

Accessibility Impacts of Bus Access to Managed Lanes

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Dedication

Thank you in earnest to the family and friends that offered encouragement at every step of my academic journey.

To the father that taught me “mind over matter” and the mother that taught me “life isn’t perfect.”

Abstract

This research introduces a method to measure changes in transit accessibility resulting from adjustments in bus-highway interactions. Operational differences between general purpose (GP) and managed lanes (ML) are measured using average travel time. Changes to transit travel time are systematically introduced to General Transit Feed Specification (GTFS) data through the use of the StopTimesEditor computer program developed for the purpose of this analysis. The methodology is tested on two express bus routes in the Minneapolis - St. Paul region (Twin Cities). The change in operating speed along portions of the selected transit routes is translated to changes in the job accessibility of the surrounding communities. The percent change in the worker-weighted average job accessibility for the area surrounding the transit routes and for the entire metropolitan region are 11.0% and 0.26% respectively. The methods introduced in this study can be used to evaluate the accessibility impacts of different highway operating environments for buses, or estimate the accessibility outcomes of different bus-highways scenarios.

Contents

Acknowledgements	i
Dedication	ii
Abstract	iii
List of Tables	vi
List of Figures	vii
1 Introduction	1
2 Accessibility	2
2.1 Calculating Transit Accessibility Using GTFS Data	3
2.2 Contribution to the State of Practice	4
2.3 Operating Environments	5
2.4 Summary	9
3 Methodology	10
3.1 StopTimesEditor Program Logic	10
3.2 StopTimesEditor Inputs	11
3.3 StopTimesEditor Update Methodology	13
3.4 StopTimesEditor Output	15
3.5 Program Assumptions and Implications	16
3.6 The Localized Case for Managed Lane Accessibility Analysis	18
4 Managed Lane Test Scenario	19
4.1 Data Sources	19
4.2 Test Setup	20

4.3	Test Scenario Results	30
4.4	Potential Enhancements	46
5	Conclusion	47
References		48

List of Tables

1	Nomenclature for mathematically describing the travel time estimation process applied by the StopTimesEditor.	14
2	Aggregate values of speed for Interstates 35W and 94 from 7–9 AM on October 5, 2016.	25
3	Worker-weighted average accessibility compared for the seven-county Twin Cities region and the impact zone.	46

List of Figures

1	The work flow and inputs needed to use the StopTimesEditor program.	11
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).	13
3	Metro Transit routes 156 and 852, speed increased to 104 km/h (65 mi/h) along highlighted links.	22
4	An example of the input file created for quantifying route characteristics—showing Metro Transit routes 156 and 852.	22
5	An example of the configuration file created for testing speed changes—showing Metro Transit routes 156 and 852.	23
6	An example of the log file created by the StopTimesEditor—showing Metro Transit route 156 and 852.	24
7	The average speed experienced by I-35W Northbound users on October 4–6th, 2016 from 7–9 am. Compare with average GTFS speed estimate, average AVL speed, and target speed.	26
8	The average speed experienced by I-35W Southbound users on October 4–6th, 2016 from 7–9 am. Compare with average GTFS speed estimate, average AVL speed, and target speed.	27
9	The average speed experienced by I-94 Westbound users on October 4–6th, 2016 from 7–9 am. Compare with average GTFS speed estimate, average AVL speed, and target speed.	28
10	The average speed experienced by I-94 Eastbound users on October 4–6th, 2016 from 7–9 am. Compare with average GTFS speed estimate, average AVL speed, and target speed.	29

11	The baseline average job accessibility within 30 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.	32
12	The ML test scenario average job accessibility within 30 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.	33
13	The baseline average job accessibility within 60 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.	34
14	The ML test scenario average job accessibility within 60 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.	35
15	The absolute difference in average job accessibility between the ML test scenario and baseline within 30 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.	36
16	The absolute difference in average job accessibility between the ML test scenario and baseline within 60 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.	37
17	The percent change in average job accessibility between the ML test scenario and baseline within 30 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.	38
18	The percent change in average job accessibility between the ML test scenario and baseline within 60 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.	39
19	Highlighted census blocks that experience a modest to large change in job accessibility within a 60 minute transit trip due to speed changes along I-35W and I-94.	41
20	The baseline and updated levels of accessibility for travel time thresholds of 30 and 60 minutes are plotted for block A in Coon Rapids, MN. . . .	42
21	The baseline and updated levels of accessibility for travel time thresholds of 30 and 60 minutes are plotted for block B in the Minneapolis CBD. . .	43
22	The baseline and updated levels of accessibility for travel time thresholds of 30 and 60 minutes are plotted for block C in South Minneapolis . . .	44
23	The absolute change in accessibility for a 60 minute transit trip is overlaid by the half kilometer impact zones which extend from transit stops located on routes 156 and 852.	45

1 Introduction

The goal of this analysis is to understand how managed lane (ML) facilities can affect accessibility to jobs using transit. Here, accessibility refers to the number of jobs that can be reached by transit within a given travel time period. Buses operating on highways experience different travel times depending on the type of lane or highway facility they use; these travel time differences translate into changes in users' ability to reach destinations by transit. This study demonstrates the development and use of a new tool which edits transit schedule datasets to reflect buses operating in different types of highway environments. The modified schedules are used to calculate accessibility to jobs, providing an opportunity to evaluate the accessibility impacts of different highway operating environments for buses.

Transit agencies around the nation work alongside state departments of transportation to use highways to carry buses. MLs work by incentivizing drivers to carpool, use lower emission vehicles, and take transit. If not, drivers accept the penalty of congestion or pay a fee to drive a single occupancy vehicle (SOV) in a priced ML. The "transit advantage" arises from the increased speed, safety, and reliability offered by ML facilities.

The Federal Highway Administration defines MLs as, "[Designated] lanes or roadways within highway rights-of-way where the flow of traffic is managed by restricting vehicle eligibility, limiting facility access, or/and in some cases, collecting variably priced tolls [in response to changing road conditions]" [1]. It is increasingly important to understand the effects ML facilities play in reforming the national transportation system. A number of factors including tightening budgets and resources, and advances in technology have shifted priorities from infrastructure expansion to infrastructure management. When the initial conditions are right, converting a GP lane to a ML may improve efficiency of the system while initiating more sustainable infrastructure investments.

Average travel time and speed are the metrics that can relate mobility with accessibility. In total, improvements to transit accessibility come through increased service frequency or speed. Noticeable speed changes cannot be realized when buses travel in mixed traffic. Placing buses in MLs is the primary way to reliably reduce trip travel time. This research looks specifically at the differences in accessibility when buses travel

in general purpose (GP) lanes and MLs. The speed increase afforded to transit vehicles operating in a ML has a compound effect on accessibility because faster speeds enable frequency increases through the recirculation of buses along a route [2]. This potential outcome will not be explored in the analysis, however, it provides a second justification for seeking to understand accessibility impacts of ML operating environments.

The following sections are a synthesis of the current research that supports this interest area. Later, a methodology for updating travel times for bus routes that use ML links is described. The proposed methodology is then applied to a set of transit routes in the Twin Cities. Finally, the impacts due to increased ML speeds are translated to the accessibility change experienced by transit users in the study region.

2 Accessibility

Accessibility measures the ease of reaching valued destinations [3]. It is a function of both land use and the transportation network, and accessibility is greatest when land use and transportation are coordinated. A travel time improvement between locations which contain few destinations would have only a small impact on accessibility, while a travel time improvement between locations with many destinations would have a much larger impact on accessibility. By focusing on access to destinations, accessibility metrics provide a good indication of the usefulness of a transportation system. Owen and Levinson [4] demonstrate that accessibility can be a powerful tool for explaining variation in mode share: in locations with higher job accessibility by transit, residents are more likely to choose transit for their commute.

The distinction between automobile and transit accessibility is clear—their transportation networks are fundamentally different. Transit vehicles operate on relatively fixed paths and schedules while automobiles are free to move wherever and whenever. That being said, transit accessibility is typically a fraction of its automobile counterpart. In the Twin Cities region, the worker-weighted average job accessibility for transit is 1.0% and 5.0% of automobile accessibility at the 30 and 60 minute travel time thresholds respectively [5]. Improvements to the transportation network by way of adding ML capacity will have a greater effect on regional transit accessibility than on automobile accessibility. This research sets the stage for testing and comparing the effects of

managed lanes on accessibility by mode.

Many different formulations of accessibility metrics exist [6]. Accessibility can be measured using fixed buffer regions, Euclidean, or network distances to determine spatial and temporal travel distance (or cost) to the user. This study 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 [3].

The bus-highway interaction methodology put forth is built upon programs previously developed by the Accessibility Observatory at the University of Minnesota. Accessibility is not a static measure. Accessibility changes from minute to minute and from one place to the next. The level of accessibility afforded to an area changes with mode, service frequency, road conditions, weather, etc. All of which can be directly or indirectly accounted for using the Accessibility Observatory Java program Batch Analyst. The Batch Analyst has been in use by researchers and has produced consistent results for spatial and temporal comparison across study regions [2] [7]. The annual Access Across America report provides a framework that encourages repeatability and fair comparison between past, present, and future states of the transportation system. This framework guides the development of new accessibility programs to be used in conjunction with the existing Accessibility Observatory programs. The review of literature informs the structure and adaptability of the StopTimesEditor program. The StopTimesEditor is used with the Batch Analyst for the advancement of the state of practice of accessibility calculations. The program answers questions such as; if a 30 minute transit trip can take a passenger farther than before, how many new job opportunities might that person gain for the same amount of travel time?

2.1 Calculating Transit Accessibility Using GTFS Data

Transit level accessibility is calculated using transit and pedestrian network datasets, origin and destination shape 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 [8] [9]. The Batch Analyst links the graph file with the origin and destination (OD) shape files. 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 [10]. 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 [7].

2.2 Contribution to the State of Practice

Special function highway facilities have not previously been accounted for in the calculation of transit accessibility. MLs were conceived to permit a new operational environment for users of the system. However, the functional characteristics are not typically considered to affect the cumulative measure of accessibility along the network. At the most comprehensive level, average link speeds have been used to measure the destinations accessible within an assigned travel time threshold [5]. The bus-highway interaction methodology proposed herein incorporates the special operating conditions of ML facilities into transit route information. The outcome being updated stop times that reflect changes in operating speed along ML links and a variety of other bus-highway environments.

The role transit plays varies between the urban and suburban context. While urban transit provides essential access to jobs, entertainment, and retail for those with and without a car, suburban transit service mainly offers commuters a second mode choice to alleviate crowded highway and arterial routes [2]. The exploration of suburban accessibility impacts through changes to transit service are important when considering the number of suburban dwellers that may be affected. Many transit routes that serve suburban commuters are considered express routes and are likely to use ML facilities to reduce travel time between suburban and urban origins and destinations.

The GTFS StopTimesEditor program allows for systematic changes to be made to transit schedules for the purpose of testing how link speed affects regional accessibility levels. The program architecture allows the user to isolate transit links, apply speed changes, document the scenarios tested, and reproduce GTFS data for downstream use. The StopTimesEditor program begins to bridge the gap between static accessibility

analyses and the evolving demands of project selection. It is intended for use in the advancement of accessibility measures as a way of conducting transportation network impact analysis. The StopTimesEditor is written in the Python 3 computer programming language.

2.3 Operating Environments

General Purpose Lanes

Before a methodology for altering transit operating conditions can be formulated, the differences between GP lanes, MLs, and bus-only-shoulder (BOS) lanes must be established. Distinctions between these three operating environments can be drawn from federal design standards, academic research findings, and automatic vehicle location (AVL) and loop detector data. It is first necessary to understand the characteristics of GP lanes as they offer a baseline for transit travel times.

A freeway is defined in the Highway Capacity Manual as “[A] divided highway with full control of access and two or more lanes for the exclusive use of traffic in each direction” [11]. These facilities are meant to provide uninterrupted flow. GP lanes are typically accompanied by a shoulder lane or emergency refuge areas for the primary purpose of maintaining safe and efficient throughput. GP lanes allow mixed traffic streams which introduces variability in the lane capacity and the resulting speed. The accessibility values calculated from operating in a GP lane illuminate the impact on accessibility when compared to special use lanes. Probe data allows for the assessment of prevailing traffic conditions and provides a basis for making changes to the operational characteristics of a freeway.

Speed and congestion data taken from loop detector or microwave radar stations on a highway network provide the most accurate trajectory for traffic, including buses, operating in the GP lane [12]. Automatic vehicle location (AVL) data is advantageous for understanding where delay occurs along a route and stop-to-stop runtimes. However, the resolution of the data does not allow for a reliable assessment of access and egress travel time or lane position. For this reason, a comparison of AVL and highway loop detector derived link speeds is needed to characterize the initial operating conditions. The behavioral characteristics of ML and GP lanes vary in their traffic flow, free-flow

speed, capacity, and vehicle type. These elements will not be explored in detail; however, their net impact on travel time is a key factor in relating ML operation to accessibility changes.

Managed Lanes

There are three primary types of MLs in use around the United States, High Occupancy Vehicle (HOV), High Occupancy Toll (HOT), and Express lanes. Improved person-throughput is the main objective of HOV lanes. HOV lanes were first installed on Shirley Highway in Northern Virginia. In the 1970s, HOV capacity was added across the United States in response to high crude oil prices and increasing congestion. Expansion of the HOV system continued into the next two decades. When these lanes are underutilized, state agencies have converted the facilities to High Occupancy Toll (HOT) lanes. The main difference being that single occupancy vehicles (SOV) may use the lane but are subject to a toll depending on the time of day or prevailing traffic conditions. Transit agencies have historically advocated for HOV/HOT lanes and are typically benefactors of the system. Additional forms of HOV/HOT lanes have developed around the nation and are grouped under the term “managed lanes.” These lanes are “managed” through the use of controlled entrance and exit points, vehicle type and occupancy, dynamic pricing (tolling) and a variety of other programs. MLs are one way to improve the transit advantage, increase mode share, and ultimately lower emissions from the traveling public [13] It is known that switching bus routes onto MLs will reduce the congestion that each bus experiences thereby making trip times shorter and more reliable. The marginal effect on accessibility offered by this change is the objective of the analysis presented in this research. With the rise of congestion around the nation, ML facilities have become attractive options for increasing capacity while limiting spending. There are over 130 ML facilities currently in place around the nation [14]. Additional research needs to be conducted to understand the operational performance and benefits offered to society through the investment in MLs.

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 MLs. 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 [15] [16] [17] [18] [1].

The success of a new ML facility depends on the initial conditions of the existing highway corridor. When the proportion of new ML capacity matches the initial proportion of ML eligible vehicles, the resulting travel time differential and mode shift make MLs superior relative to GP lanes [19]. Once a ML is established, other traffic flow relationships must be assessed to ensure that a travel time differential is maintained on the facility. The interaction between congestion on GP lanes and MLs has been shown to affect the speed to flow relationship on MLs. The depth of this interaction can vary depending on the separation type, ML operational strategy, and the number of parallel MLs [20]. A 2012 study by the NCHRP specifically analyzed MLs operating side-by-side with GP highway segments. Sensor data and simulation-generated data were used to develop speed-flow models of MLs, assess frictional effects between lane groups, determine the effect of cross-weaving traffic, and establish performance measures for ML and GP lane highway facilities [21]. Corridors where MLs run parallel to GP lanes have been found to experience a friction effect when the GP lane density meets or exceeds approximately 21.8 passenger cars per kilometer per lane (35 pcpmpl). This density equates to a level of service (LOS) D/E for a basic highway segment as noted in the Highway Capacity Manual (HCM) 2010. The free-flow speed in the ML can be significantly reduced when these adjacent lane conditions are met [21].

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 [20]. Soft buffers include plastic pylons and a variety of striping patterns while hard buffers are generally considered to be concrete barriers. Soft buffers between ML and GP lanes create friction for faster moving traffic in the ML lane, thereby decreasing speeds in the ML lane(s). This finding shows the need to consider separation

type in the modifications made to transit schedules of buses operating in MLs. Federal laws require that vehicles operating in priced MLs drive at speeds of at least 72 km/h (45 mi/h) for 90 percent or more of the duration in the lane [22].

Access and termini points to ML facilities are known to affect performance. The three main types of access are continuous, restricted at-grade access, and grade separated access. Both opening area length and access point density have been investigated by researchers for capacity impacts [23] [24]. The recommendations for spacing between GP on/off ramps and ML access/termini points by these researchers vary due to cross-weave distances [21]. One facility suggestion noted in the literature is that for an express or BRT line operating on a HOV/HOT facility, separate access/egress ramps should be included to limit weaving through traffic [25].

Bus Rapid Transit (BRT)

Much of the literature on bus-highway operation is in regards to bus rapid transit (BRT). Express bus and BRT lines are flexible in where they are placed within the transportation network and come with modest implementation and operating costs. Numerous studies have found that these bus lines offer many economic benefits to the transit agency and improve route configuration [18]. There is general agreement that 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 [18]. A 2014 highway transitway corridor study conducted by SRF Consulting Group for the Twin Cities region found that the juxtaposition of off-line BRT stations and MLs may create excessive weaving in highway corridors where prospective BRT lines had the highest potential of operating [26]. A key finding of the study was that the usefulness of the MnPASS express lane system to future highway BRT lines greatly depends on station types. The configuration and operational differences between BRT and express routes leads to the conclusion that express bus routes are the better test case for understanding ML impact on transit accessibility. Grade separated and exclusive right-of-way for bus operation is not included in this analysis.

Bus-on-Shoulders (BOS)

Based on a 2007 report titled “Bus-Only Shoulders in the Twin Cities,” it is known that BOS use can make the suburban commute via transit faster than personal vehicles along the same path [27]. With shorter trip lengths may come increased accessibility to opportunities. Based on seven case study areas around the country, including the Twin Cities region-TCRP report 151 concluded that “BOS operations have had no discernible affect on general traffic flow [28].” Knowing this helps to single out the accessibility effects by simply comparing the speed in the mainline with the observed speeds within the BOS lane. In recent years, part-time shoulder use has received increased attention. The recently published FHWA guide to implementing highway shoulder use as a traffic management strategy provides information on 14 shoulder use cases around the United States, primarily citing the Twin Cities facilities [29]. The two most common applications of part-time shoulder use are shoulder use for all vehicles, and transit-only use during peak hours [30]. The Twin Cities BOS network is exclusively for the use of transit and metro mobility vehicles as per Minnesota Statute section 169.306—Use of Shoulders by Buses [31]. In most states, the right shoulder is used because it is wider and easier to implement. The capacity of the shoulder lane depends on the width [29]. The 2014 highway transitway study mentioned previously, identified BOS lanes as the optimal running-way for highway BRT lines where inline stations are primarily used [26]. The increased application of BRT and BOS lines provides justification for studying the impacts to transit accessibility by various ML facilities.

2.4 Summary

A review of the literature on highway bus 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 [25]. To inform the development of the bus-highway interaction methodology, the best practices for transit lanes on highways is referenced. Documents include the Minnesota statutes in relation to bus shoulders, and other key governing documents [32] [33] [29] [15] [27] [28] [34]. From this point on, all unique bus-highway facilities such as priced lanes, BOS, dynamic shoulders,

etc., will be referred to as MLs.

The resources that metropolitan regions have spent on MLs should be reflected in the benefit of the users and non-users. Until now, the benefits (or lack thereof) created by ML use have not been considered when measuring accessibility in a region. The FHWA publication titled “Priced Managed Lane Guide 2012” lists nine improvements that MLs offer to the driving public and transit agencies, but accessibility to desirable destinations is not one of the benefits explicitly stated [1]. At the same time, improved mobility is cited by the FHWA in “Managed Lanes: A Primer” as an outcome of implementing MLs along congested corridors [15]. When mobility improves, it is possible for accessibility to improve. Changes to mobility are typically measured by LOS and person throughput, however, these metrics do not define changes to accessibility. Instead, accessibility changes manifest themselves through better land use mix, and reduced average travel time between origins and destinations. This research explores the later by manipulating speeds on highway links across the Twin Cities and analyzing the change in accessibility.

3 Methodology

3.1 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 greater operating speeds for all vehicles, including buses. 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 will 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 travel times between stops downstream of the ML link must be updated. This is the framework of the StopTimesEditor program. MLs are the test case for this program and BOS applications are underway. The following sections describe the inputs and logic necessary for the StopTimesEditor to make updates to GTFS data.

3.2 StopTimesEditor Inputs

Three inputs are needed for the StopTimesEditor program. A copy of the published GTFS, 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.

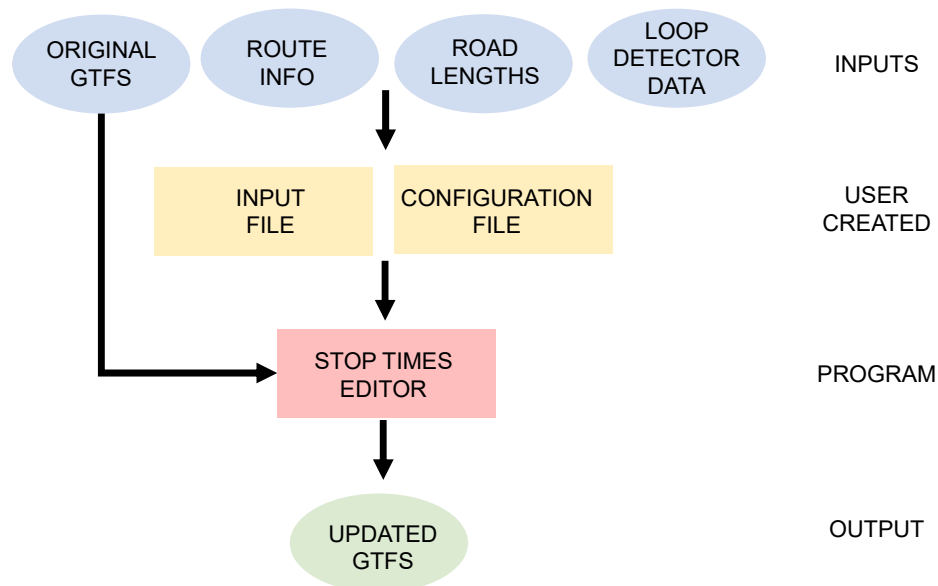


Figure 1: The work flow and inputs needed to use the StopTimesEditor program.

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.

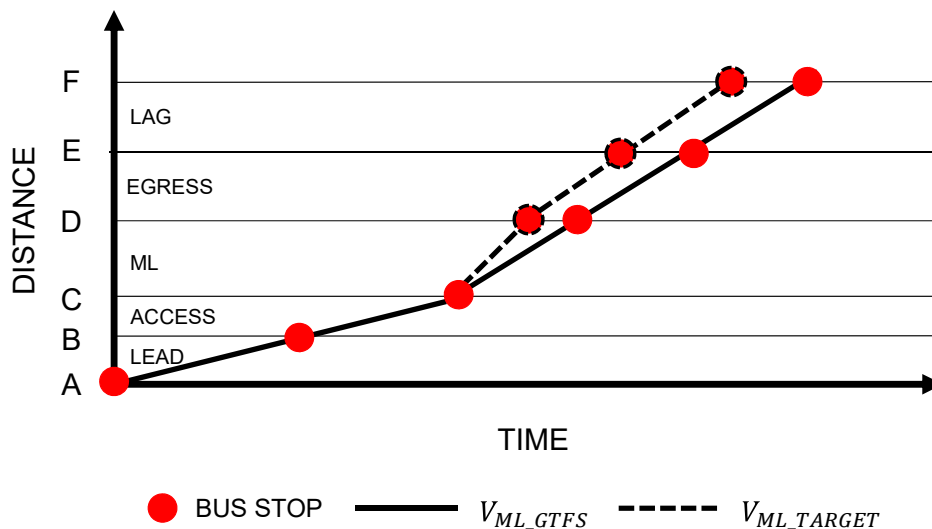


Figure 2: Space-time diagram depicting the difference in travel time due to a change in speed along the ML link (point C to point D).

3.3 StopTimesEditor Update Methodology

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 1–6 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.

$$V_{ab} = \frac{S_{ab}}{T_b - T_a} \quad (1)$$

$$V_{ef} = \frac{S_{ef}}{T_f - T_e} \quad (2)$$

The speeds calculated by Equations 1 and 2 are used as an estimate of the speed on the access and egress links in order to derive the travel time along these links.

$$t_{bc} = \frac{S_{bc}}{V_{ab}} \quad (3)$$

$$t_{de} = \frac{S_{de}}{V_{ef}} \quad (4)$$

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 3 and 4.

$$V_{cd} = \frac{S_{cd}}{T_e - T_b - t_{bc} - t_{de}} \quad (5)$$

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 5 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.

$$\Delta t_{cd} = \frac{S_{cd}}{V_{target}} - \frac{S_{cd}}{V_{cd}} \quad (6)$$

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 (see Figure 4). A comparison is made at every line in the stop times file back to the information stored in the input file. Once a ML link has been identified, the StopTimesEditor applies Equations 1 through 6 and edits the remaining stop times for that trip.

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 (see Figure 5). 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 uniqueness of the StopTimesEditor program comes from its ability to quickly change all trips that match with the route details and time window provided by the user.

3.4 StopTimesEditor Output

In addition to the updated GTFS data produced by the StopTimesEditor, the program generates a log file with enumerated trip details including travel time and speed

estimates. Summary statistics for each route are provided based on the time window specified in the configuration file. The log file provides the user with a way to verify that link information was entered properly through the comparison of estimated link speeds to observed link speeds. Please see Figure 6 in the Test Scenario section for an example of the log file.

3.5 Program Assumptions and Implications

The development of the StopTimesEditor program was accomplished through the iterative comparison of estimated GTFS speeds to other independent data sources. Historical travel time records from August 2016 through December 2016 are extracted from Automatic Vehicle Location (AVL) data and highway loop detector data. AVL data is used to find the average transit vehicle speed during the test time frame between the stops that contain the ML link (Stop B to Stop E). The average speeds derived from AVL data are recorded in the input file and used as the default speeds for access and egress links.

If there is a lack of stop information in the stop times file or the StopTimesEditor produces an unreasonable speed estimate, a default speed replaces the results from Equations 1—2. There are four cases when the StopTimesEditor will apply the default speed. First, if the route does not have a lead or lag stop (Stop A or Stop F). This commonly occurs when express bus routes terminate at park and ride lots. Second, if there is no difference in stop times between Stop A and Stop B and/or Stop E and Stop F. Stops that are spatially close may have the same stop time, thus the speed on that link would be estimated to be infinity. Third, if the recorded stops A or F do not match the stop sequence identified by the StopTimesEditor. This occurs for routes with many different shape identification numbers. The user should record the lead and lag information that best represents the access and egress link operating conditions. Fourth, if the access or egress speed estimate is lower than the default speed. The closer Stop A and Stop B or Stop E and Stop F are to one another, the more likely the speed will be underestimated. The direct relationship between distance and speed in Equations 1 and 2 represents mathematically why this occurs.

The resolution of AVL data typically does not provide information on the duration spent driving solely on a ML, thus only the average speed between stops, not points,

can be determined. An estimate of the Stop B to Stop E link speed can be compared with historic speed data from loop detectors to verify that accurate inputs have been provided to the StopTimesEditor. It can be assumed that the estimated Stop B to Stop E link speed will always be equal to or less than the ML speed. This is because the access and egress links are typically slower than the ML link and they are included in the distance used to estimate link BE speed. There is currently no systematic way to independently check the observed speed on a ML, only relative comparisons can be made. The user should review output from the log file before moving ahead with calculating accessibility.

One reason for the need to review the log file is that some routes have particularly long access or egress links. The longer these links are, the more variability is introduced to the estimate of speed along the ML link. The denominator of Equation 5 is the stage where ML speed is greatly influenced by an overestimate or underestimate of the travel time on an access (t_{bc}) or egress (t_{de}) link. The default speed is provided as a minimum speed for the access or egress link. If Equations 1 through 4 estimate a speed below the default speed, the default speed is applied. However, if the default speed does not truly capture the average speed the transit vehicles travel along the link, the issue is compounded over space and reflected in link travel time. For example, a default speed that is actually slower than the real speed will increase the estimated travel time on the access or egress links thereby reducing the denominator of Equation 5 and inflating the ML speed estimate. The sensitivity of the ML speed estimate to the default speeds and the access and egress distance is an area for improvement in the algorithmic process of the StopTimesEditor and bus-highway methodology.

Once the difference in speed along the ML link is calculated, the time difference is evenly applied to the remaining stop times. The StopTimesEditor checks that time is between 0-24 hours. So trips that run over the midnight hour (e.g. 24:00:00+) are not updated. This is a reasonable simplification as most, if not all, ML use is from 6:00 AM to 10 PM.

The shape identification number listed in each stop times text file marks changes in the sequence of stops or changes in run time along a trip between on and off-peak hours. While the later reason has no implications for the StopTimesEditor program, the former will inevitably invalidate the input text file upon changes to the bus stop

information. Updates to GTFS data will require the user to update the input file to reflect stop changes and distances.

3.6 The Localized Case for Managed Lane Accessibility Analysis

The operational environment of express bus services in the Twin Cities has changed dramatically in the past 25 years with the development of ML and BOS networks. One quantifiable measure of impact is the change in job accessibility experienced by users of express bus services. The previous and prospective accessibility landscape for Twin Cities transit users should be understood for justifiable project selection and performance tracking.

MLs are one way to alleviate highway congestion while conserving resources and budget. The recent construction of the priced managed lane system, known as MnPASS in the Twin Cities region, has resulted in many noteworthy benefits. Segments I-394, I-35W, and I-35E have experienced increased transit ridership, greater travel time reliability, and increased throughput along the selected corridors [35]. Express bus service is especially suitable for utilizing the MnPASS system due to the station placement and managed lane 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 [26]. The FHWA makes three classifications for MLs: pricing, vehicle eligibility, and access control. The MnPASS system incorporates all three 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 [1].

The assessment of transit operation in MLs requires extra scrutiny as the function and form changes considerably across the Twin Cities transportation network. A majority of the MnPASS network is single lane, soft buffer configuration which introduces friction between GP and ML lanes and reduces maneuverability. The reversible section of I-394 between Highway 100 and I-94 is a two lane facility, so it may experience less of the friction effect. Within the Twin Cities region, one-lane ML, two-lane ML and BOS lanes are all in use. There are only two ramp facilities in the Twin Cities that provide separate access for MLs, both along I-394. For this study, the access/egress type to MLs will be considered by setting access or egress specific link speeds through

the StopTimesEditor program.

Due to the variety of MLs in operation around the United States and specifically in the Twin Cities, the effects on accessibility are expected to vary. For instance, HOV/HOT lanes have a minimum speed requirement of 72 km/h (45 mi/h) while BOS lanes have a maximum speed of 56 km/h (35 mi/h). Additionally, the speed differentials between MLs and BOS lanes against the GP traffic are different—only 24 km/h (15 mi/h) maximum on BOS lanes and an agency specific cap on MLs. The StopTimesEditor program is developed to methodically test the variety of operational scenarios that can be found on U.S. highways.

The primary goal for Minnesota-based and national transportation agencies is to relieve congestion and increase mobility in metropolitan regions. The Metropolitan Council of the Twin Cities has placed new emphasis on accessibility. The long-range transportation policy plan cited 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” [35]. The 2040 long-range plan and the Minnesota Department of Transportation (MnDOT) recommend expanding the current MnPASS system. With the explicit outcome of connecting people with employment and retail destinations, accessibility functions as the essential baseline of analysis.

Alternative bus-highway operational characteristics have never been explored in depth with regards to the effects on accessibility to opportunities. The use of active traffic management strategies are on the rise in Minneapolis and St. Paul (Twin Cities) and in the nation. For this reason it is important to investigate the impact of these interventions [36].

4 Managed Lane Test Scenario

4.1 Data Sources

Information about the transit and pedestrian network are gathered from GTFS records published in 2016 and 2017 by Metro Transit, Minnesota Valley Transit Authority, and OpenStreetMap.org [37] [38] [9]. Congestion data are taken from highway microwave and loop detector stations and automatic vehicle location records [12] [39]. Supplemental data about route configuration and land use and worker population characteristics

are taken from the U.S. Census Bureau, Metro Transit, and the Minnesota Department of Transportation for 2014–2017 [40] [41] [42] [43]. The Accessibility Observatory Batch Analyst program is used for calculating transit accessibility levels at the block level (V 0.2.1) [7]. Programs Quantum Geospatial Information Systems (QGIS) V 2.18.6 and TileMill V.0.10.1 are used for database querying and map production. The StopTimesEditor was developed in Python3.

- Automatic Vehicle Location data—Metro Transit 2016 [39]
- Traffic data—MnDOT loop detector data extract program [12]
- Functional Class Roads—Minnesota Existing 2016 shape file [40]
- Transit routes & stops shape files—Minnesota Geospatial Commons 2016 [41]
- Metro Transit Interactive Map [42]
- General Transit Feed Specification—Metro Transit, Minnesota Valley Transit Authority—Fall 2016 [37] [38]
- U.S. Census TIGER 2010 Census blocks—Minnesota Geospatial Commons 2016 [43]
- U.S. Census Longitudinal Employer-Household Dynamics (LEHD) 2014 Origin-Destination Employment Statistics (LODES)
- Accessibility Observatory Batch Analyst program [7]
- Quantum Geospatial Information Systems (QGIS) V 2.18.6
- TileMill V.0.10.1

4.2 Test Setup

The StopTimesEditor and bus-highway interaction methodology is tested on the Twin Cities transit network. GTFS data for the local agencies Metro Transit and Minnesota Valley Transit Authority (MVTA) are used in the analysis [37] [38]. SouthWest Transit and Plymouth Metrolink routes are included in the Metro Transit GTFS data. The

methodology is applied to two Metro Transit express bus routes, namely, route 156 and 852. Route 156 extends from West Diamond Lake Road in South Minneapolis to the Minneapolis central business district (CBD) for a length of 7.69 kilometers. A majority of route 156 is along Interstate 35W South where MnPASS has been in operation since 2009. This section of the I-35W corridor has one ML lane and four GP lanes. The length of ML distance on route 156 is 6.3 kilometers. The posted speed limit for vehicles in the GP lanes is 88.5 km/h (55 mi/h) while the MnPASS lane is priced to maintain a speed between 80.5–88.5 km/h (50–55 mi/h) during the hours of operation. Regular operating hours for the I-35W MnPASS segment used in this analysis are 6 AM–10 AM on weekdays. Route 852 runs from Anoka, MN to the CBD along several minor collectors and on the principal arterial, Interstate 94. Just over eight kilometers of route 852 along I-94 is classified as distance subject to speed changes for simulating ML operation. At its widest, I-94 is five lanes across but reduces to four lanes north of North Dowling Avenue. Route 852 does not currently have MnPASS lanes and the posted speed limit is 96.6 km/h (60 mi/h).

The managed lane test scenario introduces a speed increase along the links of highway shown in Figure 3. The change in speed is applied solely to trips made by routes 156 and 852 for a representative week during the August 31st, 2016 through December 2, 2016 GTFS publication window. Highway speeds are increased to 104.6 km/h (65 mi/h) for trips made between 7–9 AM. Figure 3 depicts each route and the links where speed was changed on I-35W and I-94. Figure 4 summarizes the input file information, Figure 5 summarizes the configuration file applied for this test scenario, and Figure 6 gives a portion of the log file details reported for this test scenario .

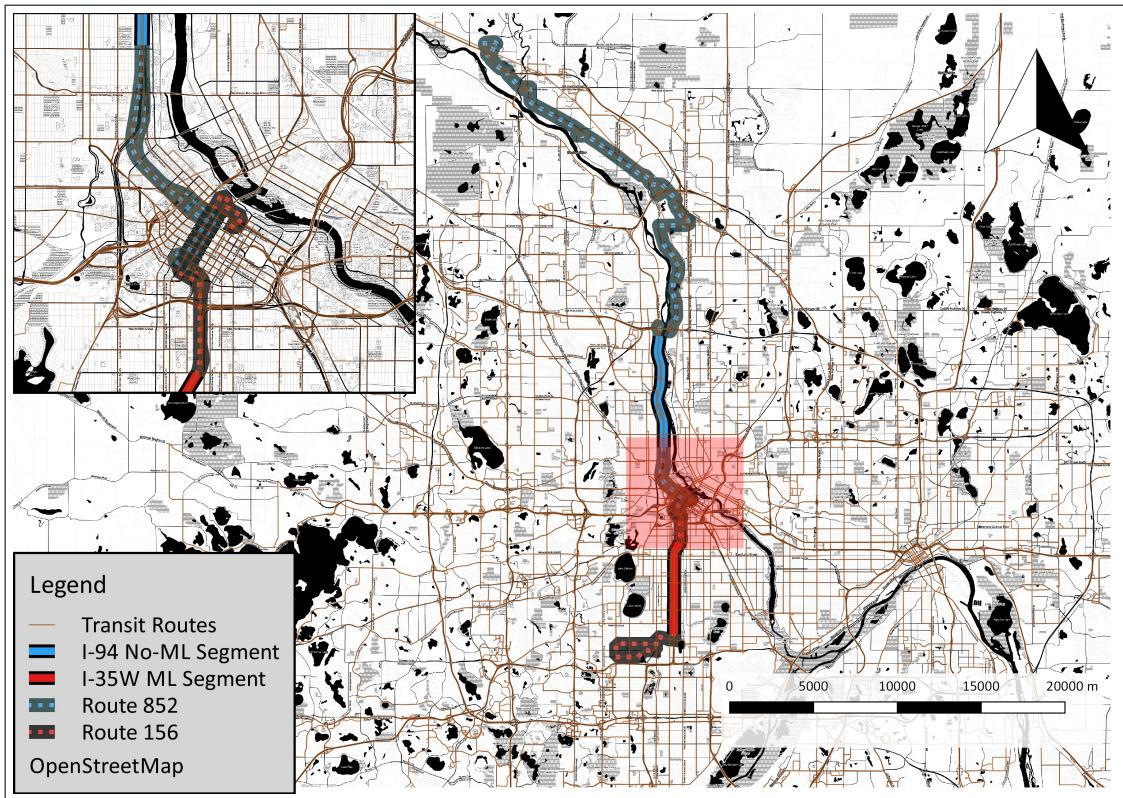


Figure 3: Metro Transit routes 156 and 852, speed increased to 104 km/h (65 mi/h) along highlighted links.

```

route_id,stopA,stopB,stopE,stopF,dir,distA_B,distB_C,distC_D,distD_E,distE_F,segment_id,spdB_C,spdD_E
852-95,12160,12163,17859,17861,southbound,313,2375,8296,1756,276,1,11.9,11.9
852-95,52832,17959,12162,12161,northbound,241,1875,8296,1805,313,2,13.5,13.5
156-95,3388,3391,17780,53315,northbound,304,351,4598,50,2744,3,15.3,15.3
156-95,3388,3391,53315,53316,northbound,304,351,6248,1094,250,4,15.3,15.3
156-95,19335,17781,3392,3393,southbound,2344,220,4506,403,206,5,10.6,10.6

```

Figure 4: An example of the input file created for quantifying route characteristics—showing Metro Transit routes 156 and 852.


```
segment_id,time_start,time_end,link_type,target_speed
1,25200,32400,managed,29.1
2,25200,32400,managed,29.1
3,25200,32400,managed,29.1
4,25200,32400,managed,29.1
5,25200,32400,managed,29.1
```

Figure 5: An example of the configuration file created for testing speed changes—showing Metro Transit routes 156 and 852.

```

RouteID: 852-95
TripID: 9541040-AUG16-MVS-BUS-Weekday-01
SegmentID: 2
Estimated access/egress TT : 138.89 sec, Using speed : 13.5 m/sec : Override: YES
Estimated access/egress TT : 133.7 sec, Using speed : 13.5 m/sec : Override: YES
GTFS speed (m/sec) for link BE: 19.96
GTFS speed (m/sec) for managed lane portion: 25.33846153846154
Target Speed (m/sec): 29.1
Change in seconds needed to get target speed on managed lane portion: -42.32 Direction: northbound

RouteID: 852-95
TripID: 9541058-AUG16-MVS-BUS-Weekday-01
SegmentID: 1
Estimated access/egress TT : 199.58 sec, Using speed : 11.9 m/sec : Override: YES
Estimated access/egress TT : 147.56 sec, Using speed : 11.9 m/sec : Override: YES
GTFS speed (m/sec) for link BE: 15.932051282051281
GTFS speed (m/sec) for managed lane portion: 19.165676567656764
Target Speed (m/sec): 29.1
Change in seconds needed to get target speed on managed lane portion: -147.77 Direction: southbound

9544503-AUG16-MVS-BUS-Weekday-06 changed between stop 3391 and 53315 by -410.85 seconds
9541040-AUG16-MVS-BUS-Weekday-04 changed between stop 17959 and 12162 by -42.32 seconds
9541058-AUG16-MVS-BUS-Weekday-01 changed between stop 12163 and 17859 by -147.77 seconds
9544502-AUG16-MVS-BUS-Weekday-06 changed between stop 3391 and 53315 by -470.85 seconds

Total change in run time for route 852-95 (hours): -0.958338888888889
From 25200 to 32400 for route 852-95, the avg time change (min) per trip was: -1.855
From 25200 to 32400 for route 852-95, the number of trips changed was: 31
Total change in run time for route 156-95 (hours): -4.411041666666667
From 25200 to 32400 for route 156-95, the avg time change (min) per trip was: -7.562
From 25200 to 32400 for route 156-95, the number of trips changed was: 35
Total change in run time between 25200 and 32400 Oclock: -19329.77
Runtime:--- 284.8664698600769 seconds ---|
Total change in run time for this scenario (hours): -5.369380555555556

```

Figure 6: An example of the log file created by the StopTimesEditor—showing Metro Transit route 156 and 852.

Table 2 compares four measures of speed during the test window on October 5, 2016 from 7–9 AM. First, the on-site microwave detection speeds are averaged over the length of the study segment and over all lanes of traffic—including MLs. The microwave detection speeds sample from the population of vehicles traversing the links during the analysis time frame. Second, the AVL speeds are averaged over the length between stops B and E, for October 4th, 5th, and 6th, from 7–9 AM. The default access/egress link speeds for the test scenario are set between 42.7 and 55.8 km/h (27–35 mi/h) in the input file based on the AVL data. Finally, the estimated average ML speed based on GTFS data are shown per link compared to the target speed. As can be seen in Figures 7, 8, 9, and 10, these estimates reflect the conservative approach that transit agencies take

when generating transit schedule data. In general, the GTFS speed estimate coincides with the minimum of the detection speed trend line. Meanwhile, the target speed is set to the maximum of the detection speed trend line. Comparing I-35W, where MLs are in use, to I-94, where they are not, reveals that average transit speeds are higher on I-35W. These data support the hypothesis that transit speed improves along corridors where ML facilities are installed.

Table 2: Aggregate values of speed for Interstates 35W and 94 from 7–9 AM on October 5, 2016.

Link	Detection Avg. Speed	Avg. GTFS Speed	AVL Avg. Speed	Target Speed	AVL Sch. Dev.
Units	km/h	km/h	km/h	km/h	sec
I-35W					
NB	50	33.8	55.8	104.6	130.0
SB	88	NA	NA	104.6	NA
I-94					
NB	107.5	48.4	48.4	104.6	-72.2
SB	95.3	42.7	42.7	104.6	44.6

The speed profile along I-94 and I-35W during the morning peak hour is shown in Figures 7, 8, 9, and 10. The ML test scenario increases the speed along these links by 19.3 km/h (12 mi/h) or about 35 percent based on the average detection speeds. Additionally, the AVL data for the same time period shows that for routes 156 and 852, the average speed and link deviation range between 38–55 km/h and 32–130 seconds respectively. Route 156 does not make any reverse commute trips during the morning peak hour, so there is no AVL or GTFS data available for the test time frame.

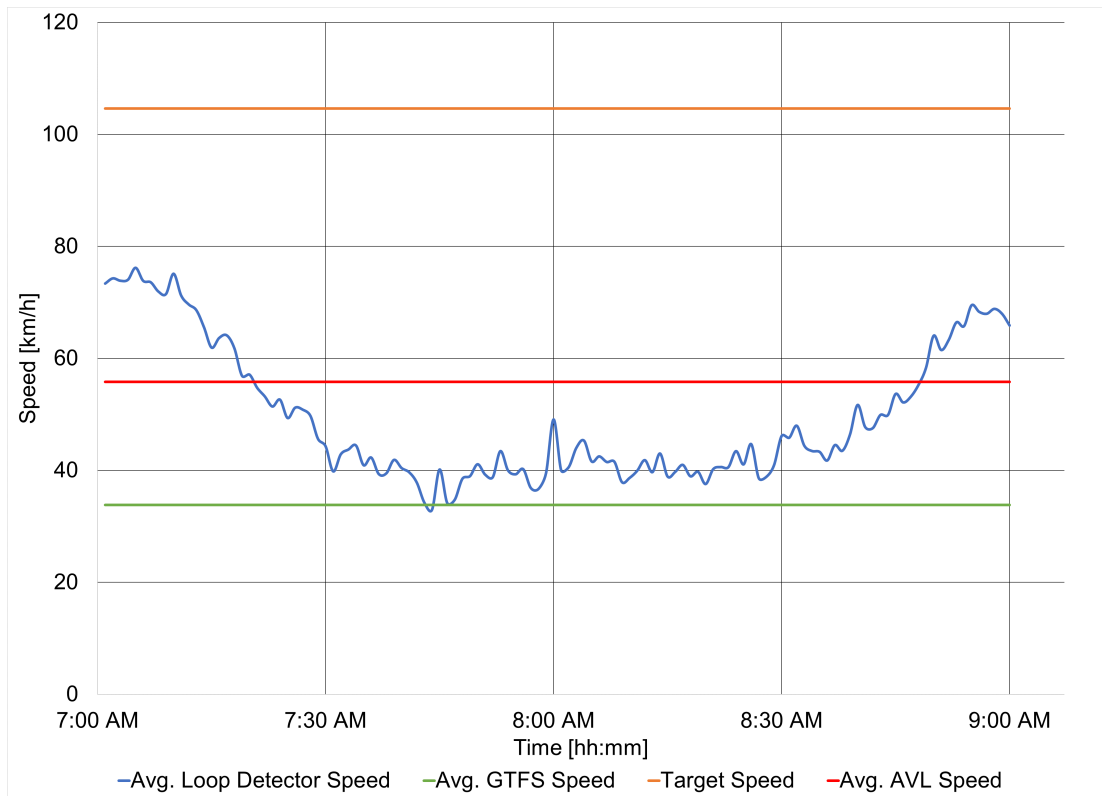


Figure 7: The average speed experienced by I-35W Northbound users on October 4–6th, 2016 from 7–9 am. Compare with average GTFS speed estimate, average AVL speed, and target speed.

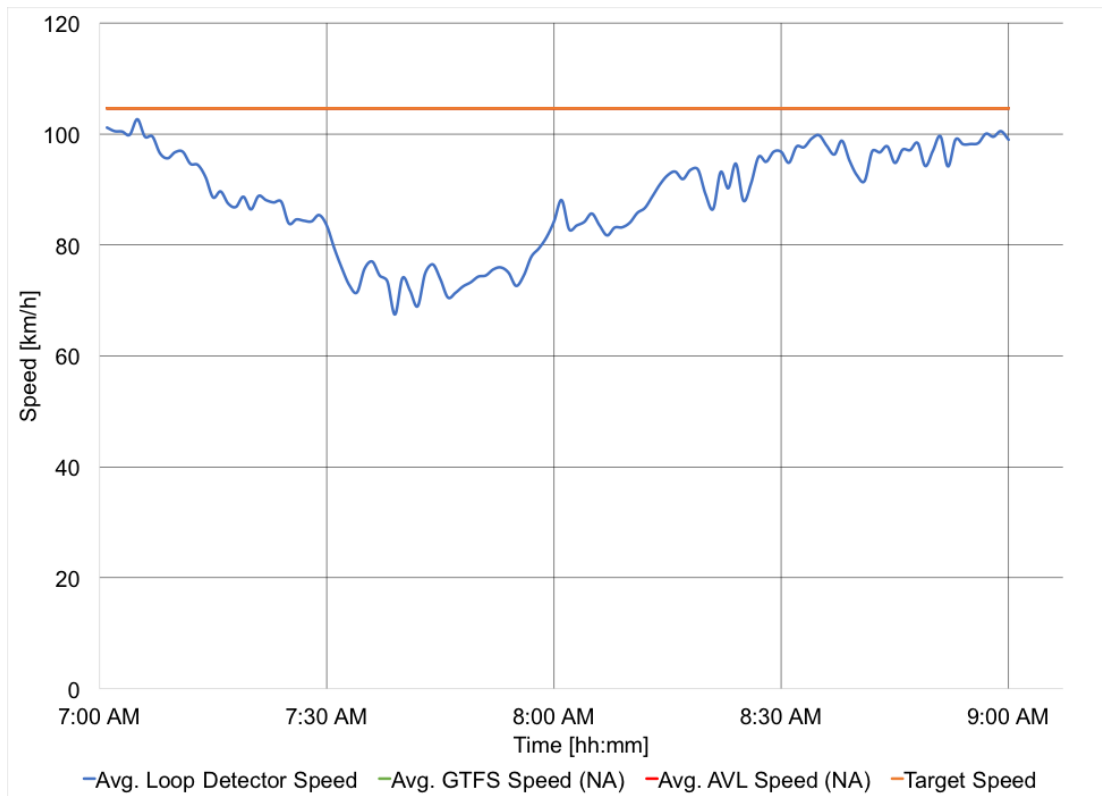


Figure 8: The average speed experienced by I-35W Southbound users on October 4–6th, 2016 from 7–9 am. Compare with average GTFS speed estimate, average AVL speed, and target speed.

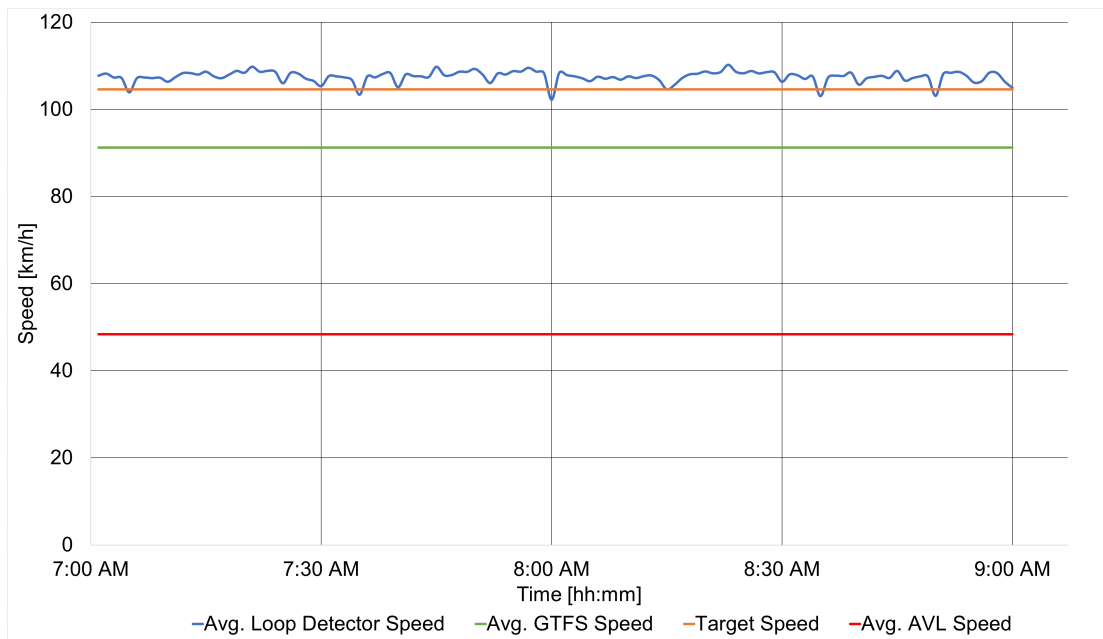


Figure 9: The average speed experienced by I-94 Westbound users on October 4–6th, 2016 from 7–9 am. Compare with average GTFS speed estimate, average AVL speed, and target speed.

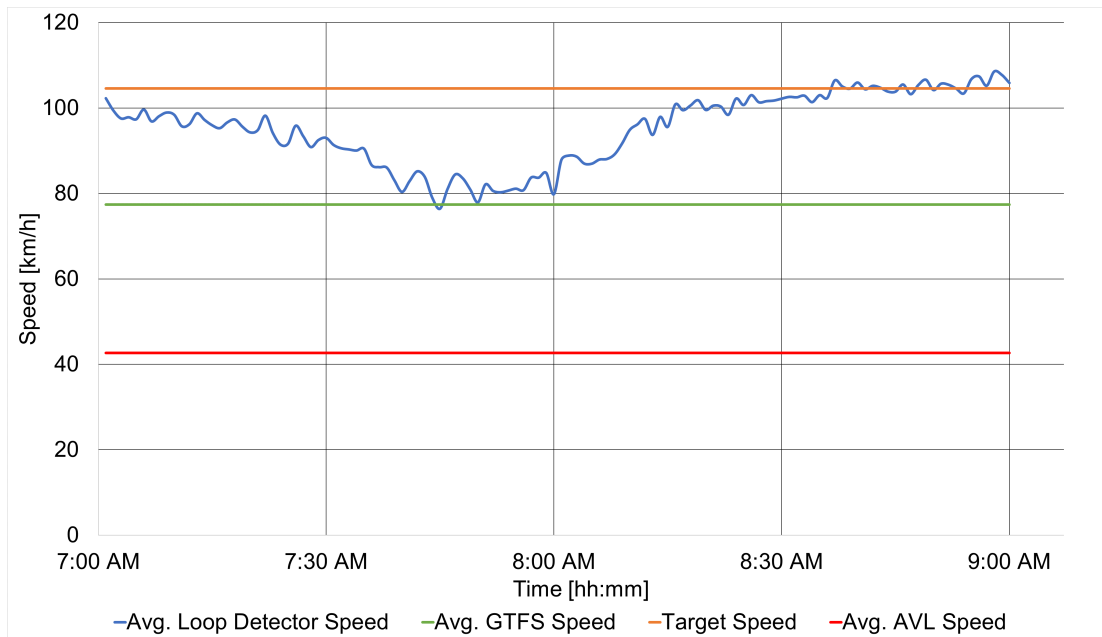


Figure 10: The average speed experienced by I-94 Eastbound users on October 4–6th, 2016 from 7–9 am. Compare with average GTFIS speed estimate, average AVL speed, and target speed.

In separate instances, the original and updated GTFS files are used to build transit graph files for use with the Accessibility Observatory Batch Analyst. Pedestrian network data is extracted from OpenStreetMap.org (OSM) in May 2017 and overlaid on the transit graphs [9]. The following steps are repeated twice, once on the original network and again on the network where the target speed along ML links I-35W and I-94 is set to 104.6 km/h (65 mi/h). A minute by minute full transit schedule job accessibility analysis is performed on the seven-county Twin Cities metropolitan region at the block level. The origin set contains approximately 54,000 census blocks and the destination set extends 60 km beyond the origin set for a total of 108,000 destination blocks. The calculation period is from 7–9 AM on Wednesday, October 5, 2016. This amounts to 120 accessibility values for each block. These values are averaged so that each block has a single job accessibility value that can be plotted and compared.

The raw accessibility values are used to calculate the worker-weighted average accessibility; a single figure reflecting the average level of accessibility experienced by Twin Cities workers. This metric helps to characterize the usefulness of accessibility for the population actually affected by operational changes to transit service. 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 intersect or are within a half kilometer of the transit stops on routes 156 and 852. These zones will be referred to as a singular “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.

4.3 Test Scenario Results

GTFS Changes

The changes to transit service on routes 156 and 852 described earlier are translated to GTFS data using the StopTimesEditor program. As a reminder, route 156 operates on an existing MnPASS corridor while route 852 does not. During the test time frame, the average end-to-end change in run time for each trip was 7.5 and 2.2 minutes for routes 156 and 852 respectively. The estimated reduction in travel time for each trip is found

by applying Equation 6 across the ML link (point C to point D), then carrying that time change through to the last stop in the trip. Twelve trips experienced run time changes during the test time window. The total run time savings for route 156 is 53 minutes, and for route 852 is 11 minutes. This amounts to 1.10 hours of time savings. These diagnostics are recorded in the log file shown in Figure 6. The potential time savings that may be accrued between in-service and dead heading trips provides a rationale for increasing the frequency along these routes. The impacts of higher frequency service are not explored in this research, but remain a plausible outcome of increased transit speeds.

Job Accessibility Changes

The speed increases to the freeway portions of routes 156 and 852 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, Figure 11 shows the state of transit accessibility during the Fall of 2016. Figures 12, 13, and 14 allow a comparison of the raw accessibility values for the 30 and 60 minute travel time thresholds before and after speed changes are made. After the speed is increased to 104.6 km/h (65 mi/h), pockets of the Twin Cities experience notable changes to their levels of job accessibility. Figures 15, 16, 17, and 18 highlight the places in the Twin Cities where accessibility changed during the test time window.

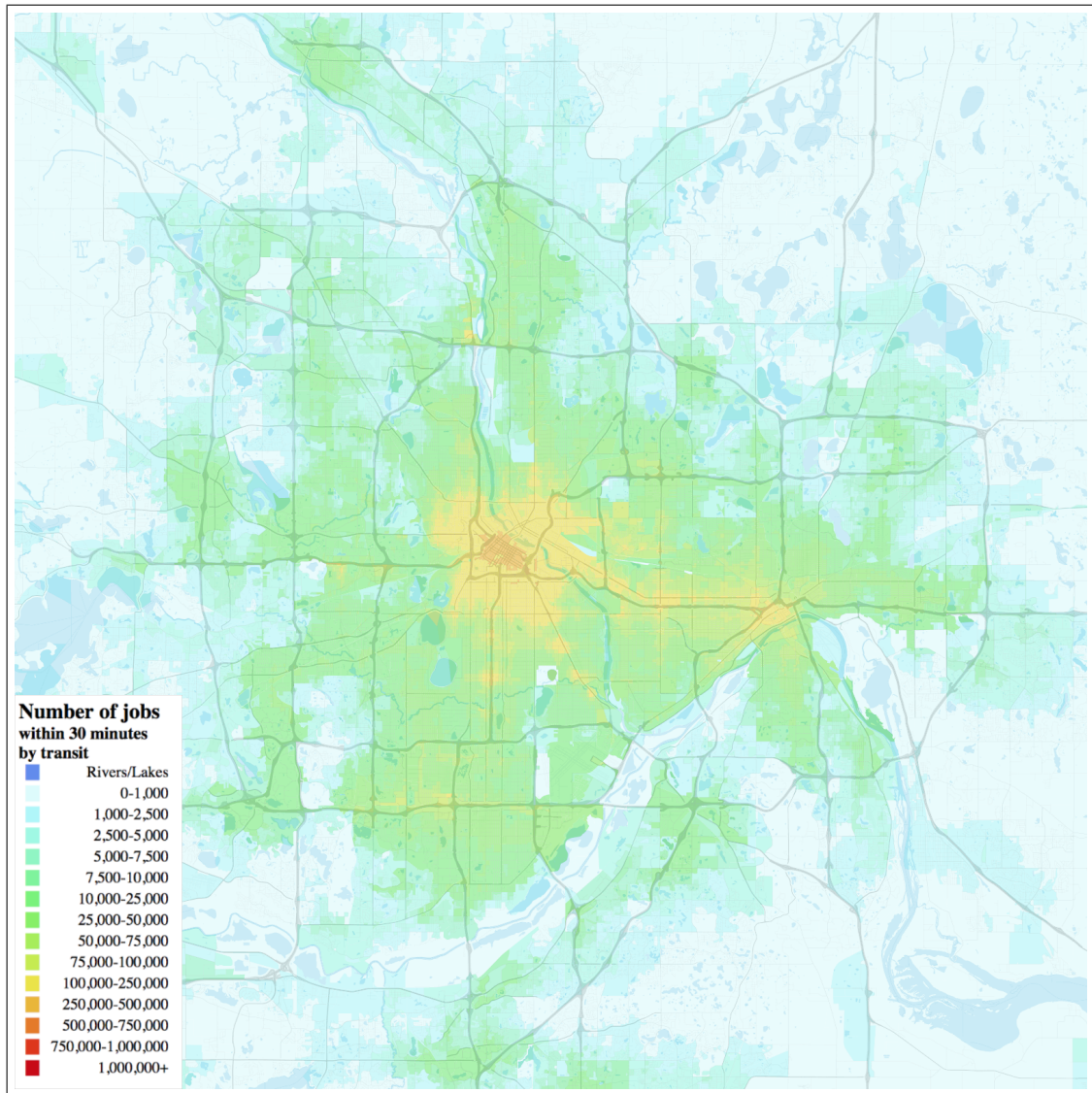


Figure 11: The baseline average job accessibility within 30 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

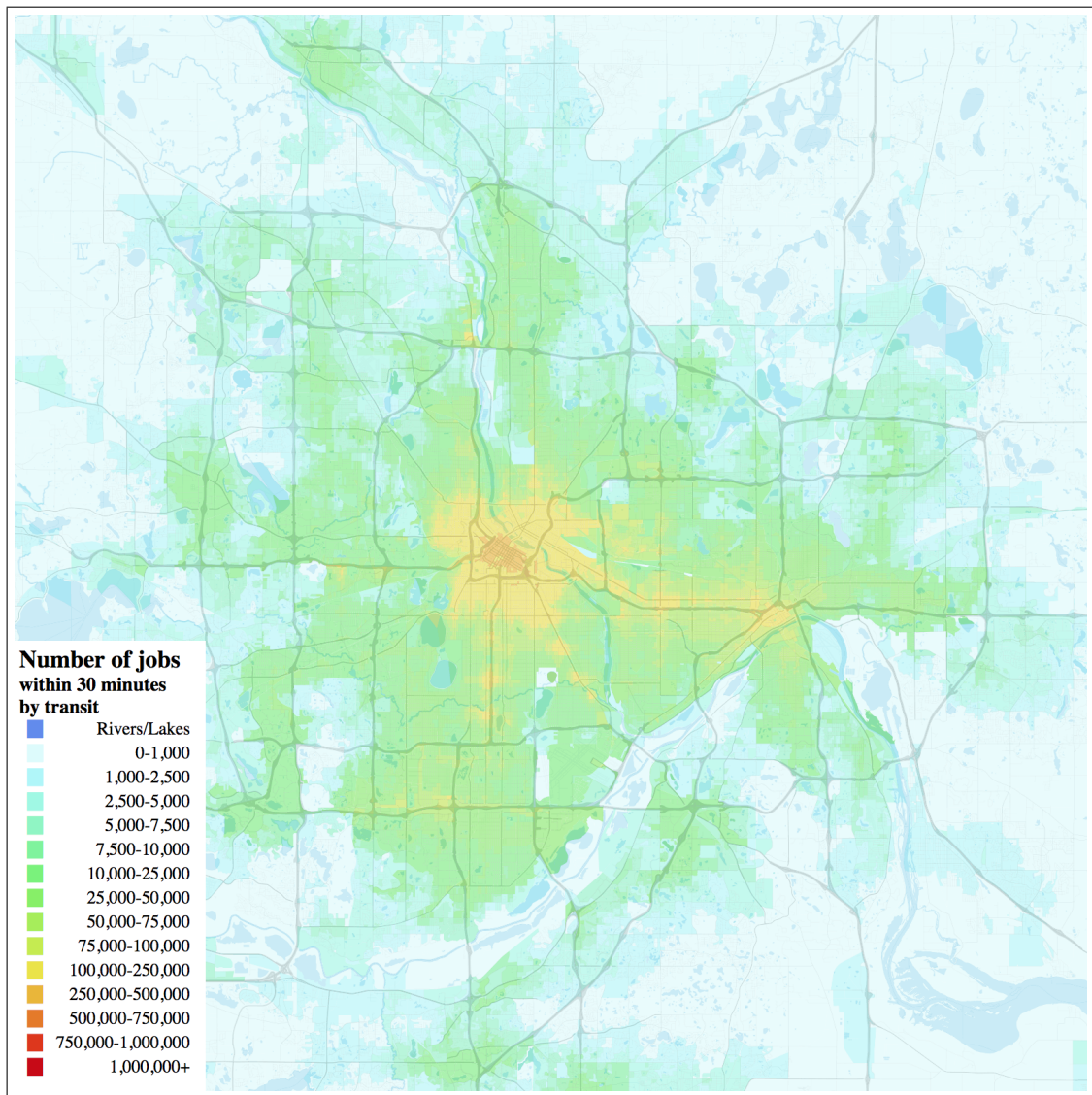


Figure 12: The ML test scenario average job accessibility within 30 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

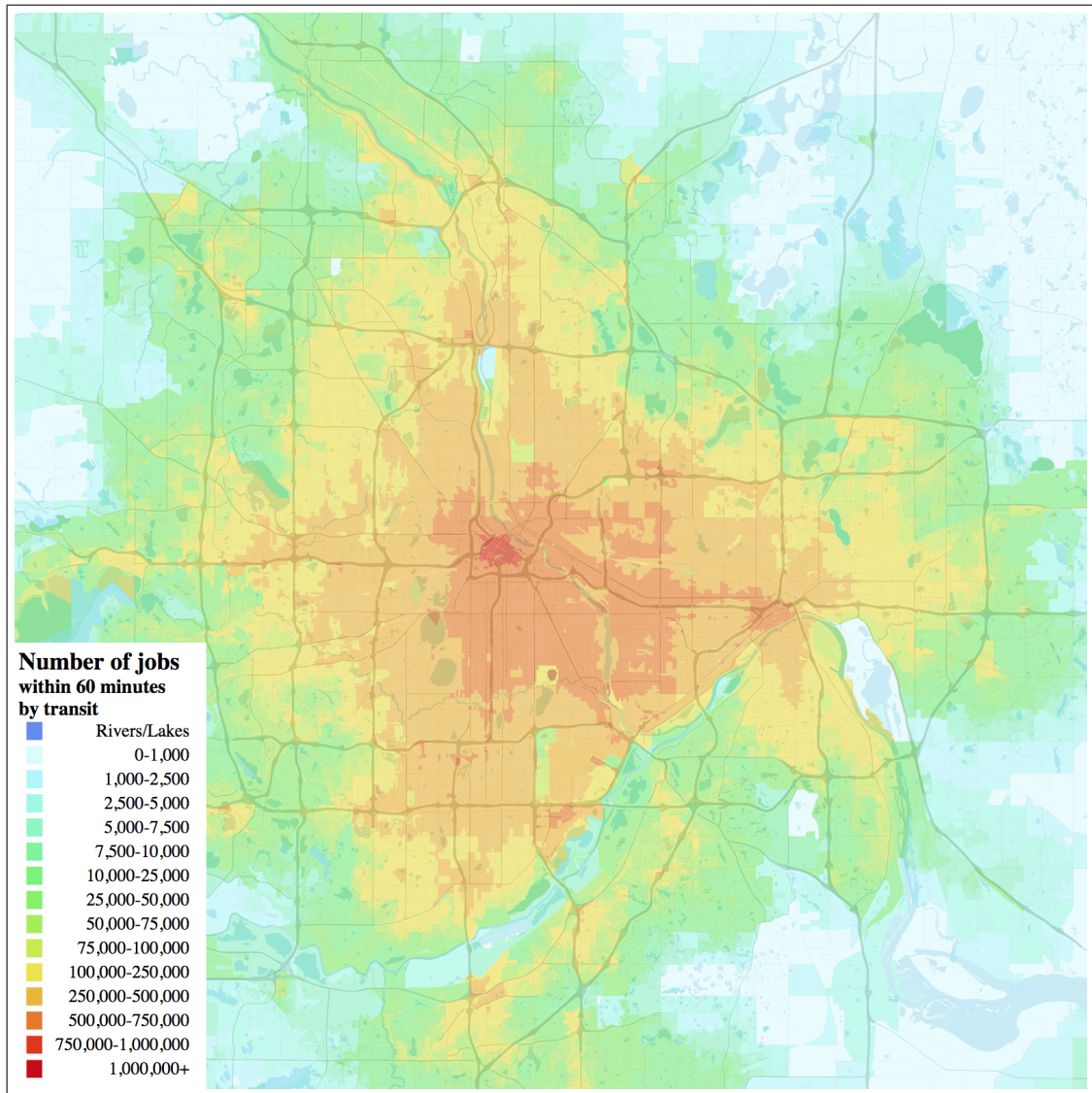


Figure 13: The baseline average job accessibility within 60 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

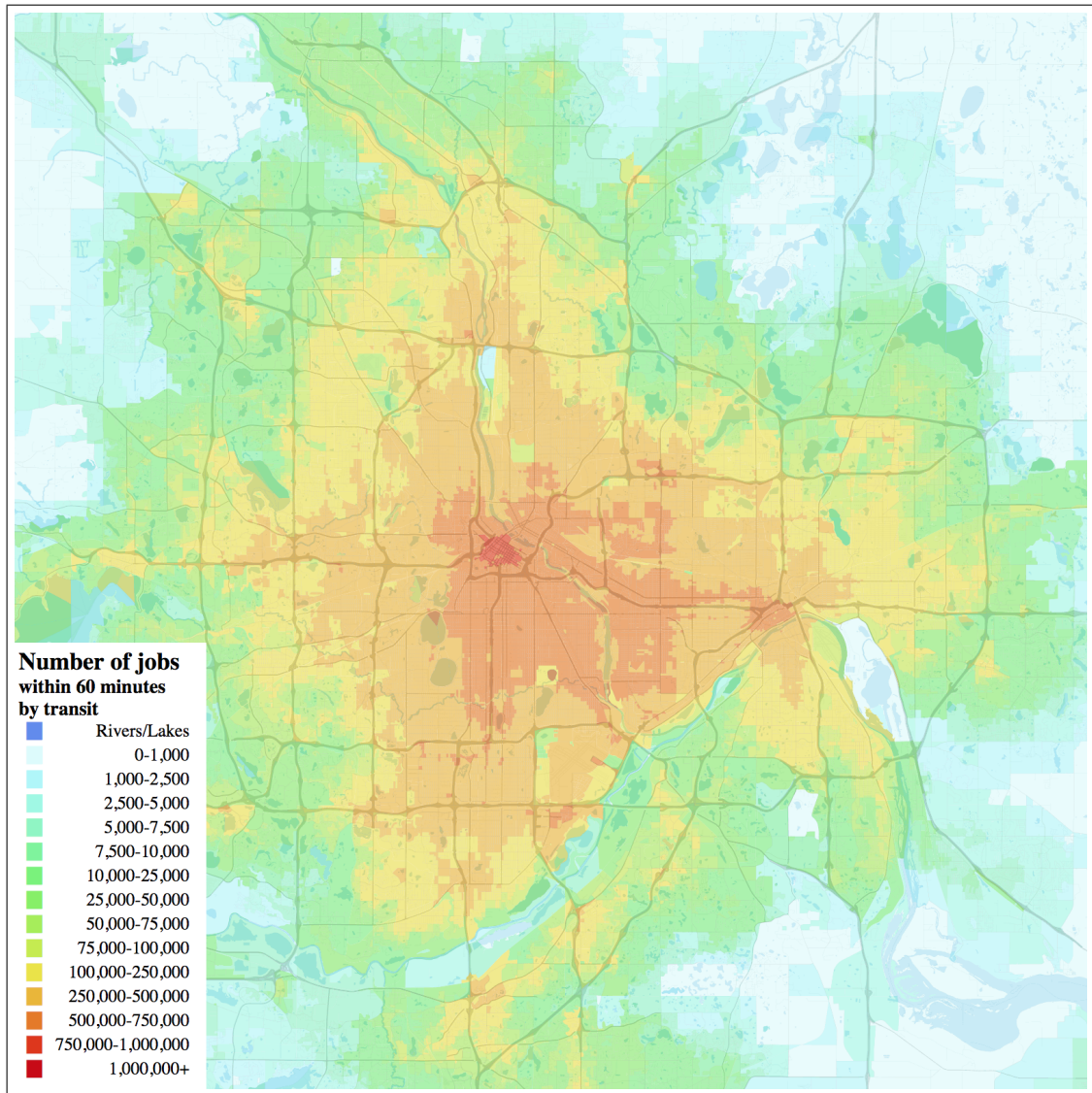


Figure 14: The ML test scenario average job accessibility within 60 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

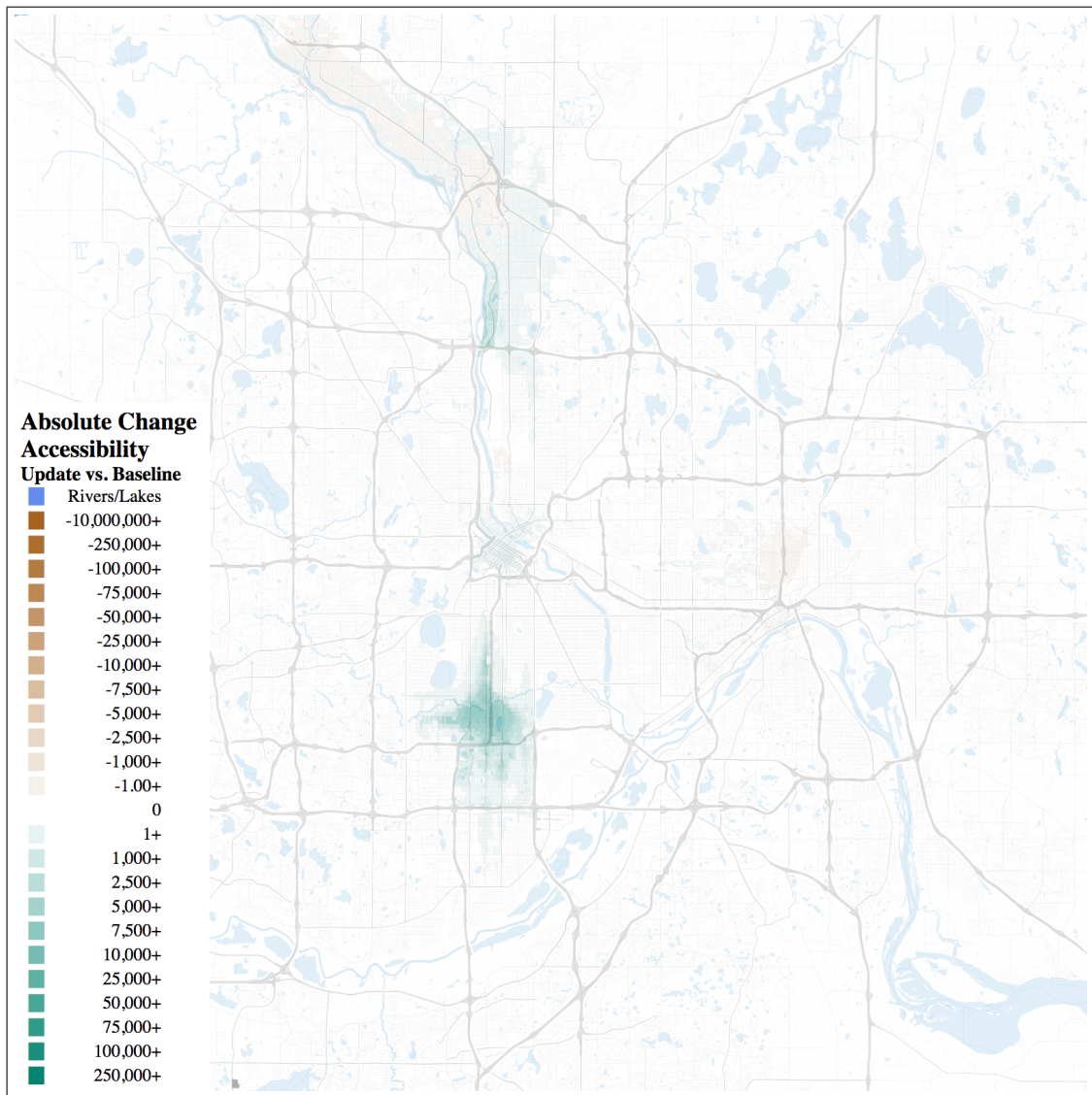


Figure 15: The absolute difference in average job accessibility between the ML test scenario and baseline within 30 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

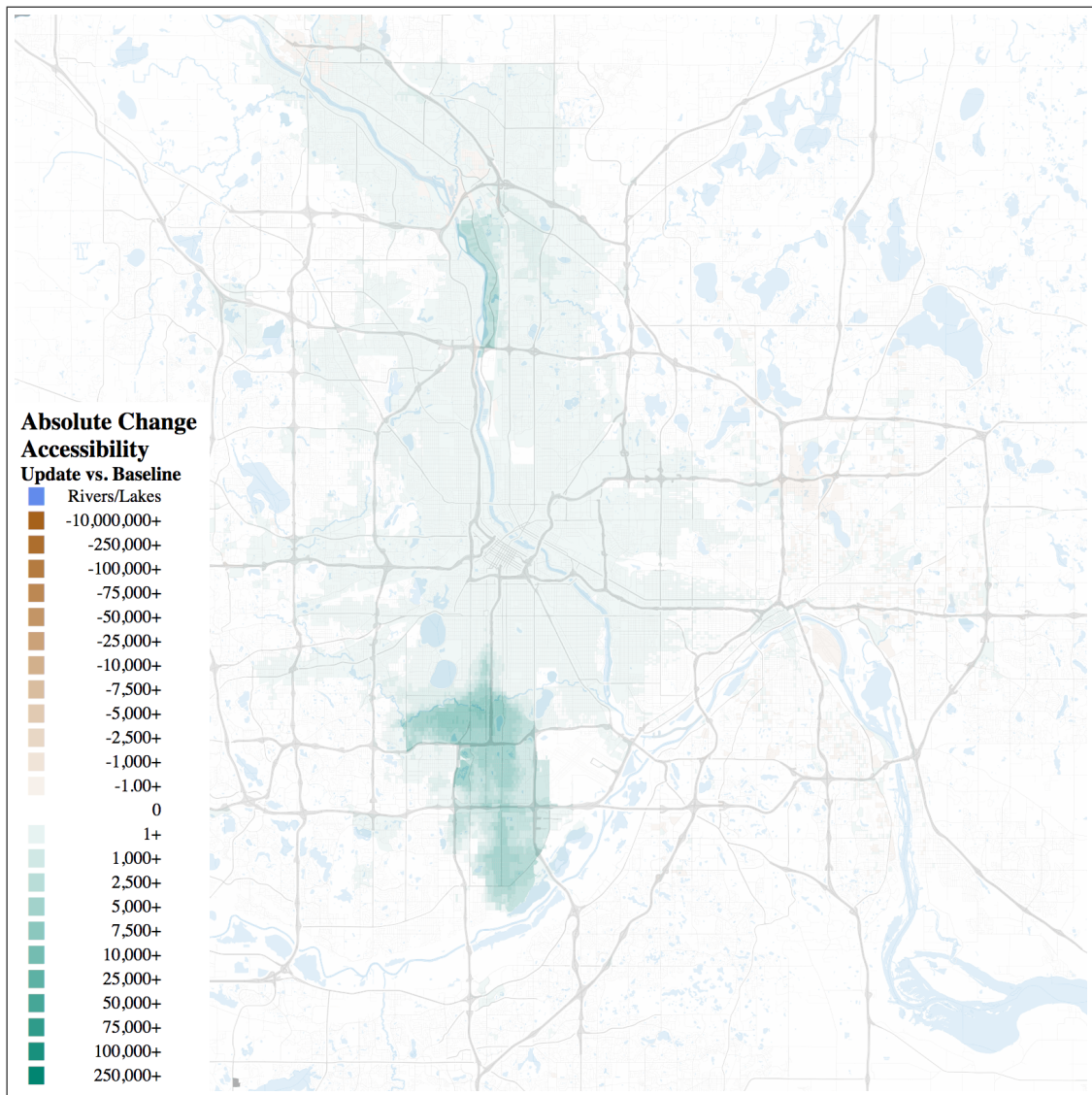


Figure 16: The absolute difference in average job accessibility between the ML test scenario and baseline within 60 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

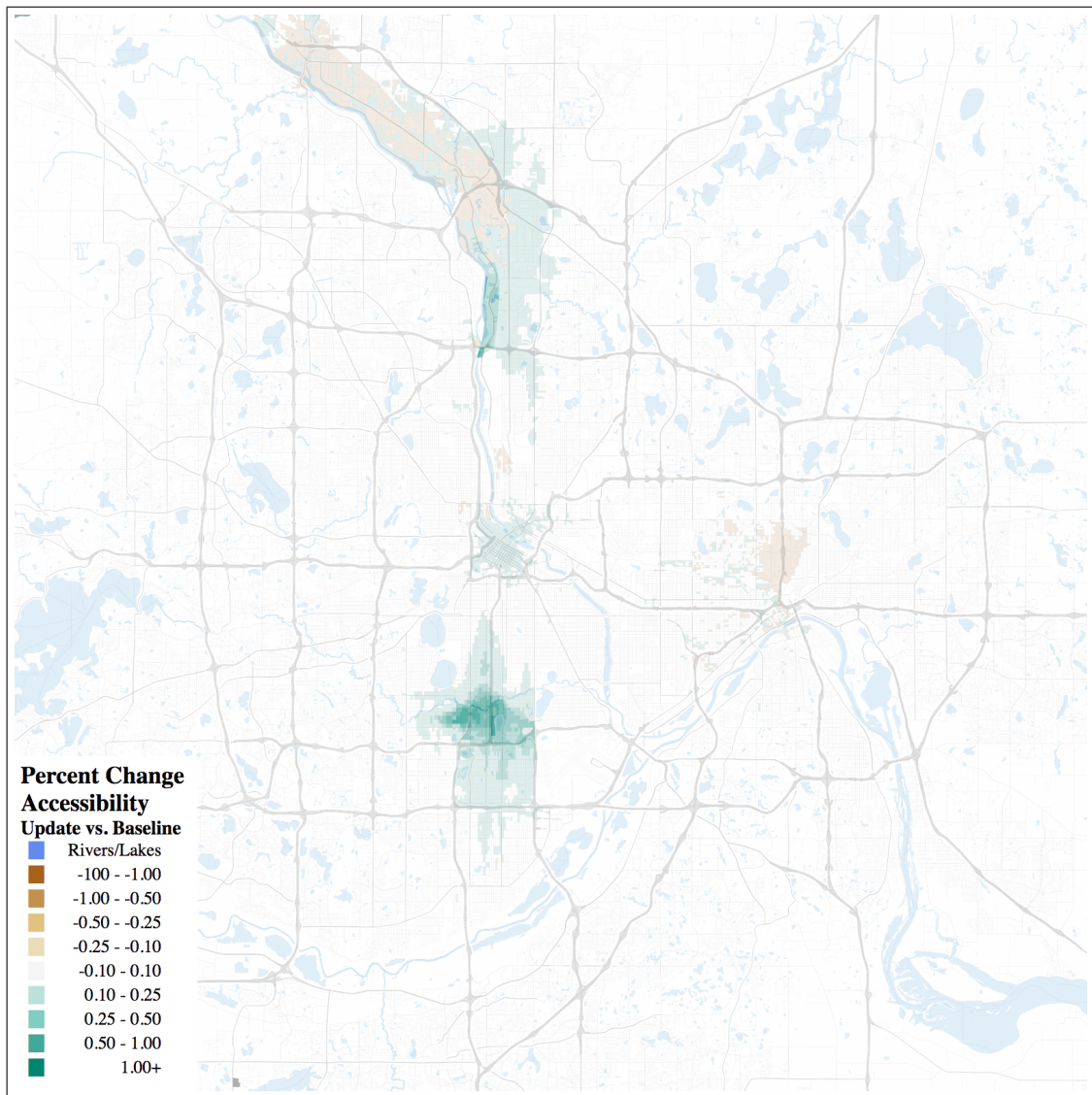


Figure 17: The percent change in average job accessibility between the ML test scenario and baseline within 30 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

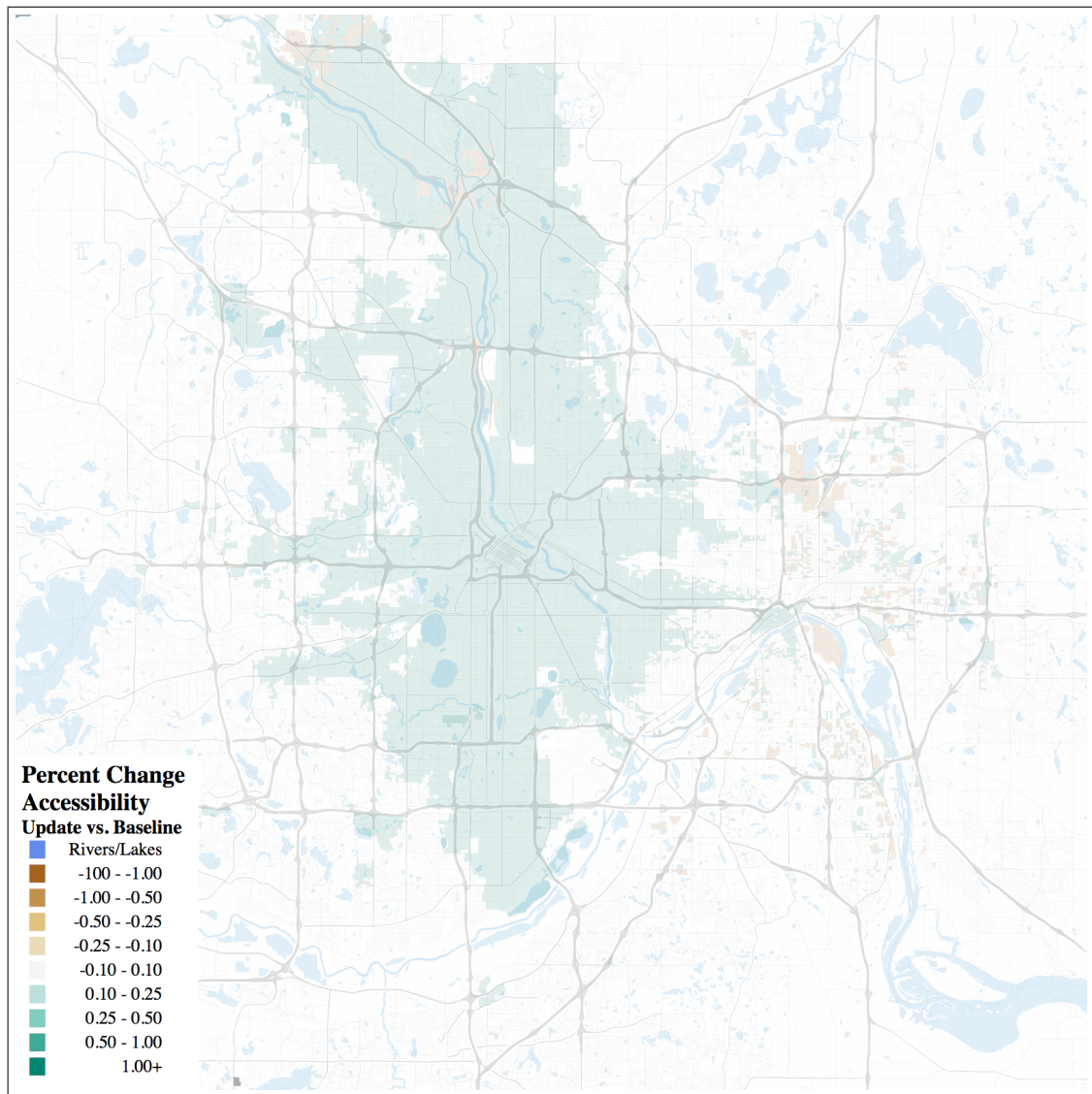


Figure 18: The percent change in average job accessibility between the ML test scenario and baseline within 60 minutes by transit from 7–9 AM on Wednesday, October 5, 2016.

The ML test scenario demonstrates the cascading effects that MLs may have on transit performance and efficiency. The greatest change in accessibility can be seen at the 60 minute travel time threshold and in areas closest to the stops just before and after

the ML link (see Figure 18). The highest accessibility changes are focused 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 ML test scenario resulted in a total time savings of 1.10 hours which can now be used for other legs of the trip, including the egress leg where jobs are accumulated. The redistribution of time manifests itself in increased job accessibility levels for transit users.

A closer look at the impact zone is provided by Figure 19. Three blocks are highlighted from each impacted neighborhood. The minute-by-minute accessibility trendlines experienced by transit users are plotted in Figures 20, 21, and 22. The 60 minute travel time threshold depicts the jump in accessibility resulting from shorter in-vehicle time and longer egress time used to accumulate jobs along walking paths in the CBD. The ML test scenario was 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 two reverse commute trips that route 852 offers during the test time window. 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 by 2.2 minutes for blocks served by route 852.

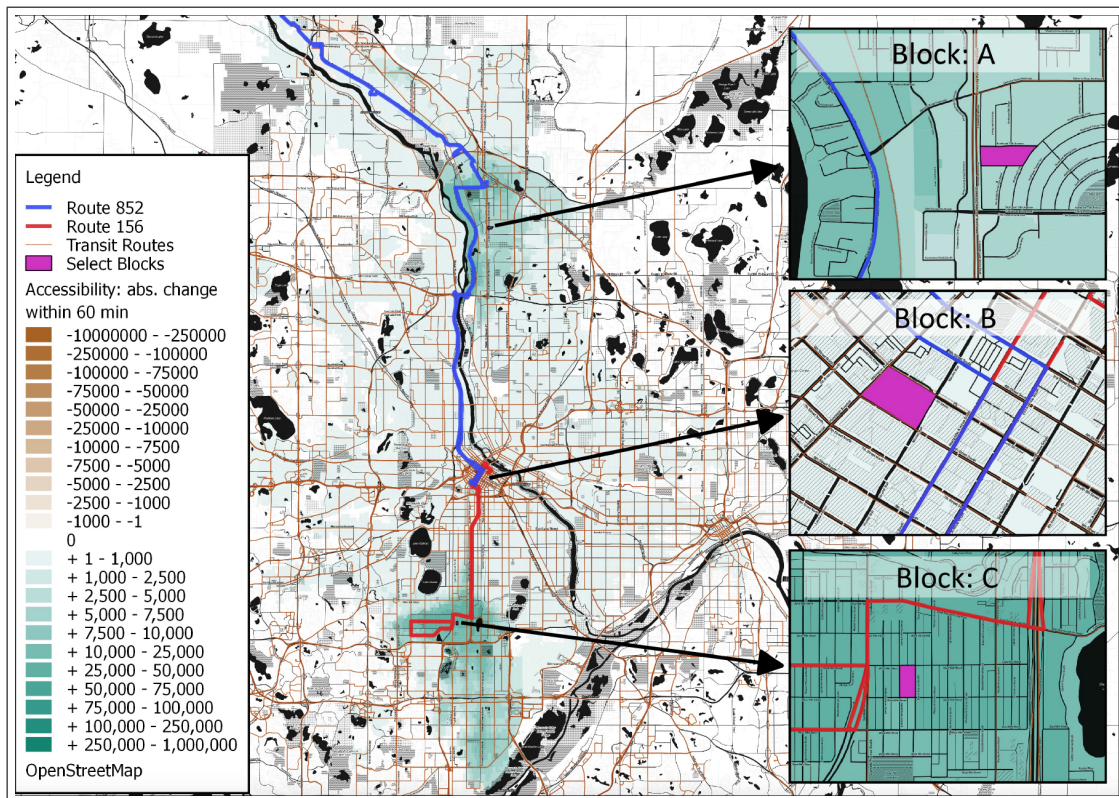


Figure 19: Highlighted census blocks that experience a modest to large change in job accessibility within a 60 minute transit trip due to speed changes along I-35W and I-94.

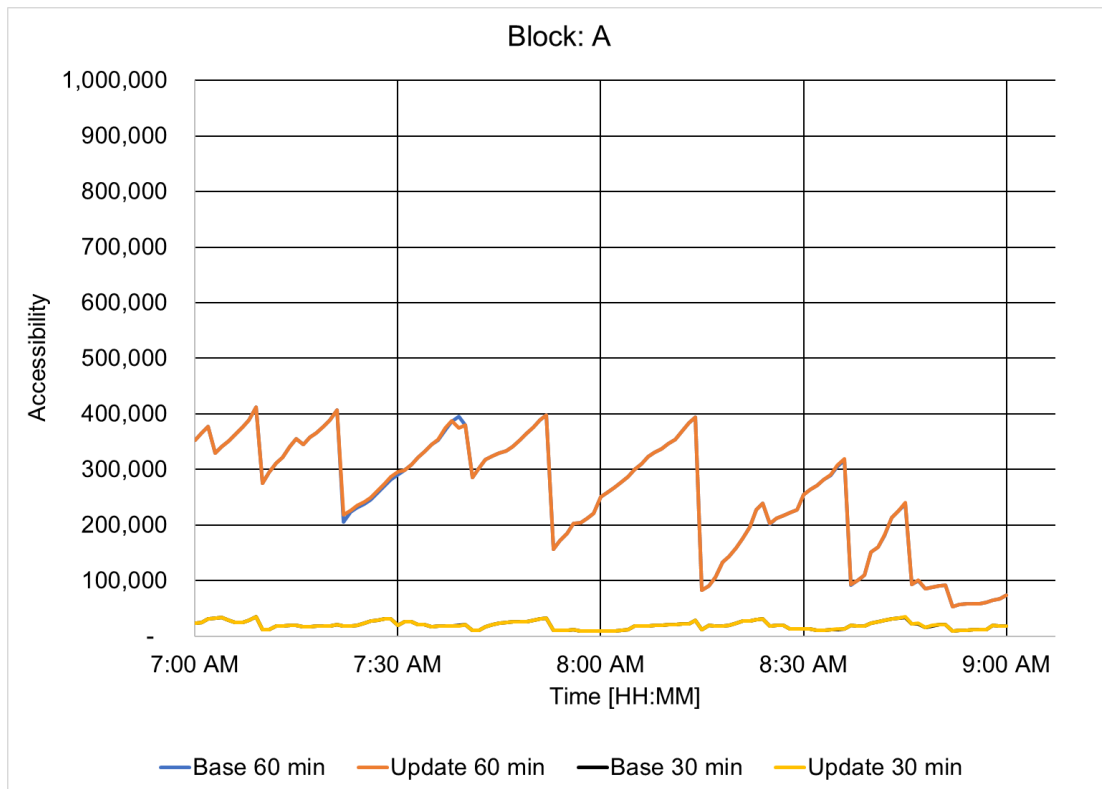


Figure 20: The baseline and updated levels of accessibility for travel time thresholds of 30 and 60 minutes are plotted for block A in Coon Rapids, MN.

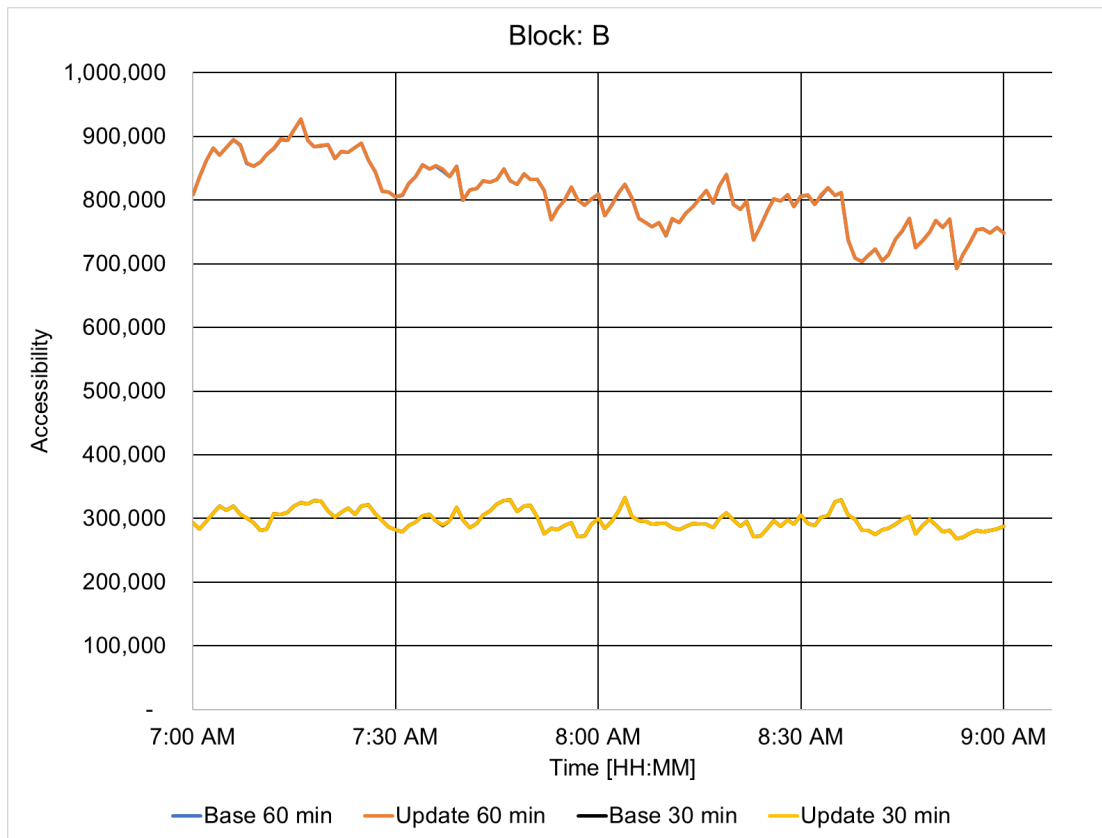


Figure 21: The baseline and updated levels of accessibility for travel time thresholds of 30 and 60 minutes are plotted for block B in the Minneapolis CBD.

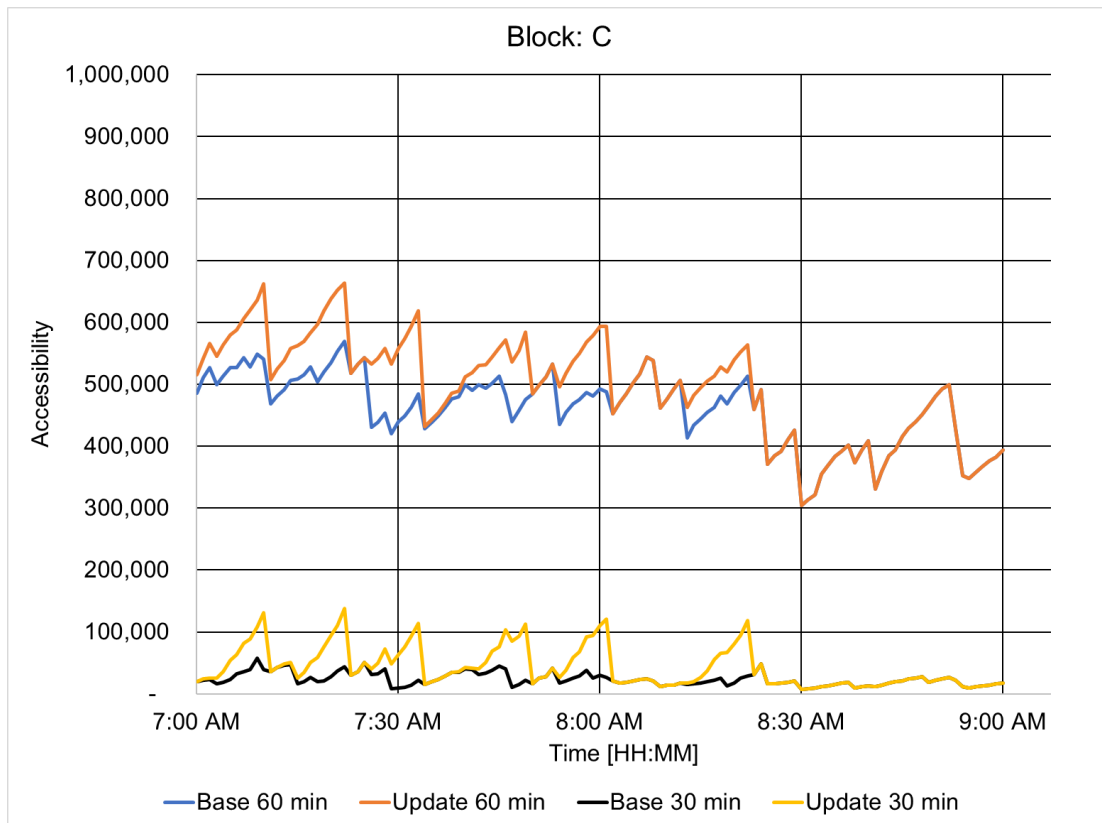


Figure 22: The baseline and updated levels of accessibility for travel time thresholds of 30 and 60 minutes are plotted for block C in South Minneapolis

The worker-weighted average accessibility for the Twin Cities can be seen in Table 3. For the origins located within the half kilometer buffer shown in Figure 23, the absolute change in worker-weighted average accessibility at the 30 and 60 minute travel time thresholds are 3,172 and 7,888 respectively. These values are translated to a percent change of 11.0% and 2.03%. And for the entire Twin Cities region, the absolute change values are 77 and 246 for the 30 and 60 minute travel time thresholds. Again, translated to a percent change of 0.26% and 0.07% 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 ML test scenario. See Table 3 for a comparison

between travel time thresholds and assessment zones.

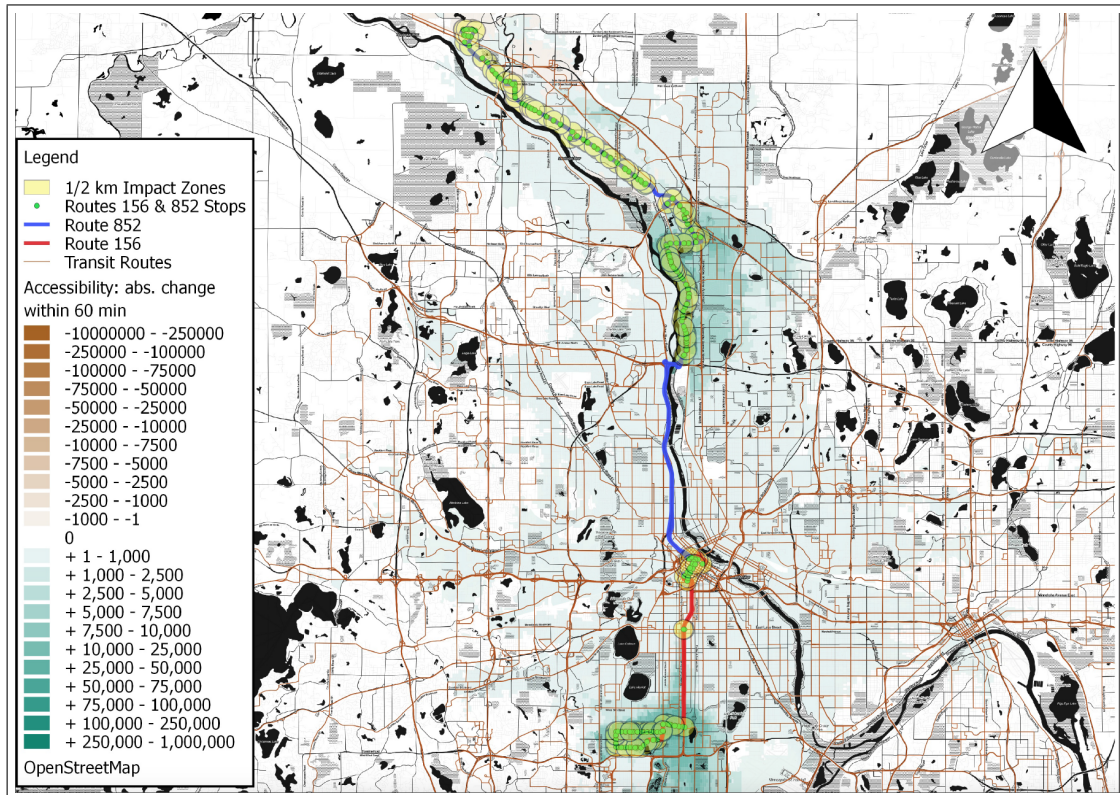


Figure 23: The absolute change in accessibility for a 60 minute transit trip is overlaid by the half kilometer impact zones which extend from transit stops located on routes 156 and 852.

Table 3: 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	62,084
ML Test Scenario 30 min	10,641	65,256
Baseline 60 min	89,702	338,036
ML Test Scenario 60 min	89,947	344,924
Abs. Change 30 min	+77	+3,172
Percent Change 30 min	0.26%	11.0%
Abs. Change 60 min	+246	+7,888
Percent Change 60 min	0.07%	2.03%

4.4 Potential Enhancements

Creating the input file is relatively time consuming and is subject to change with updates to published GTFS. Breaking the network down to the stop and road distance level is inherently tedious if algorithmic methods are not applied. Map matching algorithms may prove useful for widespread use of this program. These algorithms can match the transit network to the road network and break at nodes such as transit stops. Additionally, the estimation of access and egress link speeds is sensitive to the distances provided in the input file. Future versions of the StopTimesEditor program will reduce dependence on human input.

The workflow of the StopTimesEditor assumes that only one link of a trip runs along a ML. In most cases for the Twin Cities, this assumption holds true. For example, route 852 between Anoka, MN and Minneapolis uses Interstate 94 once between the starting and ending stops. No other prospective ML links are used along this route, so the change in total run time is taken only from the I-94 link. On the other hand, route 156 between South Minneapolis and the central business district of Minneapolis uses a mid-highway stop at Lake St. Future build-out of the I-35W MnPASS link would essentially split the ML link in two. At this time, the two-step change in time along a single route cannot be accommodated by the StopTimesEditor. However, the user can reduce the impact of this restriction by using the longest ML link within the trip.

Finally, the order in which the StopTimesEditor updates stop times does not accommodate transfer coordinated routes. The StopTimesEditor currently updates the stop times in a forward fashion, however, applying the time change backwards and considering the inbound/outbound nature of the trip would help maintain the transfer timetable established by transit authorities.

5 Conclusion

This research introduces a methodology and computer program for relaying adjustments in bus-highway interactions to programs that calculate 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 in MLs, the accessibility profile of transit users improves noticeably. The ML test scenario demonstrates the gains in job accessibility that Twin Cities workers experience when express busses are simulated to operate in ML facilities. The percent change in the worker-weighted average accessibility is 11% and 0.26% at the 30 minute travel time threshold for the neighborhood and metro-wide zones respectively. These gains are important for employers, employees, transit agencies, and the broader economy. Future work will include assessment of metro-wide express bus services operating on existing and planned ML facilities. The success of future transit service depends on data driven performance metrics, including access to valued destinations.

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