CBD and follow the grid of transit and road networks. The PNR competitiveness ratios are not determined solely by transit service characteristics. Instead, the transit serving PNR facilities and the interfacing road network both contribute to the accessibility levels that can be achieved by PNR trip types. The relationship between travel time budget and the PNR accessibility competitiveness ratio can viewed sequentially in Figure **26**. The corresponding values are listed in Figure

10. Each 15-minute increment corresponds with an approximate 7% increase in the average competitiveness ratio. The maximum PNR ratio is 36.9% during the 90-minute travel time threshold. Unlike the walk-up transit plots in Figure **24** and Appendix C Figure **56** where the most competitive zones are in the downtown core, the PNR accessibility landscape is most competitive where PNR facilities are clustered. The junction of I-694 and Highway 252 is one example shown in Appendix Section C Figure **57** where zones exhibit greater accessibility competitiveness with automobile than the surrounding region where fewer PNR facilities are located. These figures highlight the impact of including PNR trip types in accessibility analyses when considering walk-up transit and automobile modes individually.



(a) 15-minutes (b) 30-minutes (c) 45-minutes

(d) 60-minutes (e) 75-minutes (f) 90-minutes

Figure 25 The PNR accessibility as a percent of automobile accessibility at travel time thresholds of 15–90-minutes.

CHAPTER 6: MONETARY ACCESSIBILITY

Until now, this research has defined the cost of travel as the **time** spent traveling from origin to destination. Travel duration depends on distance and average travel speed along the transportation network. Consequently, the travel time-based accessibility measure is reflective of infrastructure limitations as opposed to economic conditions. Chapter 2 Section 4 discussed the variation in the value of accessibility across economic groups and destination types. A generalized monetary accessibility measure is proposed where distance-based vehicle costs, parking fees, transit fare, and wage-value of time are integrated to the cumulative accessibility framework. Accessibility remains a function of travel time in this context; however, the travel duration, distance, and fixed fees are now components in the classification of cost thresholds. We develop monetary isochrones, which indicate the level of accessibility that a traveler may achieve if willing to pay the isochrone price.

The procedure used to assign driving costs to automobile travel is the most rigorous of the monetary accessibility methodology and is described in detail in Chapter 6 Section 1. The assignment of parking charges is described in Section 6.2 and the selection of transit fare and wage-value of time variables are in Section 6.5.

6.1 DISTANCE-BASED AUTOMOBILE COSTS

This methodology incorporates automobile travel costs to the mixed-mode and single mode travel matrices described in Chapter 5 Sections **2** and **3.1** respectively. The shortest time path chosen by Dijkstra's algorithm is broken down to network links—which are individually considered in the calculation of speed and distance-based costs. The cost per link is summed along the path and the value is assigned to position ij in the OD matrix. The cost of travel can be defined using Equation **9**.

$$c_{i,j} = \vartheta d_{ij} + \kappa t_{ij} + \lambda \quad (9)$$

where

c_{ij} = total cost of travel from i to j

d_{ij} = travel distance from i to j

t_{ij} = travel time from i to j

ϑ = variable cost per unit distance of automobile travel

κ = unit value of travel time λ = Parking cost constant

The distance-based driving costs are enumerated by Equation **10**.

$$\vartheta = x_1 + x_2 + x_3 \quad (10)$$

where

x_1 = Fuel price per mile (2.335 $/gal)

x_2 = Vehicle depreciation cost per mile (cents)

x_3 = Vehicle repair cost per mile (cents)

The report titled "Exploring and Expanding Accessibility Metrics for Transportation Planning" details the user costs and time valuation used for measuring monetary accessibility by automobile [**8**]. The types of user costs included in the analysis are fuel, maintenance and repair, and vehicle depreciation. Fuel usage is a function of driving environment, vehicle type distribution, and regional driving behavior, as well as the price of fuel per gallon. The report focuses on conditions in Minnesota for 2015 commodity data. The average price for regular gasoline in 2015 (the most recent data reported in [**8**]) was $2.335. The authors propose a polynomial regression model to predict fuel efficiency as a function of speed *V*, see Equation **11**. An adjustment factor is applied to the fuel efficiency formula to account for city and highway driving.

$$mpg = 0.658 + 0.947 V mpg_{adj} - 0.009 (V mpg_{adj})^2 \quad (11)$$

$$mpg_{adj} = \begin{cases} 1.170, & \text{if } V > 45\, mph \\ 0.861, & \text{if } V <= 45\, mph \end{cases}$$

The average marginal repair cost is found using the number of vehicle registrations by car model as a weight to the standard marginal cost of maintenance per mile. The distribution of automobile to pickup/SUV/van vehicles was accounted for in the combined measure of maintenance costs per mile. Cui calculated the combined cost for different vehicle classes (automobile and pickup) as **$0.01932/mi** and **$0.01703/mi** for city and highway driving respectively and adjusted for inflation.

$$x_2 = \begin{cases} 1.703, & \text{if } V > 45\, mph \\ 1.932, & \text{if } V <= 45\, mph \end{cases}$$

The distance-based depreciation cost is weighted by vehicle model and age and calculated separately for driving environment (city or freeway) and vehicle type (automobile or pickup). Cui calculated the combined effect for different vehicle classes as **$0.0255/mi** and **$0.0300/mi** for city and highway driving respectively and adjusted for inflation.

$$x_2 = \begin{cases} 2.55, & \text{if } V > 45mph \\ 3.00, & \text{if } V <= 45mph \end{cases}$$

6.2 PARKING COST

6.2.1 Data

Parking data are collected from the City of Minneapolis and the City of Saint Paul parking websites where all government owned off-street parking ramps are detailed [**69**], [**70**]. Additional private parking ramps are found using the “ParkMe.com” website [**71**]. The parking facility data set collected in 2018 contains a total of 237 observations—all of which are in the Minneapolis and Saint Paul city limits. The pedestrian network is extracted from OpenStreetMap for the Fall of 2016 and includes both the street and skyway level networks.

Included within the parking facility data set are the daily rate, monthly rate, and capacity. The daily rate is recorded for a minimum of eight hours of parking. Only half of the parking facilities listed a monthly parking contract rate, thus the daily rate is used in the averaging process. The parking facility capacity is used in the methodology presented. Ramps with fewer parking spaces tend to be higher priced—making them less desirable for parking, all else equal. The daily parking cost is weighted to favor ramps that offer more capacity. The distribution of off-street parking capacity is shown in Figures **26** and **27**. The figures reflect policies in the Twin-Cities region that encourage parking on the fringe of the CBD to reduce congestion and pollution in the downtown core.

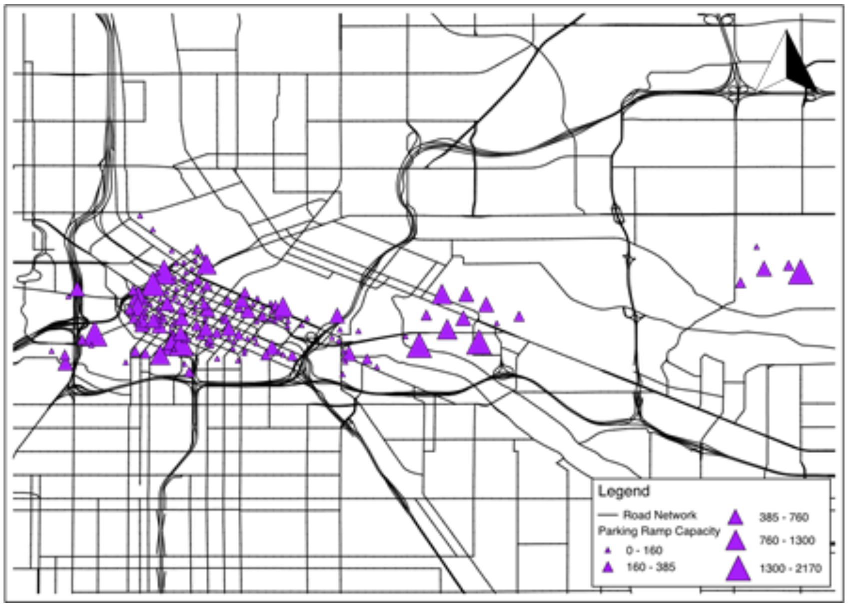


Figure 26 Off-street parking facilities in downtown Minneapolis and University of Minnesota campuses—scaled by capacity.

Figure 27 Off-street parking facilities in downtown Saint Paul—scaled by capacity.

6.3 DETERMINING THE PARKING COST TRAVELSHED

A 10-minute travel time matrix by walk is calculated. The origin set contains Census Block centroids for the City of Minneapolis and the City of Saint Paul. The destination set is comprised of the 237 parking facilities that charge a fee for use. The parking facilities that can be reached in a 10-minute walk from each of the CBD origins are used to calculate the average daily parking cost. Each parking facility is weighted by its capacity. Many block centroids on the edge of the CBDs cannot reach a for-pay parking facility—meaning the cost of parking in that Census block is free. The block level information is averaged to the TAZ level for use with the monetary accessibility automobile calculations.

6.3.1 Parking Cost Assumptions

The travel time matrix by walking is calculated for 8:00 AM on Wednesday, October 5th, 2016. Given the calculation time, the primary trip into CBD zones is assumed to be for work purposes. For this reason, on-street parking will not be considered due to the reduced likelihood for regular commuters to rely on variable parking locations and pricing.

All facilities in the data set include daily parking charges. Fewer than half of the parking facilities list monthly parking contract rates. Given the low reporting of monthly rates, the daily rate is used in the parking cost analysis. When a facility listed a separate "Early bird" rate, that rate is taken as the daily rate. The early bird rate is designed for daily commuters and is fixed to business hours. Given these assumptions, the average may be higher than what a commuter pays for contract parking on a daily basis.

6.4 SPATIAL VARIATION IN PARKING COST

The analysis found 104 TAZs associated with a fee for parking in the Minneapolis, University of Minnesota, and Saint Paul regions. The distribution of average parking price for a given zone is shown in Figure **28**. The median price to park among the zones associated with a cost is $7.06, while the regional median is $0.00 as the majority of Twin Cities zones do not charge for parking. For trips completed by automobile, the parking fee associated with the destination zone is assigned as a fixed cost to the trip. Figures **29** and **30** are color coded by the average price to park within a ten-minute walk of the TAZs in the CBDs. Where the color is white, parking is estimated to be free of charge.

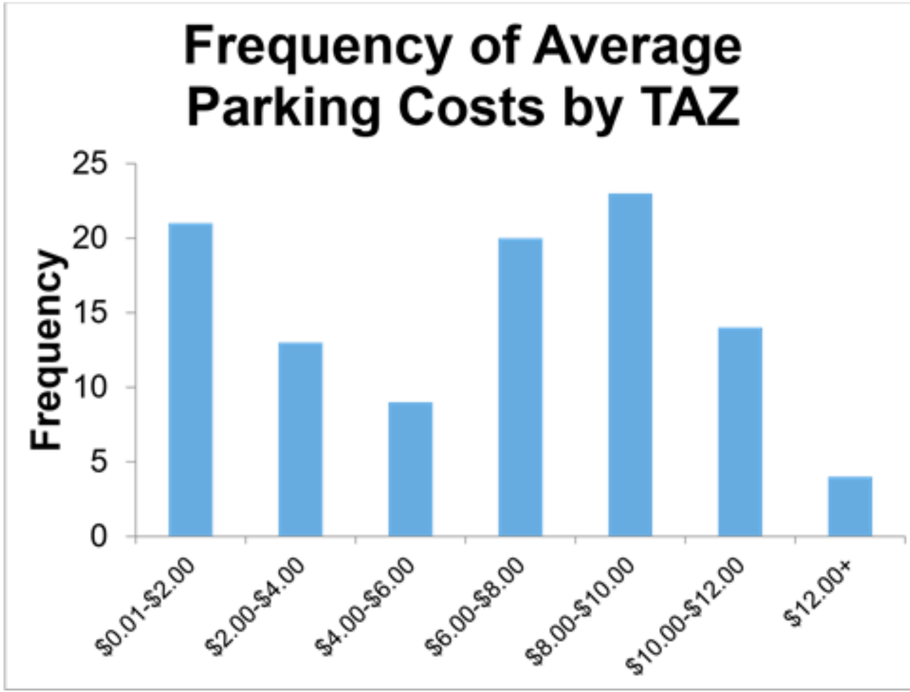


Figure 28 The distribution of the average cost of parking by TAZ.

The City of Minneapolis has a concentration of high-priced parking in the core of the CBD. Scarcity of space and dense office use in this region make higher prices viable for the central part of downtown Minneapolis. The average price to park decays as the distance from the center of the CBD increases. These regions also have fewer office spaces meaning the lower parking price may not always be realized by commuters.

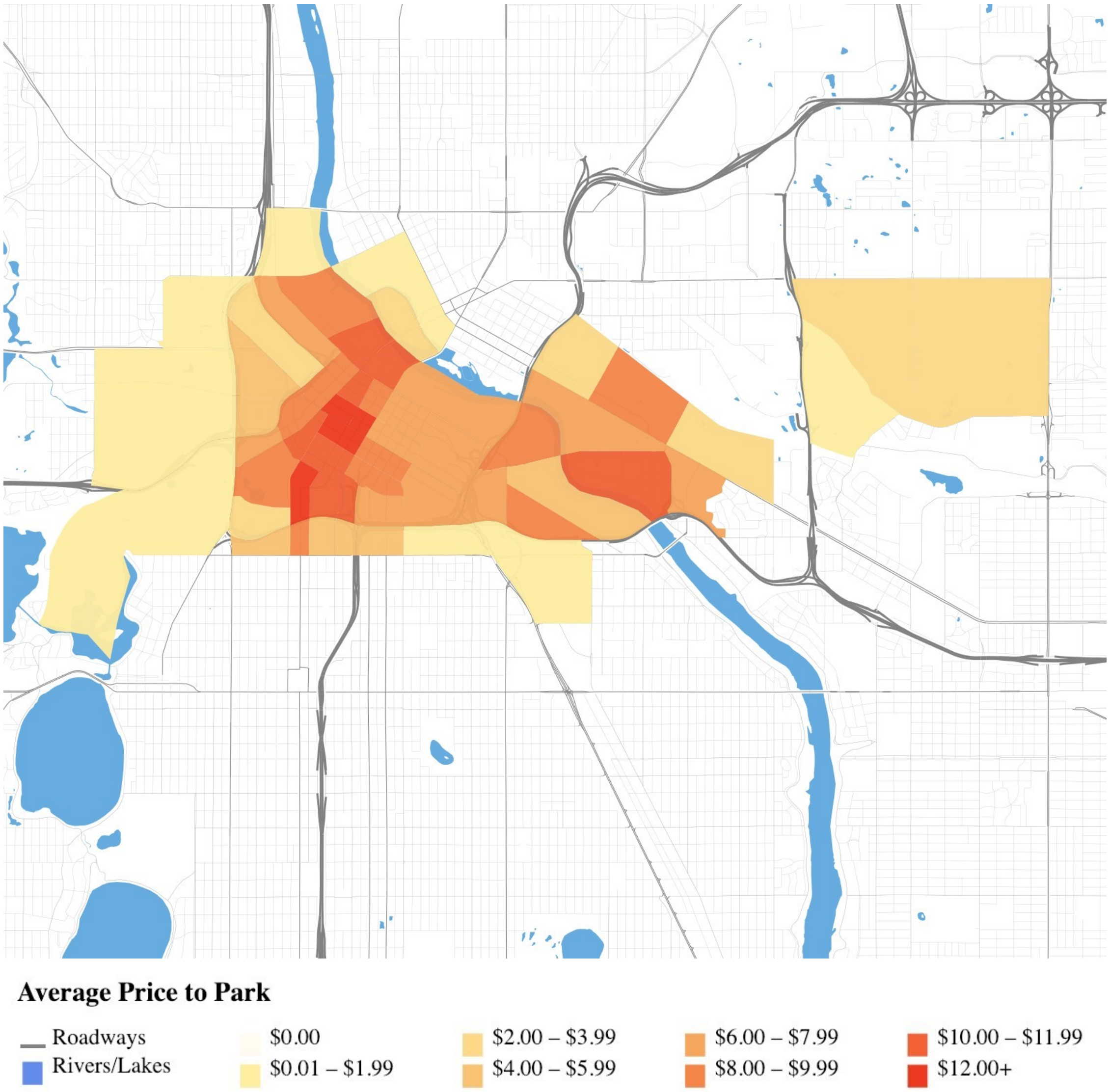


Figure 29 The spatial distribution of average parking cost for the City of Minneapolis CBD and University of Minnesota-Twin Cities campuses.

The City of Saint Paul has a different spatial distribution compared to Minneapolis. Parking in the core business district between Jackson Street, East 7th Street, the Mississippi River, and Saint Peter Street costs between $10.00–$12.00—lower than the maximum $12.00+ price range listed for the core of Minneapolis. The entertainment district of Saint Paul (just southwest of the business district) exhibits lower prices—from $2.00–$9.00.

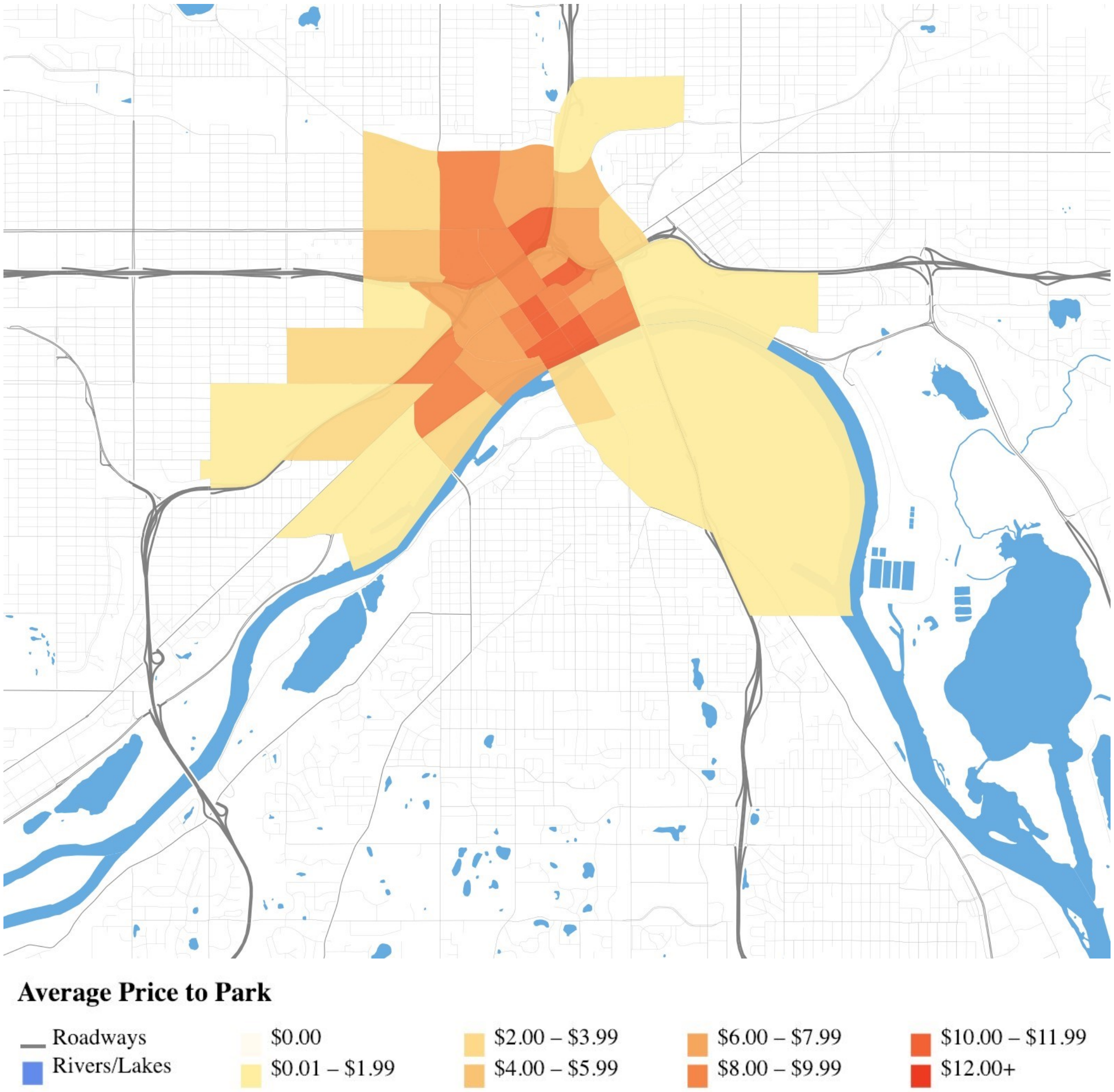


Figure 30 The spatial distribution of average parking cost for the City of Saint Paul CBD area.

6.5 TRANSIT FARE AND WAGE-VALUE OF TIME

The Twin Cities regional transit fare system charges $3.25 for rush hour fares. A single transit fare can be used for up to 2.5 hours after the first ride. Monetary accessibility by walk-up transit is treated as a constant when value of time is not considered. For PNR scenarios, $3.25 is the lower cost bound, then increases for every unit of drive time by automobile to access the PNR facility.

The travel cost equation (Equation **9**) includes VOT—also referred to as the marginal rate of substitution of travel time for money. One of the original studies into the value of time for commuters was conducted by [**72**] who found that on average, workers value their commute time as 50% of their wage, but the valuation can vary across cities and socio-economic background. [**73**] conducted a survey in

2005 on two similarly priced MLs in Los Angeles county and found that commuters value their time as 50%–90% of their wage, or about $20.00–$40.00. The Minnesota Department of Revenue provides an “auto value of travel time savings per person-hour” of $18.03 as of June, 2018 [**74**]. This value is carried forward in calculation of monetary accessibility when VOT is considered.

6.6 SCENARIO A: TRANSPORTATION COSTS

Two monetary scenarios are computed and analyzed. Scenario A captures travel costs unique to automobile, walk-up transit, and PNR modes. Automobile costs include distance-based charges as described in Section **6.1** and parking fees described in Section **6.2**. The cost of walk-up transit is fixed at $3.25—the price of a single fare as described in Section **6.5**. PNR costs combine automobile and transit costs but exclude parking fees.

Table 11 Worker-weighted Average Job Accessibility Applying Scenario A Conditions.

	$5.00	**$10.00**	**$15.00**	**$20.00**	**$25.00**	**$30.00**
Automobile	1,350,283	1,833,499	1,878,224	1,879,813	1,879,827	1,879,827
Walk-up Transit	149,615	149,615	149,615	149,615	149,615	149,615
PNR	31	13,945	97,722	273,220	445,211	539,077

6.6.1 Scenario A: Automobile Results

Cost Factors:

- Fuel
- Depreciation
- Repair/Maintenance
- Parking

Travel by automobile provides the greatest worker-weighted average accessibility for the travel cost when excluding externalities such as pollution and health and safety impacts. For $10.00, every analysis zone can reach the maximum number of jobs available in the Twin Cities. Appendix C Figure **58** depicts the job accessibility environment for $10.00, the benchmark price threshold used to compare scenarios and modes. Figure **31** depicts how little variation there is in regional accessibility after $4.50 of travel. Tables **11** and **12** compare the worker-weighted average accessibility for Scenario A across modes and cost thresholds of $5.00–$30.00.

Table 12 Walk-up Transit and PNR Accessibility as a Percent of Automobile Accessibility Shown by Worker-Weighted Average for Scenario A Conditions.

	$5.00	**$10.00**	**$15.00**	**$20.00**	**$25.00**	**$30.00**
Walk-up Transit	10.28%	10.28%	10.28%	10.28%	10.28%	10.28%
PNR	0.00%	0.75%	5.20%	14.53%	23.68%	28.68%

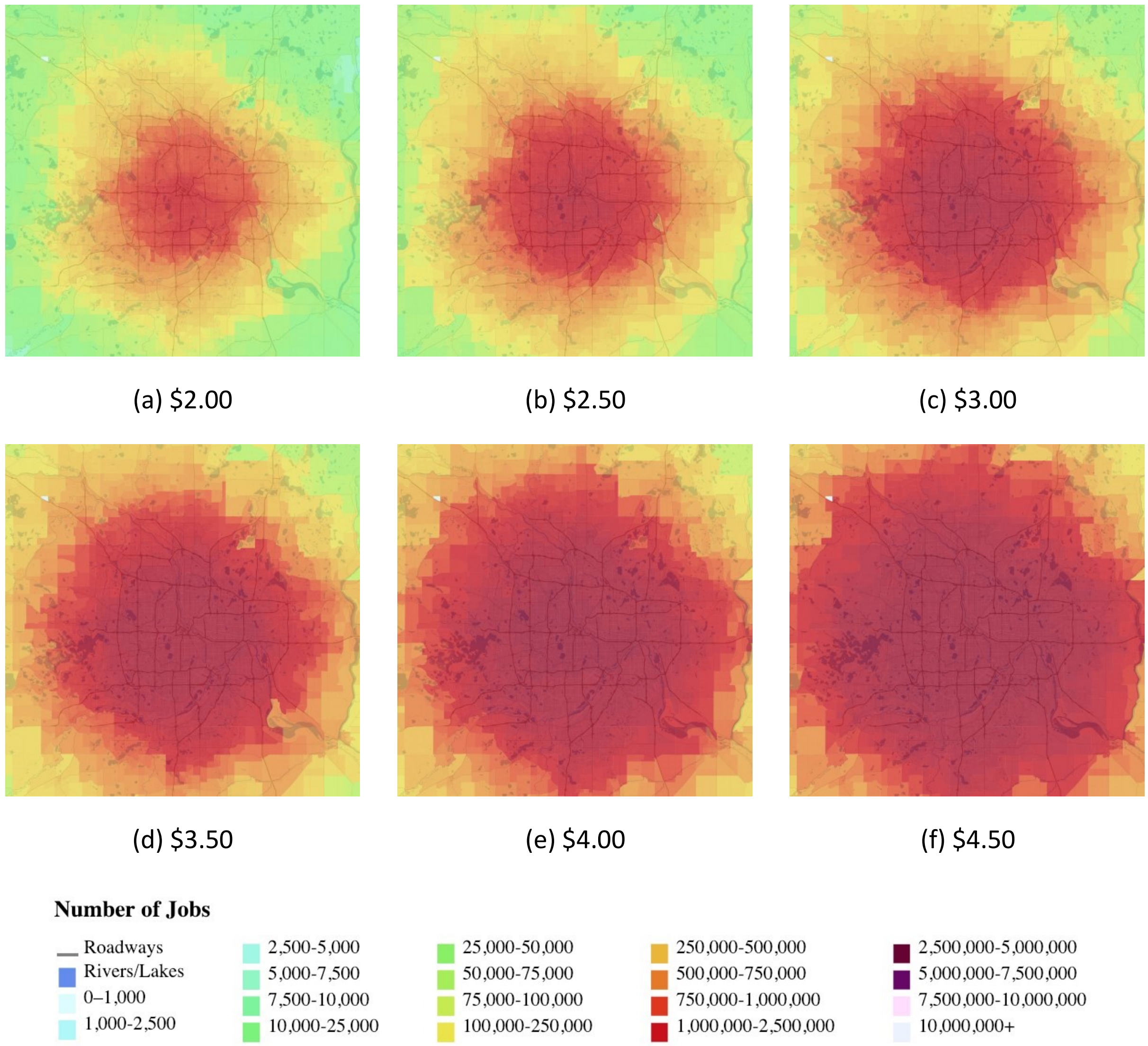


Figure 31 The automobile accessibility within $2.00—$4.50 of travel using Scenario A monetary criteria in the Minneapolis–Saint Paul metropolitan area.

6.6.2 Scenario A: Walk-up Transit Results

Cost Factors:

- Fare

The walk-up transit results for Scenario A are unique because the cost of using transit service is fixed yet travel time per fare can range from 1 minute to 2.5 hours. For this reason, walk-up transit accessibility using one $3.25 fare and 90-minutes of travel is plotted in Appendix C Figure **59**. Walk-up transit accessibility for $3.25 by Scenario A criteria is compared with automobile accessibility for the same price in Appendix C Figure **60**. Tables **11** and **12** demonstrate the fixed fare accessibility outcome for walk-up transit users as compared to automobile and PNR trip types. The worker-weighted average accessibility is 149,615—the same as the time-based scenario. The maximum ratio of walk-up transit accessibility to automobile accessibility increases from 8.06% in the time-based scenario to 10.28% in the monetary scenario. The change is due to the reduction in automobile accessibility when Scenario A monetary criteria are applied.

6.6.3 Scenario A: Park-and-Ride Results

Cost Factors:

- Fuel
- Depreciation
- Repair/Maintenance
- Fare

The results for PNR Scenario A reflect the mixed-mode travel type and the realization of costs associated with using two modes to complete one trip. Appendix C Figure **61** shows accessibility for $10.00 where $6.75 goes towards automobile costs and $3.25 goes towards transit fare. The level of accessibility for $10.00 of travel is modest and continuous across the Twin Cities region. The worker-weighted average accessibility levels between the time-based (see Table **9**) and cost-based accessibility (see Table **11**) measures show that the levels of accessibility achieved within $10.00 and $20.00 correspond with 20 and 45-minutes of travel time respectively. Figure **32** shows the progression of accessibility that can be achieved for each dollar amount.

For mixed-mode (PNR) travel, $10.00 (approximately 20 minutes) is not sufficient to complete many trips into the CBD where a majority of jobs are located. For comparison with other modes and scenarios at $10.00 of travel, Figure **62** is provided. The ratio of PNR accessibility to automobile accessibility is less than 5% across the region for $10.00. Between $10.00 and $15.00 is the point at which PNR become competitive with automobile, see Figure **33**. At the $20.00 cost threshold, the CBD market can be reached, which explains the swift increase from lower cost thresholds.

Tables **11** and **12** compare PNR travel with automobile and walk-up transit. Notable is the tenfold increase in the ratio of PNR accessibility to automobile accessibility from the $10.00 threshold to the $20.00 threshold. Overall, the maximum ratio of PNR accessibility to automobile accessibility decreases by 4.10 percentage points when measured against the travel time accessibility values listed in Table **10**. By including internal costs and excluding the negative externalities of driving, travel by automobile "looks" better compared to walk-up transit and PNR modes in the monetary landscape.

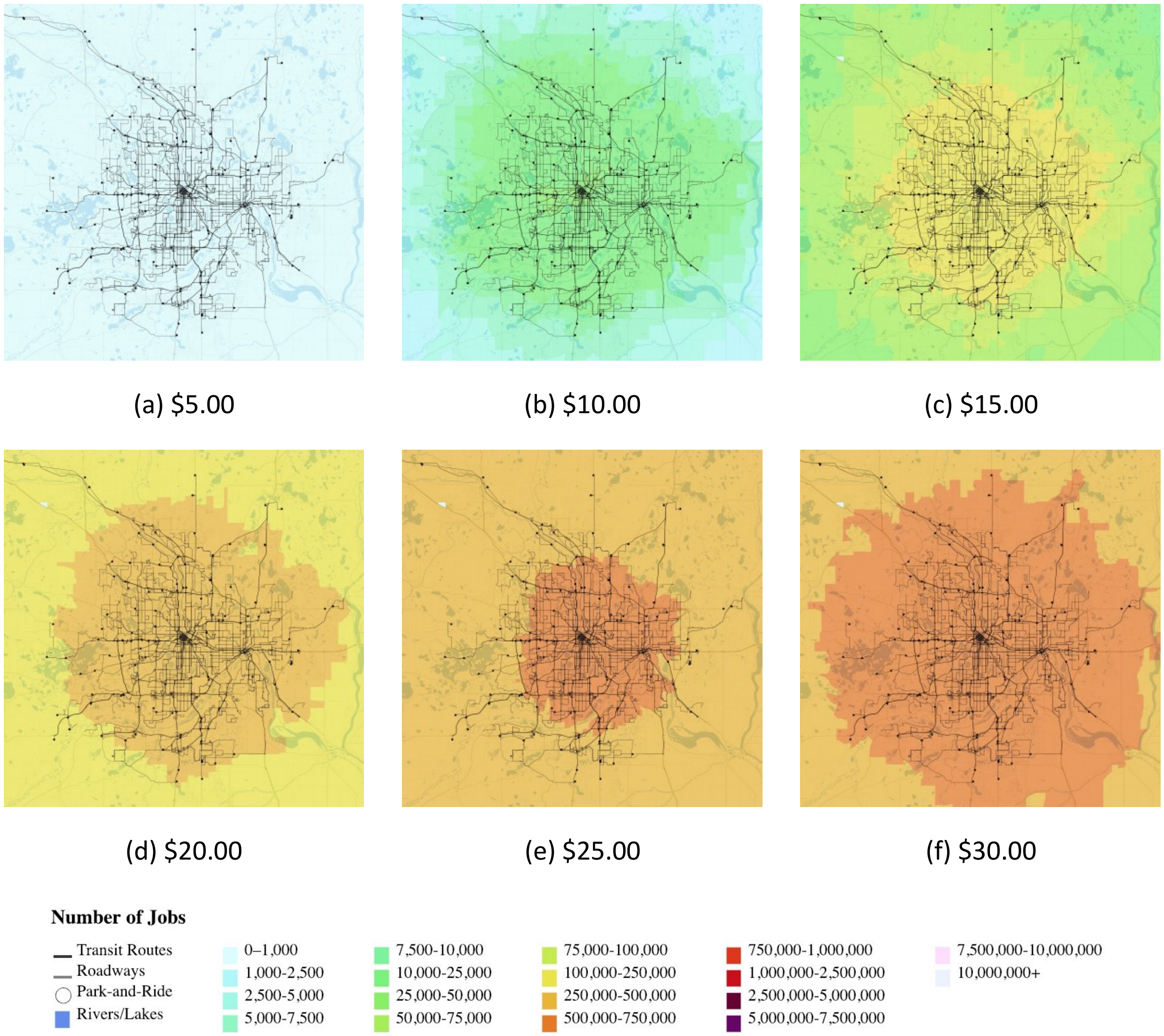


Figure 32 The PNR accessibility within $5.00—$30.00 of travel for Scenario A monetary criteria in the Minneapolis–Saint Paul metropolitan area.

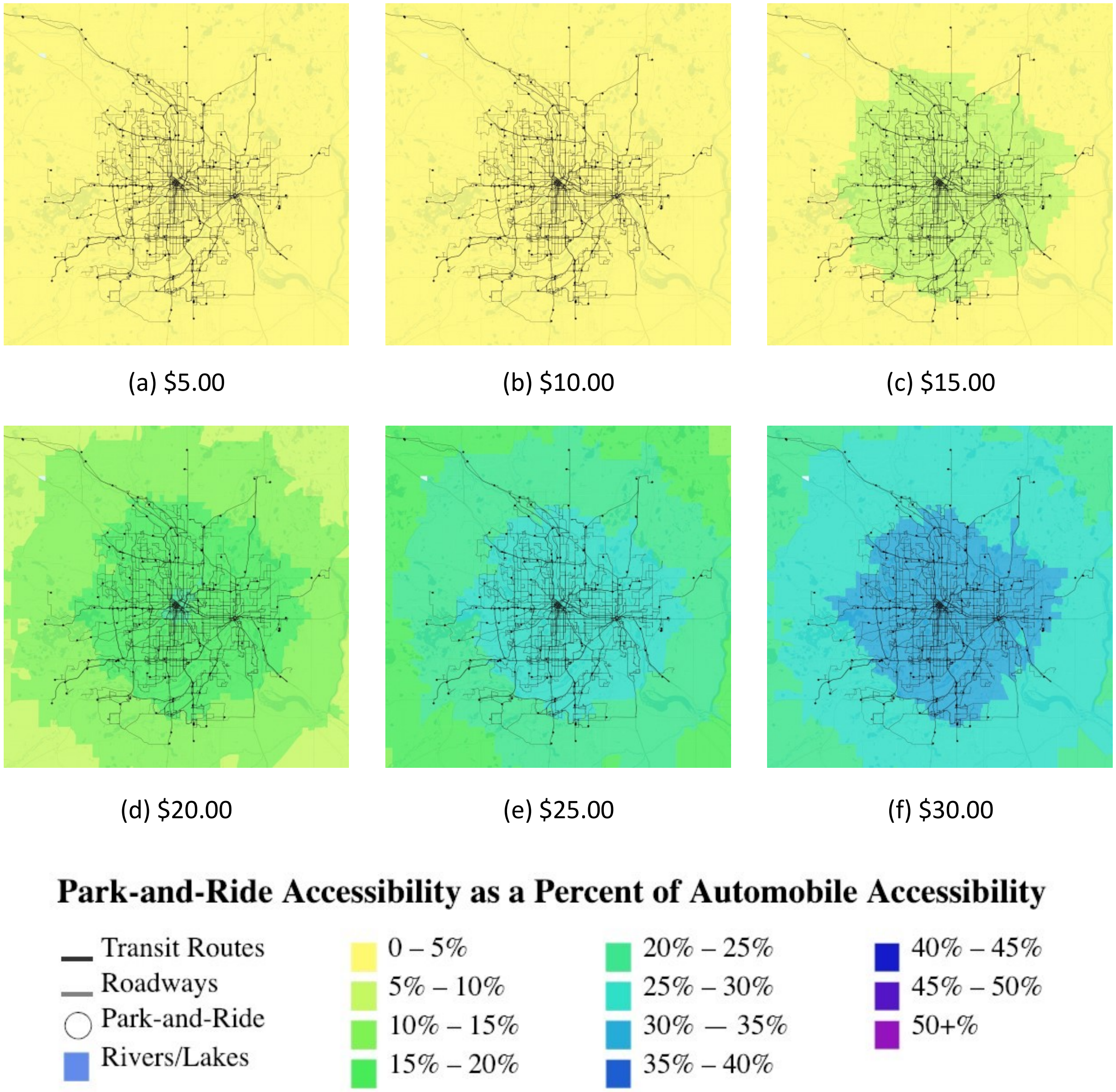


Figure 33 PNR accessibility as a percent of automobile accessibility within $5.00–$30.00 of travel for Scenario A monetary criteria in the Minneapolis–Saint Paul metropolitan area.

6.7 SCENARIO B: TRANSPORTATION COSTS + VOT

Scenario B captures travel costs unique to automobile, walk-up transit, and PNR modes as described in Section **6.6** and includes the wage-value of time.

6.7.1 Scenario B: Automobile Results

Cost Factors:

- Fuel
- Depreciation
- Repair/Maintenance
- Wage-VOT
- Parking

The monetary accessibility landscape for automobile when VOT is considered is significantly reduced from the landscape depicted by Scenario A monetary assumptions. Tables **13** and **14** compare the worker-weighted average accessibility for Scenario B across modes and cost thresholds of $5.00–$50.00. The worker-weighted average job accessibility available within $10.00 decreases by 89.6% when wage-VOT is included in the cost function. The zones with the greatest accessibility follow major highways and business districts as evidenced in Figures **34** (a) and Appendix C Figure **63**. Automobile outperforms walk-up transit and PNR at every cost threshold despite the large reduction to accessibility due to wage-VOT.

Table 13 Worker-weighted Average Job Accessibility Applying Scenario B Conditions.

	$5.00	**$10.00**	**$15.00**	**$20.00**	**$25.00**	**$30.00**	**$35.00**	**$40.00**	**$45.00**	**$50.00**
Auto-mobile	31,539	191,147	471,104	789,802	1,070,566	1,284,846	1,441,727	1,565,408	1,663,574	1,736,022
Walk-up Transit	84	3,856	42,628	111,003	149,585	149,615	—	—	—	—
PNR	0	71	1,306	8,329	30,346	79,534	160,800	260,140	353,770	429,776

Table 14 Job Accessibility as a Percent of Automobile Accessibility Shown by Worker-Weighted Average for Scenario B Conditions.

	$5.00	$10.00	$15.00	$20.00	$25.00	$30.00	$35.00	$40.00	$45.00	$50.00
Walk-up Transit	0.38%	1.58%	4.67%	8.55%	9.81%	8.96%	—	—	—	—
PNR	0.00%	0.05%	0.25%	0.81%	2.16%	4.98%	9.49%	14.83%	19.71%	23.59%

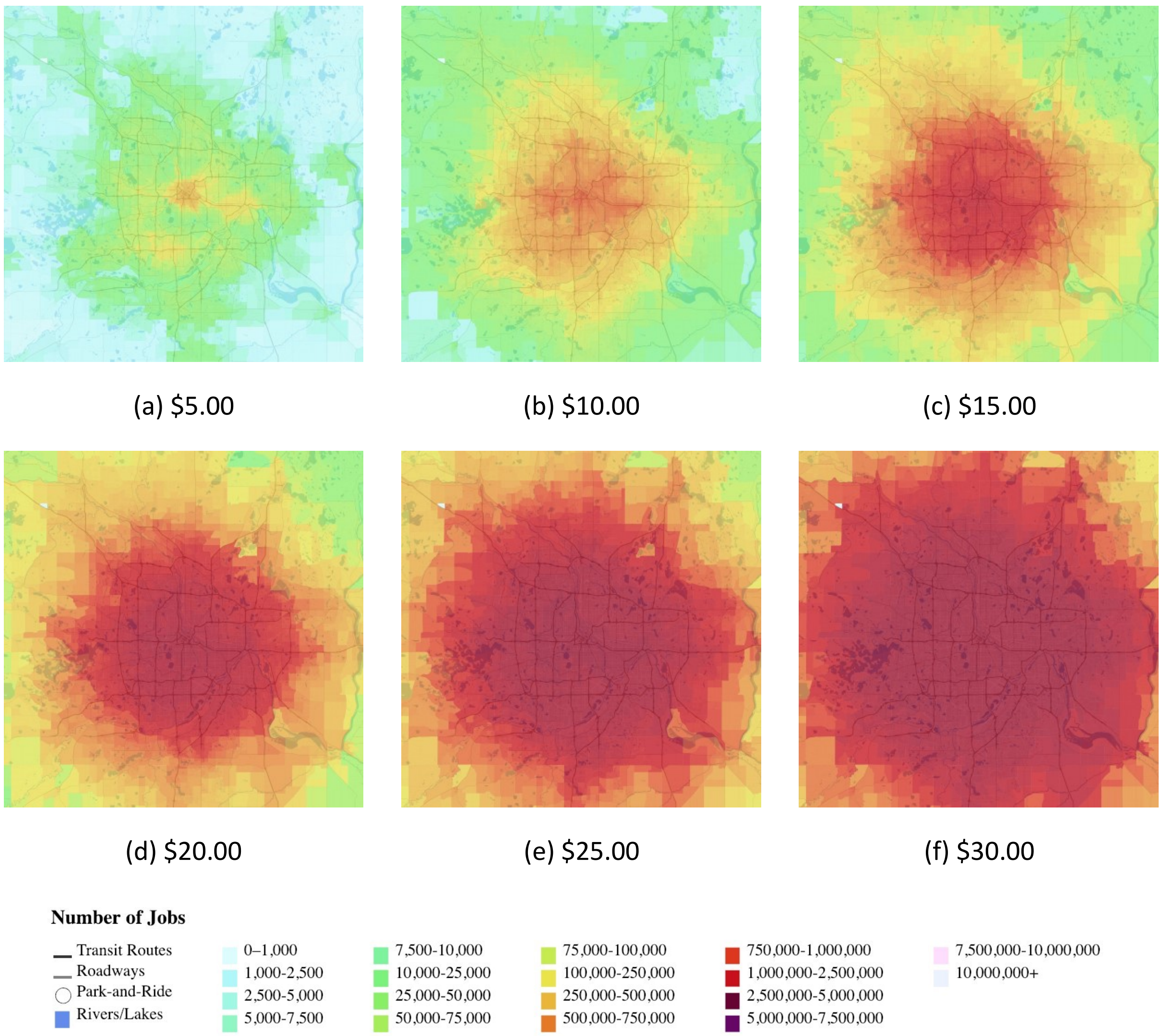


Figure 34 The automobile accessibility within $5.00—$30.00 of travel for Scenario B monetary criteria in the Minneapolis–Saint Paul metropolitan area.

6.7.2 Scenario B: Walk-up Transit Results

Cost Factors:

- Fare
- Wage-VOT

The walk-up transit accessibility profile in Appendix C Figure **64** shows suburban zones where more accessibility per dollar can be achieved compared to surrounding areas. This circumstance tends to occur along highways, especially those that are lined with PNR facilities such as I-394, Highway 10, Highway 252, and I-494. At every cost threshold, walk-up transit performs better than PNR due to the direct nature of trips. The comparison between PNR and walk-up transit is captured in Tables **13** and **14** above. The maximum ratio of walk-up transit accessibility to automobile accessibility increases by 1.83 percentage points from the travel time accessibility values listed in Table **10**.

In some urban and exurban zones, walk-up transit accessibility within $10.00 is more competitive with automobile than surrounding zones, see Appendix C Figure **65**. The pockets of competitiveness highlight where the transit network is the most robust (urban) or where automobile travel times are long compared to the express transit service offered in the area (exurban). The progression of walk-up transit accessibility for each dollar threshold is shown in two ways, by absolute value of accessibility (Figure **35**) and as a ratio of automobile accessibility (Figure **36**).

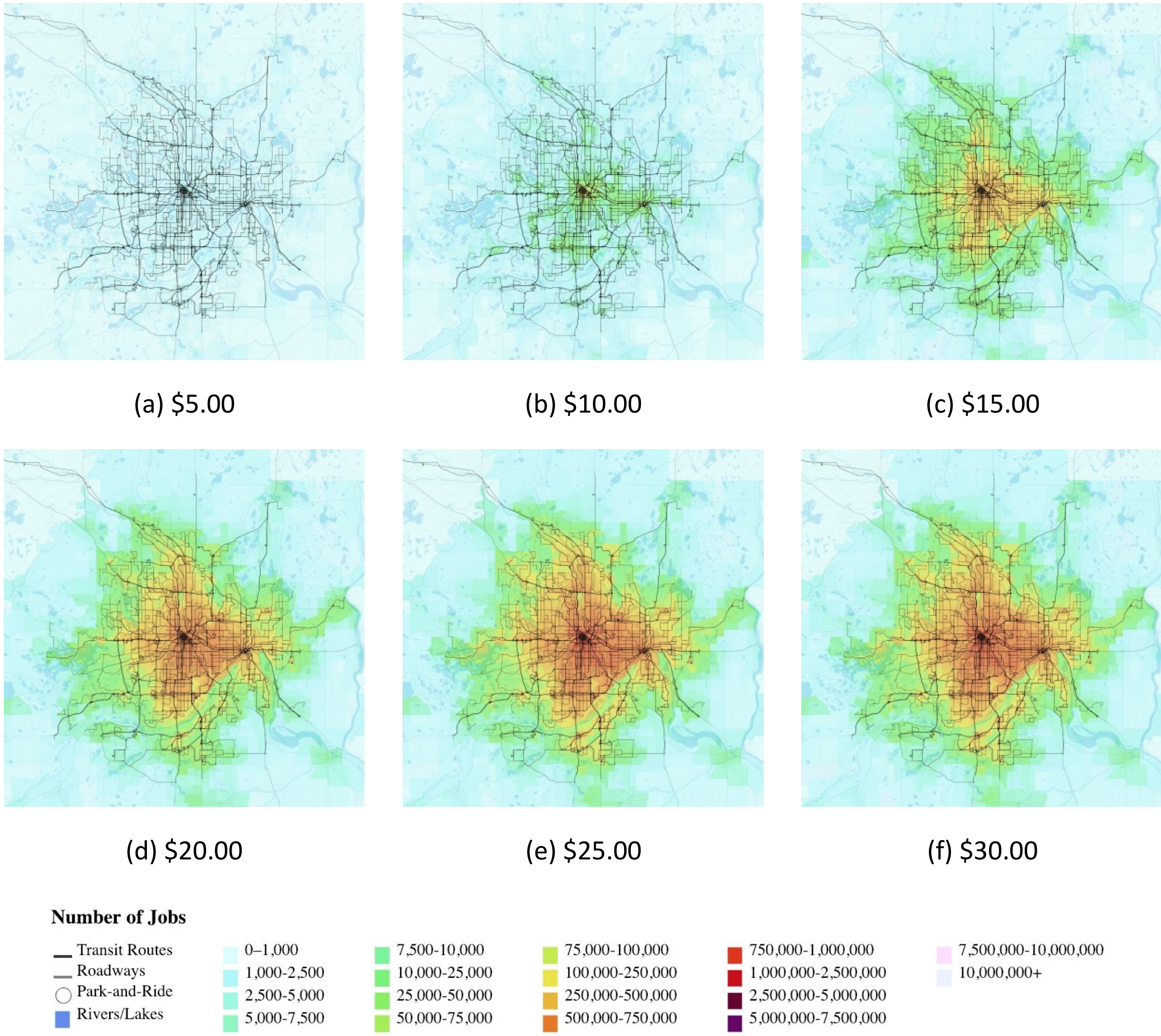


Figure 35 The walk-up transit accessibility within $5.00—$30.00 of travel for Scenario B monetary criteria in the Minneapolis–Saint Paul metropolitan area.

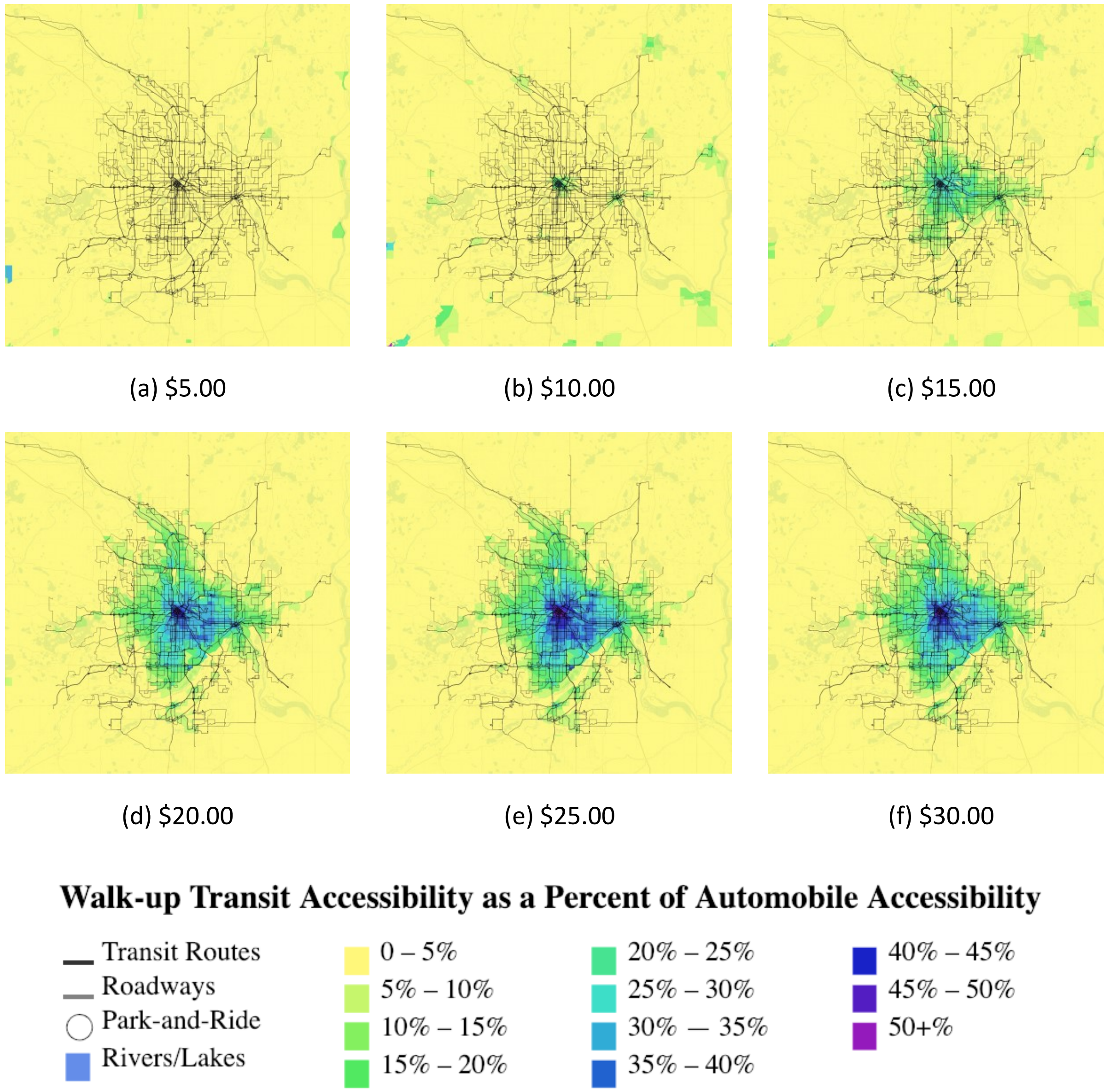


Figure 36 Walk-up transit accessibility as a percent of automobile accessibility within $5.00—$30.00 of travel for Scenario B monetary criteria in the Minneapolis–Saint Paul metropolitan area.

6.7.3 Scenario B: Park-and-Ride Results

Cost Factors:

- Fuel
- Depreciation
- Repair/Maintenance
- Wage-VOT
- Fare

The PNR Scenario B accessibility profile for $10.00 of travel shown in Appendix C Figure **66** is distinctly reduced compared to Scenario A. By including wage-VOT, the progression of accessibility per dollar threshold given in Tables **13** and **14** and shown in Figures **37** and **38** is gradual as compared to Scenario A in Tables **11** and **12** and Figures **32** and **33**. The maximum ratio of PNR accessibility to automobile accessibility decreases by 9.19 percentage points from the travel time accessibility values listed in Table **10**. In fact, the ratio of PNR accessibility to automobile accessibility is less than 5% across the region for $10.00. Between $25.00 and $30.00 is the point at which PNR become competitive with automobile. Including wage-VOT highlights the longer travel times by PNR mode compared to more time efficient automobile trips.

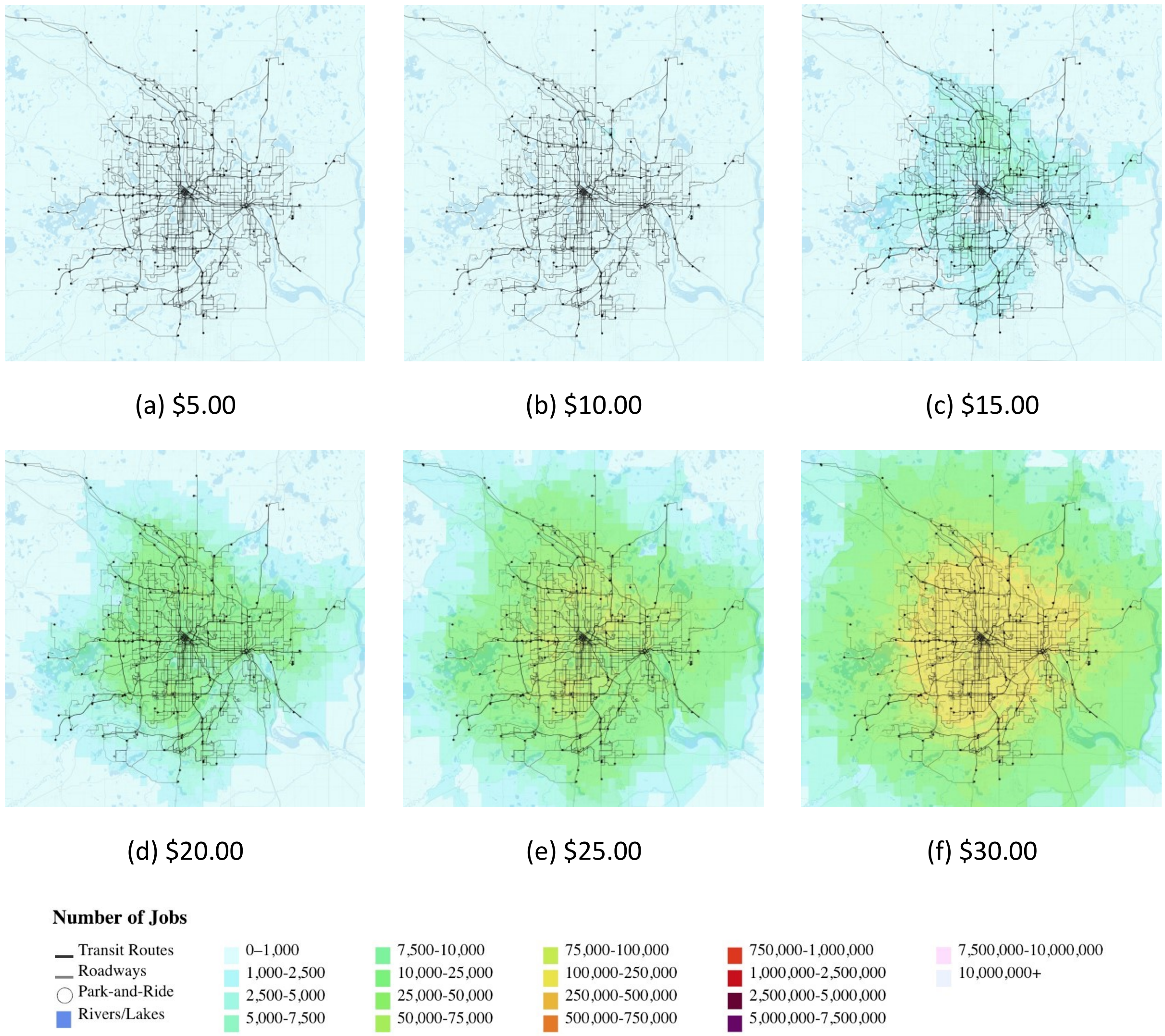


Figure 37 The PNR accessibility within $5.00—$30.00 of travel for Scenario B monetary criteria in the Minneapolis–Saint Paul metropolitan area.

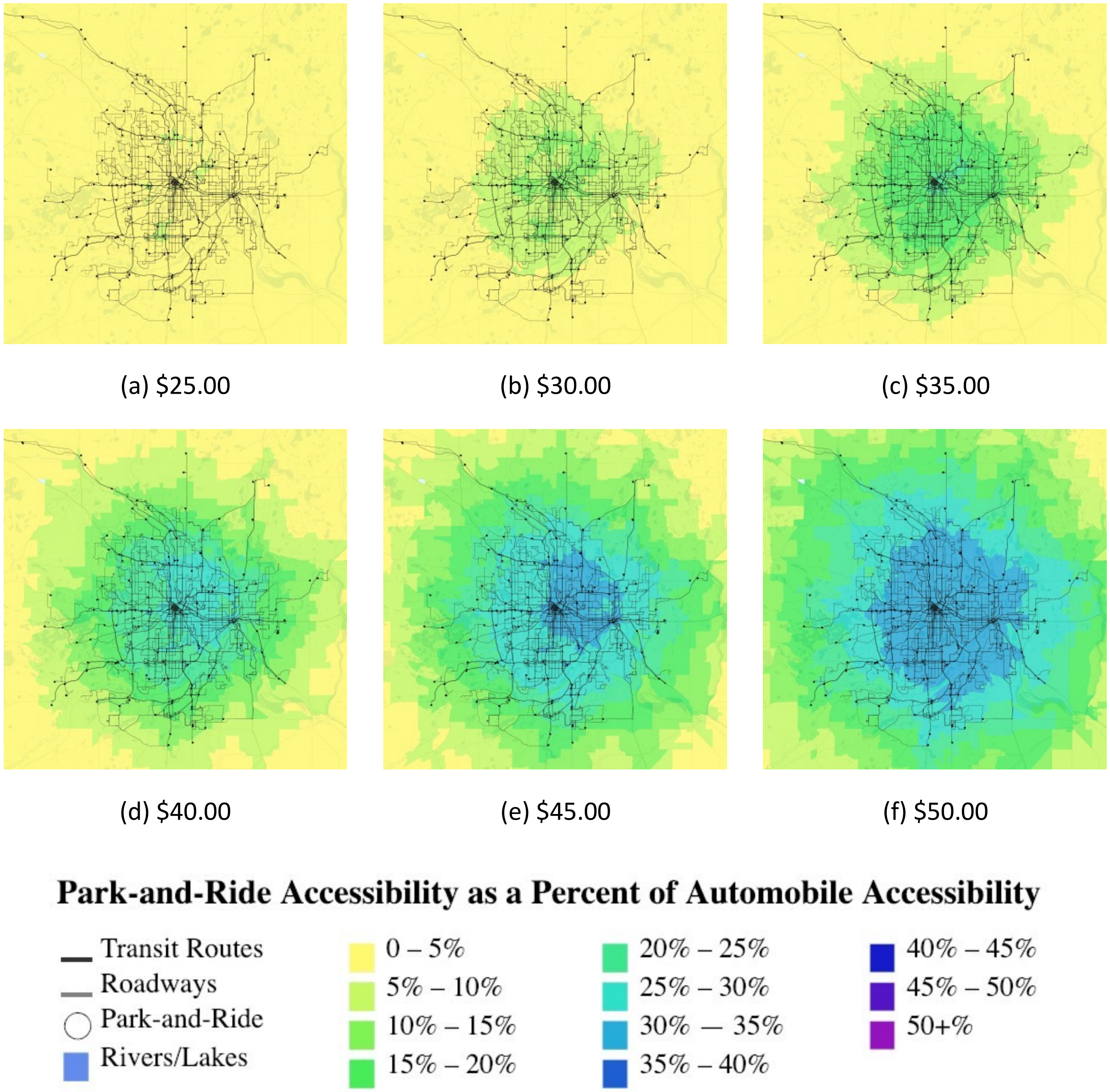


Figure 38 PNR accessibility as a percent of automobile accessibility within $25.00–$50.00 of travel for Scenario B monetary criteria in the Minneapolis–Saint Paul metropolitan area.

CHAPTER 7: ACCESSIBILITY IMPACTS OF COMPREHENSIVE BUS-HIGHWAY METHODOLOGIES

The accessibility methodologies developed for bus operation on MLs and in coordination with PNRs is applied to the 2016 transit network. Transit vehicles that operate along the existing ML network are modified to reflect speeds of 60–65 mph (see Chapter 3 Section 3 for scenario parameters). The modified GTFS records are used in a PNR accessibility analysis (see Chapter 5 Section 5 for scenario parameters). The application of both methods allows for comparisons to be made between transit accessibility with and without MLs to PNR accessibility with and without MLs. The “PNR + ML” scenario considers a PNR trip where the transit portion operates on the existing ML network along I-35W South, I-35E North, and I-394.

7.1 COMPREHENSIVE BUS-HIGHWAY ACCESSIBILITY RESULTS

The dual effect of higher operating speeds and extended service to the suburbs greatly impacts the job accessibility for the average Twin Cities worker. The job accessibility for the baseline transit scenario and three alternatives are compared in Tables **15** and **16**. The baseline scenario considers walk-up transit trips with vehicles that operate on GP lanes. Line 1 of Table **15** gives the level of walk-up transit accessibility when calculated using the prevailing transit accessibility method. The number of jobs accessible in 10–60-minutes of travel increases by 17–6,134 jobs when MLs are used, as shown in lines 1 and 2 of Table **15**.

The minimum transit accessibility when PNR trips are included is given in line 3 of Table **16**. Line 4 gives the minimum level of transit accessibility when PNR trips are included and transit vehicles operate on the existing ML network.

Table 15 Worker-weighted Average Job Accessibility of Bus-Highway Facilities During the Morning Peak Hours.

	10 min	20 min	30 min	40 min	50 min	60 min	Time-weighted Avg.
Walk-up Transit	469	3,856	15,868	42,628	84,894	140,086	5,123
Walk-up Transit + ML	469	3,873	16,297	44,431	88,504	146,220	5,305
PNR	162	6,581	51,902	180,053	340,666	459,408	17,948
PNR + ML	196	7,609	57,987	197,553	359,499	473,474	19,277

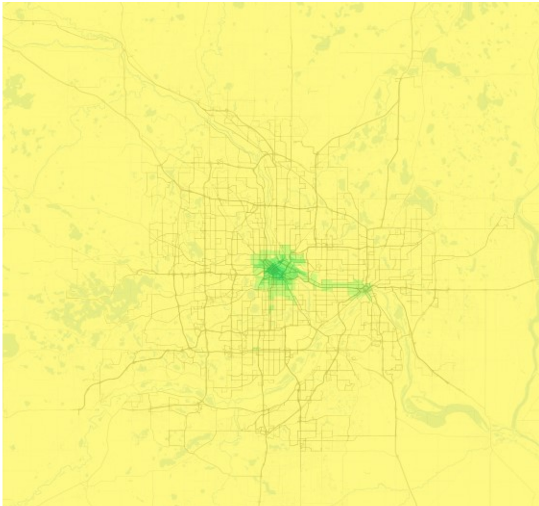
Table 16 The Minimum Worker-weighted Average Job Accessibility of Bus-Highway Facilities as a Percent of Automobile Accessibility During the Morning Peak Hours.

	10 min	20 min	30 min	40 min	50 min	60 min
Walk-up Transit	0.58%	0.62%	1.15%	2.59%	4.87%	7.76%
Walk-up Transit + ML	0.58%	0.62%	1.18%	2.70%	5.08%	8.10%
PNR	0.28%	1.38%	4.47%	11.69%	20.19%	26.01%
PNR + ML	0.33%	1.54%	4.97%	12.84%	21.35%	26.85%

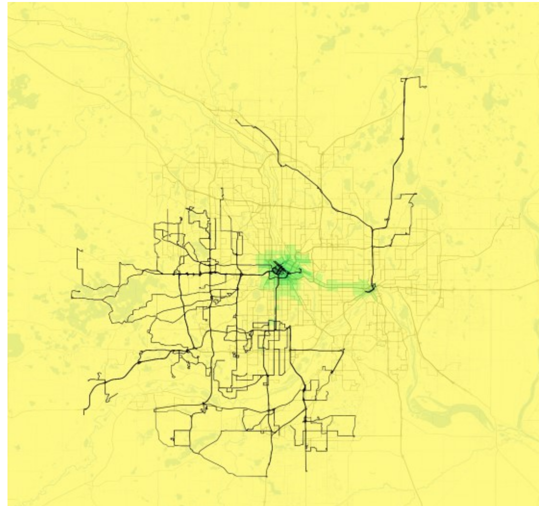
7.2 DISCUSSION

Walk-up transit and walk-up transit with ML use are not directly comparable to the PNR scenarios. Each PNR trip begins with an auto trip followed by a transit trip to connect with a destination. Destinations accessible along the first portion of the PNR trip are not considered in the total value of job accessibility. To compare the performance of walk-up transit and PNR, the automobile competitiveness ratios are provided in Table **16**. The greater the competitiveness ratio, the better the bus-highway facility mode does at competing with automobile levels of accessibility. The prevailing method for computing transit accessibility results in a competitiveness ratio given in line 1 of Table **16**. Line 4 of Table **16** gives the minimum competitiveness ratio when bus-highway facilities are used by transit. The exact value of worker-weighted average transit accessibility lies between the sum of the “Walk-up Transit” and “PNR + ML” scenarios. These values cannot be added directly due to the number of destinations that would be double counted in the accessibility metric.

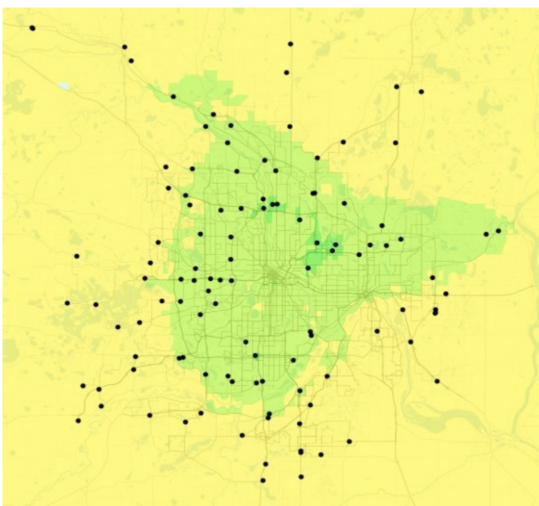
Figure **39** compares the baseline transit competitiveness ratio to those of the three bus-highway facility scenarios tested in this research. For the average Twin Cities worker, the level of competitiveness between transit modes and automobile increases from 1.15% to 4.97% for a 30-minute commute. A comparison of Figures **40** (a) and (d) shows the regions where including MLs and PNR trip types in transit accessibility greatly increase the level of competitiveness with automobile. For a 60-minute commute, the level of competitiveness increases 19.1 percentage points, moving from 7.76% to 26.85% for the average Twin Cities worker.



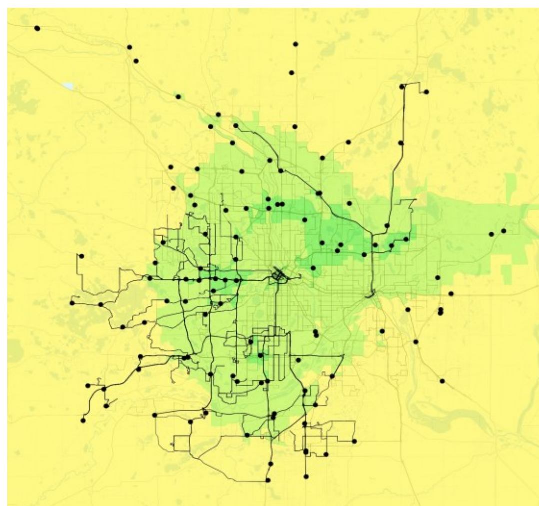
(a) Walk-up Transit



(b) Walk-up Transit + ML



(c) PNR



(d) PNR + ML

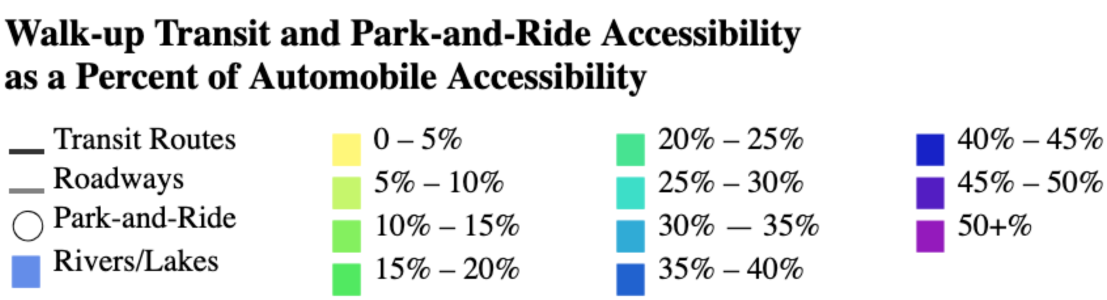


Figure 39 The bus-highway facility accessibility competitiveness with automobile for 30-minutes of travel in the Minneapolis–Saint Paul metropolitan area.

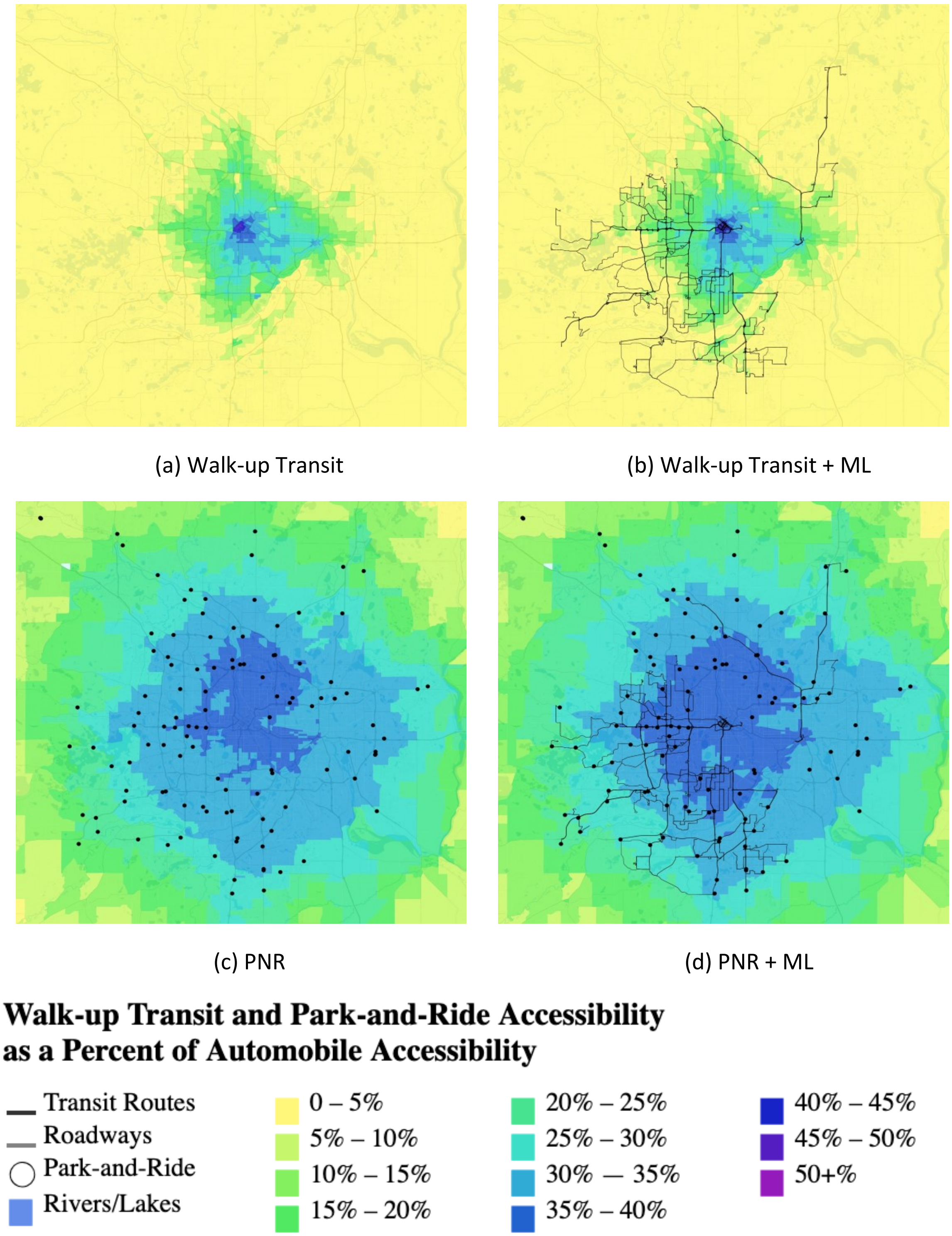
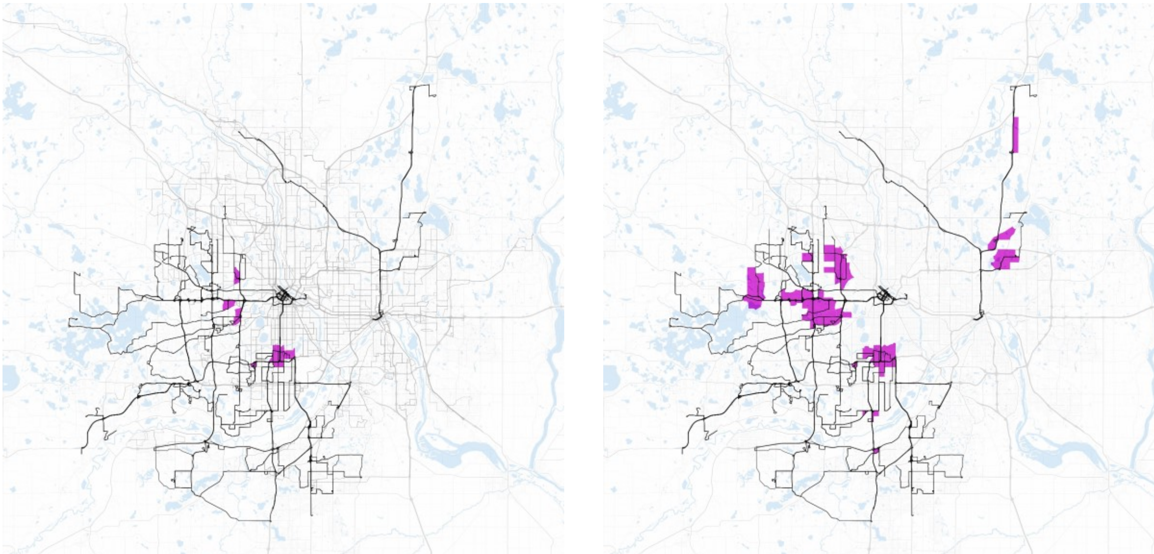


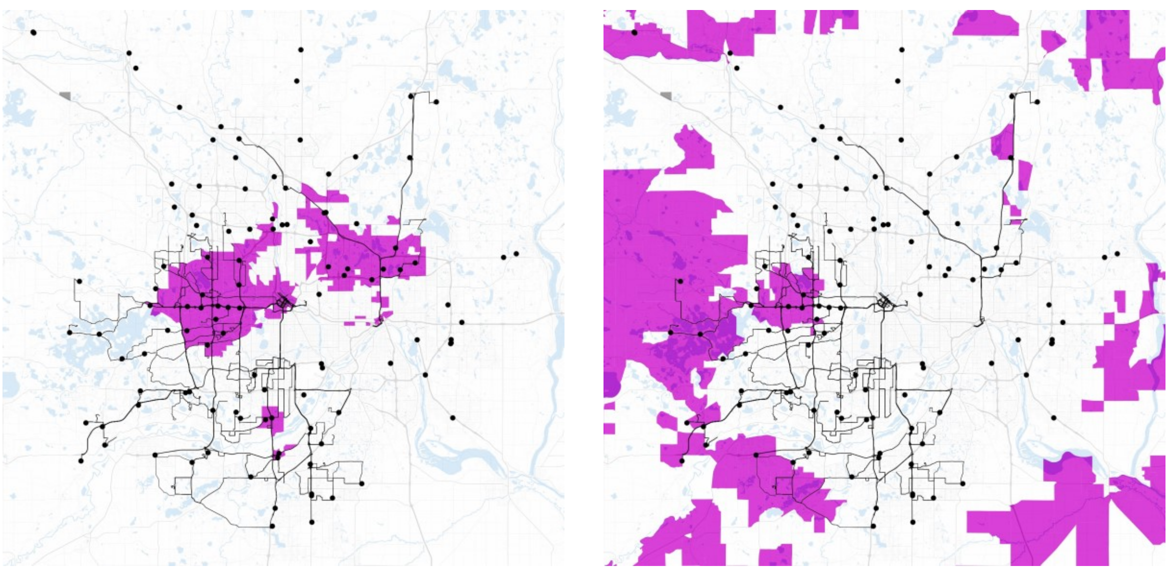
Figure 40 The bus-highway facility accessibility competitiveness with automobile for 60-minutes of travel in the Minneapolis–Saint Paul metropolitan area.

The zones that gain more than 15,000 jobs or increase job accessibility by more than 25% after MLs are incorporated to the walk-up transit and PNR analyses are shown in Figures **41** and **42**. These zones extend from the three ML corridors on I-35W South, I-35E North, and I-394. The most widespread impact occurs off I-394 where the benefits of numerous PNR facilities, local and express routes, and suburban employment hubs combine to magnify the accessibility benefit to transit users in the West metro.



(a) (b)

Figure 41 Zones that gain more than 15,000 jobs (a) or 25.0% (b) in 30-minutes of travel by walkup transit when express buses use the existing ML network on I-35W South, I-35E North, and I-394 as opposed to GP lanes.



(a) (b)

Figure 42 Zones that gain more than 15,000 jobs (a) or 25.0% (b) in 60-minutes of travel by PNR trip type when express buses use the existing ML network on I-35W South, I-35E North, and I-394 as opposed to GP lanes

CHAPTER 8: CONCLUSIONS

This research develops a set of methodologies for incorporating bus-highway facilities into transit accessibility measures. Each measure is explored individually then combined into a comprehensive transit accessibility measure. The comprehensive measure reveals where the effects of the regional ML and PNR systems are ignored using the prevailing transit accessibility measure. Bus-highway systems improve transit accessibility primarily in the first and second ring suburban regions that are located off the three main MLs in operation across the Twin Cities, including I-35W South, I-35E North, and I-394. The transit accessibility benefit is strengthened in areas with active PNR facilities such as I-35W at Highway 36 and I-94 at I-694. The combined effect of MLs and PNRs on the level of transit competitiveness with automobile results in a 19.1 percentage point increase at 60-minutes of travel—moving from 7.76% to 26.9%. The following sections discuss the key findings from each stage of this research.

8.1 ACCESSIBILITY IMPACTS OF BUS ACCESS TO MANAGED LANES

The Twin Cities regional transit accessibility profile improves with the incorporation of MLs to transit schedules. The existing ML—Express Bus scenario demonstrates the cascading effects that MLs may have on transit performance and efficiency. The percent increase in the 60-minute worker-weighted average accessibility for the Twin Cities and the transit impact zone is 3.79% and 21.12%, respectively. The greatest change to morning transit accessibility occurs in suburban regions near express bus routes. If the analyses were carried out for the afternoon peak, accessibility gains would be seen in and around the CBD regions.

The I-35W North/I-94 future scenario imposes speed changes to thirteen express bus routes. Given that these express bus trips operate at the target speed of 55 mph while on I-35W North and I-94, the percent increase in the 60-minute worker-weighted average accessibility for the Twin Cities region and impact zones is 0.94% and 11.2%, respectively. The I-94 segment results in the greatest gains to job accessibility for the Twin Cities region and the associated impact zone. For every mile of MnPASS lane simulated on I-94, the average worker gains 98 jobs (61 jobs per km) during a 60-minute commute. The changes to the accessibility landscape after MLs are incorporated shows how the impacts of ML investments may be underestimated if a transit accessibility analysis with distinct lane use characteristics are not carried out.

8.2 PARK-AND-RIDE FACILITY ACCESSIBILITY CONCLUSION

This analysis offers a look at the accessibility and travel time benefits brought to PNR facilities through the connection of express transit services. When express transit service is added to the local network, morning peak hour accessibility increases fourfold or by approximately 100,000 jobs for trips originating from PNR stops. Travel times between PNR origins and the set of destinations decrease by 10.7 minutes on average, meaning more destinations can be reached within a given travel time threshold. Taking these figures into context, the complete scenario adds sixty-four routes to the local scenario, each of which directly link suburban PNR stations with downtown Minneapolis and Saint Paul. The connectivity of the transit network to high job density land use accounts for the substantial accessibility increase between scenarios.

8.3 CENTRAL BUSINESS DISTRICT PARKING COST CONCLUSION

The analysis found 104 TAZs associated with a fee for parking. The overall median price to park for a day in the CBD areas of Minneapolis, Saint Paul, and the University of Minnesota campuses is $7.06. The City of Minneapolis has a concentration of high-priced parking in the core of the CBD. Scarcity of space and dense office use in this region make higher prices viable for the central part of downtown Minneapolis. Saint Paul has a different spatial distribution. The core business district between Jackson Street., East 7th Street, the Mississippi River, and Saint Peter Street can be reached for a parking price of $10.00–$12.00—lower than the maximum $12.00–plus listed for the core of Minneapolis. The entertainment district of Saint Paul exhibits even lower prices from $2.00–$9.00.

8.4 ACCESSIBILITY IMPACTS OF PARK-AND-RIDE: A FACILITY-CENTRIC MODE

The PNR accessibility framework is dependent on two modes converging in space and time at a fixed transfer point—the PNR facility. The characteristics of the facility, such as transit service frequency, proximity to freeway access, and density of facilities are all influencing factors in the level of accessibility that can be achieved via the PNR system. The PNR mode enables additional accessibility over walk-up transit because of the unique ability to park at a transit facility.

8.5 ACCESSIBILITY BENEFITS IN THE SUBURBS

The alignment of automobile and transit travel time matrices shows the potential offered by these networks. The mixed-mode accessibility analysis confirmed the hypothesis that PNR accessibility is a blend of automobile and walk-up transit accessibility profiles.

PNR facilities magnify the reach of transit in suburban and exurban areas where transit service is typically sparse. The combination of express bus service and the ability to drive and park at a PNR facility results in a worker-weighted average accessibility value that is four times greater than walk-up transit service. Much of that benefit is a result of improved accessibility in the suburbs. By accounting for faster access to PNR facilities by automobile, the job accessibility figures reflect how a greater proportion of the travel time budget is spent accessing jobs rather than walking to transit stops. The true destination set available to suburban transit users is found by incorporating PNR trip types into accessibility analyses.

8.6 HOW MONETARY FACTORS CHANGE THE ACCESSIBILITY PROFILE

The monetary accessibility measures applied in Chapter 6 attempt to capture the redistribution of accessibility when distance-based, wage-VOT, and fixed costs of travel are considered. For the two scenarios presented, the costs associated with driving exclude negative externalities, such as pollution and safety costs', thus, travel by automobile continues to outperform other modes when the measure of accessibility is applied. Once wage-VOT is included as a penalty in the monetary accessibility metric, automobile accessibility within $10.00 drops from 1,833,499 jobs to 191,147 jobs, a 90% reduction. Overall, PNR looks less attractive compared to automobile when accessibility is put in terms of money. PNR trips tend to have long travel times, especially from CBD regions where backtracking to a PNR occurs. This disproportionately effects the wage-VOT penalty applied to PNR.

Walk-up transit exhibits a 1.83–2.30 percentage point increase in the level of competitiveness with automobile when accessibility is measured in terms of money. While travel times by walk-up transit remain longer than automobile, the lack of vehicle costs makes walk-up transit appear more attractive than PNR for monetary accessibility scenarios. Future analyses will incorporate long-term fixed costs of vehicle ownership into the monetary accessibility measure, which may improve the level of competitiveness of walk-up transit with automobile.

8.7 MOVING FORWARD—INCLUDE MLS AND PNR TRIPS WITH TRANSIT ACCESSIBILITY

By accounting for bus-highway facilities in the transportation system, transit accessibility increases from the baseline across the Twin Cities region. ML and PNR facilities improve the transit connection between residents in the suburbs and jobs in the CBD. These changes make transit more competitive with the levels of accessibility achieved by automobile. The average worker experiences a 3.8–19.1 percentage point increase in the competitiveness ratio of transit to automobile when bus-highway facilities are included. Each transportation element included in the calculation of accessibility allows greater detail when tracking changes to accessibility across a region. This ultimately leads to an improvement in the usefulness of accessibility as an assessment tool for planners and engineers. Future transportation studies may benefit from including MLs and PNRs in the calculation of transit accessibility.

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APPENDIX A: SUPPLEMENTAL MATERIAL TO CHAPTER 3

The following figures are supplement to the express bus on ML scenarios outlined in Chapter 3. A selection of travel time thresholds and aggregations are provided for comparison with the figures given in the main body of the text.

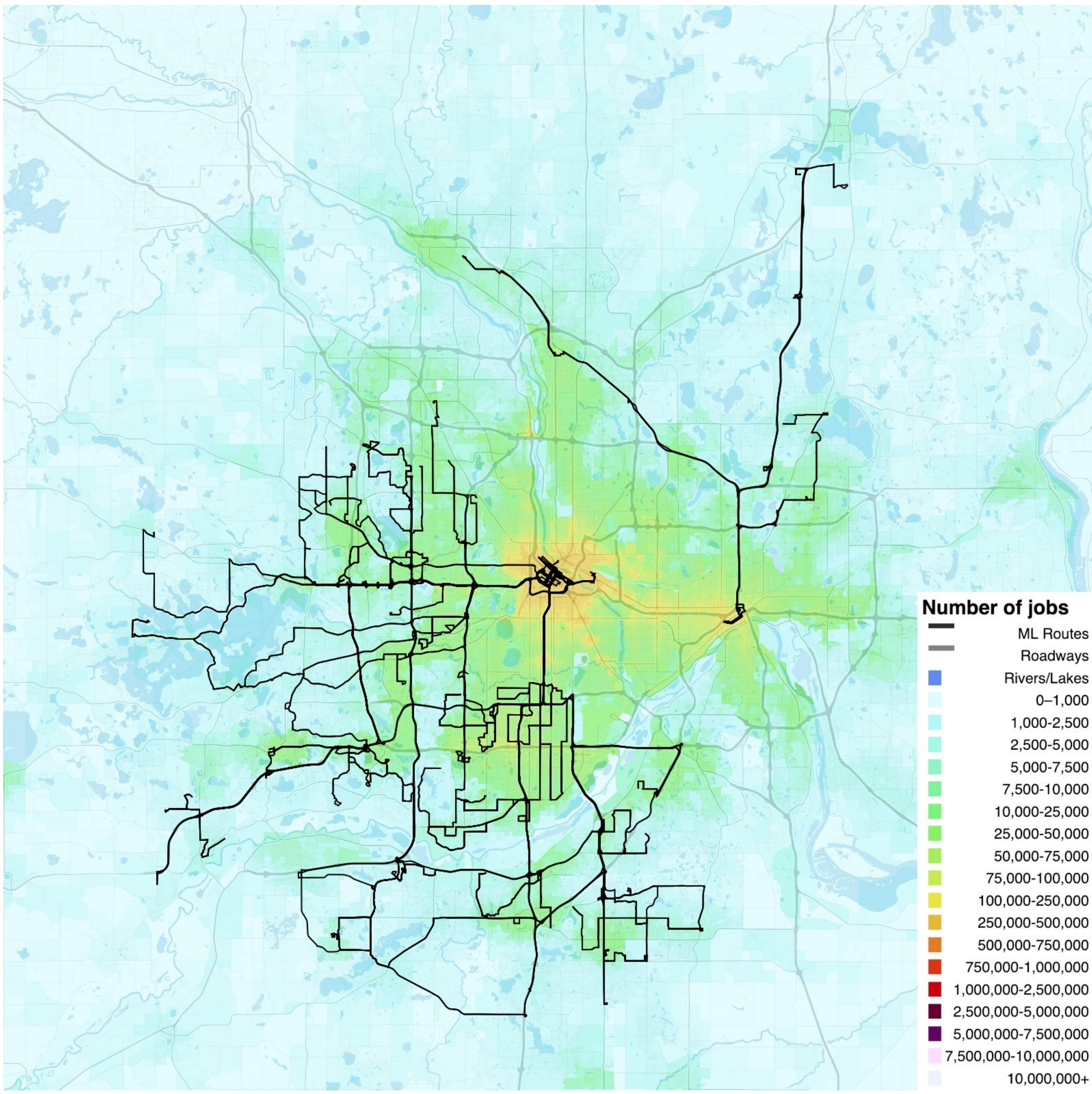

Figure 43 The baseline average job accessibility within 30-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

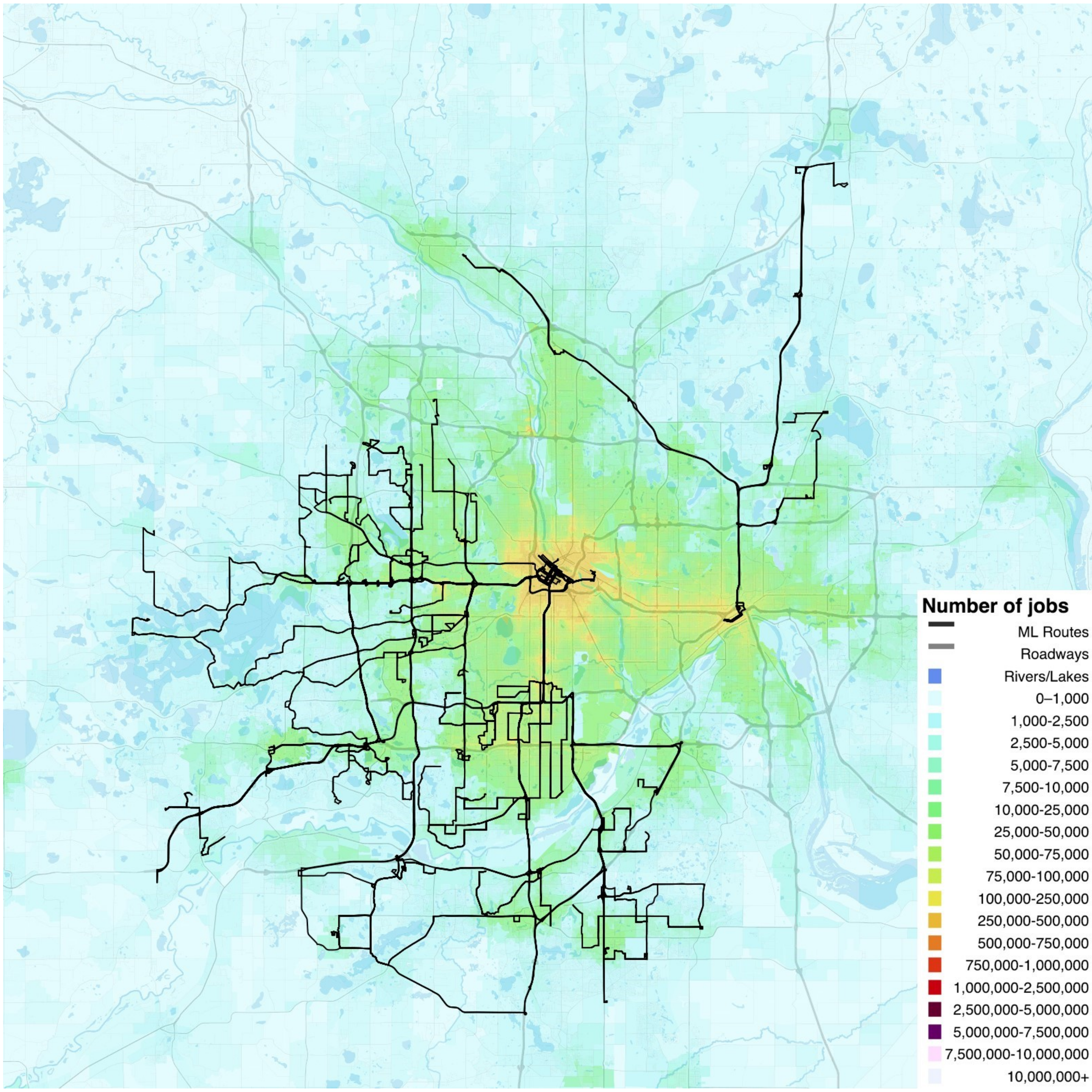

Figure 44 The existing ML—Express Bus scenario average job accessibility within 30-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

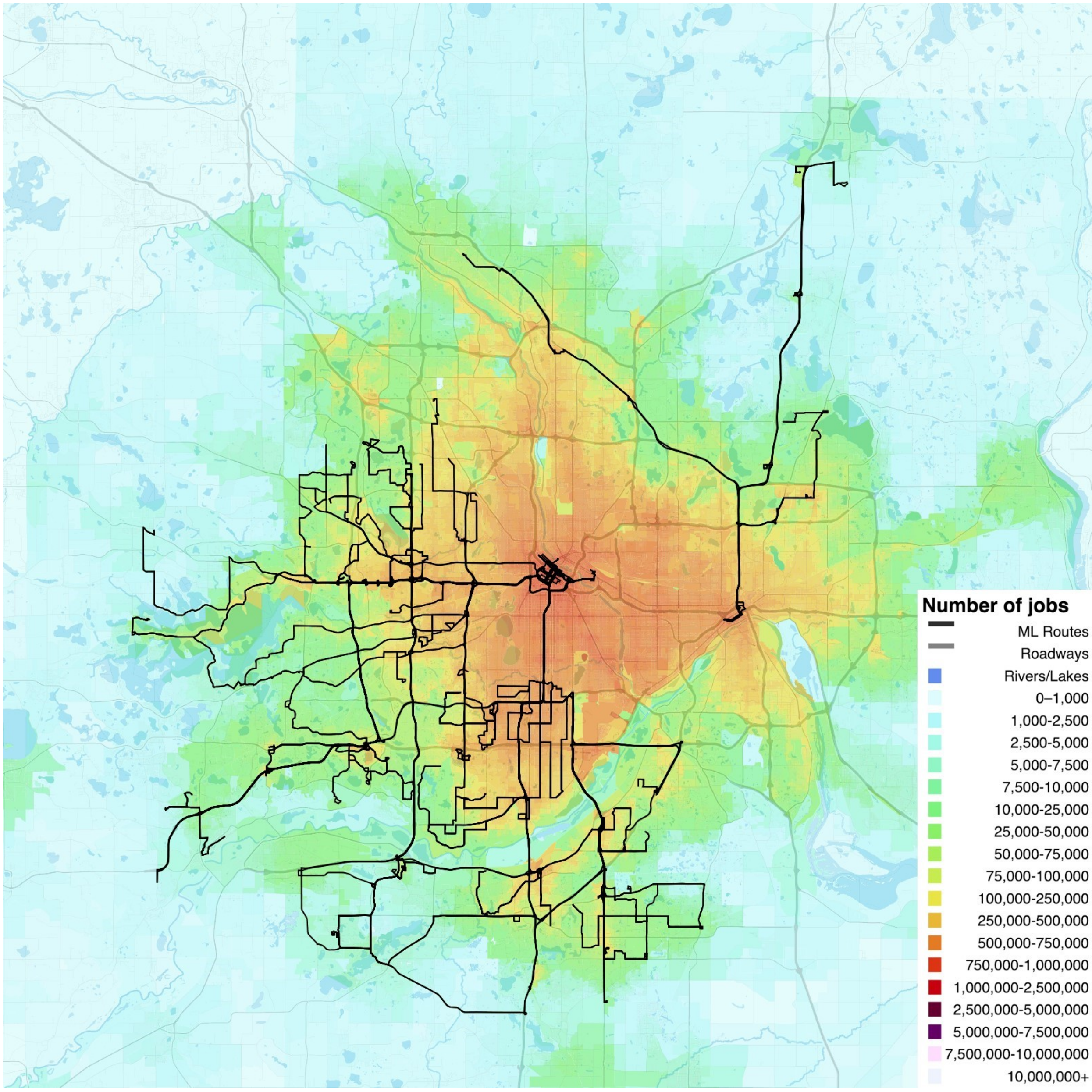

Figure 45 The baseline average job accessibility within 60-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

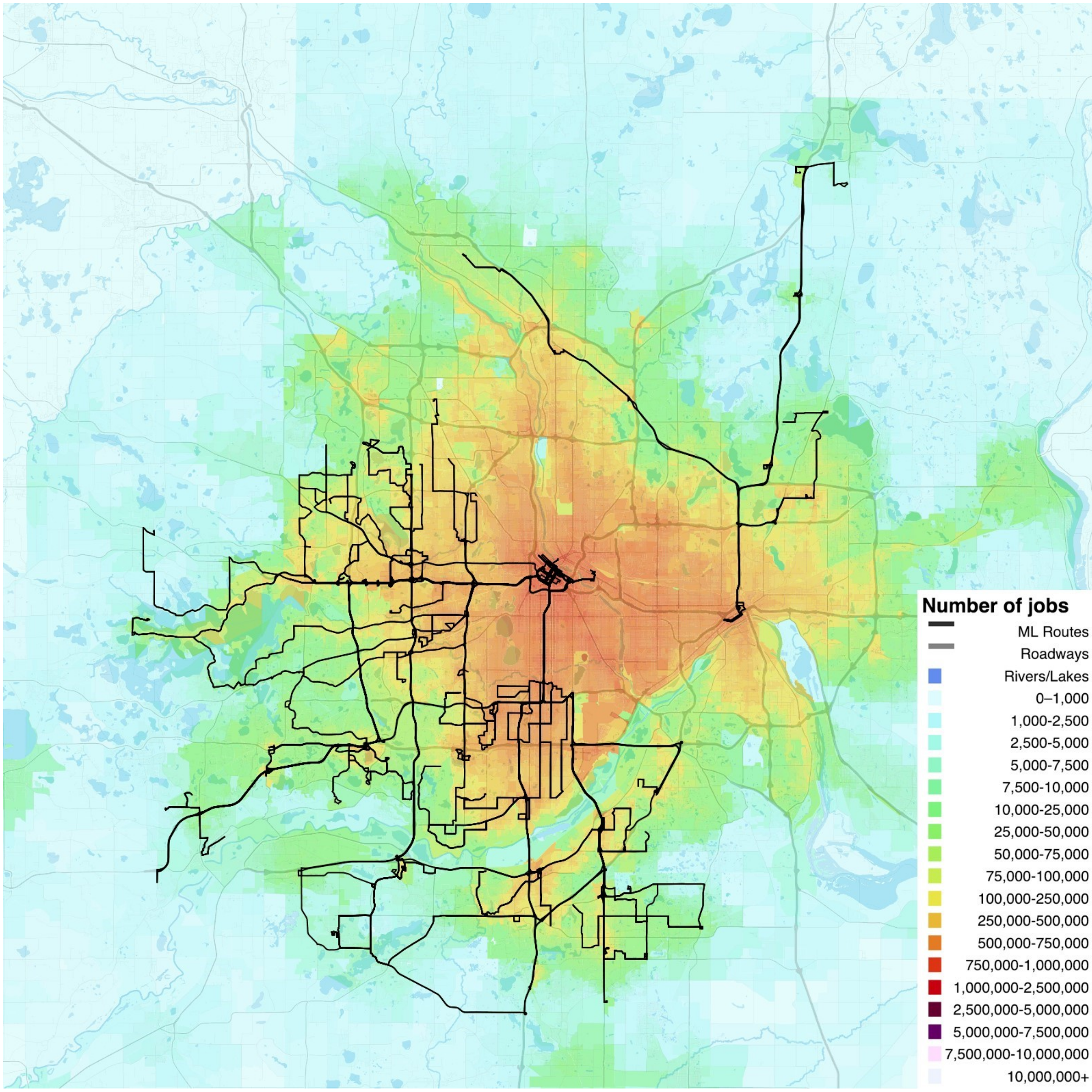

Figure 46 The existing ML—Express Bus scenario average job accessibility within 60-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

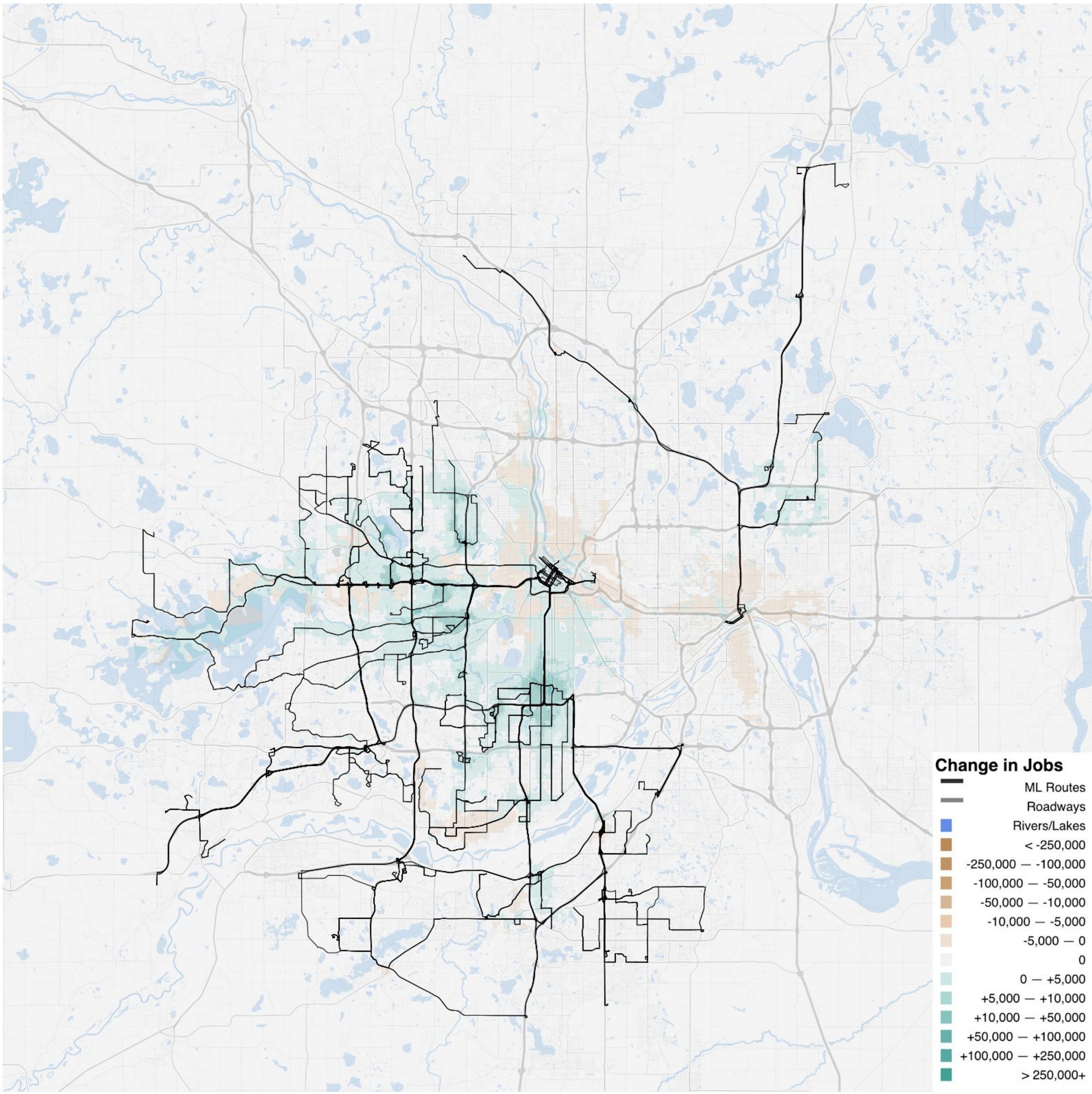

Figure 47 The absolute difference in average job accessibility between the existing ML—Express Bus scenario and baseline within 30-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

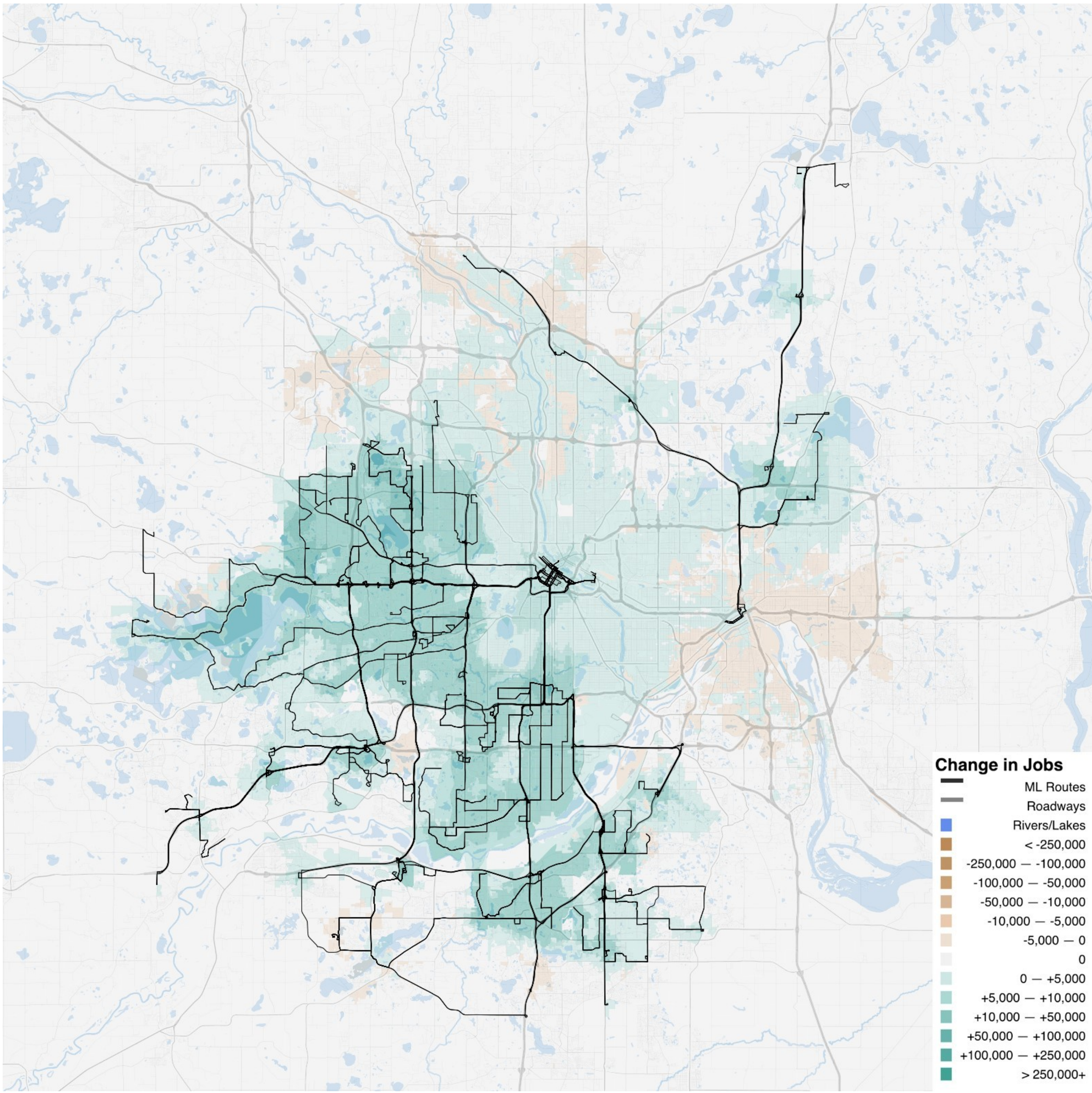

Figure 48 The absolute difference in average job accessibility between the existing ML—Express Bus scenario and baseline within 60-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

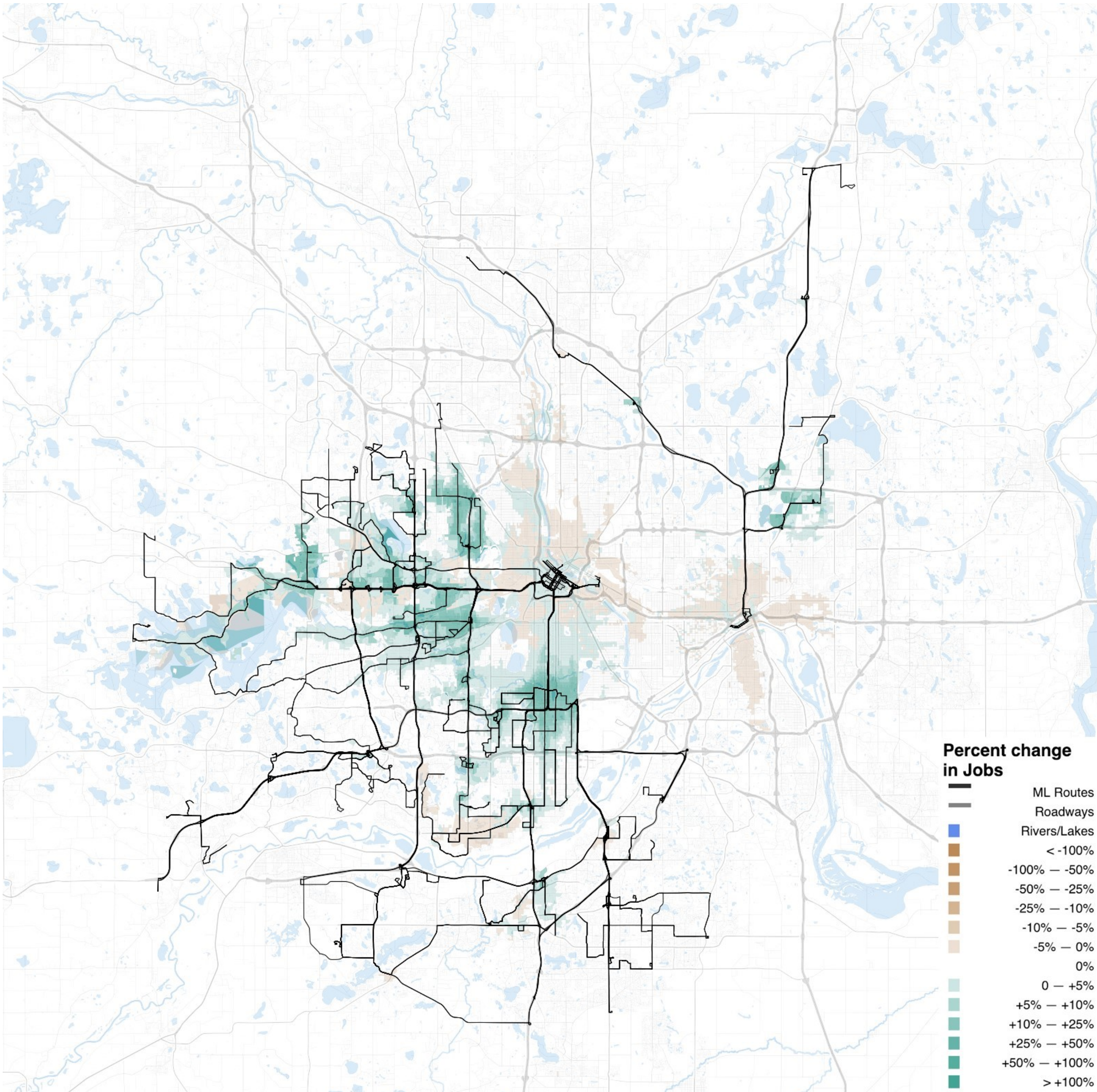

Figure 49 The percent change in average job accessibility between the existing ML—Express Bus scenario and baseline within 30-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

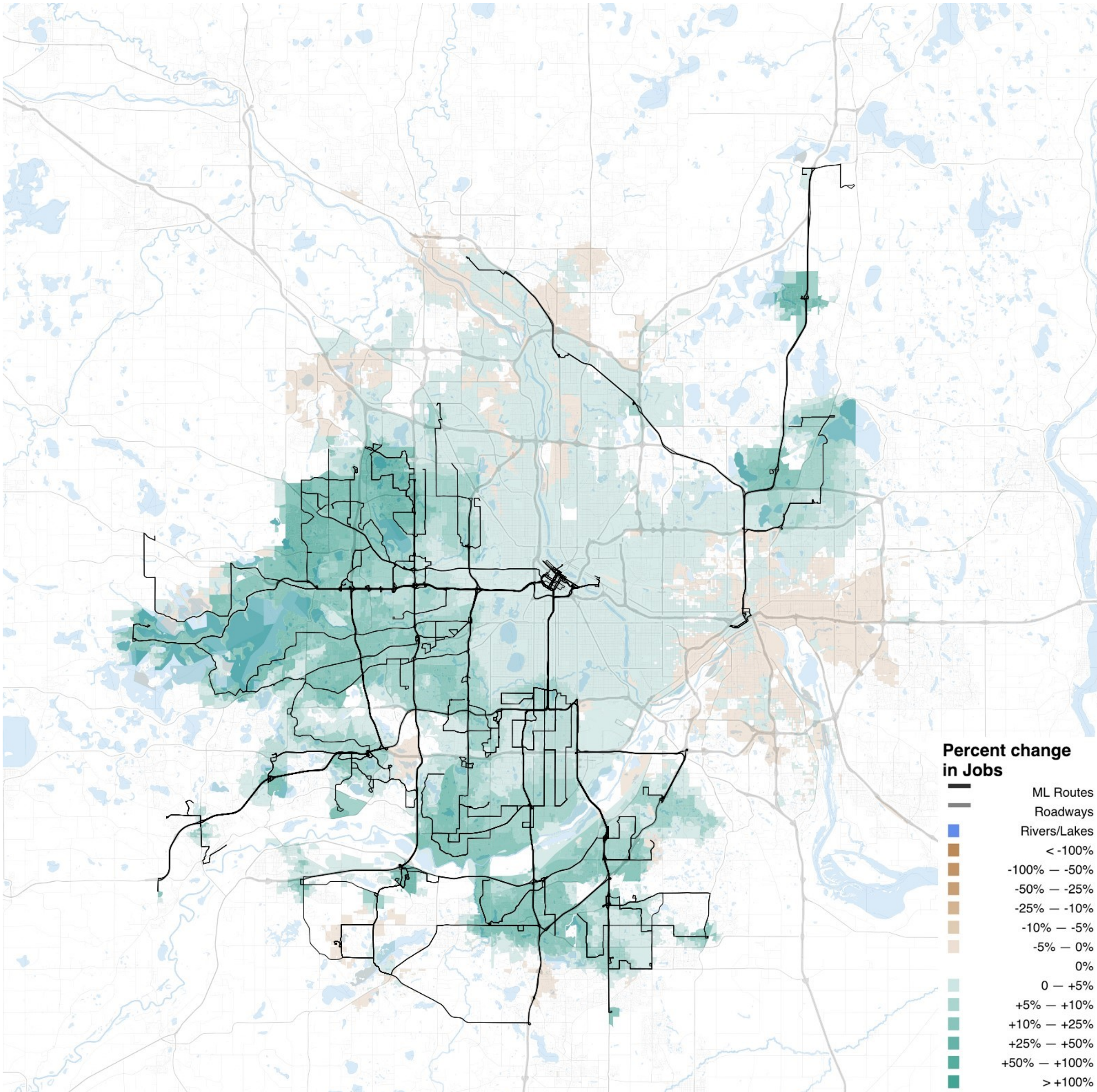

Figure 50 The percent change in average job accessibility between the existing ML—Express Bus scenario and baseline within 60-minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

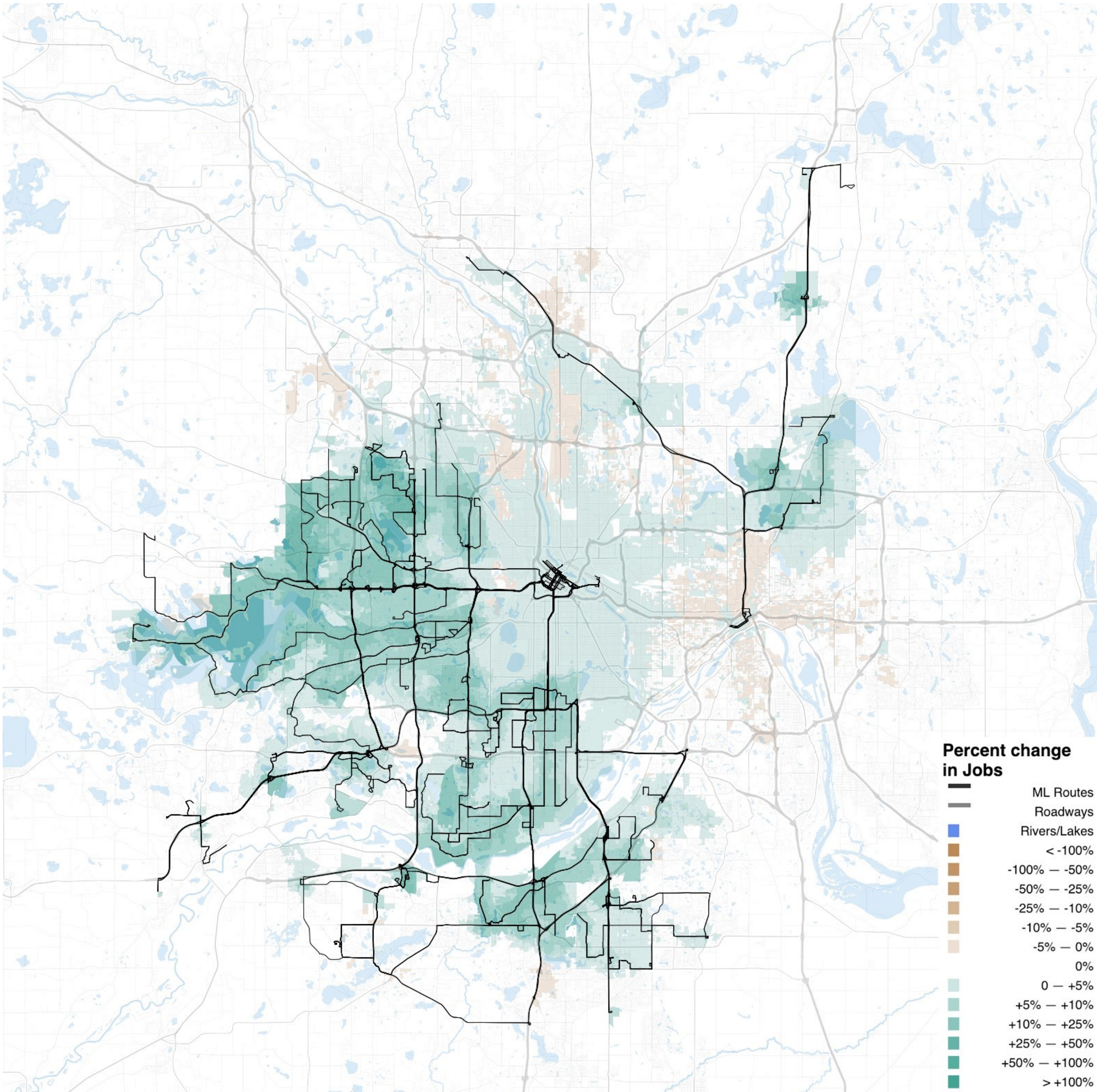

Figure 51 The percent change in average job accessibility between the existing ML—Express Bus scenario and baseline using the travel time threshold decay function.

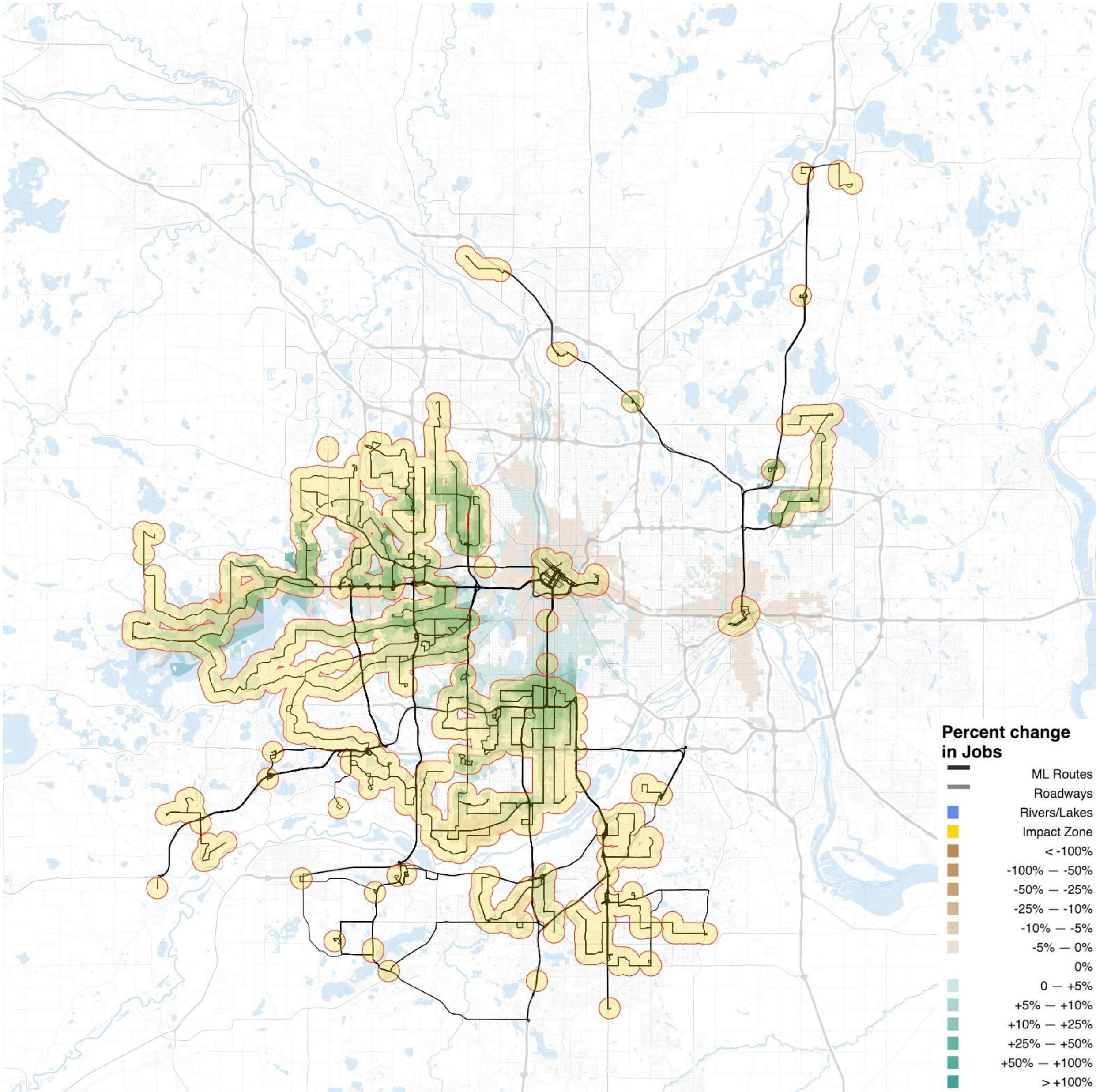

Figure 52 The percent change in accessibility for a 30-minute transit trip is overlaid by the half mile (800 m) impact zones that extend from transit stops located on express bus routes.

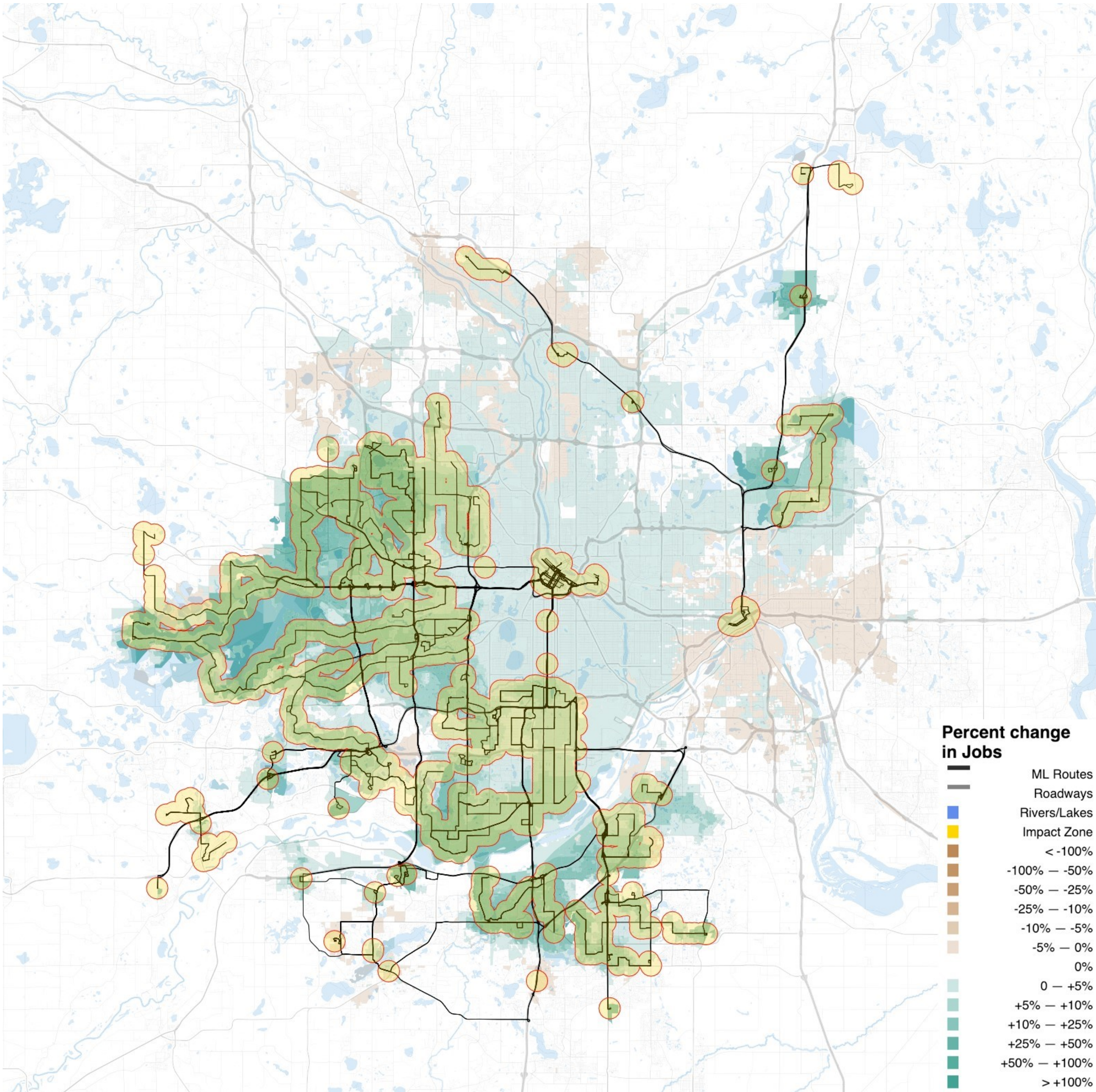

Figure 53 The percent change in accessibility for a 60-minute transit trip is overlaid by the half mile (800 m) impact zones that extend from transit stops located on express bus routes.

APPENDIX B: SUPPLEMENTAL MATERIAL TO CHAPTER 4

The following tables and figures are supplement to the PNR facility accessibility scenarios outlined in Chapter 4. The full travel time and accessibility changes per PNR facility are listed along with the 60-minute local and complete express bus network accessibility results.

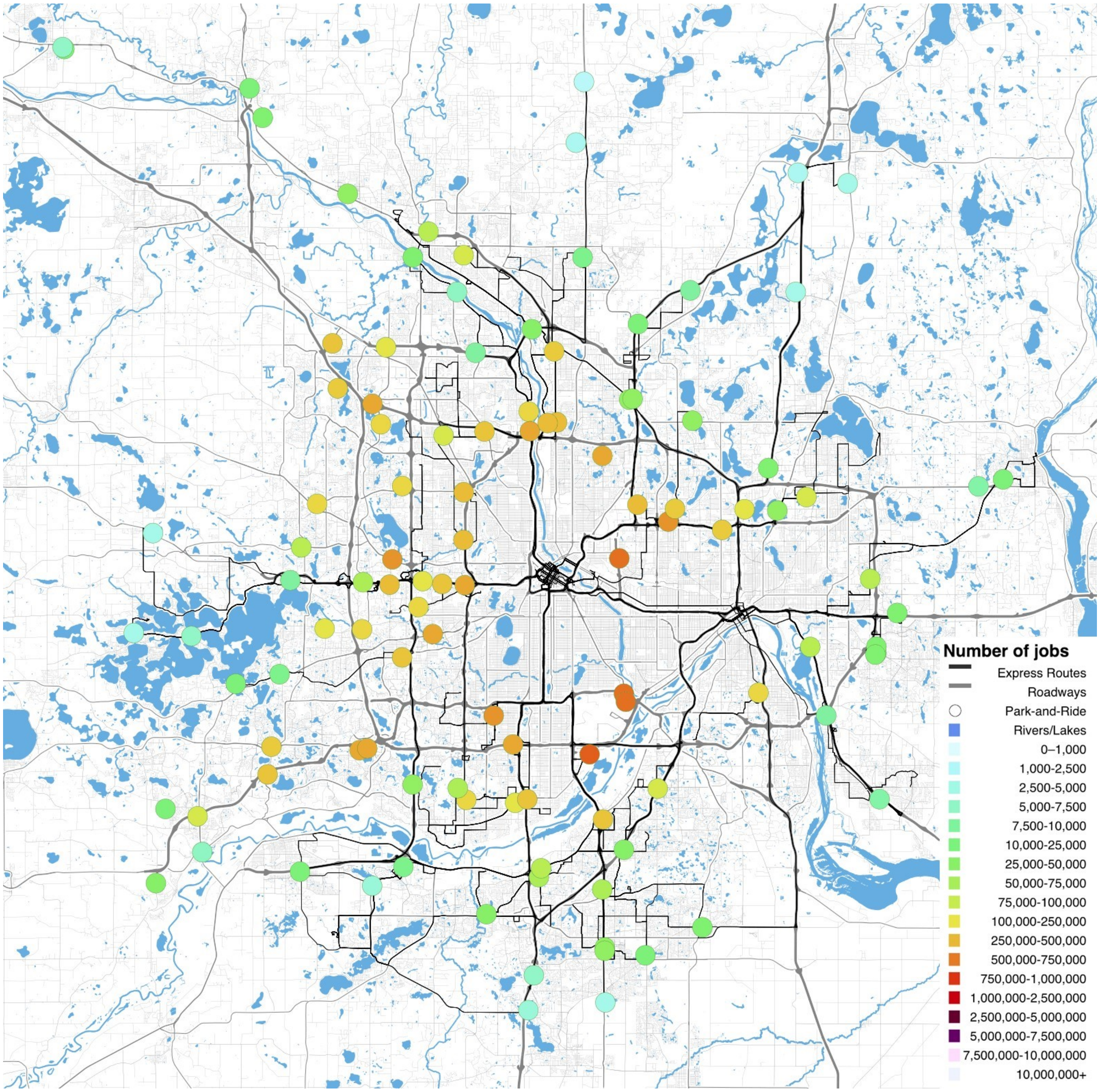

Figure 54 The average job accessibility for the local transit network at the 60-minute travel time threshold from 6–9 AM on Wednesday, October 5, 2016.

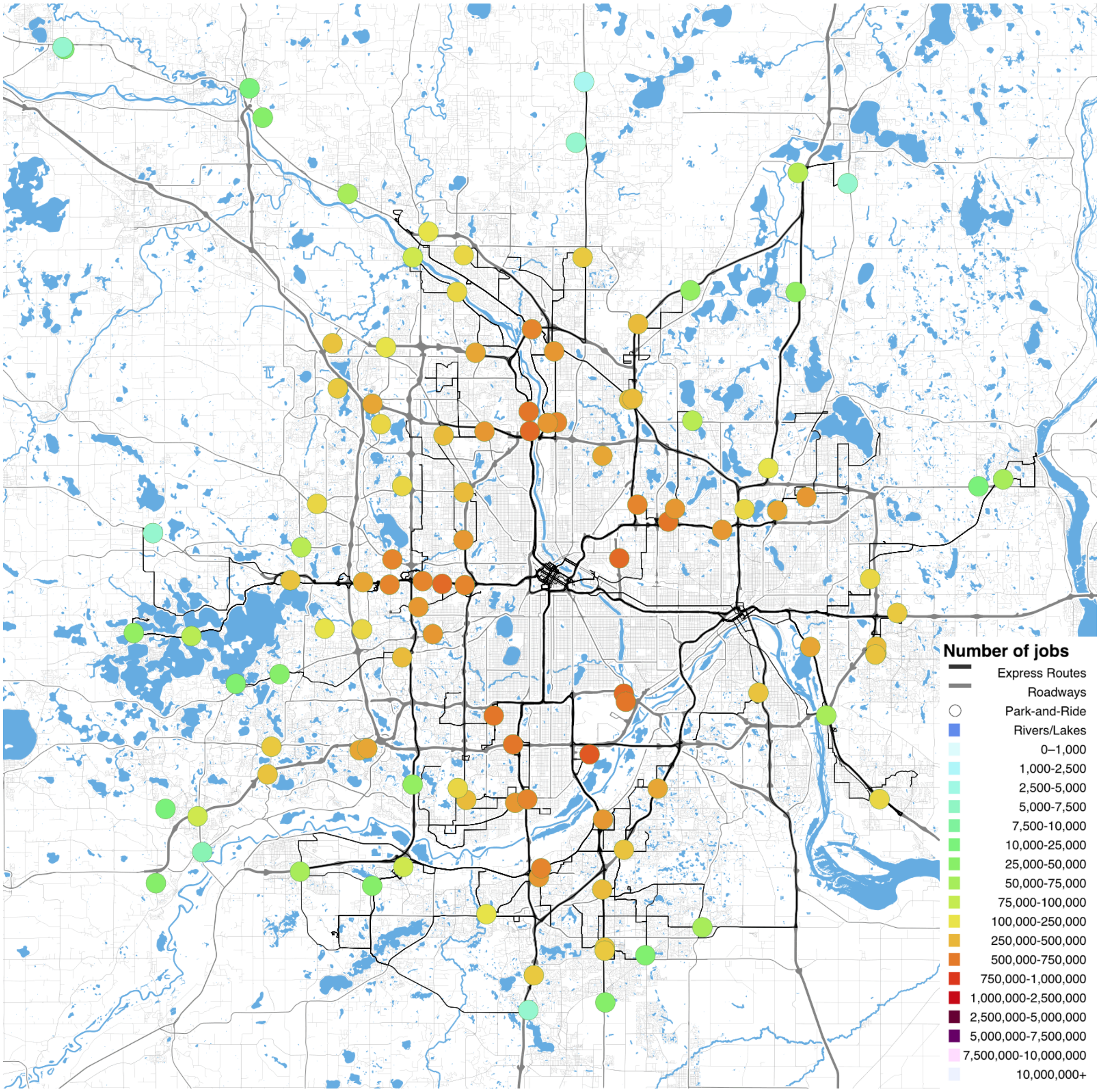

Figure 55 The average job accessibility for the complete transit network at the 60-minute travel time threshold from 6–9 AM on Wednesday, October 5, 2016. This figure can be compared to Figure 54.

Table 17 The average time savings between each origin-destination pair when comparing the local to the complete transit network.

	UMN	MPLS	ST. PAUL	AVERAGE
PNR Name	Time Change [min] (Percent Faster)	Time Change [min] (Percent Faster)	Time Change [min] (Percent Faster)	Time Change [min] (Percent Faster)
General Mills Blvd & I-394	34.5 (41.9%)	33.4 (46.3%)	-	33.9 (44.1%)
Hwy 610 & Noble	30.6 (35.2%)	40.8 (50.1%)	-	35.7 (42.6%)
Church of Nazarene	27 (37.5%)	32.2 (51.3%)	22.8 (27.3%)	27.3 (38.7%)
Richardson Park	-	32.2 (36.4%)	-	32.2 (36.4%)
Christ Episcopal Church	28.8 (32.3%)	-	34 (40.1%)	31.4 (36.2%)
St. Edward's Catholic Church	-	30.1 (35.4%)	-	30.1 (35.4%)
Woodbury Lutheran Church	29.3 (33.1%)	-	30.7 (36.3%)	30 (34.7%)
Hwy 61 & Co Rd C	39.3 (45%)	-	20 (23.4%)	29.6 (34.2%)
Burnsville Transit Station	33.6 (40.2%)	40.9 (49.7%)	8.4 (9.6%)	27.7 (33.2%)
Louisiana Ave Transit Center	28.9 (38.1%)	28.6 (44.6%)	13 (15%)	23.5 (32.6%)
Woodbury Theatre	-	-	28 (32.2%)	28 (32.2%)
Eagan Transit Station	16.8 (20.9%)	21.9 (27.6%)	38.6 (44.9%)	25.8 (31.1%)
Wayzata Blvd & Barry Ave	21.2 (24.2%)	29.6 (36.3%)	-	25.4 (30.2%)
Hwy 61 & Lower Afton Rd	27.9 (35.3%)	29.6 (34.5%)	13.2 (19%)	23.6 (29.6%)
I-35W & 95th Ave	37.8 (42.8%)	-	13.2 (15.5%)	25.5 (29.1%)
Plymouth Road Park & Ride	21.5 (25.9%)	23.1 (31.9%)	-	22.3 (28.9%)
Maplewood Mall Transit Center	26.5 (32.9%)	33.3 (38.7%)	11.3 (15.1%)	23.7 (28.9%)
Heart of the City	30.7 (35.9%)	34.3 (40.5%)	5.6 (6.2%)	23.5 (27.5%)
I-35W & Co Rd H	18 (22.2%)	23.3 (29.7%)	-	20.6 (25.9%)
Northtown Transit Center	14.6 (20.3%)	20.2 (30.5%)	22.5 (26.1%)	19.1 (25.6%)
South Bloomington Transit Center	25.2 (32.3%)	23.2 (33.9%)	6.9 (8%)	18.4 (24.7%)
Mermaid Supper Club	16.3 (20.3%)	20.9 (27%)	-	18.6 (23.6%)

Regal Cinemas 20	12.5 (19.7%)	16.5 (32.3%)	14.7 (18.5%)	14.5 (23.5%)
St. Luke's Lutheran Church	22.9 (26.8%)	29.7 (37.4%)	3.8 (4.3%)	18.8 (22.8%)
Park Place & I-394	15.8 (23.1%)	16.7 (30.7%)	11.8 (14.3%)	14.7 (22.7%)
Westwood Lutheran Church	18.8 (23.4%)	22.6 (32.7%)	10.5 (11.8%)	17.3 (22.7%)
Blackhawk	18.2 (21.5%)	26 (30.6%)	13.7 (15.5%)	19.3 (22.5%)
Knox Avenue at Best Buy	16.1 (22%)	19.6 (31.7%)	7.4 (8.6%)	14.4 (20.8%)
Guardian Angels Catholic Church	-	-	18.4 (20.7%)	18.4 (20.7%)
Palomino Hills	13.7 (16.8%)	21.9 (27.4%)	15.3 (17.6%)	17 (20.6%)
65th Ave & Brooklyn Blvd	15.6 (21.5%)	15.2 (25.9%)	11.8 (13.9%)	14.2 (20.4%)
Church of St. William	12.9 (19.1%)	17.9 (29.7%)	9.5 (11.4%)	13.4 (20.1%)
Newport Transit Station	24 (27%)	-	10.9 (12.9%)	17.5 (19.9%)
I-35W & Co Rd C	8.6 (13.9%)	20.4 (31.1%)	11.3 (14.3%)	13.4 (19.8%)
Normandale Village	11.2 (13.4%)	20.4 (25%)	14 (15.5%)	15.2 (18%)
Skating Center	12.8 (19.9%)	23 (30.8%)	1.5 (2%)	12.5 (17.6%)
Hwy 36 & Rice St	11.7 (16.8%)	23.8 (30.4%)	0.5 (0.7%)	12 (16%)
Fridley Station	11.2 (16.5%)	15 (24.7%)	4.5 (5.6%)	10.2 (15.6%)
Grace Church	8.5 (16.4%)	18.3 (29.3%)	0.1 (0.2%)	9 (15.3%)
Southdale Transit Center	10.4 (15.2%)	10.6 (19.1%)	7.3 (8.5%)	9.4 (14.3%)
Co Rd 73 & I-394 South	9.8 (14.8%)	11.6 (19.9%)	5.7 (6.9%)	9 (13.9%)
63rd Ave & Bottineau Blvd	14.6 (17.7%)	14.1 (20.1%)	3.2 (3.7%)	10.6 (13.8%)
Hwy 100 & Duluth	8.4 (11.4%)	13.3 (22.8%)	6.2 (7.4%)	9.3 (13.8%)
Shoreview Community Center	8.9 (10.7%)	14.6 (16.3%)	-	11.7 (13.5%)
Cedar Grove Transit Station	13 (17.4%)	7.3 (9.7%)	10.3 (12.3%)	10.2 (13.1%)
Navarre Center	0.4 (0.4%)	18.5 (22%)	-	9.4 (11.2%)
Walton Park	6.1 (7.1%)	2.3 (2.6%)	14 (17.2%)	7.4 (9%)

West St Paul Sports Complex	4.5 (7.3%)	7.9 (10.6%)	-	6.2 (9%)
Anoka Station	4.1 (5.4%)	5.4 (8.1%)	-	4.7 (6.8%)
Hwy 7 & Vinehill Rd	-	5.3 (6.2%)	-	5.3 (6.2%)
Coon Rapids/Riverdale Station	5.1 (6.8%)	6.4 (9.8%)	1.5 (1.7%)	4.4 (6.1%)
Ramsey Station	3.8 (4.8%)	4.7 (6.6%)	-	4.2 (5.7%)
Big Lake	-	4.6 (5.1%)	-	4.6 (5.1%)
Elk River Station (171st Ave & Tyler St)	3.3 (4%)	4.6 (5.9%)	-	4 (5%)
Big Lake Station	3.3 (3.8%)	4.6 (5.6%)	-	4 (4.7%)
Little Canada Municipal Lot	1.8 (2.5%)	8 (9.8%)	0.1 (0.1%)	3.3 (4.1%)
Hopkins Park-and-Ride	2.4 (3.1%)	3.4 (5%)	-	2.9 (4%)
Minnetonka Blvd & Baker Rd	2.7 (3.5%)	2.6 (3.5%)	-	2.7 (3.5%)
Minnetonka Blvd & Steele St	2.6 (3.2%)	2.7 (3.5%)	-	2.6 (3.3%)
Hwy 7 & Texas Ave	1.9 (2.9%)	1.4 (2.6%)	0.3 (0.3%)	1.2 (1.9%)
Excelsior City Hall	1.1 (1.2%)	1.9 (2.3%)	-	1.5 (1.7%)
Faith-Lilac Way Lutheran Church	1 (1.2%)	1.8 (2.8%)	0.7 (0.9%)	1.2 (1.6%)
Station 73	0.7 (1%)	1.3 (1.7%)	-	1 (1.3%)
Preserve Village Mall	-	0.9 (1%)	-	0.9 (1%)
Carver Station	0.7 (0.8%)	-	-	0.7 (0.8%)
Olive Lane	-	0.2 (0.3%)	-	0.2 (0.3%)
Salem Covenant Church	-	0.2 (0.2%)	-	0.2 (0.2%)
East Creek Station	0.1 (0.1%)	-	-	0.1 (0.1%)
Nathan Lane	-	0.1 (0.1%)	-	0.1 (0.1%)
Zachary Square	-	-	-	-
Como & Eustis	-	-	-	-
Shepherd of the Grove Church	-	-	-	-

Crosswinds Methodist Church	-	-	-	-
Maple Grove Transit Station	-	-	-	-
28th Ave Station	-	-	-	-
Ft Snelling Station North	-	-	-	-
Ft Snelling Station South	-	-	-	-
Clover Fields	-	-	-	-
St Andrew Lutheran Church	-	-	-	-
SouthWest Village	-	-	-	-
Parkway Station	-	-	-	-
Chanhassen Transit Station	-	-	-	-
Walnut St & Chaska Blvd	-	-	-	-
Dunkirk Park & Ride	-	-	-	-
SouthWest Station	-	-	-	-
West River Rd & 117th Ave	-	-	-	-
St. Joseph's Church	-	-	-	-
Foley Blvd	-	-	-	-
St Croix Valley Recreation Center	-	-	-	-
Co Rd 42 & Huntington	-	-	-	-
Cottage Grove	-	-	-	-
Southbridge Crossing	-	-	-	-
I-35 & Kenrick Ave	-	-	-	-
Running Aces	-	-	-	-
Forest Lake Transit Center	-	-	-	-
Maple Plain	-	-	-	-
I-35E & County Road 14	-	-	-	-

I-35E & County Road E	-	-	-	-
East Bethel Theatre	-	-	-	-
Family of Christ Lutheran Church	-	-	-	-
Paul Pkwy	-	-	-	-
Marschall Road Transit Station	-	-	-	-
Carmike Cinema	-	-	-	-
Elk River	-	-	-	-
36 & Manning	-	-	-	-
Becker Municipal Lot	-	-	-	-
I-35 & CR 60	-	-	-	-
Northstar Link Lot	-	-	-	-
Apple Valley Transit Station	-	-	-	-
Mound Transit Center	-	-	-	-
157th St Station	-	-	-	-
Eagle Creek Transit Station	106	-	-	-
Lakeville Cedar	-	-	-	-
Rosemount Transit Station	-	-	-	-

Table 18 The average absolute difference and percent change in jobs accessible within 60-minutes of travel, and the weighted percent change—comparing the local to the complete transit network.

Name	Abs. Diff. 60 Min	Pct. Chg. 60 Min	Weight Pct. Chg.
Burnsville Transit Station	407,682	648.98%	326%
General Mills Blvd & I-394	390,201	423.17%	358%
Church of Nazarene	388,151	286.95%	814%
Foley Blvd	384,939	1764.56%	1115%
Louisiana Ave Transit Center	348,272	165.84%	261%
Heart of the City	305,176	570.47%	192%
Hwy 610 & Noble	302,840	4123.08%	2798%
Hwy 61 & Co Rd C	283,039	931.97%	587%
Maplewood Mall Transit Center	280,904	309.44%	155%
South Bloomington Transit Center	272,175	130.34%	138%
Plymouth Road Park & Ride	261,010	495.31%	299%
Hwy 61 & Lower Afton Rd	239,506	347.89%	486%
St. Luke's Lutheran Church	239,460	258.12%	152%
Northtown Transit Center	234,830	144.05%	113%
I-35W & 95th Ave	231,140	1663.84%	755%
Regal Cinemas 20	226,716	67.28%	128%
Eagan Transit Station	221,695	278.56%	104%
Westwood Lutheran Church	221,388	171.94%	291%
Woodbury Theatre	214,344	1284.96%	194%
Mermaid Supper Club	211,260	542.08%	282%
Hwy 36 & Rice St	207,734	119.55%	108%
Skating Center	205,298	112.16%	125%
Blackhawk	204,777	958.47%	423%
I-35W & Co Rd H	202,726	669.70%	332%

I-35W & Co Rd C	201,764	79.75%	101%
Knox Avenue at Best Buy	196,687	63.23%	68%
Palomino Hills	194,351	369.27%	269%
Wayzata Blvd & Barry Ave	187,979	2358.88%	411%
Church of St. William	186,361	74.71%	116%
Christ Episcopal Church	184,660	1096.95%	203%
I-35 & Kenrick Ave	180,772	4037.79%	645%
Cedar Grove Transit Station	180,745	91.66%	96%
Woodbury Lutheran Church	178,474	1036.55%	176%
Apple Valley Transit Station	177,646	510.40%	94%
Co Rd 73 & I-394 South	176,877	67.00%	132%
Park Place & I-394	175,040	61.55%	97%
65th Ave & Brooklyn Blvd	174,698	89.14%	198%
Paul Pkwy	152,332	1778.13%	435%
Guardian Angels Catholic Church	152,303	845.52%	255%
63rd Ave & Bottineau Blvd	147,980	175.77%	167%
West River Rd & 117th Ave	147,913	2775.62%	1278%
Carmike Cinema	145,909	448.05%	87%
Fridley Station	144,991	59.84%	82%
Hwy 100 & Duluth	133,707	55.62%	102%
Grace Church	133,450	34.87%	70%
Cottage Grove	122,125	1836.19%	609%
Normandale Village	114,495	84.59%	46%
St. Edward’s Catholic Church	100,218	174.60%	195%
Southdale Transit Center	88,559	20.45%	27%
Co Rd 42 & Huntington	84,212	307.25%	66%

I-35E & County Road E	81,836	456.55%	115%
Southbridge Crossing	74,234	827.12%	198%
West St Paul Sports Complex	68,513	51.02%	26%
Running Aces	64,435	4602.50%	289%
Richardson Park	62,810	315.04%	97%
Walton Park	58,805	95.97%	107%
Navarre Center	56,690	1104.64%	225%
Newport Transit Station	46,985	642.40%	272%
Coon Rapids/Riverdale Station	41,091	47.23%	50%
St Croix Valley Recreation Center	39,119	309.07%	53%
Marshall Road Transit Station	38,499	301.06%	34%
Rosemount Transit Station	37,686	257.21%	32%
Hopkins Park-and-Ride	37,348	18.22%	12%
Shoreview Community Center	36,187	113.74%	72%
I-35E & County Road 14	33,423	1871.39%	253%
Mound Transit Center	28,173	1136.47%	131%
Anoka Station	27,442	40.19%	19%
St. Joseph’s Church	24,123	328.16%	194%
Eagle Creek Transit Station	22,344	661.07%	264%
Faith-Lilac Way Lutheran Church	22,016	9.49%	9%
Station 73	21,251	5.45%	4%
Lakeville Cedar	19,531	906.31%	600%
Hwy 7 & Vinehill Rd	19,118	202.46%	109%
28th Ave Station	18,637	3.14%	2%
Ramsey Station	18,601	52.96%	27%
Little Canada Municipal Lot	17,665	15.79%	7%

Hwy 7 & Texas Ave	17,226	5.26%	5%
Minnetonka Blvd & Baker Rd	16,548	12.88%	8%
Minnetonka Blvd & Steele St	12,950	13.52%	10%
Ft Snelling Station North	9,678	1.80%	1%
Como & Eustis	9,208	1.64%	0%
Ft Snelling Station South	8,947	1.68%	1%
Maple Grove Transit Station	8,445	2.72%	1%
157th St Station	7,680	67.03%	50%
Preserve Village Mall	6,885	20.94%	22%
SouthWest Station	6,612	2.10%	1%
Elk River Station (171st Ave & Tyler St)	6,372	39.06%	16%
St Andrew Lutheran Church	5,954	2.00%	1%
Excelsior City Hall	5,906	47.21%	21%
Nathan Lane	5,844	3.91%	3%
36 & Manning	3,969	58.57%	27%
Crosswinds Methodist Church	3,878	2.18%	1%
Salem Covenant Church	3,830	1.31%	1%
Chanhassen Transit Station	3,437	1.89%	1%
SouthWest Village	3,124	1.48%	1%
Dunkirk Park & Ride	2,972	2.12%	1%
Parkway Station	2,506	1.25%	1%
Olive Lane	2,168	3.20%	3%
Family of Christ Lutheran Church	1,956	129.71%	24%
Maple Plain	1,882	86.65%	21%
Forest Lake Transit Center	1,812	69.32%	30%

Shepherd of the Grove Church	1,551	0.99%	1%
Zachary Square	1,400	1.41%	1%
Big Lake Station	1,187	10.89%	4%
East Bethel Theatre	1,002	207.02%	24%
East Creek Station	998	1.25%	1%
Carver Station	367	1.76%	1%
Big Lake	155	3.10%	0%
Clover Fields	7	0.07%	0%
Walnut St & Chaska Blvd	1	0.02%	0%
Elk River	-	0.00%	0%
Becker Municipal Lot	107	0.00%	0%
I-35 & CR 60	-	0.00%	0%
Northstar Link Lot	-	0.00%	0%

APPENDIX C: SUPPLEMENTAL MATERIAL TO CHAPTER 5 AND 6

The following figures are supplement to the PNR scenarios and monetary analyses outlined in Chapter 5 and Chapter 6. A selection of travel time thresholds and aggregations are provided for comparison with the figures given in the main body of the text.

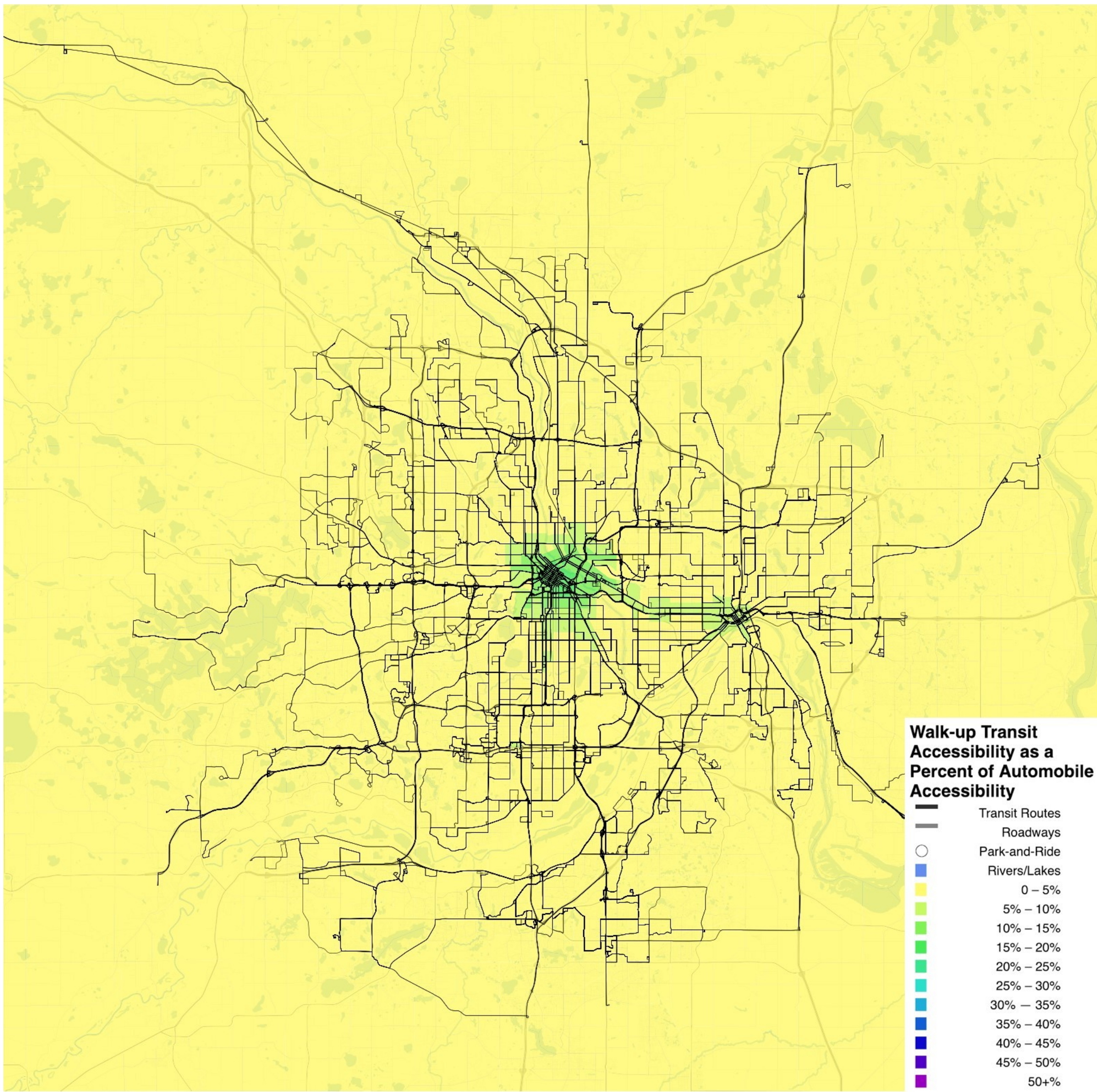

Figure 56 Walk-up transit accessibility as a percent of automobile accessibility within 30-minutes of travel in the Minneapolis–St. Paul metropolitan area.

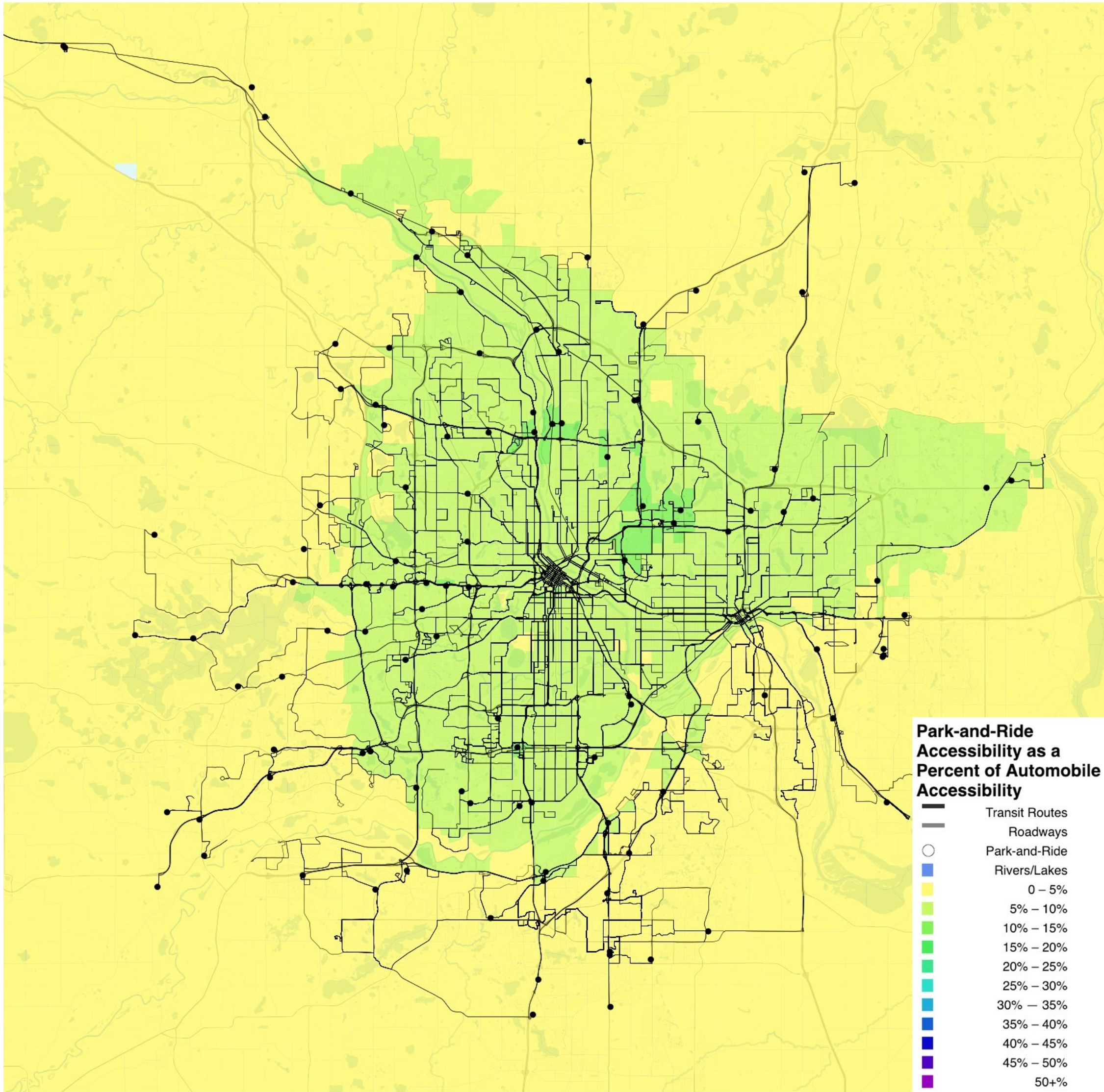

Figure 57 PNR accessibility as a percent of automobile accessibility within 30-minutes of travel in the Minneapolis–St. Paul metropolitan area.

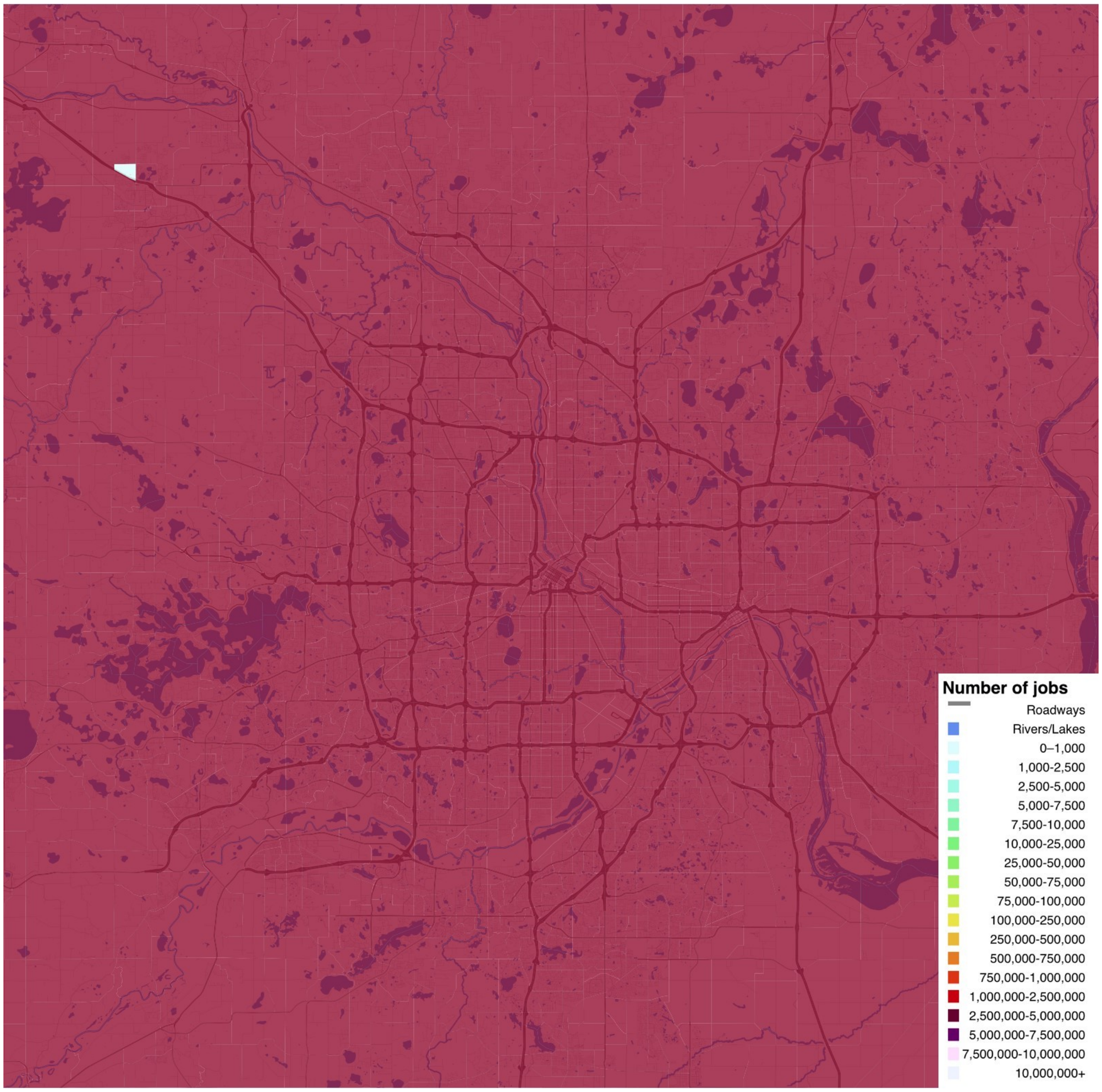

Figure 58 Automobile accessibility within $10.00 using Scenario A monetary criteria in the Minneapolis–St. Paul metropolitan area.

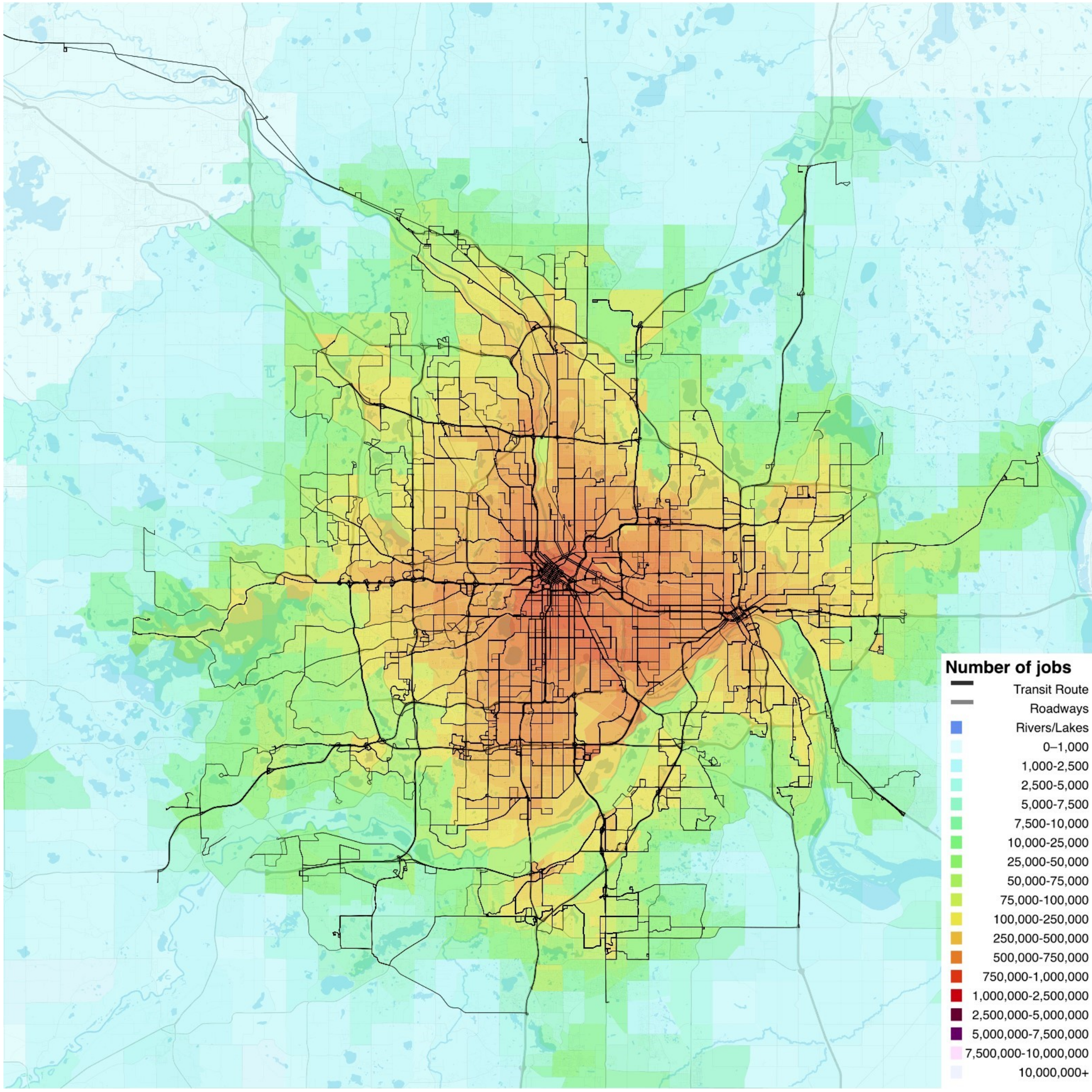

Figure 59 Walk-up transit accessibility within $3.25 of travel using Scenario A monetary criteria in the Minneapolis–St. Paul metropolitan area.

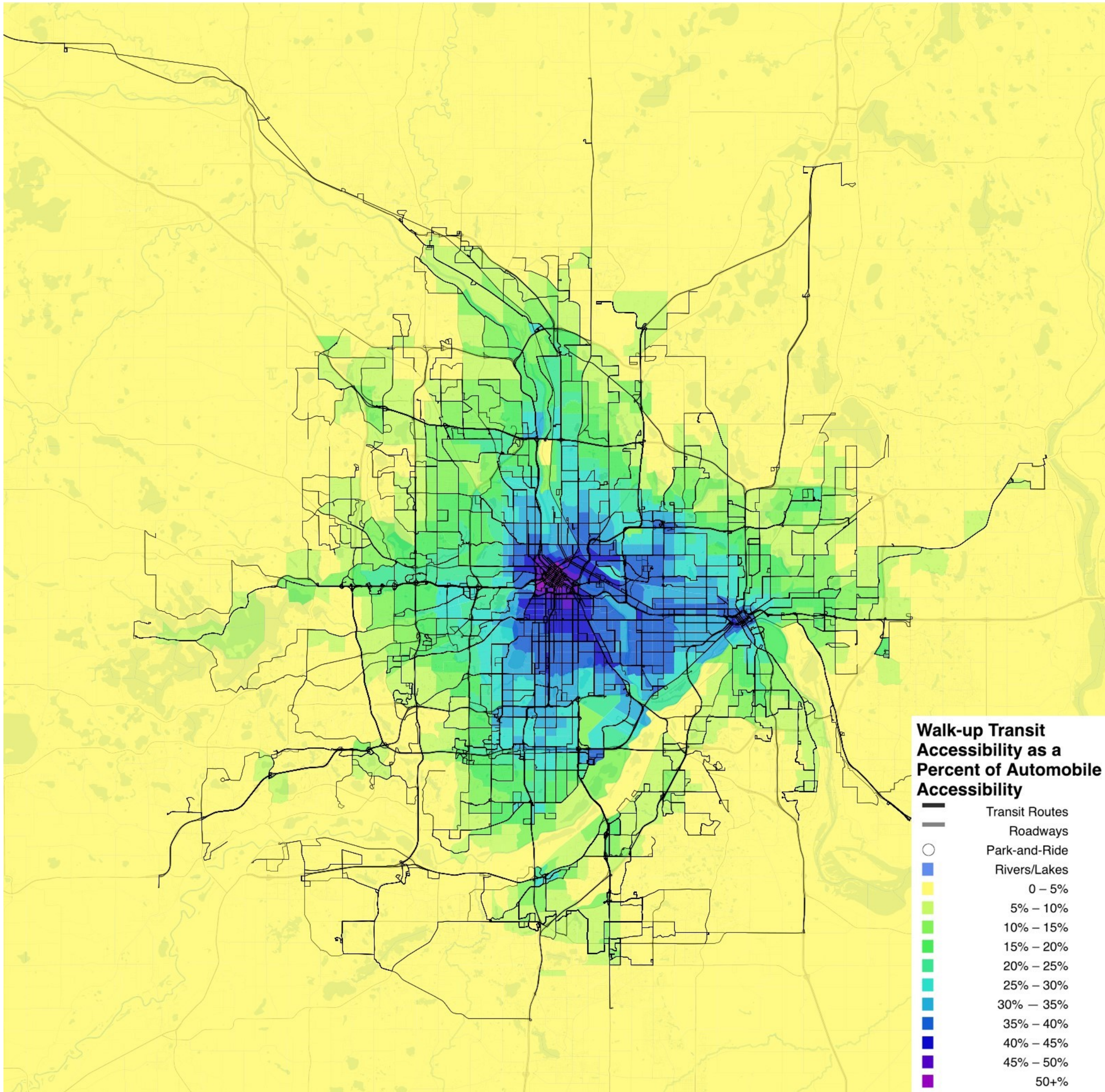

Figure 60 Walk-up transit accessibility as a percent of automobile accessibility within $3.25 of travel for Scenario A monetary criteria in the Minneapolis–St. Paul metropolitan area.

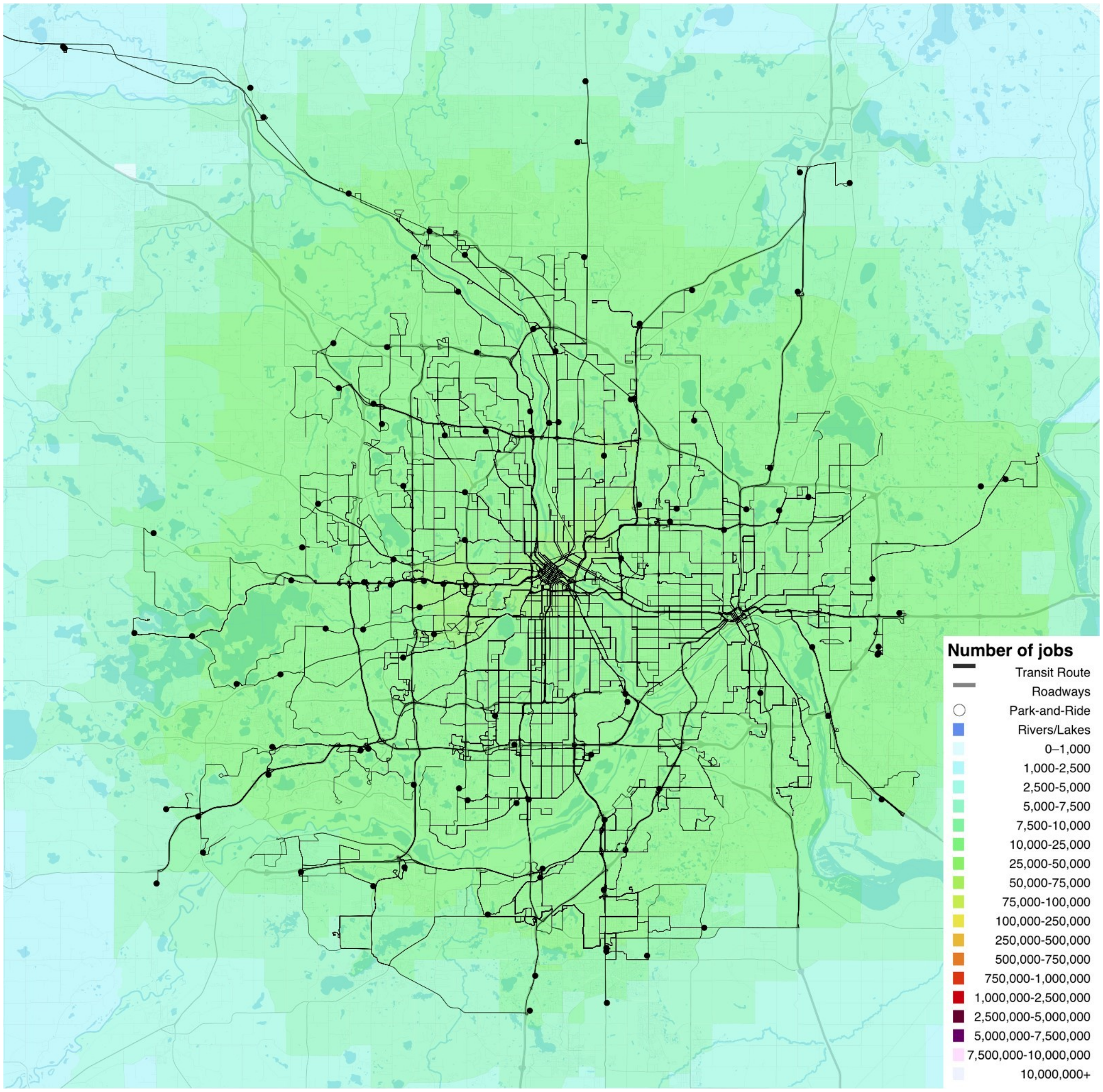

Figure 61 PNR accessibility within $10.00 of travel for Scenario A monetary criteria in the Minneapolis–St. Paul metropolitan area.

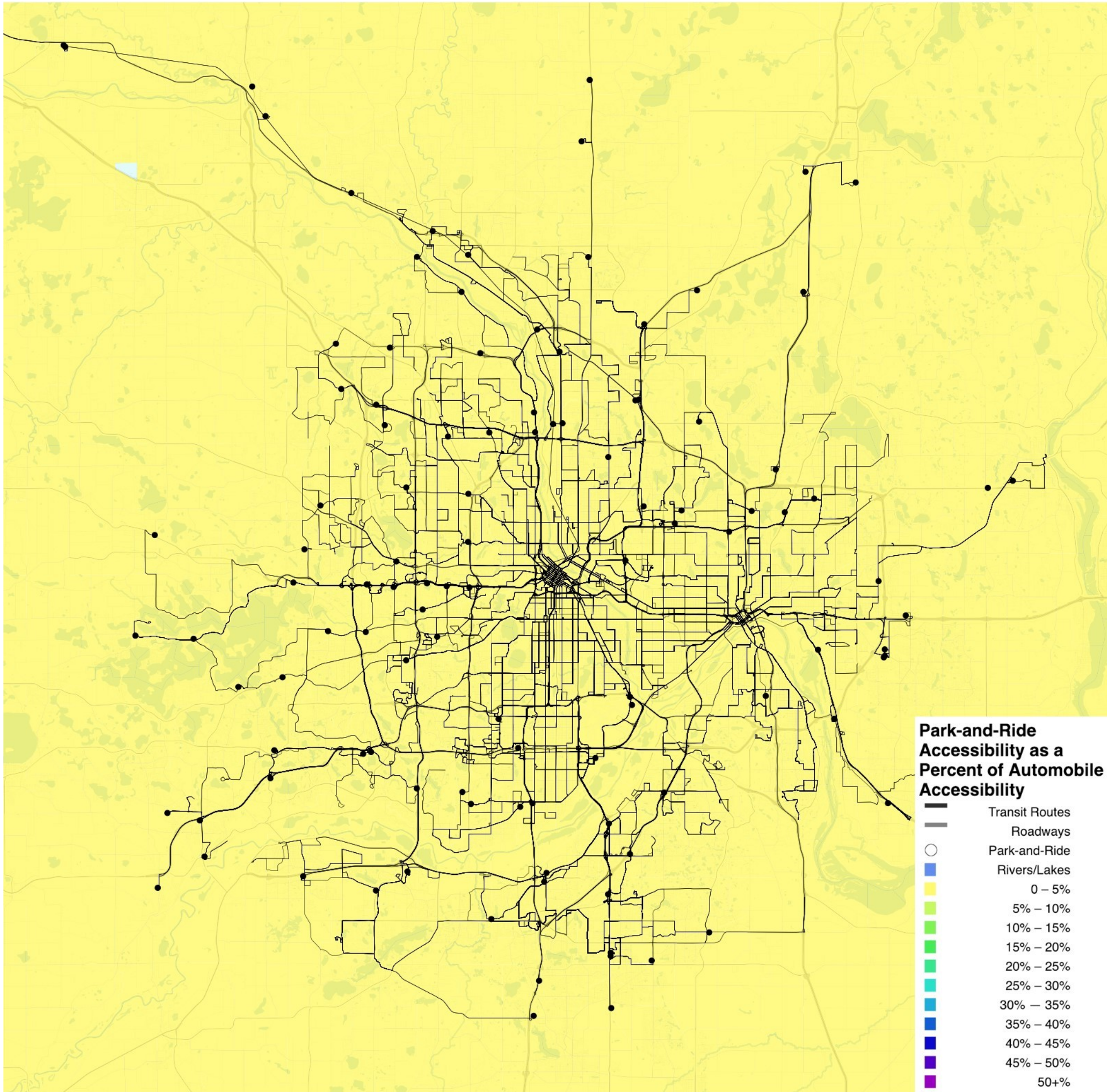

Figure 62 PNR accessibility as a percent of automobile accessibility within $10.00 of travel for Scenario A monetary criteria in the Minneapolis–St. Paul metropolitan area.

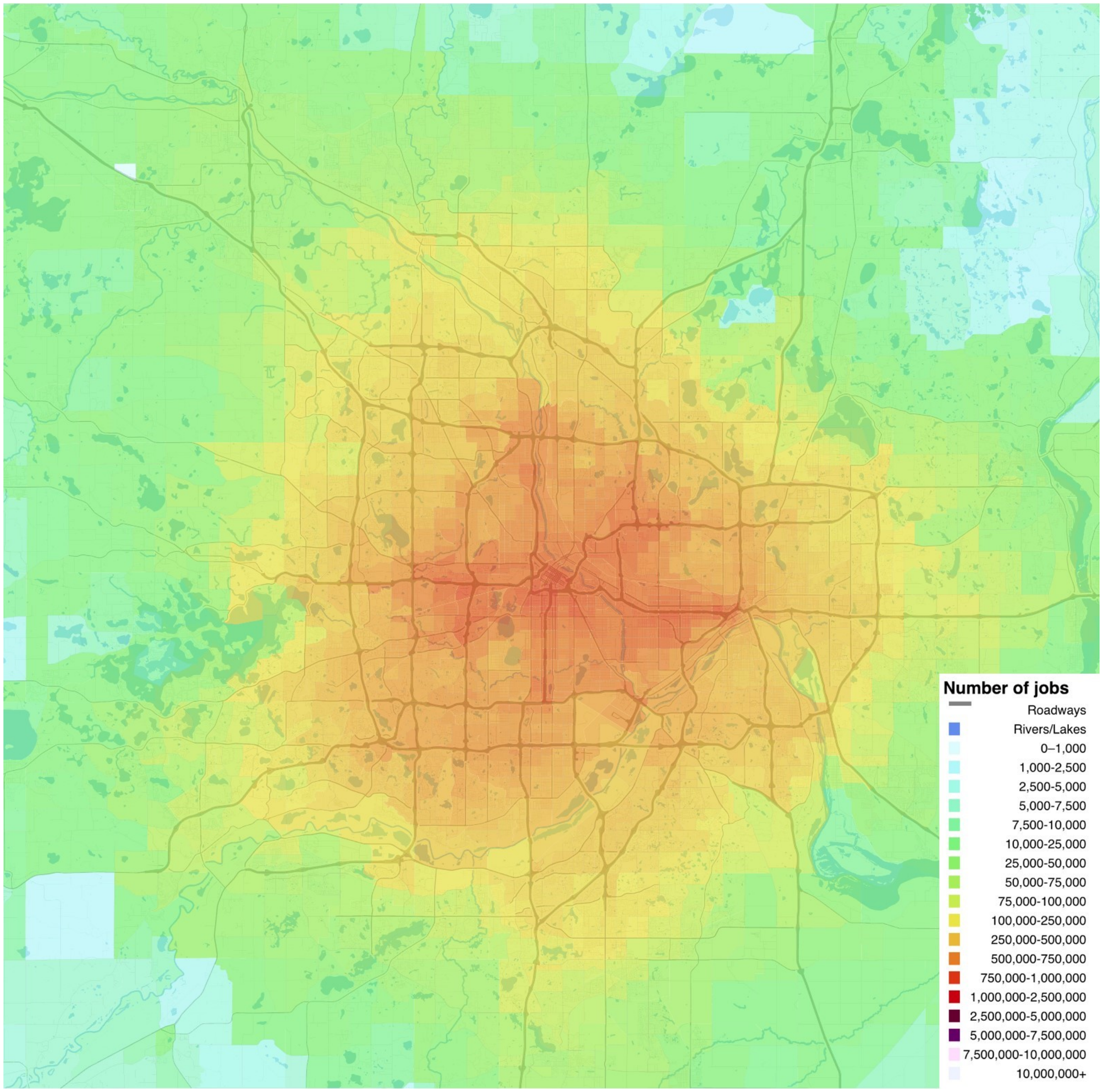

Figure 63 Automobile accessibility within $10.00 of travel for Scenario B monetary criteria in the Minneapolis–St. Paul metropolitan area.

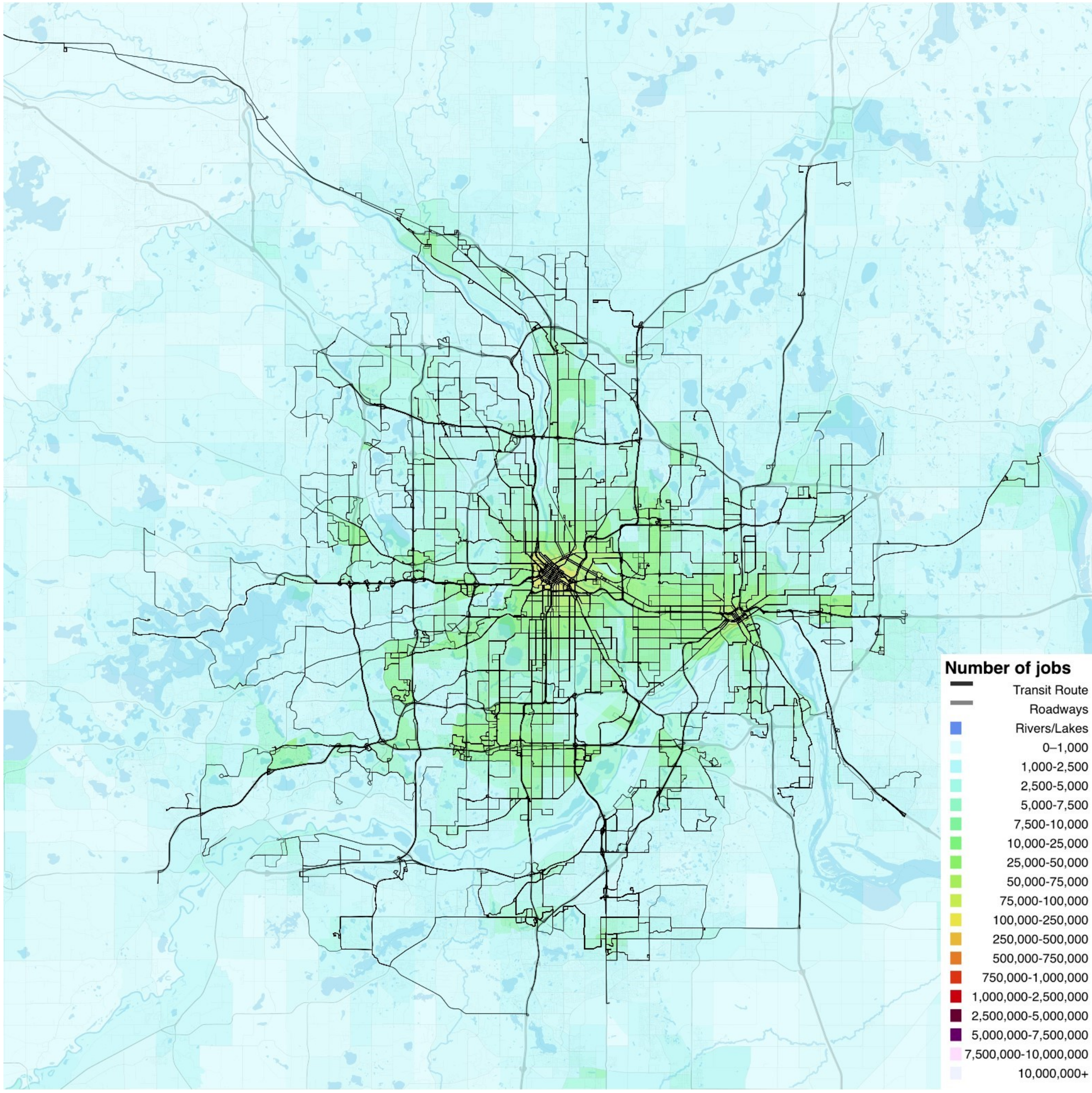

Figure 64 Walk-up transit accessibility within $10.00 of travel for Scenario B monetary criteria in the Minneapolis–St. Paul metropolitan area.

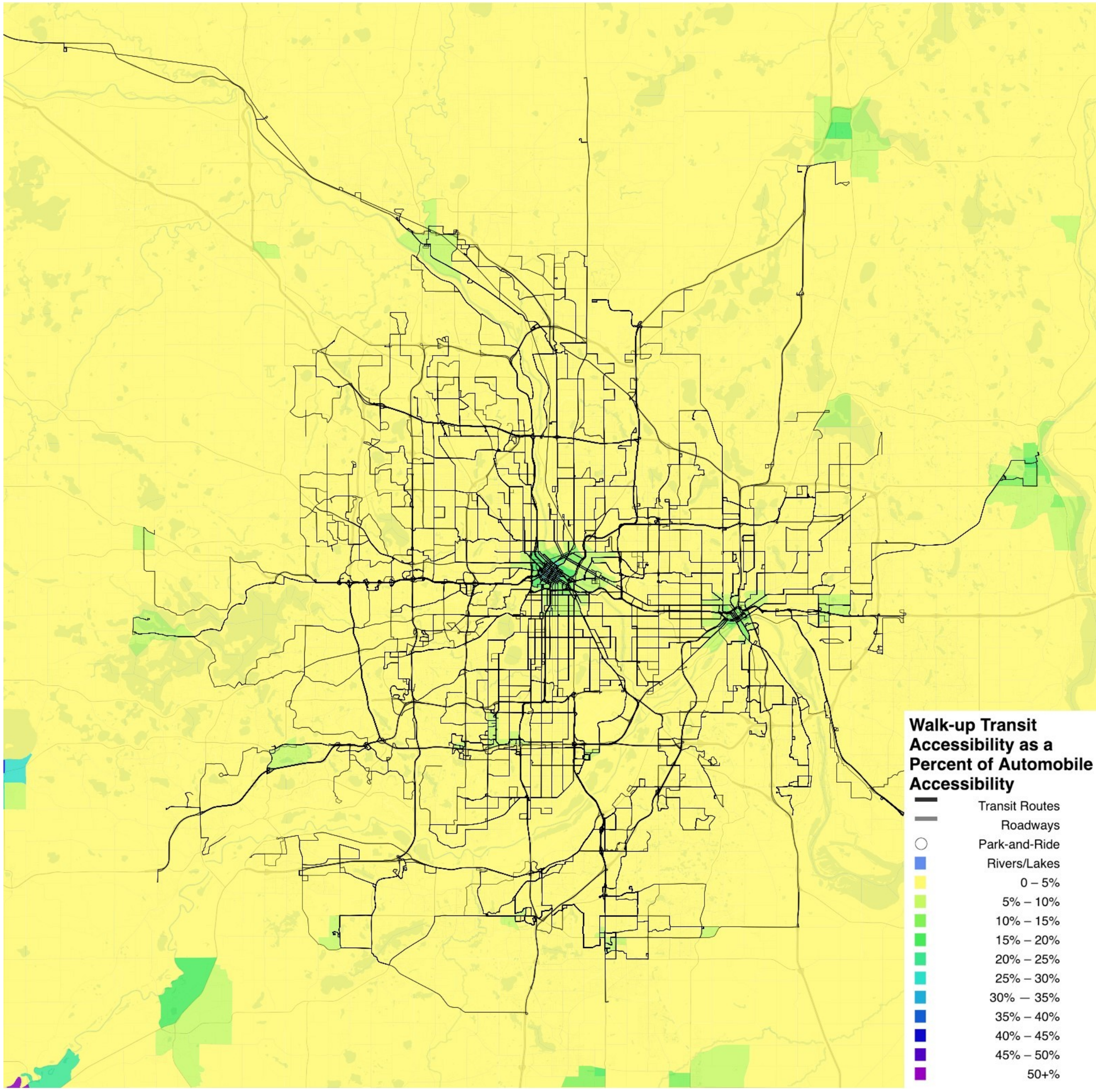

Figure 65 Walk-up transit accessibility as a percent of automobile accessibility within $10.00 of travel for Scenario B monetary criteria in the Minneapolis–St. Paul metropolitan area.

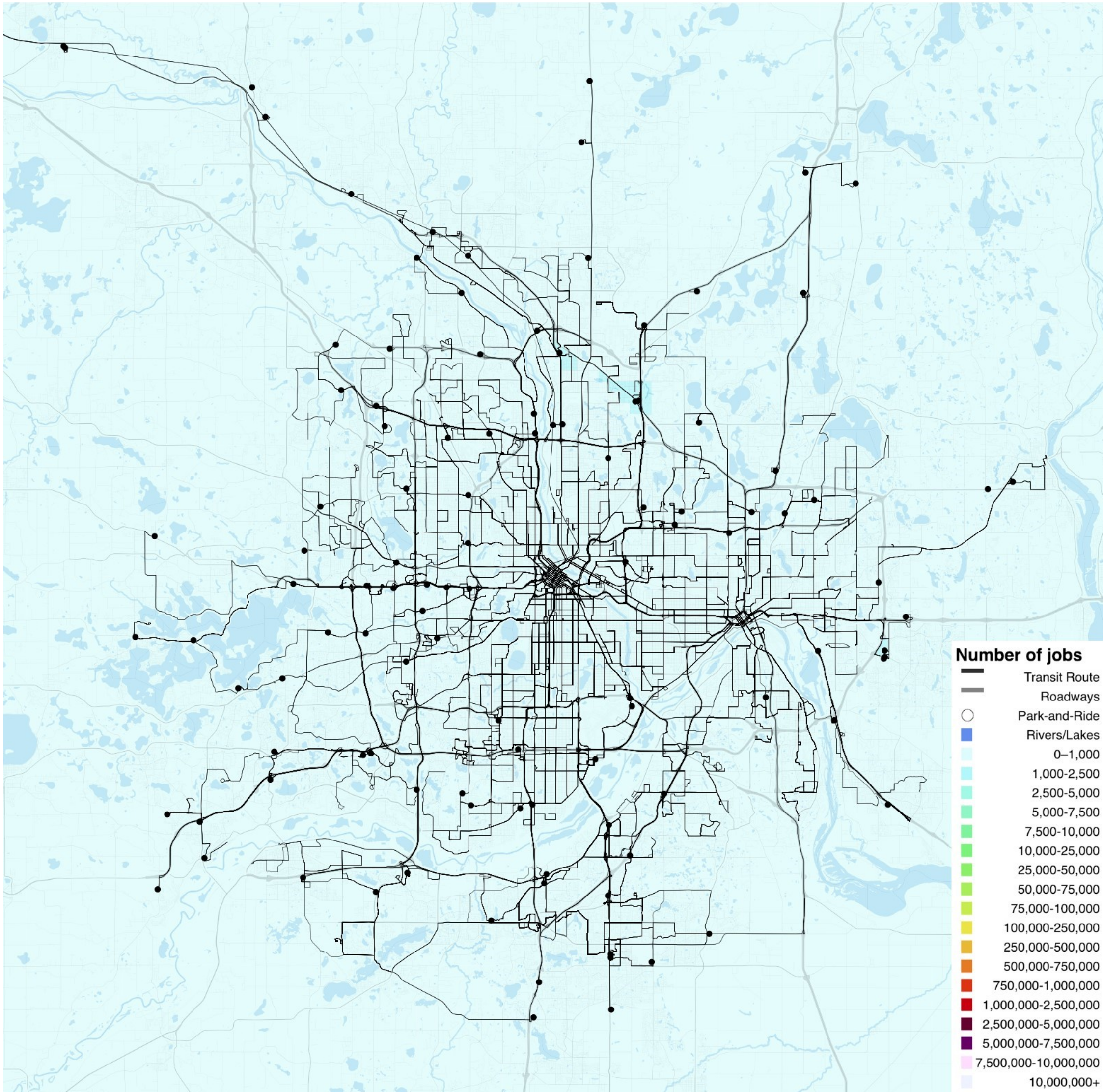

Figure 66 PNR accessibility within $10.00 of travel for Scenario B monetary criteria in the Minneapolis–St. Paul metropolitan area.

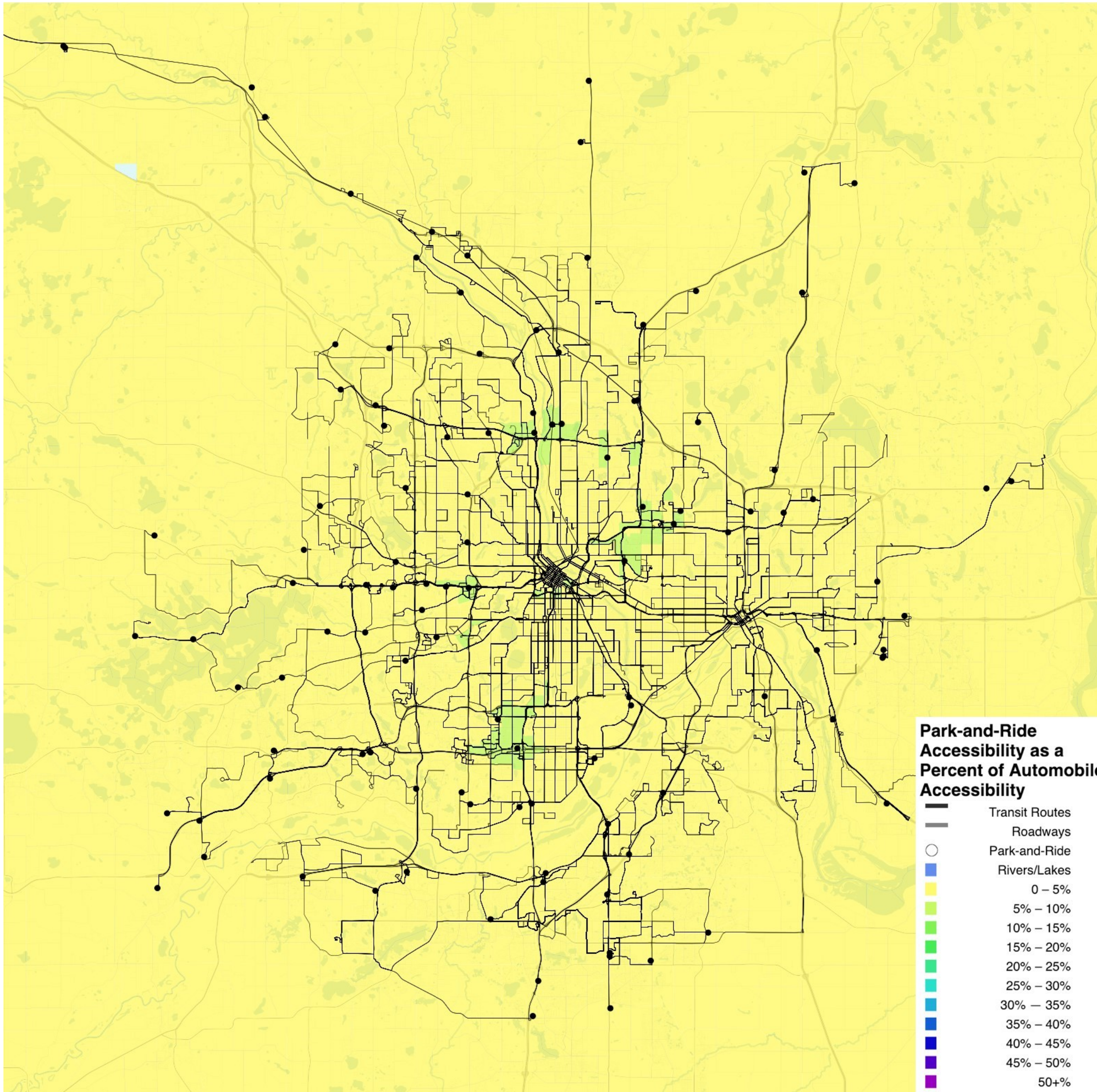

Figure 67 PNR accessibility as a percent of automobile accessibility within $25.00 of travel for Scenario B monetary criteria in the Minneapolis–St. Paul metropolitan area.