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Assessing The Potential Of Public Transit Utility In Medium-Sized Cities Using Agent-Based Simulation

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ASSESSING THE POTENTIAL OF PUBLIC TRANSIT UTILITY IN MEDIUM-SIZED CITIES USING AGENT-BASED SIMULATION

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A THESIS

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MASTER OF SCIENCE IN CIVIL ENGINEERING

ABSTRACT

At the beginning of the twentieth century, the United States was leading in the public transit sector, but following World War II, private car trips became more affordable and more popular, specially, in the last few decades. Transportation infrastructure investments that increased road capacity enabled the development of suburbs leading to urban sprawl and increase in automobile use at the expense of reduced public transit ridership. With the increase of dependency in automobiles and the continuing growth of private automobile ownership and use, various problems became major challenges in big cities of USA. These include traffic congestion, air pollution, road and parking infrastructure costs, energy consumption, traffic safety, fewer mobility options for the non-drivers, and decline in the image and use of public transit. However, medium sized cities like Birmingham, Alabama are also facing similar challenges caused by increased automobile trips. According to the Urban Mobility report 2019, an average driver in Birmingham spent 40 hours trapped in traffic congestion in 2017 at a cost for the average automobile commuter of $990/year. Still, 85% of the people drive their own car to travel to work, while less than 1% use public transit for commuting to work. These figures are worse than the national averages that report 76% driving alone and 5% using mass transit to commute to work. Given these discrepancies and the many potential benefits from reduction of automobile use, there is an interest in quantifying potential improvements in local mobility for potential shifts from automobile use into public transit options.

This study uses Birmingham as a case study to investigate the potential of public transit in the medium-sized US cities to reduce automobile trips and in turn improve the overall performance of the road network. An agent-based simulation model was developed for the Birmingham metropolitan region using the Multi-agent Transport Simulation platform (MATSim). Three scenarios were considered with gradually increased transit ridership to identify the benefits of increased public transit. Traffic volume, network average speed, and travel times were used as performance measures for the evaluation of the designated scenarios. Results suggest that modal shifts toward public transit and reduction in travel demand for automobile can result in improvements in speed and travel time for all users. Therefore, investments for improving transit quality and frequency of service as well as campaigns to improve the image of public transit and make it a mode of choice for transportation can increase transit ridership and, in turn, improve network operations, thus are deemed worthy for medium sized cities.

Keywords: Public transit, simulation, traffic volume, ridership, MATSim.

DEDICATION

This thesis is dedicated to my husband Dr. Mohammad Faisal Ahmed who motivated me to go for higher study at the first place. This thesis is also dedicated to my father, Mahmudur Rahman and my mother, Rahima Begum.

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LIST OF ABBREVIATIONS

ABM	Agent-based modeling
ACS	American Community Survey
ALDOT	Alabama Department of Transportation
API	Application Programming Interface
APTA	American Public Transportation Association
AV	automated vehicle
BART	Bay Area Rapid Transit
BJCTA	Birmingham-Jefferson County Transit Authority
Cadyts	Calibration of Dynamic Traffic Simulations
CDC	Center for Disease Control
CNG	compressed natural gas
GDP	gross domestic product
GTFS	General Transit Feed Specification
ITS	Intelligent transportation systems
JOSM	Java OpenStreetMap
MAPC	Metropolitan Area Planning Council

MATSim	Multi-Agent Transport Simulation
MAX	Metro Area Xpress
MTA	Metropolitan Transportation Authority
OTFVis	On the Fly Visualizer
SURE	seemingly unrelated regression equations
TNC	Transportation Network Company
TRANSIMS	TRansportation Analysis and SIMulation System
TTI	Texas A&M Transportation Institute

INTRODUCTION

Background

In the early 20th century, the United States of America led the world in the development and use of public transit, but after World War II, private car became dominant while in the other countries, public transit played larger roles. For the last several decades, the number of private cars have grown more rapidly than the population (Shapiro, Hassett, & Arnold, 2016). Excessive car uses are contributing to serious environmental and urban problems such as traffic congestion and greenhouse gas emissions. For example, 14 percent of global CO_2 emissions by 2010 were solely attributed to the transportation sector (Pachauri et al., 2014) causing 2200 premature deaths and more than $18 billion expenditures in public health in the US (Levy, Buonocore, & Von Stackelberg, 2010). Although, manufacturers are focusing on cleaner vehicles and fuels to address this issue, other proactive measures should now be undertaken to reduce the demand for car travel and control the accumulation of the emissions in the atmosphere (Tao, He, & Thøgersen, 2019). Public transit can play a crucial role in addressing such concerns as it moves travelers more efficiently than the automobile due to its higher vehicle occupancy. It is estimated that emission per passenger mile for buses is only 20% of the carbon monoxide emitted by a single occupant auto. Commuter trains generate nearly 100% less carbon monoxides and hydrocarbons as well as energy used per passenger mile is 23.7% less than an automobile (Delware Department of Natural Resources and Environmental Control, n.d.).

However, the transit ridership in the US remains low. Though public transit received 23% of federal highway and transit expenditure in 2010, it accounted for only 1% of passenger miles traveled. In many communities, especially in the South, public transit availability is limited, and transit primarily serves the transit-dependent populations rather than being a mode of choice for commuting and other trips. Even the second busiest metro system in the United States located in Washington, DC had only 5% of passenger miles traveled (Anderson, 2014). These figures indicate that US remains an automobile-dependent nation. In fact, roadway improvements and expansion of roadway capacity in the recent decades attracted more people to choose private car over traveling by public transit. These trends contributed to further deterioration of public transit service in many locations. Investment in public transit infrastructure as well as improvement of the image of transit service can contribute to a possible shift from private automobile use to public transit. A well-organized transit system with frequent service, reduced wait time and reduced travel time might attract a portion of travelers towards public transit. This investment, in turn, might reduce congestion and environmental impacts of traffic and improve traffic safety (Duranton & Turner, 2011).

Some people perceive automobile trips to be faster than the public transit trips often disregarding the positive impact of transit on traffic operations due to the reduction of the number of automobile trips (Litman, 2020). Moreover, advantages like comfortability, privacy and convenience are immediately available to the car users but the cost behind purchasing and maintaining private automobiles, parking availability and cost, and the inconvenience and risk associated with driving an automobile should also be considered. On the contrary, the disadvantages of public transit like poor weather exposure, longer travel times, and lack of door-to-door service affect travel choices as travelers tend to focus on short term impacts rather than long term ones such as environmental impacts or easing of network congestion (Cools, Moons, Janssens, & Wets, 2009). Good quality transit service is less stressful as well as provides the advantages of resting, writing, reading or working for passengers (Litman, 2008). Given that transit service is comfortable along with the flexibility to work or relax, perceived cost per travel hour can be lower even if the time is not saved (Litman, 2007).

To get the benefit of increased use of public transit, implementing plans like a subsidy policy might be an appropriate approach to start with. A fare subsidy policy might encourage people to use more public transit (Xu, Wang, & Wei, 2018). Also, campaigns that encourage people to consider alternative modes of travel, including transit and shared modes can have an impact in assisting travelers to make informed decisions about their travel options.

Problem Statement

Public transit is also known as public transport, urban transit, mass transit and public transportation. It includes a variety of transportation modes and services such as buses, trains, ferries, vanpools, paratransit etc. which are available to general public (Litman, 2020). Though the population of the United States was doubled from 1957 to 2017 (172 to 326 million), the number of transit trips in these 60 years remained almost similar. Number of transit trips in 1957 was 10.4 billion which was 10.1 billion in 2017.

The development of the US interstate system and the continued expansion of the transportation network infrastructure encourages the use of private of automobiles in the US. Besides the comfort and flexibility of using automobiles, another important reason behind the reduction of transit ridership is urban sprawl. When affordable housing is far away from the job location and is spread in less densely populated areas, transit accessibility becomes limited thus leading to increased automobile use (Blumenberg et al., 2020). Many studies recognize that the increase in dependency on automobile generates various problems such as traffic congestion, road and parking infrastructure costs, parking congestion, excessive energy consumption, less mobility options for the non-drivers etc. Shifting some of the automobile trips to public transit might help to solve some of these problems (Litman, 2020).

The issues related to transit availability and use highlighted above are also present in Birmingham, Alabama. Despite an estimated Birmingham Metro population of over 1.1M , the public transit options are currently limited to a bus transit system that has faced systemic problems of low ridership and lack of resources and revenues. Reasons behind these issues include the unfavorable image of transit use, lack of resources and support for public transit, and limited service availability. Therefore, evaluating the potential impact of increased transit ridership in current condition might help to infer the worthwhile of investment for public transit in medium-sized cities like Birmingham.

Objective

Using Birmingham, AL as a case study, this study aims to investigate the utility of public transit for medium sized cities in the United States. To meet this objective the study undertook the following steps.

- Accumulating literatures on the advantages of using public transit including social, economic, environmental and health benefits as well as the congestion reduction. Documenting the case studies related to the benefits of public transit for improving the traffic performance.
- Establishing a base MATSim model of the Birmingham region without including bus services.
- Simulating the current scenario reflecting current bus ridership on the road network.
- Simulating two other scenarios using the MATSim model with increased bus ridership as future scenarios.
- Comparing the finding to interpret the potential benefits of public transit use in terms of traffic volume, speed and travel time.
- Analyzing a modification applied on the study area public transit route service.

Significance of the Study

This study contains the information on the benefits of bus services. To invest for reliable public transit services with an aim for increasing ridership, it is necessary to understand whether increase in public transit would help to improve the overall transportation network performance. Examining the impact of increased transit ridership on network operations could provide valuable insights about the utility of public transportation and can help decision makers to justify the benefit from a future investment in transit services. Overall, the findings of this study are expected to provide guidance to the public transit authority for their future planning and the findings could be used towards making decision for public transit investment in Birmingham and other medium sized cities where transit services are currently limited.

Thesis Organization

This thesis consists of five chapters. They are introduction, literature review, methodology, results and discussion, and conclusion and recommendations. These chapters are organized as follows.

- Chapter 1 provides the background on the public transit use in the early century, current trend of car use, problem statement, objective and significance of this study.
- Chapter 2 reviews the reasons behind choosing private cars over public transportation, impact of recently entered shared modes on the public transit ridership, case studies on the public transit benefits, history of public transit and current traffic condition of the study area.
- Chapter 3 gives an overview on the agent-based model and MATSim tool, model calibration, describes scenario designs, data retrieval and filter process, and time selection for the result analysis.
- Chapter 4 discusses the results found by analyzing the model outputs.

- Chapter 5 presents the summary of the results, concluding remarks, and recommendation for future approaches.

LITERATURE REVIEW

This chapter discusses attitudes of people towards using public transit as well as the recent impact of shared modes and ride hailing service on public transit ridership based on literature review. Then the benefits of public transit based on past studies are documented. Economic, environmental, social, health and other benefits of public transit are discussed elaborately followed by demonstration of traffic performance change associated with introducing or improving public transit. Finally, an overview on the current traffic condition and public transportation services of the study area is provided.

Attitudes of Travelers towards Public Transit

The main stated reasons for selecting the automobile as a mode of transportation are privacy and flexibility. In addition to the mobility convenience, owning a car can give a driver a sense of independence, power, control, enjoyment and prestige. Automobile ownership and use has become a symbol of pride and an integrated part of modern society (Jensen, 1999). Moreover, a car journey is fully under the control of the driver, who can drive alone or with chosen persons rather than unknown individuals (Cools et al., 2009). These perceptions strengthen the behavior of using car for daily travel and make them unable to avoid their well-established habit (Gärling, Gillholm, & Gärling, 1998). Thus, car ownership creates a strong commitment to use car as well as an attitude to undervalue the alternative transport modes. This tendency biases peoples' choices when they come to transportation mode selection and more often than not keep them away from more environmentally friendly public transportation (Tao et al., 2019). Income is another catalyst towards increase of car ownership and use (Zhang, Schmöcker, Fujii, & Yang, 2016). From 1997 to 2000, the number of cars per 1000 people in 15 European Union countries rose from 451 to 2000. By 2001, most of the people there had at least one car whereas the UK data show that two cars became common to more than 25% of the households. Journey by car became essential even for the teenager aged between 14-16. A quarter of these UK car journeys were under 2 miles, majority of which could be happened by bicycle, bus or foot (Kingham, Dickinson, & Copsey, 2001). According to the 2018 US census, percentage of people without having access to a vehicle is 8.7% (ValuePenguin, 2020)which means over 90 percent of households had at least one light vehicle at their disposal in that same year. However, the percentage decreased to 7% in 2019, resulting in 93% of households in America with access to at least one car (Covington, 2020).

Yet, there are some people who might not choose the private cars for their daily travel because they cannot afford the money needed to maintain cars, some might enjoy to read a book or magazine instead of driving to their destinations, and some might talk and have fun with their colleagues who take the same bus or train. Moreover, lack of availability and high cost of parking in the downtown areas even for the medium sized cities may discourage travelers to use their private automobile.

Despite the advantages of public transit for individual riders and the transportation network operation as a whole, a shift from private automobile use to public transit is not likely without sufficient public transit services. Both the geographic area coverage and frequency of service availability are determinants of transit use. Also, authorities should provide real time information on departure and arrival, maintain frequent and dependable service, provide fleets with comfortable seats, clean and attractive stations, schedule the required numbers of buses/train to avoid overcrowding during peak hours, keep people updated about any route change information, provide a fare structure that is reasonable, and make every effort to maintain a good level of service (Beirão & Sarsfield Cabral, 2007). Initiatives such as introducing higher capacity transit systems, implementing bus lanes, and using intelligent transportation systems (ITS) to increase user convenience and safety could be taken to promote shift from car to public transport (Kamba, Rahmat, & Ismail, 2007).

Incentives for transit use offered by the employers can also increase the motivation towards selecting public transportation over driving alone. A study of 4,630 regular commuters in Washington, DC region showed that employees given free parking benefits with no public transportation benefits were less likely to choose public transportation whereas the choice of public transit for commuting purposes became 11 times more likely when employees were offered only public transportation incentives (Hamre & Buehler, 2014).

A remarkable portion of American people use private cars for their travel because they do not have any other options available. Unavailability of reasonable transit alternatives and the spread of the suburbs in the US are among the reasons behind their driving (Handy, Weston, & Mokhtarian, 2005). Many studies emphasize the need to incorporate transit in the urban development process and provide viable alternatives to automobile use which might reduce the need for driving along with reducing the attraction towards private cars. Providing alternatives such as introducing, expanding, or improving the public transport services could be a measure to promote these goals (Beirão & Sarsfield Cabral, 2007).

Impact of Shared Modes on Public Transit

In the recent years, shared modes were introduced as alternatives to automobile travel in urban markets. Though using shared modes or ridesourcing services offered by Transportation Network Company (TNC) are reducing car ownership, studies indicate that such modes often increase the total number of trips and have negative impacts on transit use. For example, up to 2015, the largest ridesourcing service Uber has conducted 1 billion trips in 6 years period which increased to 2 billion in the next 6 months (Lavieri, Dias, Juri, Kuhr, & Bhat, 2018). Along with increasing trips, they may also cause diversion from public transportation towards them and have adverse impacts on traffic congestion. Lavieri et al. conducted a study using data found from an open source database released by RideAustin in Austin, Texas. The study results showed spatial dependence in TNC-serviced trips among proximally located zones, as well as correlation between weekday and weekend trips originating in a zone. More interestingly, their results indicate that bus frequencies had a negative impact on the generation of TNC-serviced trips during the week, suggesting a substitution effect between TNC services and transit use for weekday trips.

The reduction of transit ridership due to using TNC as substitution is noticeable for the cities with longer TNC operations. An example is the San Francisco Bay Area where TNC has operated longer than any other cities in the United states (Wasserman, Taylor, Blumenberg, & Garrett, 2020). The San Francisco County Transportation Authority partnered with researchers from Northeastern University who developed a methodology for collecting data through TNCs Application Programming Interfaces (APIs) with high spatial and temporal resolution. Despite not having an independent data source to validate against, they were able to quantify the market penetration rate of TNCs in the study area. They estimated that TNCs serve over 170,000 trips on a typical weekday compared to 40,000 passengers served by public transit. Furthermore, they concluded that TNC trips followed traditional time-of-day distributions and were mostly transit substitution trips (Cooper, Castiglione, Mislove, & Wilson, 2018). On the other hand, the San Francisco Bay area lost over 27 million transit riders in 2017 and 2018 which is over five percent of annual riders (Blumenberg et al., 2020).

A report by the Boston Metropolitan Planning Organization surveyed 1,000 travelers who frequently use Uber and/or Lyft. That survey concluded that introducing TNCs in Boston, MA resulted in transit substitution at a rate of 54% with 12% occurring during the morning or afternoon commute periods. The survey also concluded that transit substitution was more frequent among riders with a weekly or monthly transit pass. Thus, those who ride the transit more often are more likely to drop it for TNC services. Metropolitan Area Planning Council (MAPC) researchers surveyed TNC riders about their choice in absence of TNCs. 42% of the survey participants responded that they would take public transit and 12% would walk or take bike (Gehrke, Felix, & Reardon, 2018).

Schaller raised concerns about the effects of TNCs on traffic congestion, emissions, and their potential to undermine public transit and taxi services that are essential components of urban transportation networks in New York. His concerns were based upon the fast-growing market share of TNCs. In 2016, TNCs transported 15 million passengers per month, and the ridership tripled between June 2015 and the fall of 2016. In addition, his analysis indicated that TNCs added 600 million miles of vehicular travel to the city. Furthermore, he proposed a type of road pricing scheme to counter the rapid growth of TNCs (Schaller, 2017).

Beside the ridesharing services of TNC like Uber and Lyft, another service named AMoD (Automatic Mobility on Demand) may also threaten to replace the public transit. This service is a combination of ridesharing service and automated vehicle (AV) technology. The results from a 24 hours simulation (Basu et al., 2018) indicate that AMoD service will be highly efficient by reducing labor costs, emissions, travel time uncertainty, and crashes etc. However, the results also indicate that replacement of mass transit by AMoD will result in heavy congestion as the capacity of a bus is 30 times that of a car, whether it is automated or not.

Impact of Reduced Transit Trips

Congestion is a universal phenomenon which is caused by increased demand for automobile trips, insufficient infrastructure, expansion of freight and delivery services etc. Traffic congestion impacts both social and economic aspects. INRIX, the world leader in mobility analytics and connected car services, published a cross national rankings in its 2018 Global Traffic Scorecard based on the analysis of congestion and mobility trends in more than 200 cities across 38 countries. According to this Scorecard, the top 10 congested cities are European, and the reason was the old road infrastructure, mainly designed for horses. Boston and Washington D.C. are the two US cities who are in top 20 congested cities. In these two cities, drivers spent annually an average of 164 hours and 155 hours respectively due to congestion. Chicago and Seattle are also cited as among the worst cities worldwide with respect to congestion. However, congestion is not an issue affecting only large metropolitan areas. In fact, drivers nationwide waste 97 hours in congestion, and the congestion costs is $87 billion annually in 2018 which translates to an average of $1,348 per driver. In terms of speeds, New York City, San Francisco and Philadelphia have the slowest speeds downtown where speeds average at 9 mph, 10 mph and 10 mph respectfully (Reed, 2019).

Beyond the congestion problem, people in the United States are paying billions of dollars in terms of air pollution, lost time and productivity, and wasted energy. A mobility survey for 494 US urban areas by The Texas Transportation Institute’s (TTI’s) reported that, due to the congestion, Americans wasted additional 8.8 billion hours which made them spend 166 billion dollars for 3.3 billion gallons of fuel. In 1982, wasted fuel per commuter was 5 gallons which became 17 gallons in 2017. The rate of the congestion cost changed by 19% from 2012 to 2017 (Schrank, Eisele, & Lomax, 2019).

Benefits of Public Transit

Environmental Benefits

From 1990 to 2007, CO_2 emissions from global transport increased by 45%. This trend is expected to continue with an expected further increase of 40% by 2030 (Kwan & Hashim, 2016). This prediction indicates that the time has already arrived to put emphasis on sustainable transport systems for the purpose of reducing greenhouse gas emissions.

Sustainable refers to developing a system by which the needs of both the present and future generations can be ensured without any compromise (Burton, 1987). Public transportation can support sustainability by reducing the use of private cars and other motorized transport and their environmental impacts. It transports people collectively and produces 45% less CO_2, 95% less CO, and 48% less NO_2 than private vehicles (Kwan & Hashim, 2016).

Many studies document the impact of public transit toward improving the air quality. For example, hourly air quality data after a rail system opening in Taiwan indicates that CO was reduced by 5-15% and another environmental assessment after rail service expansion in Germany indicates the reduction of pollutants such as NO, NO_2 and CO (Beaudoin, Farzin, & Lawell, 2015). Public transportation systems play a great role in reducing environmental pollution because they burn less fuel per mile traveled or per person transported. Thus, reducing the automobile trips and traveling by public transit reduces the energy consumption per person and per mile traveled, thus improving the environment without any government regulation. It is estimated that if 5% of American used public transit instead of private car or if every American used public transit for 5% of their trips during 1970 to 1998, the CO pollution reduction would be more than all the CO emitted from all metal processing plants and chemical manufacturing section combined (Shapiro et al., 2016).

Economic Benefits

According to a report published by American Public Transportation Association (APTA) in 2009, each year, an investment of one billion dollar use in public transportation capital supports 24,000 jobs. Also, spending one billion dollars in public transportation operations, management and maintenance of vehicles and facilities supports over 41,000 jobs. These jobs contribute to other economic benefits such as, added business output, added gross domestic product (GDP), added worker income and corporate income which in turn add around $500 million federal, state and local tax revenues. These investments might increase mobility and give extended economic benefits as well. If the investment in capital and operations of public transport can shift the use from automobile to public transit, it might reduce the cost needed to afford vehicle ownerships. The reduced travel by automobile can help to reduce congestion that will help to gain business productivity. The report also analyzes the impact on congestion from modal shifts toward transit modes resulting from added investment per year over the period of 2010-2030. Overall, the report shows that for one billion dollars of annual investment in public transportation, there might be more than $1.7 billion dollars of added annual GDP (Weisbrod & Reno, 2009).

Depending on some factors such as mileage reduction, declining vehicle ownership etc., shift from automobile to transit not only helps to reduce consumer cost but rather to provide cost savings (Litman, 2009b). Such shift helps to save fuel and oil, insurance costs, parking costs etc., and can reduce the vehicle ownership per household. The cost savings by reducing vehicle ownership can be about $1300 per household in a city if there exist well-developed rail transit systems (Litman, 2020).

Social Benefits

Available public transit services can be beneficial for the people with low income who cannot afford automobile ownership thus providing ways to travel for work, medical appointments, services etc. It also can reduce the isolation of elderly and disabled persons by offering convenient and affordable service for them. Thus, it increases social and economic opportunities for physically, socially and economically disadvantaged people along with achieving equity objectives. Moreover, it may provide options and value to those who own an automobile currently but might need or choose public transportation for personal, cost, and other reasons as well as during any personal or other community-wide emergencies (Litman, 2020).

The Institute for Transport Studies at the University of Leeds conducted interviews with 912 unemployed people in June-July 2013 and found that 77% of the responders did not own car, van or motorbike. 60% of the sample mentioned that they could not have a better chance in finding jobs without bus services and over a third of the responders felt that improved fare and journey times of the bus services could improve their chances of securing a job (Johnson, Mackie, & Shires, 2014).

Being able to avoid chauffeuring is another important social benefit of public transit. For example, people usually spend lots of time to drop off their children to sport activities or school, any relatives or friends to their destinations, family members to their jobs etc. As these drop-off trips often require additional miles to be driven, they can be inefficient and can become a burden, especially when confliction arises for other important activities. Those undesirable trips can be avoided with transit-oriented development and the availability of quality transit services (Litman, 2009a).

Health Benefits

Public transit is considered as an active transportation mode because it involves walking from and to stations. It can introduce certain physical activity into the daily routine of the users (Wasfi, Ross, & El-Geneidy, 2013). People who live in proximity of good quality public transportation have higher probability of walking, cycling and using public transit rather than depending on automobile (Litman, 2015). This trend not only reduces the automobile trips, reduces crashes, and pollution but also promotes physical fitness and mental health. The automobile dependent residentials have four times more traffic fatality rate per capita than the transit-oriented residential areas. Studies show that, even though more interactions between different modes of transportation take place at transit-oriented development areas or densely urban areas, the crash severity is lower compared to that of lower density areas or areas without transit presence due to low speeds. Thus, transit-oriented communities can contribute positively to the overall traffic safety of a community (Litman, 2015).

According to the US Center for Disease Control (CDC) and prevention, at least 30 minutes of daily physical activity such as bicycling, walking or just working around yard or house is necessary to stay healthy for the adult people (CDC, 2005). An Atlanta, Georgia survey found that transit users tends to cover more daily average distance than the non-transit users. The goal of the survey was to investigate the role of transit and car trips in meeting the recommended physical activity. The results showed that almost two-thirds of the recommended daily physical activity is achieved by the transit users which is ten times greater than the average walking reported by the non-transit users (Lachapelle & Frank, 2009). According to national travel diary data, transit users in the US walk on average 19 minutes each day. Around one third of these transit users reach the recommended level of physical exercise for 30 minutes or more, just based on the walking related to transit use (Saelens, Vernez Moudon, Kang, Hurvitz, & Zhou, 2014).

Centers for Disease Control and Prevention (CDC) suggests that 30 minutes physical activity a day, 5 days a week is enough to provide the necessary fitness. On the other hand, lack of the recommended physical activity leads to numerous health problems such as diabetes, obesity, coronary heart disease, hypertension, and certain cancers which in turn increase annual death and medical cost (CDC, 2005). An interesting finding in relation with cost is that the medical expenses are 32% lower ($1,019 per year) for the adults who achieve the recommended physical activity than those who do not ($1,349 per year) (Litman, 2015). According to another study, 21 minutes of walking can help to burn 65.1 to 98.7 calories and 100 kilocalories burn per day might save $12, 500 dollars per person in obesity-associated medical costs (Freeland, Banerjee, Dannenberg, & Wendel, 2013). These findings clearly show the value of transit in the wellbeing of transportation users, an issue that is often overlooked by decision makers when they appropriate funding for transportation services and projects.

Congestion Reduction

Commuters realize a relief from traffic congestion from the availability of public transportation options, even if they rarely use them. That may be one of the reasons why 67% of the Los Angeles County residents voted for allocating 26 billion dollars in 2008 for transit improvements, though only few of them used to ride public transit. The congestion reduction benefit was explored by studying Washington, DC transit system with a simulation model. The model results showed that the existing transit system resulted in a reduction of congestion estimated at 184,000 person-hours per day.

Jou et. al established seemingly unrelated regression equations (SURE) model to observe the factors that affect using public transportation, motorcycles and automobiles in various townships in Taiwan. The model used different population densities and public transportation usage and determined that 50 percent increase of city bus routes in highly populated areas reduce car usage by 1.4%. This reduction of car trips corresponds to 300,000 vehicles. Additionally, CO_2 emission was reduced from 7.0 million tons to 6.5 million tons. After examining other scenario and different estimation, the study concluded that public transport improvements can reduce car usage and motorcycle usage as well as reduce congestion (Jou & Chen, 2014).

A research study for the San Francisco Bay area, California indicates that without the Bay Area Rapid Transit (BART) system, congestion in Bay bridge area would become terrible. In a model with no BART service, everyone was assigned to drive which resulted to four to five times more delay in the Bay area. An analysis on the impact of the absence of BART services during the morning peak area showed that driving times increased significantly in multiple corridors. For example, more than five hours could take for a trip to the Bay Bridge from the Antioch city which takes only one and a half year if the normal condition exists (BART, 2016).

In a mildly congested city, Rotterdam in the Netherlands, a study was conducted to study the effect of strikes on car speed during a transit strike. The study results focused on 13 strikes that happened from 2001 to 2011 and showed impacts on traffic congestion in the absence of transit. The mean car speed for the transit strike days was 7% lower than normal days and such effect was similar for both sort term and full day transit strikes. The mean vehicle flow was higher for strike days by 15% (Adler & van Ommeren, 2016).

In 2003, the Los Angeles County Metropolitan Transportation Authority (MTA) workers held a strike for 35 days and shut down bus and rail lines of MTA. During that time, a study was performed to collect hourly traffic speeds for all major freeways in Los Angeles and use the data to estimate a regression discontinuity (a pretest-posttest program-comparison) design. The study found that average delays during peak periods increased by 47%. The result was consistent throughout the strike. Moreover, the effect of increased delay was largest in the freeways which usually supports heavy ridership transit lines. On the other hand, for neighborhoods and facilities unaffected by the strike, the effect was statistically insignificant (Anderson, 2014).

A study on Salt Lake City's University TRAX light-rail system in 2014 found that normal vehicle traffic has reduced with the expansion of the light rail system. In spite of significant development in the area, roadway traffic reduced significantly after the completion of the light rail transit line. On the study corridor, the study found 22,300 vehicles per day on that corridor post the introduction of light rail system, a reduction of nearly 50% considering that 44,000 vehicles used the same corridor prior to TRAX (Ewing, Tian, & Spain, 2014).

The study on 498 US urban areas by Texas A&M Transportation Institute’s (TTI) reported that public transportation systems handled 56 billion passenger miles of travel in 2011. In the absence of public transit, the total delay for those urban areas would be 15 percent higher adding almost 865 million hours of delay and causing 450 million gallons of additional fuel consumption (Schrank, Eisele, & Lomax, 2012).

Another recent study considered the social-demographic attributes, transit service variables, vehicle characteristics and land-use characteristics, to develop integrated model for the Washington Metropolitan area. The goal was to estimate the household decisions over vehicle ownership based on the above data and as an impact of improved bus and metro services. The result showed that vehicle ownership could be reduced by 1.5-2.0% and miles traveled decreased by almost 1.6-8% in the presence of improved bus services. This study indicated the potential link between improving transit service and reducing the use of private automobile (Liu & Cirillo, 2015).

Another similar study was conducted in Copenhagen metropolitan area, Denmark. The study developed a model for choosing both car ownership and residence location as a function of the public transit quality. According to the predictions of the model, the willingness for living around the center of the area under construction increased as observed from the rise in population and house prices around that area. Also, a drop in car ownership of 2-3% was documented after the extension of the metro network (Mulalic, Pilegaard, & Rouwendal, 2016).

These studies provide some links between transit availability and transportation mode choices and highlight the potential positive impacts from introduction or expansion of transit services in a region, for individuals, the transportation network operations, and the community. However, given local differences, it is important to conduct local studies in order to gain an understanding of potential impacts of transit ridership increase on local congestion and quantify such impacts. The following paragraphs detail such an effort undertaken in Birmingham, AL, a medium-sized city with limited availability of a bus transit system.

Overview of Study Area

Traffic Condition in Study Area

According to the Urban Mobility report 2019, the average driver in the study area Birmingham, Alabama lost 40 hours in 2017 due to the congestion an increase of over 2% compared to the year before (Schrank et al., 2019). The annual cost of local congestion is $990 per the Birmingham driver due to the lost time and fuel while stuck in congestion (TRIP, 2019). Yet, 85% of the people drive their own car to travel to work, while less than 1% use public transit for commuting to work. On the other hand, the percentages are 76% and 5% respectively for driving alone and public transit for the whole nation (U.S. Census Bureau, 2019). The Birmingham highway network experiences a congestion level of 9% whereas the level is 24% for non-highways (TomTom, 2020). Number of households without vehicles in Birmingham was 15.8% in 2015 which decreased in the following year by 3.5%, means over 85% households of Birmingham owns private car (GOVERNING, 2017).

Public Transportation in Study Area

The City of Birmingham provides public transportation for more than 100 years starting in 1884 with street railway. The state legislature passed permission for the formation of publicly operated transit authorities in Alabama in 1972 and consequently Birmingham Jefferson County Transit Authority (BJCTA) was created (MAX, 2017b). It serves a demand population of almost 400,000 in more than 200 square miles. The service area covers Birmingham, Hoover, Bessemer, Mountain Brook, Center Point, Vestavia Hills, Midfield and Tarrant. BJCTA operates only Compressed natural gas (CNG) buses to control the air quality and pollution (MAX, 2017a).

BJCTA is the primary provider of public transportation in Birmingham which provides both the fixed route and paratransit service named Metro Area Xpress (MAX)-DIRECT Paratransit. BJCTA offers no service on Sunday and usually the service goes from 4:00 AM to 11:30 PM. Paratransit service operating hours are also the same as fixed route buses, and the service can be used only within the Birmingham City to Jefferson County limits. BJTCA also has micro transit system named MAX – DIRECT which gives the option to request a ride, get an estimated pick up time and track their bus in real time through a smartphone App called TransLoc. This service is offered by a 15-passenger shared ride service on Monday to Friday from 8:00 AM to 9:30 AM and in the afternoons from 2:00 PM to 3:30 PM and is only available for the trips from central station to the city of Mountain Brook and back at the regular fixed route cost.

This study considers only the fixed routes for evaluating the public transit utility by simulating their benefit. All bus routes originate from a central point which is MAX Central passenger transfer facility located on Morris Avenue between 17th Street North and 18th Street North. BJCTA has eighty-seven 40-foot vehicles, forty-three 26-foot vans, and, twenty-six non-revenue vehicles. According to a report published in February 2018, the total transit system ridership on a typical weekday was 10,634 (BJTCA, 2018b).

METHODOLOGY

An agent-based transportation simulation is used to simulate the impact of changes in transit ridership on the transportation network operations. MATSim tool is selected to develop the base model as well as to simulate the designed scenarios. To measure the performance of the transportation network, 5 time periods and 93 representative roadway sections are selected for evaluation.

Agent-based Modeling

Agent-based modeling (ABM) comprises of collections of agents and relations between them and can be used for simulating a system which is formed with behavioral entities (Bonabeau, 2002). In the field of transportation, agents refer to the travelers and behavior stands for travelers' daily activity. ABM starts with the individual agents along with their possible interactions and the end behavior is generated by the simulated interactions. The ABM uses a set of rules to produce analyzable data (Bernhardt, 2007).

Simulation Platform Selection

Besides the public transportation in the study area, there are also private cars as well as other modes such as ride hailing or ride sharing services. Changes in the demand of any of these modes impact the others. Therefore, it is necessary to model the modes together to understand the effect of public transit in the network operation. This requires multi-modal simulation with mode choice options where all the travelers can be simulated individually (Manser, Becker, Hörl, & Axhausen, 2020) at the microscopic level of analysis. CO_2

TRANSIMS (TRansportation Analysis and SIMulation System) and MATSIM (Multi-Agent Transport Simulation) are two of the more eminent agent-based models for traffic simulation. Both of them offer traffic simulation for large metropolitan areas but MATSim runs more quickly compared to the prolonged run time in TRANSIMS (Bernhardt, 2007). After considering model capabilities and study needs, the MATSim platform was selected as the simulator of choice for this study.

Overview of MATSim

Introduction

MATSim is an activity-based simulation framework that allows for developing agent-based modules to be used with transportation planning models. It is an open-source platform and implemented in Java. The MATSim is capable of simulating behaviors of millions of agents in a metropolitan area. The agent-based simulation follows microscopic description by tracing daily schedules of agents and their travel decisions (Horni, Nagel, & Axhausen, 2016).

Simulation through Iteration

MATSim is based on co-evolutionary principle where agents compete for space-time slots with all other agents on the transportation network as well as optimize their daily activity schedule through a variable number of iterations. Activity plan, microsimulation, activity re-plan, microsimulation etc. are performed iteratively until a stationary state of the system is reached. Every agent in the system has a memory of fixed number of daily plans and each plan contains a daily activity chain and an associated score. More specifically, the following procedures take place during the iteration (Horni et al., 2016).

- Initial demand is generated. The demand contains full list of agents, their daily plans and activities such as, work, shopping, home etc. as well as information about leaving home, reaching work etc.
- Each agent chooses a plan from its memory. The memory consists of fixed number of daily plans and each plan contains a daily activity chain and an associated score.
- Then the simulation is performed by the MATSim mobsim (mobility simulation).
- After the simulation, plans are scored.
- The next step is re-planning where a subset of agents modifies their plans. In this step, agents with many plans remove the plan with the lowest score and agents that did not undertake re-planning select from the existing plans.
- The stop criterion is stabilizing the average population score. If this criterion is satisfied, then the simulation stops. Otherwise, it is repeated until the stabilization is reached (Zheng et al., 2013).

Design of MATSim

MATSim is designed for modeling a single day, thus wrapping around time of the model is 24 hours. Therefore, the last activity is merged into the first one. For example, if the first activity ends at 9 AM and the last activity starts at 12 PM, then it is assumed that this is same activity which continues till 9 AM. However, multi-day options could be used by modifying the available open source code (CIVITAS, 2020). MATSim designs two layers. The physical layer is a microsimulator where the physical world is simulated for the agents to move. The mental layer is the model logic where the agents choose mode, route and their daily activity plans by generating strategies. Agents' daily activity decision is created in the mental layer where every agent has a 24-hour activity agenda. These two layers interact to produce the traffic simulation of the selected roadway network at a microscopic level (Zheng et al., 2013).

Traffic Flow Model of MATSim

MATSim does not use the complex car-following or lane-changing behavior, but rather uses a queue-based model to simulate the network loading. When a car enters into a road segment or street (network link) from an intersection, it is added to the tail of the queue formed in that network link. The car remains in that queue until it is at the head of the queue or the free flow travel time has passed. Free flow travel time is calculated by dividing the road length by the free flow speed, which represents the maximum speed of the road that takes place in the absence of congestion and other adverse conditions. Practically, free flow travel time is the time a car takes to travel a link when using free flow speed. The queuing model adopted by MATSim is based on two link characteristics, namely the Storage Capacity that refers to the number of cars that can fit on a network link and the Flow Capacity, i.e., the number of travelers can leave the link per unit time.

Required Inputs in MATSim

There are three types of input requirements in MATSim: a) the Network file, b) the Population file, and c) the Configuration file.

The network.xml file describes the road network to be simulated for the agents and vehicles to move around. This file consists of nodes (intersections) which are connected by links (roadway segments). Node refers to the intersection of two roadways and link refers to a roadway section between two nodes. A screenshot of the network file used in this study is shown in Figure 1. Every node and link have a respective id. Nodes have x and y coordinate value. The attributes of the links are range of nodes, length, capacity, lanes, modes allowed and free flow speed (Bischoff, Márquez-Fernández, Domingues-Olavarría, Maciejewski, & Nagel, 2019).

```
    <node id="pt_998" x="522172.9426157217" y="3710678.4655769994" >
    </node>
    <node id="pt_999" x="522387.1556358209" y="3710793.1579909744" >
    </node>
</nodes>

 ==================================================================== -->

<links capperiod="01:00:00" effectivecellsize="7.5" effectivelanewidth="3.75">
    <link id="100283795_0" from="56419245" to="56339453" length="128.11204496584656"
                freespeed="8.333333333333334" capacity="600.0" permlanes="1.0" oneway="1" modes="car" >
    </link>
    <link id="100283795_0_r" from="56339453" to="56419245" length="128.11204496584656"
                freespeed="8.333333333333334" capacity="600.0" permlanes="1.0" oneway="1" modes="car" >
```

Figure 1: Screenshot from the network File of the study area

The MATSim population.xml file describes the daily activity plans of the agents, commonly used as plans.xml. Activity plans are listed hierarchically in the file (Figure 2). Each plan has activities and legs. Start time and end time of the activities are mentioned with the location coordinate. Legs define how the agents plan to travel for an activity, thus legs must have been assigned a mode of transportation. However, these attributes are for simplified plan files. There are other features that can be used such as assigning a link to the activities instead of coordinates, assigning a score as attribute etc.

```xml
<person id="p_17265">
    <plan selected="yes">
        <activity type="Home" x="515048.5798157464" y="3682323.0632012454" start_time="00:00:00" end_time="07:16:07" >
        </activity>
        <leg mode="car">
        </leg>
        <activity type="Work" x="527266.5287635917" y="3712345.16392916" start_time="07:58:15" end_time="15:51:24" >
        </activity>
        <leg mode="car">
        </leg>
        <activity type="Home" x="515048.57986506505" y="3682323.0631722854" start_time="16:31:24" end_time="24:00:00" >
        </activity>
    </plan>

</person>
```

Figure 2: Screenshot from the plan file of the study area

The MATSim config.xml file configures the available settings for simulation in MATSim. Parameters here are referred to as pairs of a parameter name and a parameter value. These pairs are again grouped into modules (Figure 3). One module contains settings for controllers, another one has input files, some have settings for mobsim, etc.

```xml
<module name="network">
    <param name="inputNetworkFile" value="network.xml" />
</module>

<module name="plans">
    <param name="inputPlansFile" value="plans.xml" />
</module>

<module name="controler">
    <param name="outputDirectory" value="results/experiments/experiment_30%_plans" />
    <param name="lastIteration" value="10" />
    <param name="overwriteFiles" value="overwriteExistingFiles" />

</module>
```

Figure 3. Screenshot from the config File of the Study Area

For adding public transit into the MATSim simulation, the transit schedule and transit vehicles files are also needed. Transit schedules have an id for each stop facility, stop name, their coordinates and whether the stops are blocking the roadway. Transit vehicle files contain vehicle id type of the public transit such as, bus, train etc. This file optionally can contain additional details including the number of seats for the passengers, and number of persons that are allowed to stand.

Data Collection and Input File Generation

Network File Preparation

The road network for this study was obtained by converting data from OpenStreetMap (OpenStreetMap) into the MATSim network.xml file format. This study is an extension of STRIDE (Southeastern Transportation Research, Innovation, Development and Education Center) project B-Technology influence on travel demand and behaviors that developed a prototype model of the greater Birmingham, AL in MATSim including the Jefferson and Shelby Counties (Sisiopiku, Hadi, Steiner, McDonald, & Ramadan, 2019). While the same network file is used in both studies, the study presented in this thesis has a narrower focus, as it concentrates mainly on BJCTA service area which covers the Jefferson county and part of Shelby county.

Population File Preparation

In the Birmingham Metro Area, a comprehensive travel diary questionnaire survey was conducted as a part of the STRIDE Project B- Technology influence on travel demand and behaviors. Participants were requested to report their detailed 24-hr travel diary (detailed activity for a typical day) including trip purpose, origin and destination of each trip and mode of transportation used for those trips. This survey helped to collect travel diary data for 451 respondents. As it is quite impossible to collect activity daily plans for all the population of the entire study area, population synthesis was used to mirror the true population. Modeling techniques for the synthesis were based on the sample data, US census data and land use data. Details about population synthesis methods are available in Ramadan and Sisiopiku (2019) (Ramadan & Sisiopiku, 2019) and specifics on how the survey sample was expanded using open source data in order to scale for the population of the study network can be found in (Guo, Khalil, Yan, & Sisiopiku, 2019).

Necessary Files for Public Transit

Two additional files were needed in order to simulate public transit using MATSim. They were ‘transit schedule’ and ‘transit vehicle’. To generate these two files, General Transit Feed Specification (GTFS) was used from the BJTCA MAX website. GTFS have several text files containing the information such as vehicle pick up/drop off locations, stop id, stop name, longitude and latitude, route id, time of departure and arrival, service starts dates etc.

Scenarios Design

Without Public Transit

A base model scenario is developed using only the private car as mode of transportation in the study network. This is a typical baseline scenario used in most simulation studies where the transit mode is often disregarded. The base model is established using the network file and plan file generated. Activity types considered are services (Bank, Post office etc.), shopping-grocery, shopping-retail, pick-up and drop-off passenger, school, eat/get take-out, work, home, nightlife/bar etc. There are more one million agent plans in the plan file.

To run the MATSim simulation, using a 10% sample from the whole population is a standard practice. In Sweden, a MATSim model was developed for assessing the impact of large-scale electrification for the long distance trips, where 10% samples are used (Bischoff et al., 2019). To simulate the improvements in the schedule of public transport in Vorarlberg, Austria, a MATSim model is run for 10% of the population. For a MATSim model in Seoul, South Korea metropolitan Area, 10% sample of the 21.5 million was generated for the simulation. As using 10% populations speeds up computational performance, MATSim models in Berlin, Germany, in Paris, France, in Zurich, Switzerland and some others used 10% population (MATSim, n.d.). Therefore, based on these past literatures and to speed up the computation, this study also used 10% of the total agents. Link capacities were also reduced accordingly to ensure that the simulator represents real traffic conditions properly. The simulation was run for 50 iterations.

With Public Transit

To evaluate the benefit of BJTCA bus service, three scenarios are designed. The public transit market penetration increased from one scenario to the next to simulate the performance of the network operation while more people are using transit instead of private car. The scenarios used actual bus routes and stops data from BJCTA_GTFS_0219_Database folder retrieved from MAX transit website. According to this folder, 32 bus routes are used for all the scenarios. These scenarios use the 10%

population as well. The modes of transportation considered are car and public transit (bus). Following characteristics are considered while designing the model for these three scenarios.

- The activities considered are those that can be performed using public transit.
- The model considers an activity to be performed by public transit, when that activity such as bank service is within walking distance of at least one of the public transit stations.
- For public transit agent plans, the zip codes with the lowest incomes are used as home locations to account for transit-dependent users.
- To get the zip codes with the lowest income, the poverty level variables are used in the Census API (Application Programming Interface) of the American Community Survey (ACS). Census API helps the users to access census data by selecting variables and geographies as well as gives the ability to connect to analysis software within their applications.
- No specific agent plans were generated where agents will use public transportation. Instead, the MATSim decides for the agents to choose public transit during the simulation according to the above criteria.

According to a report on BJCTA transit development plan, the number of passenger for a typical weekday is 10,634 (BJTCA, 2018a), which is around 1% of the total population of 1,090,435 (U.S. Census Bureau, 2019). Scenario 1 is designed such that it represents the current ridership of BJTCA. Thus, for the first scenario, probability of equals or less than 0.1 is assigned because with this probability, 1.1% of total agents choose public transit and 1.4% choose walking. The preference for walk has happened for the reasons such as few bus lines or public transit waiting time. To determine the impact of increased ridership on speed, travel time and vehicle count due to the added transit trips, the probability is then set as less than or equal to 0.5 and 0.9 respectively for scenario 2 and scenario 3. The study scenario design is summarized in Table 1. Table 1 also shows the expected market share of the various modes considered in the study (namely car, transit, and walk) under the 3 scenarios tested (namely probability of ≤0.1, ≤0.5, ≤0.9).

Table 1: Scenario design criteria

	Scenario 1	Scenario 2	Scenario 3
Probability of Choosing Public Transit (PT)	≤0.1	≤0.5	≤0.9
Car Percentage	97.5%	87%	76.4%
Public Transit Percentage	1.1%	5.7%	10.1%
Walk Percentage	1.4%	7.3%	13.5%

Table 1 shows that as the probability increased, more agents shift to public transit, but also more agents prefer to walk than using public transit.

With Modified Routes

During this study, a modification in the number of routes happened in the BJCTA service. From November 4, 2019, some of the routes were changed either by cut or reducing frequency due to the low ridership and associated funding concerns. Also, some of the routes were combined together as a part of the change (MAX, 2019). Before the effective date of this modification, there were 32 routes in which were reduced to 22 routes after the modification. Therefore, this study executed another scenario with the modified routes to observe the impact of these service eliminations or consolidations. For this scenario, design criteria were similar to the scenario 1 described in Table 1, except that some routes were eliminated, and the total number of routes considered was 22.

Model Calibration and Validation

The MATSim model output includes traffic volume and speed on an hour by hour basis. Traffic volume refers to the number of vehicles that pass through a reference point of a roadway section per hour (veh/hr). The speed refers to the operating speed expressed in meter/sec. Traffic volume data used for this calibration were for selected freeway and state highway sections/links located in the Jefferson and Shelby counties. Total of 90 links along I-459 N, I-459 S, AL 25 S, I-65 N, AL 3 N, AL3 S, AL 5 E, AL 38 E, and the junction of I-65 and I-59 were considered for this validation. Standard MATSim-Cadyts (Calibration of Dynamic Traffic Simulations) combination was used to calibrate the model. Therefore, all internal parameters were left as default and the calibration was run jointly with the simulation.

Comparing the traffic count retrieved from the simulation model with actual traffic counts is a usual approach of validating simulation models, including MATSim (Bischoff et al., 2019). The traffic counts from the MATSim model were compared to traffic volumes obtained from Alabama traffic data collected by Alabama Department of Transportation (ALDOT). Alabama traffic data are collected by the traffic monitoring section, which is under the maintenance bureau section of ALDOT. ALDOT records the volumes for each hour starting at 12 AM for the major roadway sections in Alabama and available as portable document format (pdf) format to download by users (ALDOT, 2018).

The traffic volume data for this study were collected for April 2018. To get the representative volume data for weekday, median volumes of Tuesday-Thursday were taken. Model gives validation for each scenario and for 24 hours. Figure 4 and 5 shows validation for two time periods (7 AM to 8 AM and 5 PM to 6 PM) of a day for scenario 1. X-axis on the figures represent the collected traffic volume from ALDOT and Y-axis represents the simulated volume by model. The three diagonal lines in the graphs represent the simulated versus real volume ratio of 2:1, 1:1 and 1:2 which are named as 2 count, count and 0.5 count respectively. Counts fall between 2 count and 0.5 count are considered acceptable (Van der Merwe, 2011). Most of the data points representing simulated versus real volume in the following figures are within the boundaries, thus the validation seems acceptable.

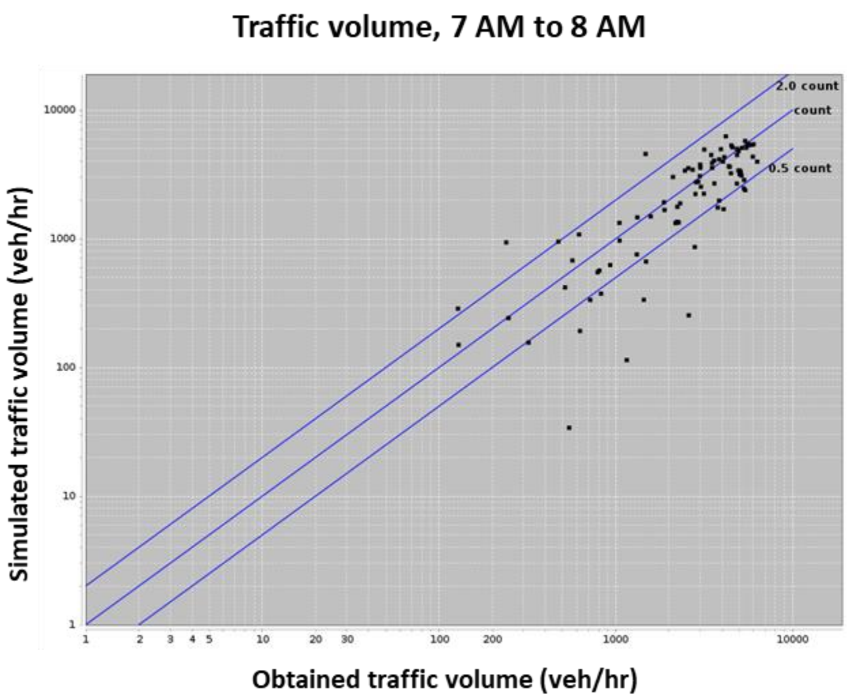

Figure 4: Comparison between simulated and obtained traffic volumes of validation links for 7 AM to 8 AM

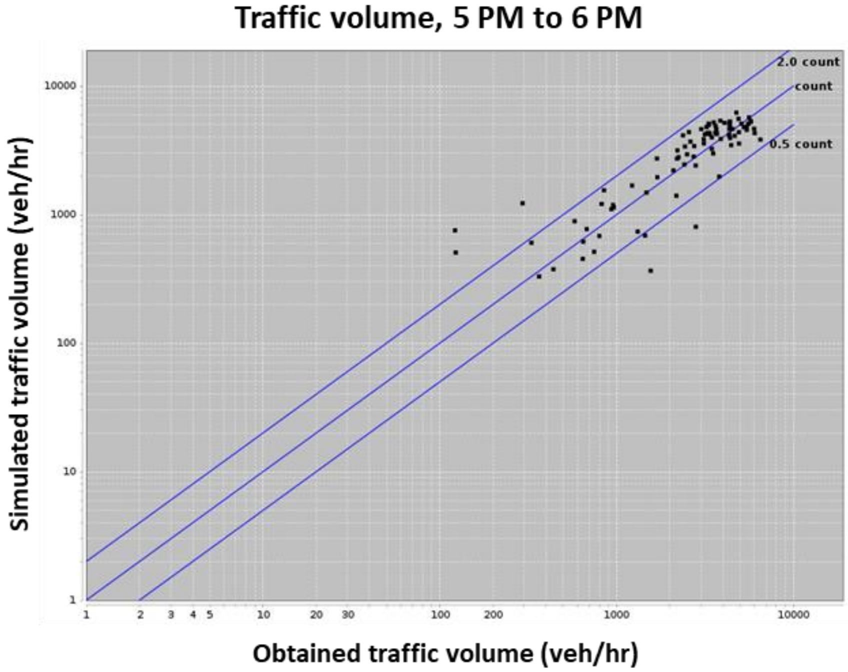

Figure 5: Comparison between simulated and obtained traffic volumes of validation links for 5 PM to 6 PM

Link ID Selection

The service area of the BJCTA which was selected for evaluating the utility of bus services in this study is shown in Figure 6. The area is mainly located in Jefferson county area (orange boundary) and a very small portion in Shelby county area near Chelsea (green boundary). MATSim generates output according to the link ID. Link ID refers to the identity of the roadway sections in the MATSim platform. Every road section between two junction has a distinct link ID. The link IDs are retrieved using MATSim plug-in into the Java OpenStreetMap (JOSM).

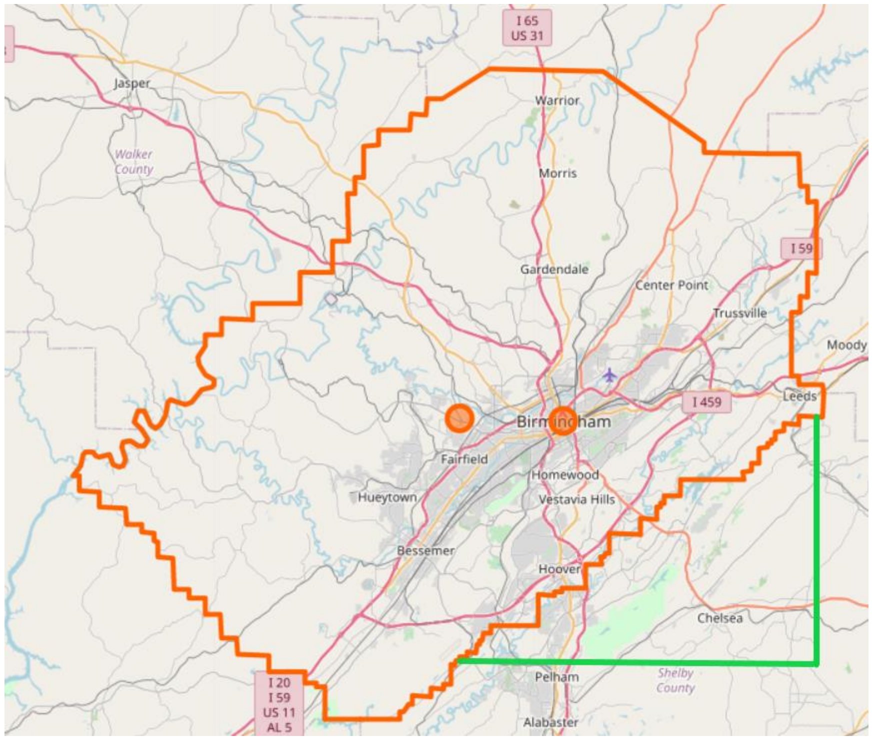

Figure 6. Screenshot of the study area

The network selected for this study has 284015 links. As, it is not possible to separate the links where public transit operates, the links near the bus stops are used for the analysis. GTFS database of BJCTA provides the stop names with their coordinates. Total number of stops covered by the BJTCA bus service is 1761. Therefore, to retrieve output for performance analysis, links were selected by visually inspecting the links in the google map. Taking the Morris Avenue in front of the BJCTA terminal as the center of the network, all the links were selected such that they represent the different types of roadway. For example, junction of University Boulevard and 20th Street South is usually busy in typical weekday and also has capacity of 2000 veh/hr, on the other hand junction of 6th Ave N and 16th St N with a capacity of 1000 veh/hr were selected to represent less busy roadway. In essence, both highways and arterials were considered in the selection which resulted in total of 206 links. Figure 7 shows the location of selected links (blue lines) which are spread over the whole service area.

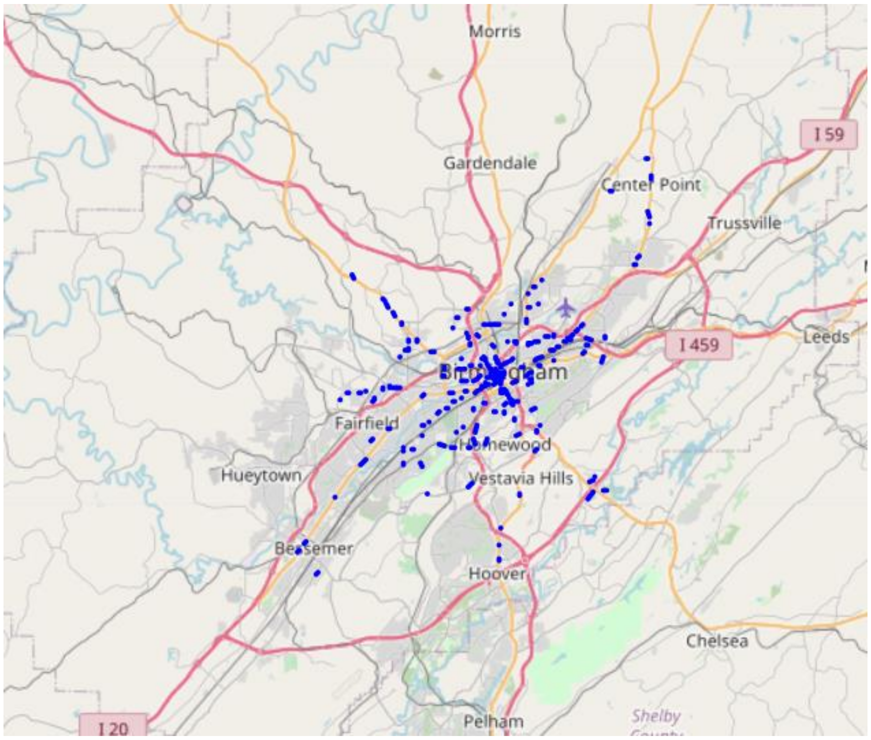

Figure 7: Location of the selected links (blue line)

After retrieving results for the 206 links, IDs were then matched with the same from the other two scenarios to enable comparisons. Traffic volume values were missing for some of the links. Thus, those links omitted in the process so that the analysis are performed for the same links in the three scenarios. Also, a decision was made to disregard links where volumes were less than or equal to 100 veh/hr. After applying these filters and selection criteria, a total of 93 links were selected for further processing. The selection processes are summarized in Figure 8 as flow chart.

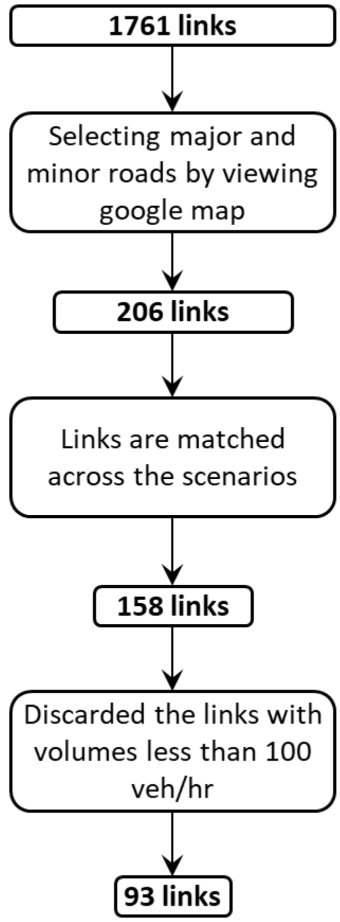

Figure 8: Flow chart of the link selection

All the above filters were applied in the data retrieved for 7 AM to 8 AM (the first hour of morning peak). At this stage, lowest and highest volume present in those 93 links for scenario 1 and 7 AM to 8 AM period was 120 veh/hr and 2520 veh/hr respectively. To accommodate this big range of volume in five different groups, a frequency table with bin size 5 was drawn (Figure 9). Range of the volume in every bin is similar (480 veh/hr) but the frequency of the number of links in every bin came out inconsistent. The first bin has 48 links while the other four have remaining 45 links together.

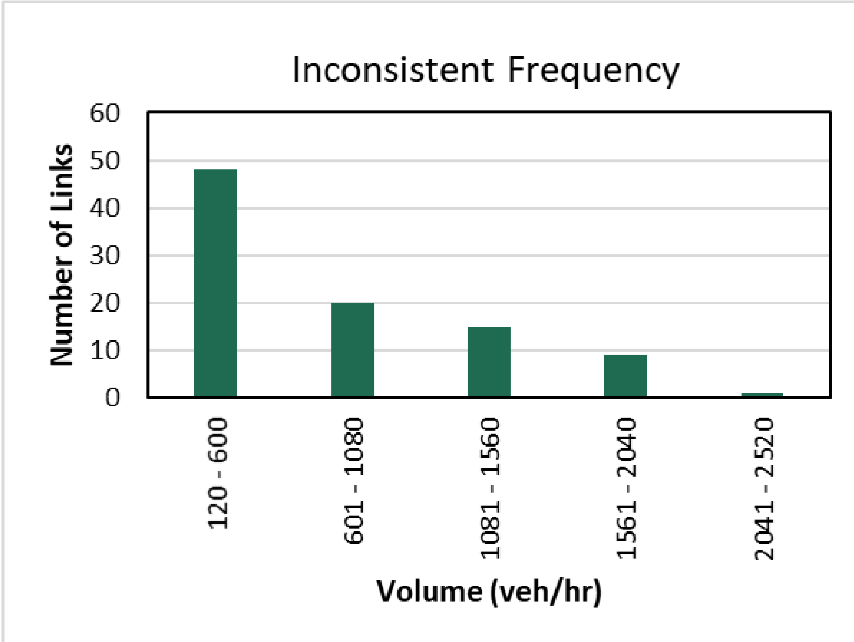

Figure 9: Frequency table with inconsistent link numbers

To get the bin with consistent frequency process described in Figure 10 was followed. After several iterations, the range shown in Figure 11 was considered as consistent frequency and selected to apply throughout all other scenarios and time frames selected later.

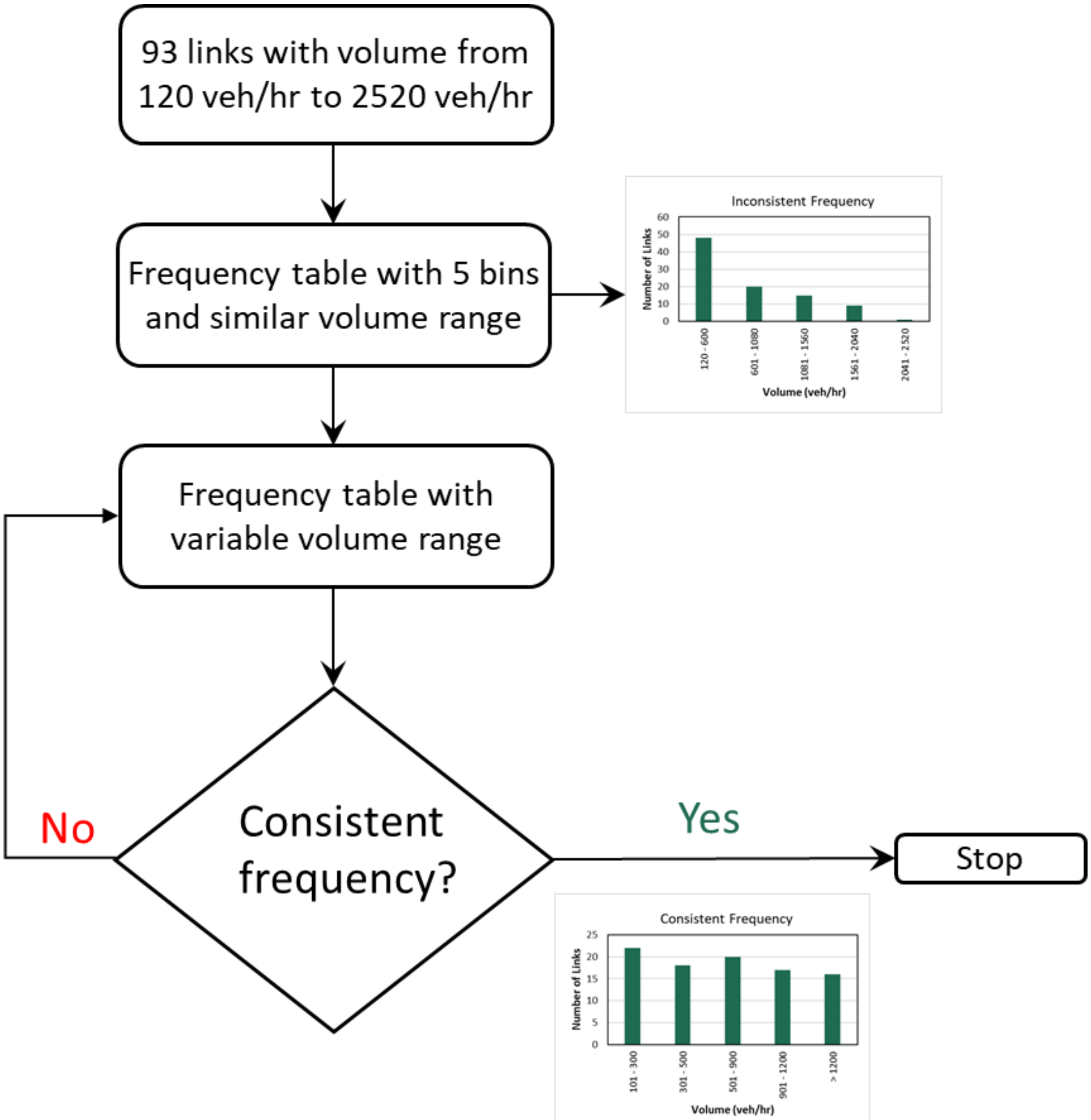

Figure 10: Group identification process

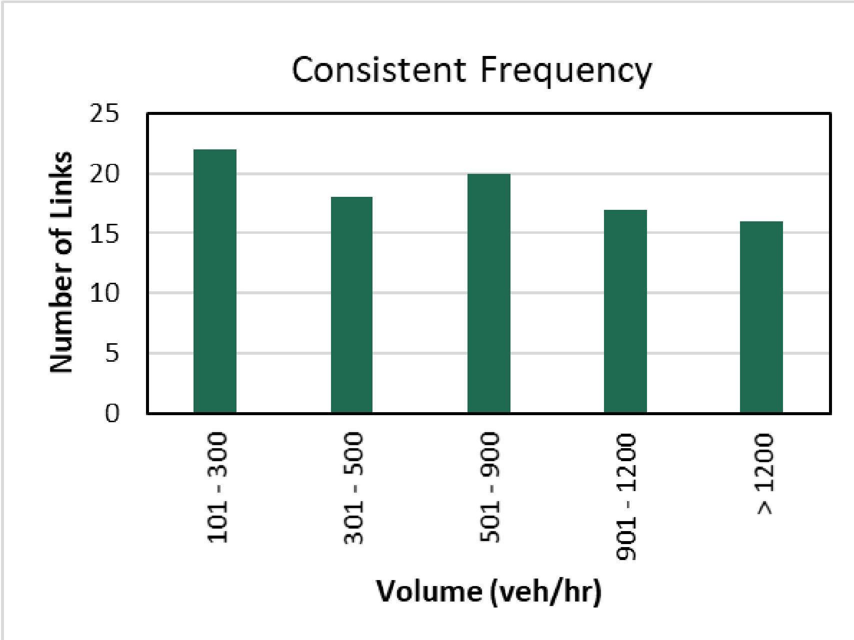

Figure 11: Frequency table with consistent link numbers

The volume range shown in Figure 11 was followed to categorize the links in five groups (Table 2). The varying traffic volume in different time frames will result in different such categories, but the same criteria are used to maintain the comparison between similar groups.

Table 2: Grouping the links

Groups	Traffic Volume (veh/hr)	Number of Links
Group 1	101 - 300	22
Group 2	301 - 500	18
Group 3	501 - 900	20
Group 4	901 - 1200	17
Group 5	>1200	16

Group 1 consists only of links with simulated traffic volumes of 11-30 veh/hr, group 2 includes links with simulated traffic volume of 31-50 veh/hr, group 3 and 4 contain links with simulated volumes of 51-90 veh/hr and 91-120 veh/hr respectively. All the links with greater than 120 veh/hr simulated volumes are considered under group 5. The highest volume contained in this group is 295 veh/hr. It should be noted that the simulated traffic volumes are 10% of the total. For example, group 3 that shows simulated volumes of 51-90 veh/hr represents links with actual traffic volumes of 510-900 veh/hr. Also, the volumes are total volumes per link (directional volumes with all lanes combined).

Time Selection

The MATSim model generates data for 24 hours. To select appropriate time slots for documenting the effect of increased public transit ridership on traffic performance, we examined Birmingham congestion patterns based on data collected in and available at the live traffic website (TomTom, 2020). According to this site, traffic congestion in the Birmingham region peaks from 5 to 6 PM for a typical weekday. This time slot experiences 50% congestion in a typical weekday which denotes that an additional 50% of travel time is needed compared to the travel time in free flow condition. As far as congestion severity time period is concerned, the 5 PM to 6 PM period is followed by 4 PM to 5 PM, 3 PM to 4 PM, 7AM to 8 AM and 8 AM to 9 AM, during which travel times are 43%, 36%, 33% and 27% higher respectively, as compared to travel time under free flow conditions. The study selected the same five time periods for further analysis.

Performance Evaluation

ANOVA Single Factor Test

ANOVA single factor is a test used to determine the difference between the mean of three or more groups. The null hypothesis (H_o) of this test is that the means of all groups compared are equal and the alternative hypothesis (H_a) is that the means of all groups compared are not equal. The confidence level selected was 95%, thus significance level is 0.05. Before moving forward to the pair-wise significance test between the scenarios, an ANOVA single factor test was performed among all three study scenarios. If the null hypothesis is rejected, then the means of at least two of the three scenarios are different. Therefore, further significance tests between the scenarios should be performed.

T-Test

T-tests are used when two sets of observations are present for the same group. For the data of this study, there the observation sets are named as scenario 1, scenario 2 and scenario 3 for the same links. Thus, to compare the significant difference between any two scenarios the t-test is appropriate. Variances in the different scenarios were different in this study, hence "two-sample assuming unequal variances" test is executed. The null hypothesis (H_o) of this test is that the means of two groups compared are equal and the alternative hypothesis (H_a) is that the means of two groups are not equal. Same confidence level as ANOVA single factor test was selected (95%).

Other Excel Functions

After selecting the 93 links from the three scenarios of 7AM to 8 AM, traffic volume and speed for other four time frames were retrieved. As initially there were 206 links, VLOOKUP function was used to record data only for the 93 links from the excel file with 206 links. Another function MATCH is used to determine whether the links selected from the scenarios are matched exactly.

RESULTS AND DISCUSSION

Visualization of Model Output

Traffic volume, speed and average travel time were analyzed for the selected 5 time slots. To visualize the model output of the network, 3 time slots (7 AM to 8 AM, 3 PM to 4 PM and 5 PM to 6 PM) were selected for demonstration purposes. To show the movement of agents around the modeled area, several screenshots of animated simulation runs were taken. On the Fly Visualizer (OTFVis) was used for running the live simulation. OTFVis is available as source code, written in JAVA and users can extend its functionality based on their needs (Horni et al., 2016).

Figure 12 shows agent movement for the base model and other three scenarios. The red color dots refer to agents experiencing congestion in the network. Close inspection of the results shows that the number of red dots increases as going from left to the right of this Figure. That is due to heavy traffic load in the afternoon peak (5 PM to 6 PM) than the morning peak (7 AM to 8 AM). Also, the red color density decreases as going from top to the down, which implies that with the increase of public transit ridership the congestion reduces in the network. However, the detailed analysis of these effects of public transit ridership are discussed in the following sections.

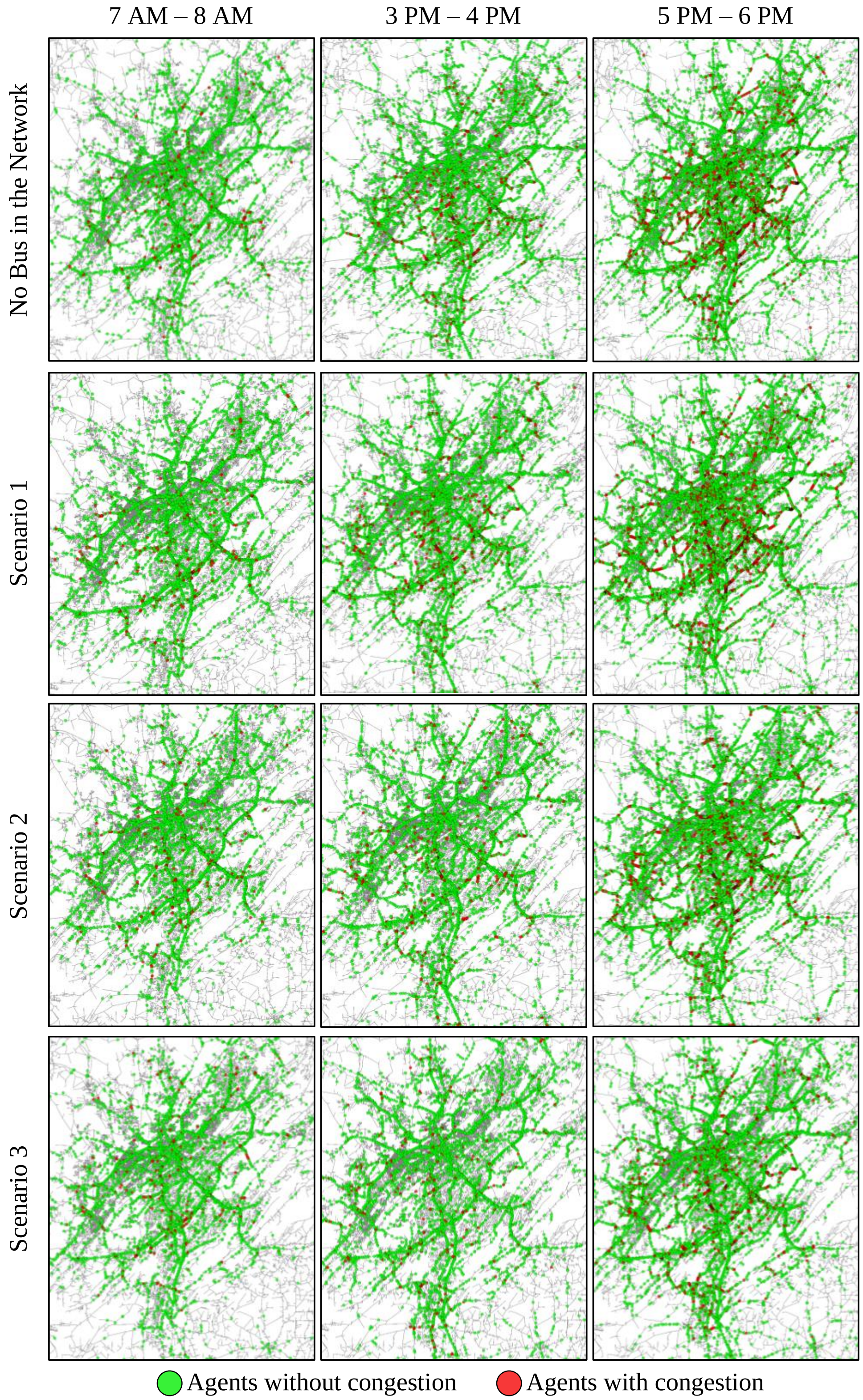

Figure 12: Screenshots of the animated simulation runs depicting agents in the study area under various study scenarios and time periods

Traffic Volume Analysis

Traffic volume results from the Birmingham network simulation of scenario 1 and for the first time slot (7 AM to 8 AM) were obtained for 93 study links along the bus corridors. After that, similar data were retrieved from other two scenario results and compared. Similarly, traffic data were extracted from MATSim outputs for the remaining 4 time slots for the selected links for all study scenarios. The retrieved traffic flow values are available in Appendix A, Table A1 to Table A3. To observe how traffic volumes vary form one scenario to another, their mean values were calculated and then represented in graphs according to their groups. The purpose of showing the traffic volume data for the study scenarios based on the groups is to allow for understanding how increased transit ridership affects network operations under different volumes levels.

Traffic Volume Change for Group 1

In Figure 13, mean traffic volumes are shown for scenario 1, 2 and 3 and for study links with very low volumes (101-300 veh/hr).

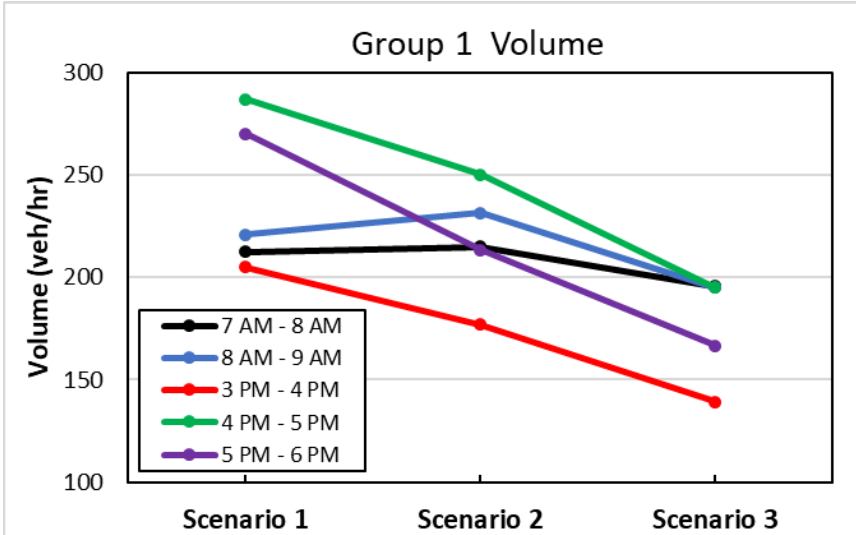

Figure 13: Traffic volume variation with increased transit ridership in group 1 links

The black line, blue line, red line, green line and purple line in Figure 10 stands for the traffic volumes between 7 AM to 8 AM, 8 AM to 9 AM, 3 PM to 4 PM, 4 PM to 5 PM and 5 PM to 6 PM respectively. The probability of travelers choosing public transit increases from scenario 1 to scenario 2 and scenario 2 to scenario 3. With the increased transit ridership, it is expected to see a decrease in automobile trips, which is the case, except from the black and blue lines that show negligible effects on traffic volume between scenario 1 to scenario 2. It can be observed that the mean traffic volume is reduced by 100 veh/hr from scenario 1 to scenario 3 both for green and purple lines. The reduction (40 veh/hr) is also similar from scenario 2 to scenario 3 for these two lines as well as for the green line. Overall, the traffic volume for this group of roadway links is reduced due to the increase in public transit probability.

Traffic Volume Change for Group 2

Figure 14 shows the traffic volume change for group 2 which consist of links with volume from 301-500 veh/hr. To facilitate comparisons, the line color scheme used in the analysis represents the same time slots for this group as for group 1 and all other groups afterwards.

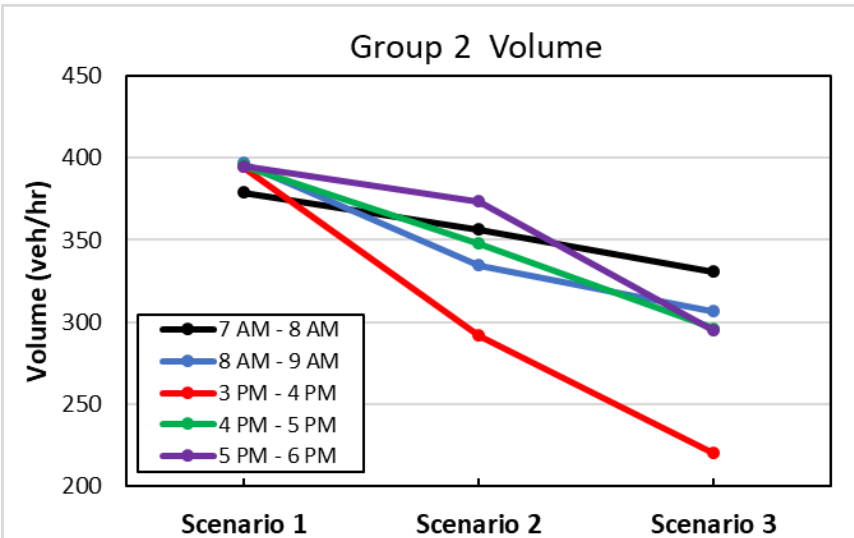

Figure 14: Traffic volume variation with increased transit ridership in group 2 links

The links of group 2 shows traffic volume reduction throughout the 5 time periods considered for increasing transit probability both from scenario 1 to scenario 2 and from scenario 1 to scenario 3 (Figure 11). The red line (3 PM to 4 PM) shows the highest reduction from scenario 1 to scenario 3 (nearly 170 veh/hr), noticeable with the steep downward slope, whereas black line (7 AM to 8 AM) has a flat slope as mean traffic volume is reduced only by 20 veh/hr from scenario 1 to scenario 2 and by 30 veh/hr from scenario 2 to scenario 3.

Traffic Volume Change for Group 3

From scenario 1 to scenario 3, all the time slots for this group show noticeable traffic volume reduction (Figure 15) as the probability of transit use increases. The highest reduction of 320 veh/hr takes place during the 3 PM to 4 PM time period (red line). The volume reduction is also noticeable from scenario 1 to scenario 2, where the red (3 PM to 4 PM) and purple lines (5 PM to 6 PM) show highest mean volume reductions of 300 veh/hr and 130 veh/hr respectively.

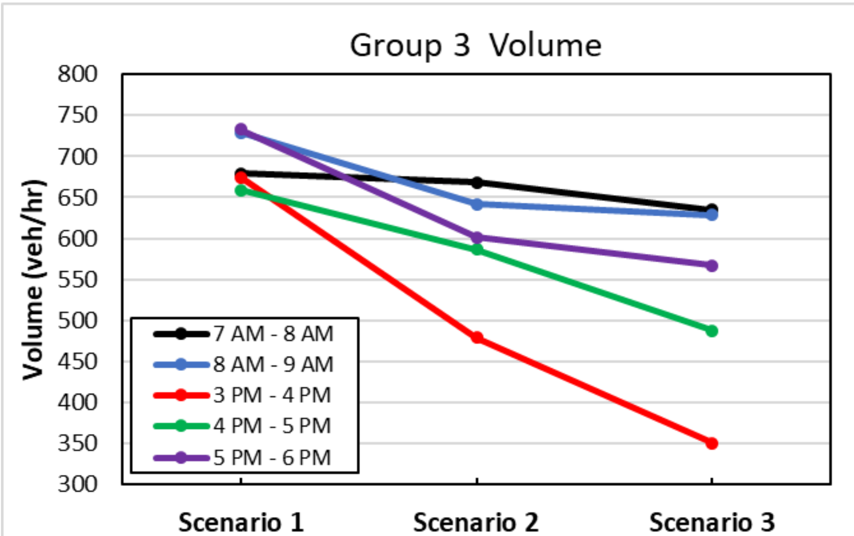

Figure 15: Traffic volume variation with increased transit ridership in group 3 links

Traffic Volume Change for Group 4

Comparison of the simulation outputs for Group 4 links shows little to no change in the traffic volumes during the 7 AM to 8 AM time slot from scenario 1 to scenario 2 to scenario 3 (black line) (Figure 16). During all other time periods, traffic volume drops as transit ridership increases during the 4 study time periods. Once again, the highest such impact is observed during the 3 PM to 4 PM time slot (red line) where the mean traffic volume reduction between scenario 1 and 3 is 380 veh/hr.

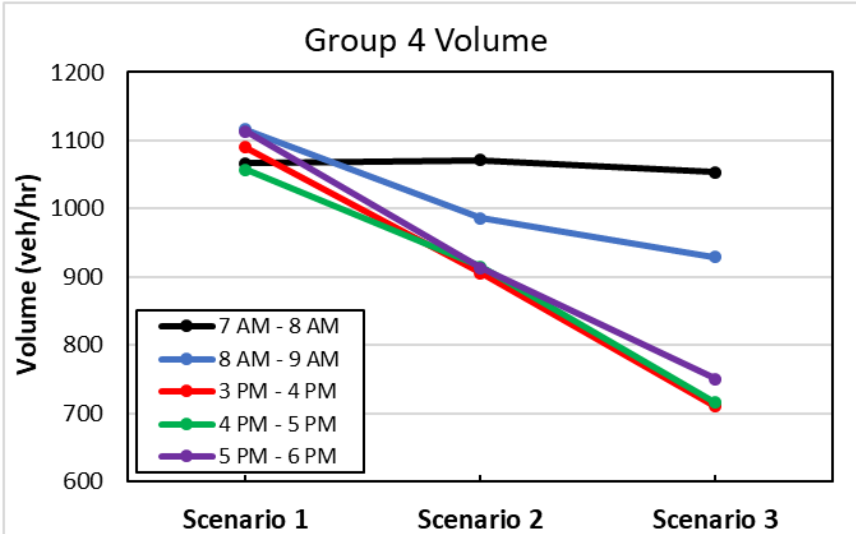

Figure 16: Traffic volume variation with increased transit ridership in group 4 links

Traffic Volume Change for Group 5

Figure 17 shows the traffic volume change for traffic group 5. Overall, the mean traffic volume is reduced for all timeframes and for both changes in transit probability considered (i.e., scenario 2 and 3) as compared to the scenario 1 results. The most significant impact is observed during the 3 PM to 4 PM time period (red line) where mode shift toward transit (from scenario 1 to scenario 3) results in reduction of average traffic volume on group 5 links from 1700 veh/hr to 1100veh/hr (or 580 veh/hr). The reduction is also high (320veh/hr) when the transit ridership is changed from scenario 1 to scenario 2.

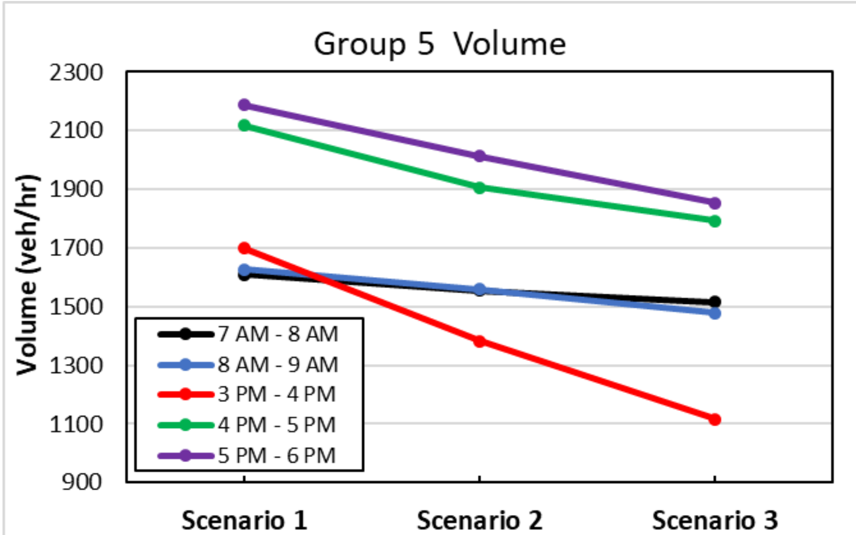

Figure 17: Traffic volume variation with increased transit ridership in group 5 links

Percent Change in Volume from Base model to Scenario 3

The following steps were undertaken in order to further quantify the impacts on traffic volume as a result of changes in transit ridership, from no transit availability (base model) to the bus service with current ridership (scenario 1) to scenarios 2 and 3 that assume a future increase in transit ridership. The results are summarized in Table 3.

1. Comparing the base model volume (no public transit availability) with scenario 1, which represents the current public transit ridership. This comparison helps to understand if the current transit ridership level has any impact on traffic operations by reducing traffic volume. Equation 1 is used for calculating this percentage of flow reduction.

$$\frac{Base\ model\ volume - Scenario\ 1\ volume}{Base\ model\ volume} * 100 \qquad \text{Eq. 1}$$

2. Comparing scenario 1 with scenario 2 to observe whether increasing the transit probability from 0.1 (current condition; scenario 1) to 0.5 (scenario 2) is helping to improve the current traffic conditions by reducing traffic volume on network links. Equation 2 is used for calculating this percentage.

$$\frac{Scenario\ 1\ volume - Scenario\ 2\ volume}{Scenario\ 1\ volume} * 100 \qquad \text{Eq. 2}$$

3. Comparing scenario 1 with scenario 3 to observe whether increasing the transit probability from 0.1 (current condition; scenario 1) to 0.9 (scenario 2) for the same purpose described in number 2. Equation 3 is used for calculating this percentage.

$$\frac{Scenario\ 1\ volume - Scenario\ 3\ volume}{Scenario\ 1\ volume} * 100 \qquad \text{Eq. 3}$$

Table 3: Traffic volume reduction percentages in different scenarios

Time Periods	Base model to scenario 1	Scenario 1 to scenario 2	Scenario 1 to scenario 3
7 AM - 8 AM	-4.2%	2.0 %	5.6%
8 AM - 9 AM	3.6%	7.3%	12.5%
3 PM - 4 PM	3.3%	20.0%	36.6%
4 PM - 5 PM	0.7%	10.5 %	18.1%
5 PM - 6 PM	-3.4%	9.1%	16.8%

According to the results shown in Table 3, the current public transit ridership has a small impact in reducing traffic volume in three time periods (8 AM to 9 AM, 3 PM to 4 PM, 4 PM to 5 PM), when compared to the no transit option. While increasing the transit ridership in scenario 2, the network performance improves as the traffic volume reduction percentage is higher than the current condition. Further increase of the public transit ridership in scenario 3 reduces the traffic volumes even further, with the highest reduction percentage of 36.6% occurring between 3 PM to 4 PM.

Traffic Speed Analysis

Traffic speed analysis was performed for the same links used in the traffic volume analysis. MATSim gives speed as meter/second. The output speed is converted into mile/hr (mph). Speed data in mph for the 93 study links are enlisted in Appendix A, Table A4 to Table A6. As the probability of choosing public transit is 0.1 in scenario 1 and then increased to 0.5 and 0.9 in scenario 2 and scenario 3 respectively, an improvement in traffic performance is expected in terms of traffic speed increases associated with higher transit ridership. In other words, with the increased transit ridership, and for significant reduction of traffic volume in a particular roadway section, the speed should be increased.

Traffic Speed Change for Group 1

Free flow speed refers to the average speed which is traveled by a motorist in absence of congestion or adverse conditions in a roadway. The MATSim results show that for free flow traffic conditions (group 1) the impact of mode shifts from automobile to transit on speed is negligible. As shown in Figure 18, speed differences are small for all time periods considered when comparing results from scenario 1 to scenario 2 to scenario 3.

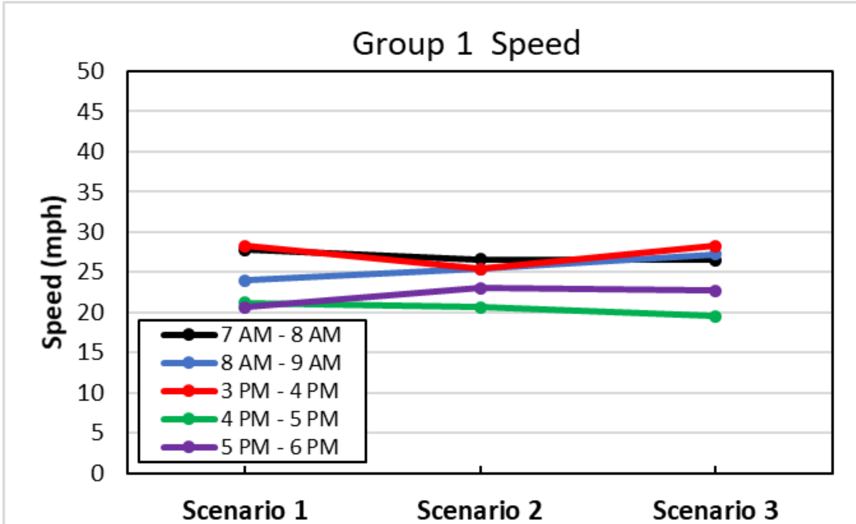

Figure 18: Traffic speed variation with increased transit ridership in group 1 links

Traffic Speed Change for Group 2

Group 2 represents near free flow conditions. For this traffic group, the effects on speed from ridership shifts toward transit are still small. As it can be observed from Figure 19, speed is increased overall by 2 to 3 mph except during the 3 PM to 4 PM time period.

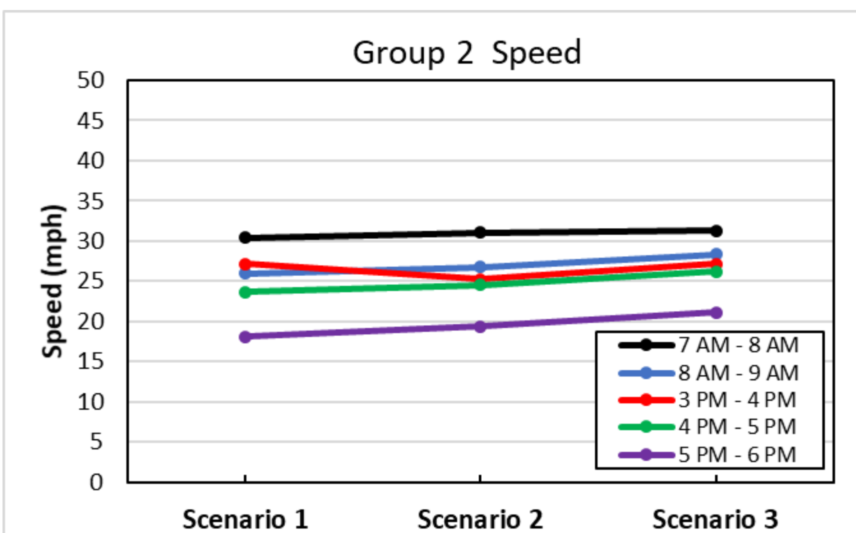

Figure 19: Traffic speed variation with increased transit ridership in group 2 links

Traffic Speed Change for Group 3

The study results confirm that speeds increased by 3 to 4 mph during the afternoon peak times (green line- 4 PM to 5 PM and purple line- 5 PM to 6 PM) both in scenario 2 and scenario 3. Speeds for other three lines remain almost constant or slightly decrease till the execution of scenario 3 (Figure 20).

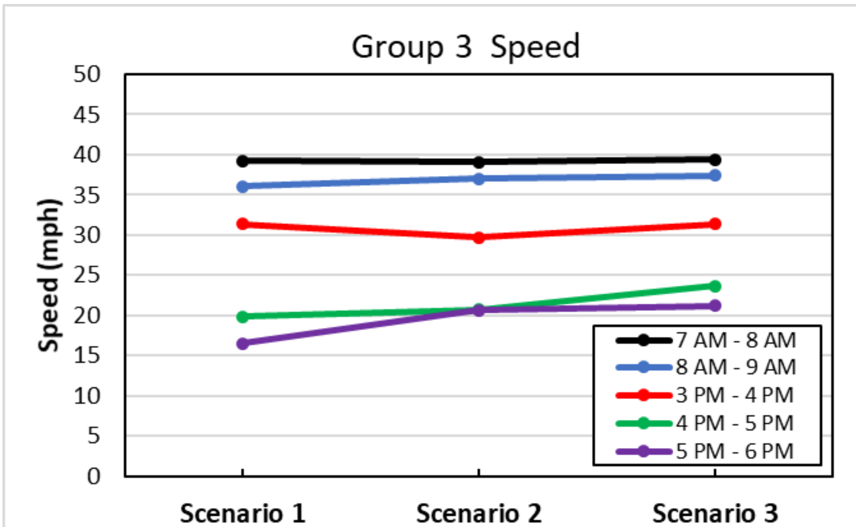

Figure 20: Traffic speed variation with increased transit ridership in group 3 links

Traffic Speed Change for Group 4

Red, blue and black lines are three horizontal lines in Figure 21, which denotes zero speed change in response to shifts in ridership under group 4 conditions. As transit ridership increases (from scenario 2 to 3), green and purple lines representing afternoon peak times (green line- 4 PM to 5 PM and purple line- 5 PM to 6 PM) show overall speed increases of nearly 4 mph and 7 mph respectively .

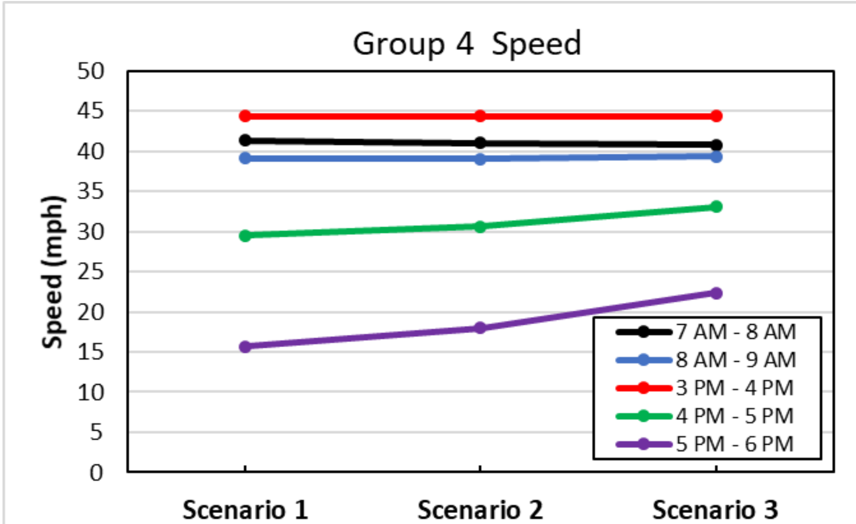

Figure 21: Traffic speed variation with increased transit ridership in group 4 links

Traffic Speed Change for Group 5

For study links with traffic conditions described by group 5, the highest speed increase happens for the purple line (5 PM to 6 PM) with the mean speed increase of 5 mph in scenario 2 and 7 mph in scenario 3, as compared to scenario 1 (Figure 22). The second highest increase is visible for the green line (4 PM to 5 PM) with average speed increase of 3 mph in scenario 2 and 5 mph in scenario 3, as compared to scenario 1. The speeds of remaining three time slots studied are almost similar throughout the three scenarios.

Though the volume reduction was noticed to be higher for 3 PM to 4 PM, speed increase for this time period was almost zero for group 1 to group 4. Thus, free flow speeds of the 93 links were observed and compared with the operating speed for scenario 1 in 3 PM to 4 PM. The findings from the observation showed that, most of the links have near free flow condition in this time period (Table 4). Therefore, speed did not increase noticeably with the volume reduction in scenario 2 and scenario 3.

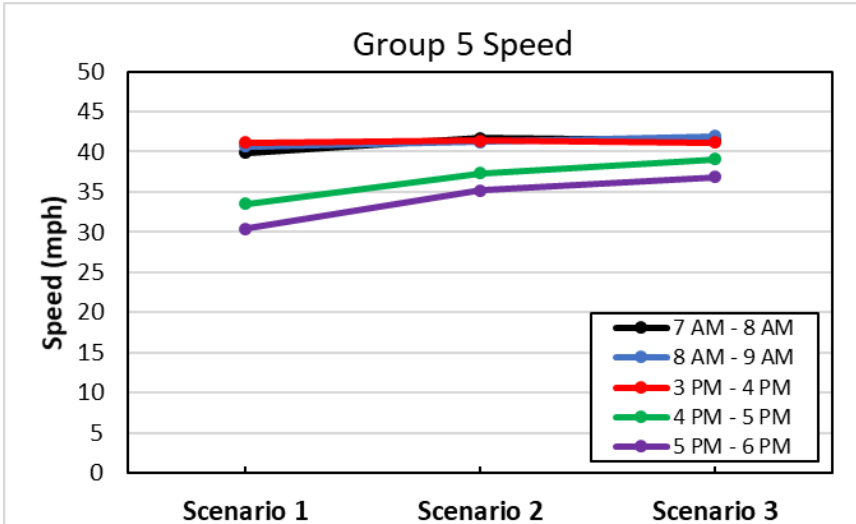

Figure 22: Traffic speed variation with increased transit ridership in group 5 links

Table 4: Comparing operating speed with free flow condition

Link ID	Operating speed in scenario 1 (mph)	Free Flow speed (mph)	Difference between Free flow and operating speed (mph)
107920507_14	36	37	1
259336961_0	36	37	1
323899401_8	49	50	1
7782325_7_r	37	37	0
259970324_1_r	26	28	2
7742120_1_r	36	37	1
592215806_4_r	37	37	0
259311994_2	36	37	1
7740932_2	27	28	1
394283610_3	19	19	0
7782325_5	37	37	0
7740932_0	28	28	0

Percent Change in Speed from Base model to Scenario 3

A similar comparison setup was followed to document the percent speed increase resulting from the assumed increase in ridership in Birmingham as expressed by increased transit use probability in scenarios 2 and 3. The details are the following and the findings are summarized in Table 5.

1. To understand any improvement that current transit ridership has on travel speeds, the base model speeds for all study links are compared with the speeds in scenario 1 using Eq. 4.

$$\frac{Scenario\ 1\ speed - Base\ model\ speed}{Base\ model\ speed} * 100 \qquad \text{Eq. 4}$$

2. To understand the potential improvement in speeds with increasing transit probability (0.1 to 0.5), scenario 1 speeds are compared with scenario 2 speeds using Eq. 5.

$$\frac{Scenario\ 2\ speed - Scenario\ 1\ speed}{Scenario\ 1\ speed} * 100 \qquad \text{Eq. 5}$$

3. To understand the potential improvement with further increasing transit probability (0.1 to 0.9), scenario 1 speeds are compared with scenario 3 speeds using Eq. 6.

$$\frac{Scenario\ 3\ speed - Scenario\ 1\ speed}{Scenario\ 1\ speed} * 100 \qquad \text{Eq. 6}$$

Table 5: Traffic speed changes for different scenarios

Time Periods	Base model to scenario 1	Scenario 1 to scenario 2	Scenario 1 to scenario 3
7 AM - 8 AM	0.4%	0.2%	0.2%
8 AM - 9 AM	0.1%	2.1%	4.8%
3 PM - 4 PM	8.8%	-2.5%	0 %
4 PM - 5 PM	-2.4%	8.8%	15.2%
5 PM - 6 PM	-2.3%	16%	22%

According to the results shown in Table 5, current transit ridership level has contribution in increasing speed between 3 PM to 4 PM. The largest increases in speeds as a result of increased ridership are expected between 4 PM to 5 PM and 5 PM to 6 PM while speeds in remaining three time periods have very little or no increase in speed.

Travel Time Analysis

Travel time for a particular roadway link refers to the time needed to drive from start point to the end point of that link. The model does not give the travel time directly for a particular section (link). As the speed is an output of the model, travel time is calculated from speed and length of the corresponding roadway link and enlisted in Appendix B, Table B1 to Table B3. Travel time is expressed in seconds in this document. The expectation is that modal shifts from automobile to transit may result in reduction of link travel times, thus resulting in an improvement of traffic network performance.

To verify this expectation, an analysis of travel time data was performed for the study links and for the 5 study time periods. First, the travel times were calculated for the same links used in the volume and speed analyses. Then average travel time was estimated by group for the 5 groups considered in the analysis. Average travel times for the three scenarios were drawn according to the group for the performance analysis. The findings are discussed next.

Travel Time Change for Group 1

Figure 23 shows mixed results with respect to changes in average travel times in response to modal shifts towards transit. Overall, those impacts are small (1 to 2 sec) for all time slots considered.

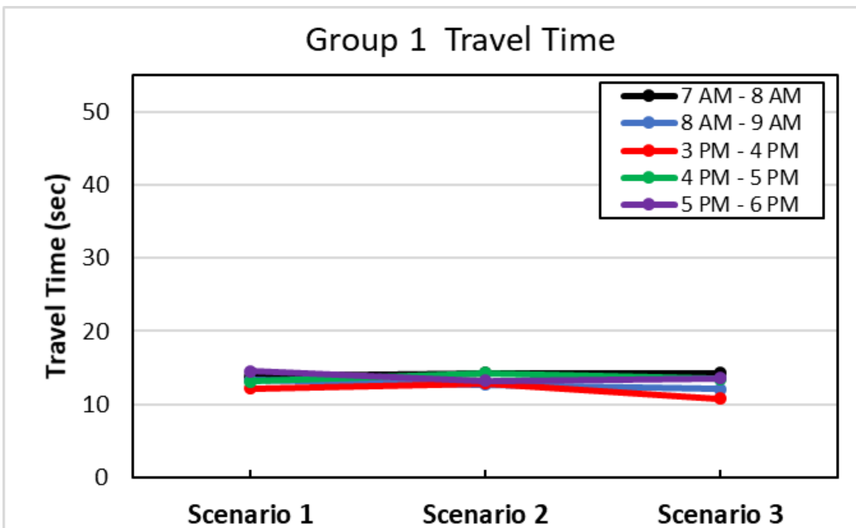

Figure 23: Travel Time variation with increased transit ridership in group 1 links

Travel Time Change for Group 2

Under group 2 conditions, there is little to no change observed to average travel time as transit ridership increases from scenario 1 to scenario 2 and from scenario 1 to scenario 3. An average travel time decrease by around 3 seconds for the purple line (5

PM to 6 PM) from scenario 1 to 2 and around 6.5 seconds from scenario 1 to scenario 3, represents the highest decrease of this group (Figure 24).

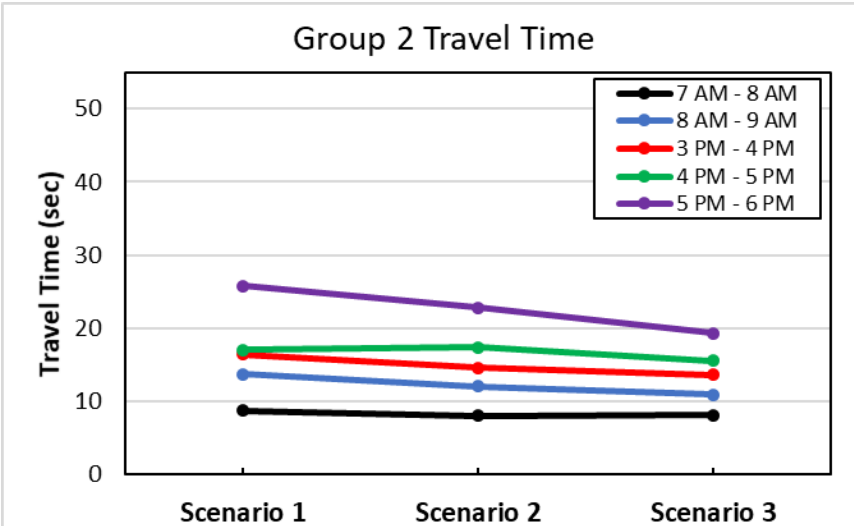

Figure 24: Travel Time variation with increased transit ridership in group 2 links

Travel Time Change for Group 3

Under group 3 traffic conditions, some reductions in travel times are realized during the afternoon peak time periods (green line- 4 PM to 5 PM and purple line- 5 PM to 6 PM) as transit ridership increases in scenario 2 and scenario 3 as shown in Figure 25. The average travel time is decreased by almost 10 seconds for the green line in scenario 3 and the decrease is almost 8 seconds for the purple line.

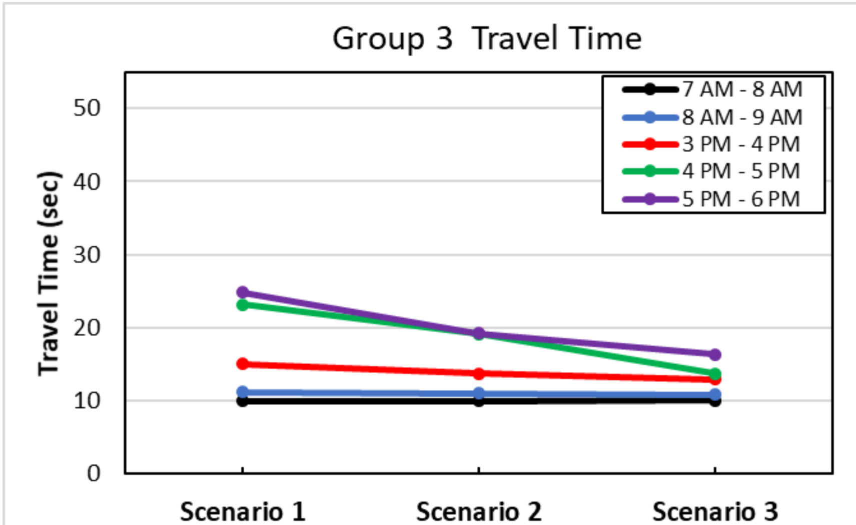

Figure 25: Travel Time variation with increased transit ridership in group 3 links

Travel Time Change for Group 4

As Figure 26 indicates, there is no visible impact on travel time from changes in transit ridership during the 7 AM to 8 AM (black line), 8 AM to 9 AM (blue line) and 3 PM to 4 PM (red line) time periods. The opposite is true for the afternoon peak times, as shown by the green line and purple line in Figure 27 Based on the simulation results, the average travel time during the 5 PM to 6 PM time period (purple line) decreased by 9 seconds from scenario 1 to scenario 2 and a total of 26 seconds from scenario 1 to scenario 3. The decrease in travel time values during the 4 PM to 5 PM time period (green line) are around 1 second and 8 seconds when comparing results from scenario 1 to scenario 2 and scenario 3 respectively.

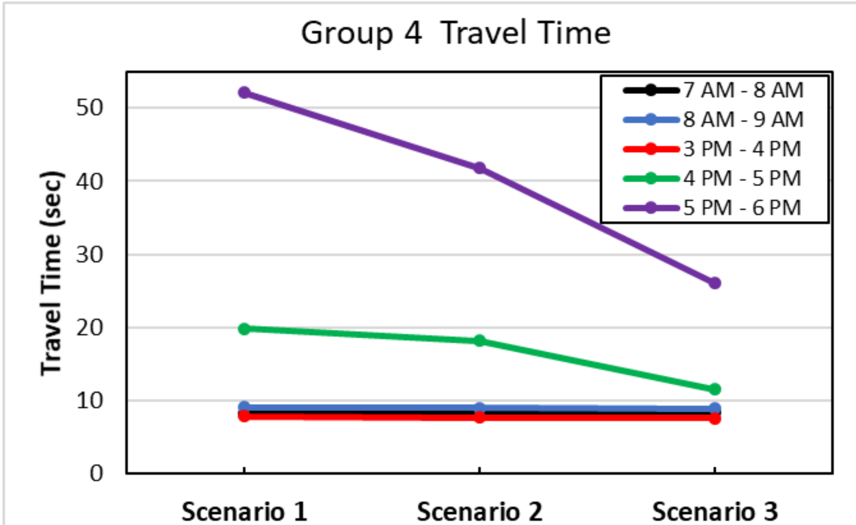

Figure 26: Travel Time variation with increased transit ridership in group 4 links

Travel Time Change for Group 5

Results for group 5 conditions are displayed in Figure 27. It can be seen that during 7 AM to 8 AM, 8 AM to 9 AM and 3 PM to 4 PM (black, blue and red lines respectively) there is very little or no change in average link travel times for the two scenarios considered as compared with the current conditions (scenario 1). However, during the 4 PM to 5 PM time period (green line) as well as the 5 PM to 6 PM time period (purple line) travel time values decreased by 3 seconds and 9 seconds respectively, when transit ridership changed from scenario 1 to scenario 3 conditions.

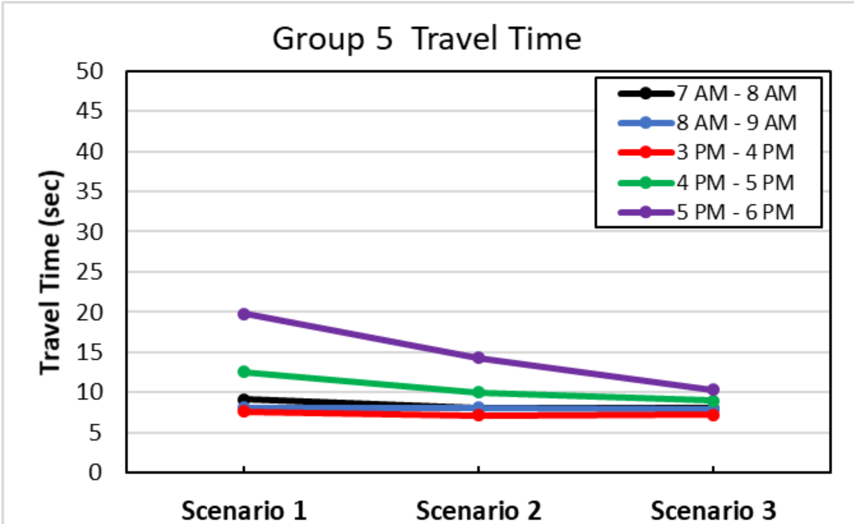

Figure 27: Travel Time variation with increased transit ridership in group 5 links

Percent Change in Travel Time from Base model to scenario 3

Using the same comparison setup as the one used for determining impacts on traffic volumes and speed and applying the Eq. 7, Eq. 8, and Eq. 9, the percent change of average travel time was calculated for the 5 study time periods. The results are reported in Table 6.

1. Base model to scenario 1

$$\frac{Base\ model\ travel\ time - Scenario\ 1\ travel\ time}{Base\ model\ travel\ time} * 100 \qquad \text{Eq. 7}$$

2. Scenario 1 to scenario 2

$$\frac{Scenario\ 1\ travel\ time - Scenario\ 2\ travel\ time}{Scenario\ 1\ travel\ time} * 100 \qquad \text{Eq. 8}$$

3. Scenario 1 to scenario 3

$$\frac{Scenario\ 1\ travel\ time - Scenario\ 3\ travel\ time}{Scenario\ 1\ travel\ time} * 100 \qquad \text{Eq. 9}$$

Table 6: Travel Time percentage change in different scenarios

Time Periods	Base model to scenario 1	Scenario 1 to scenario 2	Scenario 1 to scenario 3
7 AM - 8 AM	0.8%	2.3%	1.9%
8 AM - 9 AM	-1.0%	4.5%	8.5%
3 PM - 4 PM	10.3%	6.8%	11.4%
4 PM - 5 PM	-2.4%	13.8%	29.1%
5 PM - 6 PM	-5.2%	23.1%	40.7%

Though current transit ridership has no effect in reducing average travel time (except for the time between 3 PM to 4 PM), travel time is reducing while transit ridership is increased in scenario 2 and scenario 3. The reduction is higher for the scenario with more transit probability (i.e., scenario 3) and for groups 4 and 5 where the network carries heavier traffic loads.

Significance Test Analysis

To understand whether the traffic flow reduction associated with changes in transit ridership is statistically significant, several significance tests were performed. First, a significance test was performed to test difference within the three scenarios. If the traffic flow reduction was significant within the scenarios, then tests between the scenarios are performed. Table 7 shows the p-value of the significance tests performed herein.

Table 7: Statistical significance test scores (p-value) for traffic volume changes

Groups	Base model with scenario 1	Within three scenarios	Scenario 1 with scenario 2	Scenario 1 with scenario 3
Group 1	0.7801	**0.0169**	0.2240	**0.0175**
Group 2	0.6078	**0.0006**	**0.0222**	**0.0055**
Group 3	0.5706	**0.0285**	**0.0323**	**0.0327**
Group 4	0.6728	**0.0050**	**0.012**	**0.021**
Group 5	0.9968	0.2827		

These tests were performed using the 95% confidence level, hence, a p-value less than 0.05 indicates that the difference is statistically significant between/within groups. Testing for statistically significant differences within the 3 scenarios shows that all but group 5 have p-values less than 0.05. Therefore, the volume reduction in the roadways in group 5 is not statistically significant. As a result, tests between scenario 1 and 2 and between scenario 1 and 3 are done only for groups 1 to 4.

The results from the statistical tests between the base model and scenario 1 imply that the current level of public transit use does not have any significant impact on traffic volumes. This is evident from the high p-values documented in Table 7 resulting from the comparison of traffic volumes between the base model and with scenario 1. Furthermore, results show that traffic flow reduction is statistically significant when comparing results from scenario 1 to scenario 2 as well as scenario 1 to scenario 3. The only exception is for group 1 which shows a p-value of 0.224>0.05, indicating that there is no evidence to support that there is a statistical difference in traffic volumes from scenario 1 to scenario 2 during free flow conditions (group 1).

Table 8 and Table 9 show the p-values of the significance tests done for speed and travel time change respectively.

Table 8: Statistical significance test scores (p-values) for speed changes

Groups	Base model with scenario 1	Within three scenarios
Group 1	0.8958	0.9517
Group 2	0.6599	0.7837
Group 3	0.8967	0.9394
Group 4	0.9413	0.9536
Group 5	0.9322	0.2999

Table 9: Statistical significance test scores (p-values) for travel time changes

Groups	Base model with scenario 1	Within three scenarios
Group 1	0.9738	0.5976
Group 2	0.7644	0.7221
Group 3	0.7142	0.4394
Group 4	0.8730	0.7504
Group 5	0.6853	0.4117

The results show that there is not enough evidence to suggest that there is a statistically significant differences in speed or travel time associated with the increase in transit ridership as per the study scenarios.

Impact Analysis of Service Modifications

As the model of this study was already validated, this study attempted to observe the impact of the service eliminations and consolidations applied in November 2019. To do so, volume, speed and travel time for a new scenario with the modified route systems were compared to the scenario before this modification (scenario 1). Given the routes are reduced, number of travelers choosing private cars are expected to increase. In other words, volumes and travel times are expected to increase, while on the contrary, speed is expected to decrease due to the reduced number of routes. Table 10, Table 11 and Table 12 show the result of volume, speed and travel time changes respectively.

Table 10: Volume change due to transit route service reduction

Time Periods	Volume increase	Significance of the change
7 AM - 8 AM	0.29%	0.9951
8 AM - 9 AM	2.63%	0.9563
3 PM - 4 PM	-2.27%	0.9677
4 PM - 5 PM	0.96%	0.9719
5 PM - 6 PM	-2.53%	0.9499

Volume changes are shown in terms of percent increase and significance tests. Though, the number of bus routes decreased from 32 to 22, little or no volume increase in network traffic volume is visible in Table 10. Also, the p-values of the significance tests are greater than 0.05 for all the time periods which implies that there are no significant changes in volume that happened due to the route modification.

Table 11: Speed change due to transit route service reduction

Time Periods	Speed reduction	Significance of the change
7 AM - 8 AM	-0.95%	0.9176
8 AM - 9 AM	-0.03%	0.9910
3 PM - 4 PM	5.99%	0.6731
4 PM - 5 PM	15.96%	0.7331
5 PM - 6 PM	4.70%	0.2347

A speed decrease by 15.96% in 4 PM to 5 PM was observed, whereas there was very little or no reduction for other time periods. However, similarly to the results from the analysis of volumes, significance tests for the speed change imply that the speed reductions resulting from the changes in transit routes are not significant for any study time period.

Table 12: Travel time change due to transit route service reduction

Time Periods	Travel Time increase	Significance of the change
7 AM - 8 AM	-2.46%	0.8510
8 AM - 9 AM	0.33%	0.9549
3 PM - 4 PM	0.88%	0.9185
4 PM - 5 PM	28.36%	0.4944
5 PM - 6 PM	20.25%	0.4699

In terms of significance tests, travel time did not increase significantly due to the route modification, but afternoon peak periods (4 PM to 5 PM and 5 PM to 6 PM) showed 28.36% and 20.25% increase in travel time in terms of percent increase.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The objective of this study was to quantify and assess the potential impacts of increases in transit ridership in the Birmingham region. The study used a comprehensive activity-based simulation model of the Birmingham area to simulate traffic operations under various transit ridership scenarios. First, the model was run without transit. Then the transit module was developed and used to introduce the current level of transit use into the model (scenario 1). Three performance measures were used to measure the effect of existing public transit ridership on the Birmingham road network, namely traffic volume, speed and average link travel time. Using the same performance measures, two additional simulated scenarios were tested (scenarios 2 and 3) assuming increased transit ridership and the results were compared to the baseline and among the scenarios considered. The analysis considered variations over time by analyzing five 1-hr long time periods and controlled for variations in traffic demand by grouping study links according to the level of traffic demand that they serve (groups 1 through 5). The main findings from this study are summarized below.

- Current public transit ridership has no significant effect on traffic volume reduction for the roadway sections with 101 veh/hr to 300 veh/hr demand.
- When the probability of choosing transit increases i.e. transit ridership is increased, volume is reducing significantly in the roadways with volume

between 301 veh/hr to 1200 veh/hr but for the roadways with volume between 101 veh/hr to 300 veh/hr, further increase in ridership is needed to make the reduction significant. Though roadways with traffic volume from 1201 veh/hr to 3000 veh/hr have 18.5% reduction of traffic volume for scenario 3, the reduction is not statistically significant.

- Current ridership of public transit is not very helpful in increasing the speed. While increasing the ridership, though, speed is increasing for 4 of the 5 time periods considered in this study, those changes are not statistically significant.
- Similarly, travel time is not decreasing with the existence of current transit ridership. Also, with the increase of transit ridership travel time is decreasing, but not significantly.
- Due to the low transit ridership, a reduction of bus routes in the study area did not result in any significant difference in network volume, speed and travel time.

Based on the study findings, traffic volume reduced significantly due to the increased public transit ridership in the roadways with traffic volume less than 1200 veh/hr, however, speed increase and travel time reduction is not found to be significant for the study network. Higher levels of modal shifts from private cars to bus might be necessary to see the significant differences in speed and travel time. However, though not significant, some network performance improvement as a result of increased transit ridership was documented in the percent reduction of volume and travel times, and percent increase of speed. This implies that benefits of increasing transit ridership in medium sized cities like Birmingham can contribute to improving the performance of the road network. Increase in transit ridership in the given road network by expanding the number of bus routes, and/or frequency of service, is expected to have a positive impact in traffic performance of the Birmingham road network.

The findings from this study highlight the potential benefit of increased bus ridership in the medium sized US cities. The study results may encourage the local transit authority, transportation planners and decision makers to think of ways to improving public transit services in order to attract new public transit users. The investment for those improvements can be justified using the potential benefit deduced by this study.

Recommendations for Existing Condition

Providing convenient door-to-door bus services has a good potential for increasing interest for public transit in the Birmingham region. For example, designing walkways for the passengers so that they can comfortably walk to the bus stops, improving bus quality and frequency of service, and strategically position new bus stops near the residential areas might promote the bus trips.

Providing incentives for public transit use through employer-sponsored programs and/or implementing disincentives for automobile use can also contribute to model shifts. For example, providing passes for free or reduced fares on transit buses, implementing congestion pricing during peak hours or controlling parking spaces and increasing parking fees could incentivize transportation users to consider public transportation as an alternative to automobile use. Some of the revenues from such increased fees can be used in supporting transit services as well as for transportation user education and encouragement campaigns. Mid-sized cities such as Birmingham can benefit by examining lessons learned from other cities that used transit as a means to improve livability, equity, accessibility, economic growth, and overall quality of life in their communities. For example, congestion pricing together with the improved public transit in central London reduced traffic volumes by 15 percent. (DeCorla-Souza, 2008).

Additionally, initiating a feeder service to provide first and last mile service connections for the distant passengers shows a good potential to increase transit ridership (Luk & Olszewski, 2003). BJCTA can integrate with the existing ride hailing services in Birmingham (namely Uber and/or Lyft) for providing the first and last mile services to and from the bus stops, which is expected to benefit both the transit service and the Transportation Network Companies involved.

Limitations and Recommendations for Future Study

While the study focused on changes in transit ridership, such changes affected both automobile trips and walking trips. An increase in walking trips may have also an impact on network operations. However, such impact was combined with that of the increased transit ridership increase. Thus, the results reported in this document are based on the reduction of automobile trip due to shifts to other modes, not just transit.

This study only considered the transit routes for simulation before and after service reduction. In future work, adding more transit routes and then increasing the probability of choosing public transit is recommended to document impacts and help to justify the further extension of public transit in Birmingham region.

Also, simulating the BJCTA services with the integration of ride hailing services would be helpful to identify the benefit of enabling feeder services to increase ridership in public transportation sector.

REFERENCES

Adler, M. W., & van Ommeren, J. N. (2016). Does public transit reduce car travel externalities? Quasi-natural experiments' evidence from transit strikes. *Journal of Urban Economics, 92*, 106-119.

ALDOT. (2018). Alabama Traffic Data. Retrieved from https://aldotgis.dot.state.al.us/TDMPublic/

Anderson, M. L. (2014). Subways, strikes, and slowdowns: The impacts of public transit on traffic congestion. *American Economic Review, 104*(9), 2763-2796.

BART. (2016). *BART's Role in the Region*. Retrieved from https://www.bart.gov/sites/default/files/docs/Role%20of%20BART%20in%20Region%20-%20Final%20Web%20Oct%202016_2.pdf

Basu, R., Araldo, A., Akkinepally, A. P., Nahmias Biran, B. H., Basak, K., Seshadri, R., . . . Ben-Akiva, M. (2018). Automated Mobility-on-Demand vs. Mass Transit: A Multi-Modal Activity-Driven Agent-Based Simulation Approach. *Transportation Research Record*, 0361198118758630.

Beaudoin, J., Farzin, Y. H., & Lawell, C.-Y. C. L. (2015). Public transit investment and sustainable transportation: A review of studies of transit's impact on traffic congestion and air quality. *Research in Transportation Economics, 52*, 15-22.

Beirão, G., & Sarsfield Cabral, J. A. (2007). Understanding attitudes towards public transport and private car: A qualitative study. *Transport Policy, 14*(6), 478-489. doi:https://doi.org/10.1016/j.tranpol.2007.04.009

Bernhardt, K. (2007). Agent-based modeling in transportation. *Artificial Intelligence in Transportation, 72*.

Bischoff, J., Márquez-Fernández, F. J., Domingues-Olavarría, G., Maciejewski, M., & Nagel, K. (2019). *Impacts of vehicle fleet electrification in Sweden–a simulation-based assessment of long-distance trips.* Paper presented at the 2019 6th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS).

BJTCA. (2018a). *Transit Development Plan-Technical Memorandum 1*.

BJTCA. (2018b). *Transit Development Plan-Technical Memorandum 2: Recommendations Report*.

Blumenberg, E., Garrett, M., King, H., Paul, J., Ruvolo, M., Schouten, A., . . . Wasserman, J. (2020). What's Behind Recent Transit Ridership Trends in the Bay Area? Volume I: Overview and Analysis of Underlying Factors.

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the national academy of sciences, 99*(suppl 3), 7280-7287.

Burton, I. (1987). Report of the World Commission on Environment and Development: Our Common Future *Environment: Science and Policy for Sustainable Development* (Vol. 29, pp. 25-29).

CDC. (2005). Adult Participation in Recommended Levels of Physical Activity --- United States, 2001 and 2003. Retrieved from https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5447a3.htm#:~:text=The%20findings%20in%20this%20report,and%2045.9%25%2C%20respectively).

CIVITAS. (2020). Tool Inventory. Retrieved from https://civitas.eu/tool-inventory/matsim-multi-agent-transport-simulation.

Cools, M., Moons, E., Janssens, B., & Wets, G. (2009). Shifting towards environment-friendly modes: profiling travelers using Q-methodology. *Transportation, 36*(4), 437-453.

Cooper, D., Castiglione, J., Mislove, A., & Wilson, C. (2018). *Profiling TNC Activity Using Big Data.* Paper presented at the Transportation Research Board 97th Annual Meeting, Washington, DC.

Covington, T. (2020). Cost of Car Ownership: 2020 Data. Retrieved from https://www.thezebra.com/research/car-ownership-statistics/#:~:text=93%25%20of%20households%20in%20the,cars%20(Cesus.gov).

DeCorla-Souza, P. (2008). *Congestion Pricing—A Primer: Overview*. Federal Highway Administration, Washington, DC.

Delware Department of Natural Resources and Environmental Control. (n.d.). The Environmental Benefits of Riding Public Transit. *Division of Waste and Hazardous Substances.* Retrieved from http://www.dnrec.delaware.gov/dwhs/info/Pages/OzonePublicTrans.aspx#:~:text=Public%20transit%20moves%20people%20efficiently,as%20a%20single%2Doccupant%20auto

Duranton, G., & Turner, M. A. (2011). The fundamental law of road congestion: Evidence from US cities. *American Economic Review, 101*(6), 2616-2652.

Ewing, R., Tian, G., & Spain, A. (2014). *Effect of light-rail transit on traffic in a travel corridor*. Retrieved from https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1060&context=trec_reports

Freeland, A. L., Banerjee, S. N., Dannenberg, A. L., & Wendel, A. M. (2013). Walking associated with public transit: moving toward increased physical activity in the United States. *American journal of public health, 103*(3), 536-542.

Gärling, T., Gillholm, R., & Gärling, A. (1998). Reintroducing attitude theory in travel behavior research: The validity of an interactive interview procedure to predict car use. *Transportation, 25*(2), 129-146. doi:10.1023/A:1005004311776

Gehrke, S. R., Felix, A., & Reardon, T. (2018). *Fare Choices: A Survey of Ride-Hailing Passengers in Metro Boston*. Retrieved from http://www.mapc.org/wp-content/uploads/2018/02/Fare-Choices-MAPC.pdf

GOVERNING. (2017). Vehicle Ownership in U.S. Cities Data and Map. Retrieved from https://www.governing.com/gov-data/car-ownership-numbers-of-vehicles-by-city-map.html

Guo, G., Khalil, J. M., Yan, D., & Sisiopiku, V. (2019). *Realistic Transport Simulation: Tackling the Small Data Challenge with Open Data.* Paper presented at the 2019 IEEE International Conference on Big Data (Big Data).

Hamre, A., & Buehler, R. (2014). Commuter mode choice and free car parking, public transportation benefits, showers/lockers, and bike parking at work: evidence from the Washington, DC region. *Journal of Public transportation, 17*(2), 4.

Handy, S., Weston, L., & Mokhtarian, P. L. (2005). Driving by choice or necessity? *Transportation Research Part A: Policy and Practice, 39*(2), 183-203. doi:https://doi.org/10.1016/j.tra.2004.09.002

Horni, A., Nagel, K., & Axhausen, K. W. (2016). *The Multi-Agent Transport Simulation MATSim*: ubiquity press London.

Jensen, M. (1999). Passion and heart in transport — a sociological analysis on transport behaviour. *Transport Policy, 6*(1), 19-33. doi:https://doi.org/10.1016/S0967-070X(98)00029-8

Johnson, D., Mackie, P., & Shires, J. (2014). *Buses and the Economy II: Main report*. Retrieved from https://greenerjourneys.com/wp-content/uploads/2014/07/Buses_and_the_Economy_II_main_report_july.pdf

Jou, R.-C., & Chen, T.-Y. (2014). Factors affecting public transportation, car, and motorcycle usage. *Transportation Research Part A: Policy and Practice, 61*, 186-198. doi:https://doi.org/10.1016/j.tra.2014.02.011

Kamba, A. N., Rahmat, R., & Ismail, A. (2007). Why do people use their cars: a case study in Malaysia. *Journal of Social Sciences, 3*(3), 117-122.

Kingham, S., Dickinson, J., & Copsey, S. (2001). Travelling to work: will people move out of their cars. *Transport Policy, 8*(2), 151-160. doi:https://doi.org/10.1016/S0967-070X(01)00005-1

Kwan, S. C., & Hashim, J. H. (2016). A review on co-benefits of mass public transportation in climate change mitigation. *Sustainable Cities and Society, 22*, 11-18. doi:https://doi.org/10.1016/j.scs.2016.01.004

Lachapelle, U., & Frank, L. D. (2009). Transit and health: mode of transport, employer-sponsored public transit pass programs, and physical activity. *Journal of public health policy, 30*(1), S73-S94.

Lavieri, P. S., Dias, F. F., Juri, N. R., Kuhr, J., & Bhat, C. R. (2018). A Model of Ridesourcing Demand Generation and Distribution. *Transportation Research Record: Journal of the Transportation Research Board*. doi:10.1177/0361198118756628

Levy, J. I., Buonocore, J. J., & Von Stackelberg, K. (2010). Evaluation of the public health impacts of traffic congestion: a health risk assessment. *Environmental health, 9*(1), 65.

Litman, T. (2007). Evaluating rail transit benefits: A comment. *Transport Policy, 14*(1), 94-97.

Litman, T. (2008). Valuing transit service quality improvements. *Journal of Public transportation, 11*(2), 3.

Litman, T. (2009a). Rail transit in America: a comprehensive evaluation of benefits.

Litman, T. (2009b). Transportation cost and benefit analysis. *Victoria Transport Policy Institute, 31*.

Litman, T. (2015). *Evaluating Public Transportation Health Benefits*. Retrieved from https://www.vtpi.org/tran_health.pdf

Litman, T. (2020). *Evaluating public transit benefits and costs*: Victoria Transport Policy Institute Victoria, BC, Canada.

Liu, Y., & Cirillo, C. (2015). Measuring transit service impacts on vehicle ownership and use. *Public transport, 7*(2), 203-222.

Luk, J., & Olszewski, P. (2003). Integrated public transport in Singapore and Hong Kong. *Road & Transport Research, 12*(4), 41.

Manser, P., Becker, H., Hörl, S., & Axhausen, K. W. (2020). Designing a large-scale public transport network using agent-based microsimulation. *Transportation Research Part A: Policy and Practice, 137*, 1-15.

MATSim. (n.d.). Scenario Gallery.   Retrieved from https://matsim.org/gallery/berlin

MAX. (2017a). Fixed Route.   Retrieved from https://maxtransit.org/fixedroute/

MAX. (2017b). History.   Retrieved from https://maxtransit.org/about-us/history/#

MAX. (2019). UPDATED SERVICE MODIFICATIONS.   Retrieved from https://maxtransit.org/november-2019-service-modifications/

Mulalic, I., Pilegaard, N., & Rouwendal, J. (2016). Does improving public transport decrease car ownership? Evidence from the Copenhagen Metropolitan Area.

OpenStreetMap.   Retrieved from https://www.openstreetmap.org/changeset/87521230#map=9/33.7616/-86.5091

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., . . . Dasgupta, P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (9291691437). Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf

Ramadan, O. E., & Sisiopiku, V. P. (2019). A Critical Review on Population Synthesis for Activity- and Agent-Based Transportation Models *Transportation*: IntechOpen.

Reed, T. (2019). *INRIX Global Traffic Scorecard. INRIX Research*. Retrieved from https://interactive.wusa9.com/pdf/INRIX_2018_Global_Traffic_Scorecard_Report__final_.pdf

Saelens, B. E., Vernez Moudon, A., Kang, B., Hurvitz, P. M., & Zhou, C. (2014). Relation between higher physical activity and public transit use. *American journal of public health, 104*(5), 854-859.

Schaller, B. (2017). *UNSUSTAINABLE? The Growth of App-Based Ride Services and Traffic, Travel and the Future of New York City*. Retrieved from http://schallerconsult.com/rideservices/unsustainable.pdf

Schrank, D., Eisele, B., & Lomax, T. (2012). *TTI's 2012 urban mobility report*. Retrieved from https://mediaassets.kjrh.com/html/pdfs/2012urbanmobilityreport.pdf

Schrank, D., Eisele, B., & Lomax, T. (2019). *2019 URBAN MOBILITY REPORT*. Retrieved from https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2019.pdf

Shapiro, R. J., Hassett, K. A., & Arnold, F. S. (2016). Conserving energy and preserving the environment: The role of public transportation.

Sisiopiku, V. P., Hadi, M., Steiner, R., McDonald, N., & Ramadan, O. E. (2019). *Technology Influence on Travel Demand and Behaviors*. Retrieved from https://stride.ce.ufl.edu/wp-content/uploads/2020/06/STRIDE-Project-B-Final-Report.pdf

Tao, S., He, S. Y., & Thøgersen, J. (2019). The role of car ownership in attitudes towards public transport: A comparative study of Guangzhou and Brisbane. *Transportation Research Part F: Traffic Psychology and Behaviour, 60*, 685-699. doi:https://doi.org/10.1016/j.trf.2018.12.005

TomTom. (2020). Birmingham traffic. Retrieved from https://www.tomtom.com/en_gb/traffic-index/birmingham-alabama-traffic/

TRIP. (2019). *Birmingham Transportation by the Numbers*. Retrieved from https://tripnet.org/al_birmingham_transportation_by_the_numbers_trip_report_february_2019/

U.S. Census Bureau. (2019). American Community Survey 1-year estimates. Retrieved from https://censusreporter.org/profiles/01000US-united-states/

ValuePenguin. (2020). Car Ownership Statistics. Retrieved from https://www.valuepenguin.com/auto-insurance/car-ownership-statistics#:~:text=According%20to%202018%20census%20figures,points%20points%20compared%20to%202010.

Van der Merwe, J. (2011). *Agent-based transport demand modelling for the South African commuter environment.* University of Pretoria.

Wasfi, R. A., Ross, N. A., & El-Geneidy, A. M. (2013). Achieving recommended daily physical activity levels through commuting by public transportation: Unpacking individual and contextual influences. *Health & place, 23*, 18-25.

Wasserman, J., Taylor, B. D., Blumenberg, E., & Garrett, M. (2020). Why is Bay Area Transit Ridership Falling?

Weisbrod, G., & Reno, A. (2009). *Economic impact of public transportation investment*: Citeseer.

Xu, P., Wang, W., & Wei, C. (2018). Economic and Environmental Effects of Public Transport Subsidy Policies: a Spatial CGE Model of Beijing. *Mathematical Problems in Engineering, 2018*.

Zhang, D., Schmöcker, J.-D., Fujii, S., & Yang, X. (2016). Social norms and public transport usage: empirical study from Shanghai. *Transportation, 43*(5), 869-888.

Zheng, H., Son, Y.-J., Chiu, Y.-C., Head, L., Feng, Y., Xi, H., . . . Hickman, M. (2013). *A primer for agent-based simulation and modeling in transportation applications.* Federal Highway Administration, United States.

APPENDIX A

MATSIM OUTPUTS (VOLUME AND SPEED)

Table A1: Volume data for 7AM to 8 AM

Link ID	Volume (veh/hr) in scenario		
	1	2	3
7744301_0	120	200	210
7743601_12	130	180	110
259311994_2	160	120	170
7782154_2_r	160	210	130
592215806_4_r	160	190	180
7779547_1_r	160	250	120
259617265_1	170	270	170
7740026_3_r	200	380	260
7770584_0_r	200	210	110
7740932_2	200	130	190
7764464_16	210	170	170
260003382_0	220	190	110
7740026_0	230	150	320
165419497_7_r	230	150	150
259333888_0	230	130	170
259883863_1	240	270	200
637330666_4	240	230	220
259333891_1	260	350	360
394283610_3	270	320	300
260566720_1	280	170	240
259336961_0	300	260	220
259318944_1	300	200	190
183413733_0	310	350	210
259323199_7	310	230	220
7778900_3_r	320	290	300
7740932_0	320	220	290
259314439_3	330	210	190
7770188_0_r	340	340	280
119882420_4	350	310	400
259970298_0	350	290	260
83144692_0_r	350	320	310
608662037_8_r	360	400	270
260566007_0_r	370	270	250
259314448_1	370	340	320
260566003_0	400	630	370
259970324_1_r	410	270	280
7782325_5	430	550	420
7782325_7_r	440	330	360
7770185_2	460	460	490

259323200_2	490	550	630
7742120_1_r	490	410	430
259314445_1	540	660	560
259333883_0_r	560	520	520
259899754_0	560	490	420
260513234_1	560	520	450
7744295_23	570	670	510
608654955_0	580	770	550
7744893_0_r	600	740	550
259885808_1	610	530	540
107920507_14	620	470	560
7782325_1_r	620	450	600
165419574_0	660	440	470
259333882_3_r	690	620	580
203055723_10	720	800	770
203055723_4	790	820	770
323899401_11_r	820	760	730
323899401_8	840	910	930
48689129_3	840	850	1000
7744134_0	850	830	750
203055723_1	870	840	800
165419545_15	920	840	820
165419545_14	950	890	910
648168632_0_r	960	940	1060
259365070_2	970	1040	980
7744295_2	980	930	830
259311989_2	1000	1130	1000
48689134_0	1080	1120	1280
48689143_1	1080	1120	1100
174194212_4	1090	1080	1000
173180101_5	1100	1080	1000
173180101_0	1100	1140	1040
173180101_1	1110	1120	1040
174194202_7_r	1120	1090	1170
7775257_2_r	1130	1250	1010
165419545_8	1170	1090	1220
259365070_28	1170	1180	1110
129230175_3	1200	1170	1330
165419545_19_r	1240	870	730
259310836_13_r	1270	1400	1090
323899401_18	1280	1190	1140
165419545_5	1310	1220	1380
259617233_0_r	1380	1340	1340

259617249_0_r	1530	1660	1650
106664406_0	1570	1500	1700
259492955_1_r	1580	1650	1360
48688394_2	1580	1450	1570
106664313_0_r	1600	1580	1570
259365070_40	1610	1570	1560
259365070_47	1680	1740	1660
174194202_8	1790	1600	1620
318475224_11_r	1860	1610	1510
259338307_0	1940	2000	1910
129230176_2	2520	2510	2460

Table A2: Volume data for 8 AM to 9 AM and 3 PM to 4 PM

Link ID	Volume (veh/hr) in scenario			Link ID	Volume (veh/hr) in scenario		
	1	2	3		1	2	3
259311994_2	140	190	200	592215806_4_r	130	140	140
7743601_12	160	220	220	259311994_2	140	150	160
7782154_2_r	160	220	180	7740932_2	160	190	150
592215806_4_r	180	240	230	7764464_16	170	130	110
7740932_2	180	240	150	7779547_1_r	210	120	110
165419497_7_r	180	160	190	637330666_4	220	250	110
7779547_1_r	220	220	180	165419497_7_r	240	210	110
7770584_0_r	230	190	110	7743601_12	250	190	210
259333888_0	230	180	270	259318944_1	250	260	170
637330666_4	260	310	230	259314439_3	280	130	120
259314439_3	270	160	170	7740932_0	320	280	220
7764464_16	280	250	210	7782154_2_r	330	240	170
259883863_1	300	320	200	259333888_0	330	180	190
259318944_1	300	340	190	259883863_1	340	220	170
7744301_0	320	280	240	7770584_0_r	360	250	120
259617265_1	330	300	200	259970298_0	360	200	140
7740932_0	350	340	220	260566720_1	380	180	110
259970298_0	350	270	300	7742120_1_r	380	460	380
7740026_3_r	360	290	300	260003382_0	400	350	280
7742120_1_r	360	400	420	259333891_1	400	340	250
260003382_0	380	180	150	394283610_3	400	340	240
259333891_1	380	380	280	259323199_7	410	320	210
259323199_7	380	330	260	183413733_0	430	370	380
260566720_1	390	310	340	7770188_0_r	440	300	200
183413733_0	400	320	260	7744301_0	450	270	150
7770188_0_r	400	280	340	83144692_0_r	450	460	260
7740026_0	410	190	370	259314448_1	450	250	230
259314448_1	430	340	360	7740026_3_r	470	240	260
259899754_0	430	550	370	259617265_1	540	270	150
608662037_8_r	450	350	340	7770185_2	540	450	360
83144692_0_r	460	360	340	7782325_5	570	270	210
7778900_3_r	470	390	320	259899754_0	580	500	370
394283610_3	490	500	410	7740026_0	590	280	300
119882420_4	520	430	330	7778900_3_r	590	490	510
7770185_2	520	490	440	260566003_0	590	540	400
7782325_5	620	530	570	608662037_8_r	600	270	230
259323200_2	670	690	730	259314445_1	620	310	260
260566003_0	690	620	460	259970324_1_r	700	410	280
7744893_0_r	690	510	510	7744134_0	720	760	520

260513234_1	720	690	670	260513234_1	750	610	370
7744134_0	730	810	830	259885808_1	790	740	490
259314445_1	750	620	650	7744893_0_r	820	500	430
259970324_1_r	760	510	480	107920507_14	890	600	410
7744295_23	760	770	740	259336961_0	900	660	310
259336961_0	770	500	550	323899401_8	970	1060	1090
259885808_1	780	700	610	119882420_4	1000	510	280
608654955_0	810	760	730	260566007_0_r	1060	540	220
165419574_0	810	630	780	7782325_7_r	1070	560	330
323899401_8	890	930	970	165419574_0	1080	640	350
259333883_0_r	900	720	630	323899401_11_r	1120	1490	1370
107920507_14	930	580	540	648168632_0_r	1160	1020	780
7782325_7_r	970	750	620	323899401_18	1170	1450	1450
260566007_0_r	1050	820	490	259323200_2	1180	880	520
323899401_11_r	1050	1130	1090	48689129_3	1220	1040	820
259333882_3_r	1100	900	750	165419545_19_r	1270	530	390
203055723_4	1130	1000	930	173180101_5	1300	1080	940
48689129_3	1140	950	890	608654955_0	1310	1090	600
165419545_15	1140	1100	1060	259311989_2	1330	1210	860
203055723_1	1150	1060	970	48689134_0	1330	1090	890
173180101_1	1180	1140	1250	7744295_23	1340	960	790
648168632_0_r	1190	1060	1070	48689143_1	1360	800	670
173180101_5	1190	1150	1240	173180101_1	1400	1160	1050
203055723_10	1200	1040	880	48688394_2	1410	1070	750
173180101_0	1200	1130	1220	259338307_0	1410	1720	1450
7744295_2	1230	980	1060	174194202_7_r	1420	1640	1450
323899401_18	1260	1320	1330	173180101_0	1430	1270	1070
165419545_14	1290	1190	1170	203055723_1	1450	860	670
259365070_2	1310	1260	930	174194212_4	1480	1790	1680
259365070_28	1320	1150	1040	203055723_4	1490	870	650
174194202_7_r	1350	1340	1160	7744295_2	1500	1370	1200
174194212_4	1380	1360	1320	7782325_1_r	1510	810	480
48689134_0	1410	1120	1190	259617249_0_r	1550	1260	920
259311989_2	1430	1280	1260	203055723_10	1560	880	680
259492955_1_r	1460	1440	1500	165419545_15	1590	880	600
7782325_1_r	1470	1040	890	259333883_0_r	1600	1010	870
165419545_8	1500	1570	1570	165419545_14	1630	920	620
48689143_1	1550	1240	1300	259617233_0_r	1720	1350	980
7775257_2_r	1560	1510	1450	259492955_1_r	1780	1800	1320
259365070_47	1570	1660	1590	318475224_11_r	1780	1750	1480
259617233_0_r	1580	1460	1520	259333882_3_r	1800	1050	920
129230175_3	1610	1900	1830	106664406_0	1840	1200	1040
259310836_13_r	1610	1450	1540	165419545_8	1870	1060	760

165419545_19_r	1660	1230	1140	174194202_8	1950	1830	1990
174194202_8	1690	1770	1720	165419545_5	1960	1180	840
48688394_2	1730	1960	1540	106664313_0_r	2090	2050	1810
259365070_40	1730	1860	1510	259365070_47	2100	2290	1870
165419545_5	1810	1800	1760	259310836_13_r	2130	1820	1350
106664313_0_r	1840	1810	1580	7775257_2_r	2210	1850	1260
259617249_0_r	1990	1910	1610	259365070_28	2270	2110	1540
129230176_2	2050	2320	2260	259365070_40	2290	2290	2090
106664406_0	2070	2000	1950	259365070_2	2310	1930	1400
318475224_11_r	2280	2070	2080	129230176_2	2340	2000	1640
259338307_0	2430	2200	2060	129230175_3	2600	2420	2230

Table A3: Volume data for 4 PM to 5 PM and 5 PM to 6 PM

Link ID	Volume (veh/hr) in scenario			Link ID	Volume (veh/hr) in scenario		
	1	2	3		1	2	3
7779547_1_r	200	160	150	7740932_2	250	290	220
7764464_16	230	210	140	637330666_4	270	230	170
637330666_4	240	290	210	7764464_16	290	120	110
165419497_7_r	280	220	220	165419497_7_r	310	250	270
7740932_2	300	240	210	394283610_3	310	450	190
259883863_1	300	250	220	7779547_1_r	360	280	130
260566720_1	310	270	190	259311994_2	370	330	250
259323199_7	330	290	330	259883863_1	380	420	280
259314439_3	330	230	140	259323199_7	400	390	290
7743601_12	350	340	140	7743601_12	410	360	370
259311994_2	370	300	330	7770584_0_r	410	310	190
7770584_0_r	370	340	160	260566720_1	430	280	280
260003382_0	410	420	340	7740932_0	430	470	350
394283610_3	410	470	380	83144692_0_r	430	460	470
259318944_1	430	350	250	7770185_2	500	480	470
592215806_4_r	440	260	240	259314439_3	540	350	460
7770185_2	440	410	510	260003382_0	560	520	520
7740932_0	450	350	420	259318944_1	610	350	490
259333888_0	500	490	420	183413733_0	610	660	530
7742120_1_r	520	540	570	259970298_0	620	630	360
259333891_1	550	490	360	259333891_1	660	560	670
7770188_0_r	570	400	240	259333888_0	680	520	410
83144692_0_r	580	570	490	7770188_0_r	690	330	390
7782154_2_r	600	460	330	608662037_8_r	730	450	450
7740026_0	610	730	530	7740026_0	740	660	490
260513234_1	610	720	640	259314448_1	750	820	570
183413733_0	620	630	520	259899754_0	780	680	550
7744301_0	670	460	490	7782154_2_r	800	540	460
608662037_8_r	670	590	430	7742120_1_r	800	670	710
259970298_0	680	470	400	7744134_0	840	890	830
7740026_3_r	760	580	430	592215806_4_r	850	440	310
7744134_0	770	800	800	259970324_1_r	880	900	1080
259899754_0	820	770	530	260513234_1	890	800	800
259314448_1	850	590	550	7744301_0	900	660	690
259970324_1_r	910	940	720	259885808_1	1010	940	830
7778900_3_r	950	900	770	7744893_0_r	1130	810	690
259617265_1	1000	830	580	7778900_3_r	1200	990	730
119882420_4	1050	990	780	260566003_0	1230	980	820
7782325_5	1090	700	520	7740026_3_r	1250	990	550

260566003_0	1100	730	650	119882420_4	1270	870	600
7744893_0_r	1100	910	830	323899401_8	1340	1430	1260
259885808_1	1100	960	810	7782325_7_r	1350	1400	1430
259314445_1	1120	770	460	259617265_1	1370	1340	740
259323200_2	1150	1420	1040	7782325_5	1400	1080	790
7782325_7_r	1310	1320	1070	259314445_1	1430	1080	820
259336961_0	1320	1080	820	259336961_0	1540	1330	1030
259311989_2	1380	1410	1310	260566007_0_r	1620	1750	1780
107920507_14	1510	1140	840	648168632_0_r	1680	1390	1350
323899401_8	1540	1530	1350	259311989_2	1680	1470	1390
173180101_5	1580	1490	1530	259365070_47	1700	2080	2320
648168632_0_r	1590	1370	1330	323899401_11_r	1710	1850	2040
174194202_7_r	1700	1740	2120	173180101_5	1770	1710	1510
259338307_0	1710	1810	1900	608654955_0	1800	1380	1510
608654955_0	1750	1550	1210	174194202_7_r	1800	2080	1840
323899401_11_r	1760	1650	1830	7782325_1_r	1810	1850	1940
173180101_1	1780	1560	1620	323899401_18	1910	1730	1750
260566007_0_r	1790	1560	1250	173180101_1	1930	1910	1650
7782325_1_r	1800	1910	1540	259492955_1_r	1940	2080	1870
173180101_0	1840	1570	1640	259338307_0	1960	1970	1730
323899401_18	1870	1900	1670	174194202_8	2000	2100	2000
48688394_2	1900	1850	1510	173180101_0	2010	1900	1680
48689129_3	1910	1610	1260	259323200_2	2020	1550	1150
7744295_23	1960	1800	1550	174194212_4	2030	2340	2310
259617249_0_r	2050	2210	1980	107920507_14	2070	1730	1180
165419574_0	2070	1500	1410	48689129_3	2240	1850	1530
48689134_0	2070	1560	1520	259617249_0_r	2240	2140	1970
174194212_4	2100	1930	2180	48688394_2	2250	1950	1690
48689143_1	2120	1560	1150	48689134_0	2260	2000	1730
174194202_8	2120	2320	1980	259365070_28	2290	2140	2480
165419545_19_r	2130	1590	1260	259365070_40	2390	2340	2610
259365070_47	2130	2290	2430	318475224_11_r	2490	2520	2100
259492955_1_r	2140	2130	1670	129230176_2	2530	2400	2250
318475224_11_r	2190	2400	2010	106664313_0_r	2550	2770	2320
7744295_2	2240	1960	1640	7744295_23	2640	2210	1580
203055723_4	2330	1790	1710	259365070_2	2660	2650	2690
259365070_28	2330	2540	2460	259617233_0_r	2680	2330	2280
165419545_15	2340	1860	1860	165419545_19_r	2690	2300	1960
203055723_10	2350	1770	1800	165419545_15	2720	2350	2100
203055723_1	2370	1860	1690	7744295_2	2720	2330	2160
106664313_0_r	2420	2310	2660	165419545_5	2760	2630	2560
165419545_14	2450	1900	1930	106664406_0	2760	2830	2510
259333883_0_r	2510	1830	1890	259310836_13_r	2770	2620	2460

259333882_3_r	2530	1850	1890	203055723_1	2790	2190	2270
259365070_2	2560	2530	2370	165419545_14	2790	2540	2260
259365070_40	2570	2400	2460	259333882_3_r	2810	2440	2370
106664406_0	2580	2290	2410	203055723_4	2810	2200	2360
259310836_13_r	2600	2490	2040	203055723_10	2820	2360	2380
259617233_0_r	2600	2140	2020	259333883_0_r	2830	2430	2400
165419545_8	2690	2120	2150	129230175_3	2830	2910	2940
129230176_2	2690	2530	2410	7775257_2_r	2860	2730	2670
165419545_5	2700	2250	2310	165419574_0	2880	2180	1920
7775257_2_r	2860	2670	2320	165419545_8	2910	2650	2520
129230175_3	2950	2940	2860	48689143_1	2920	2390	1700

Table A4: Speed data for 7 AM to 8 AM

Link ID	Speed (mph) in scenario		
	1	2	3
7744301_0	24	23	17
7743601_12	28	26	28
259311994_2	36	36	36
7782154_2_r	34	26	34
592215806_4_r	37	37	37
7779547_1_r	25	25	25
259617265_1	32	34	32
7740026_3_r	34	34	34
7770584_0_r	16	16	18
7740932_2	27	27	27
7764464_16	14	10	17
260003382_0	33	21	37
7740026_0	35	33	27
165419497_7_r	13	19	12
259333888_0	28	35	34
259883863_1	27	17	15
637330666_4	25	27	27
259333891_1	31	21	20
394283610_3	19	19	19
260566720_1	21	27	17
259336961_0	36	36	35
259318944_1	36	36	36
183413733_0	30	27	22
259323199_7	22	23	21
7778900_3_r	30	26	29
7740932_0	28	28	28
259314439_3	20	36	26
7770188_0_r	31	31	31
119882420_4	47	47	47
259970298_0	34	34	35
83144692_0_r	15	22	26
608662037_8_r	20	19	21
260566007_0_r	32	32	32
259314448_1	32	32	32
260566003_0	38	37	37
259970324_1_r	26	25	26
7782325_5	36	36	36
7782325_7_r	37	36	35
7770185_2	20	26	26

259323200_2	48	48	48
7742120_1_r	32	25	36
259314445_1	34	34	34
259333883_0_r	44	45	45
259899754_0	36	33	31
260513234_1	33	33	33
7744295_23	48	48	48
608654955_0	44	44	44
7744893_0_r	26	22	26
259885808_1	32	31	29
107920507_14	34	36	34
7782325_1_r	28	27	29
165419574_0	47	47	47
259333882_3_r	46	45	47
203055723_10	39	39	39
203055723_4	42	43	43
323899401_11_r	48	47	48
323899401_8	48	49	49
48689129_3	45	45	45
7744134_0	30	33	36
203055723_1	42	42	42
165419545_15	46	47	47
165419545_14	46	46	46
648168632_0_r	47	45	45
259365070_2	48	46	46
7744295_2	48	48	48
259311989_2	38	38	38
48689134_0	29	28	23
48689143_1	46	46	46
174194212_4	48	47	49
173180101_5	29	29	29
173180101_0	35	35	35
173180101_1	34	34	34
174194202_7_r	47	47	46
7775257_2_r	46	46	46
165419545_8	47	47	47
259365070_28	27	24	23
129230175_3	42	45	45
165419545_19_r	47	48	48
259310836_13_r	46	46	46
323899401_18	47	47	47
165419545_5	27	32	36
259617233_0_r	49	48	44

259617249_0_r	47	44	42
106664406_0	46	46	46
259492955_1_r	39	40	43
48688394_2	45	46	46
106664313_0_r	49	49	49
259365070_40	34	35	36
259365070_47	44	44	44
174194202_8	14	27	18
318475224_11_r	47	47	47
259338307_0	38	36	38
129230176_2	19	32	33

Table A5: Speed data for 8 AM to 9 AM and 3 PM to 4 PM

Link ID	Speed (mph) in scenario			Link ID	Speed (mph) in scenario		
	1	2	3		1	2	3
259311994_2	36	30	36	592215806_4_r	37	37	37
7743601_12	26	26	26	259311994_2	36	36	36
7782154_2_r	30	34	31	7740932_2	27	27	27
592215806_4_r	37	37	37	7764464_16	17	10	17
7740932_2	27	27	27	7779547_1_r	25	25	25
165419497_7_r	17	20	15	637330666_4	27	26	27
7779547_1_r	25	25	25	165419497_7_r	23	11	23
7770584_0_r	15	16	18	7743601_12	26	26	26
259333888_0	28	24	30	259318944_1	29	29	29
637330666_4	25	25	26	259314439_3	36	27	36
259314439_3	18	36	36	7740932_0	28	28	28
7764464_16	15	17	11	7782154_2_r	32	29	32
259883863_1	15	10	27	259333888_0	31	29	31
259318944_1	22	29	36	259883863_1	27	26	27
7744301_0	20	21	21	7770584_0_r	16	12	16
259617265_1	32	33	32	259970298_0	34	34	34
7740932_0	27	28	28	260566720_1	27	14	27
259970298_0	34	34	34	7742120_1_r	36	36	36
7740026_3_r	35	35	35	260003382_0	37	29	37
7742120_1_r	27	21	22	259333891_1	36	24	36
260003382_0	25	39	37	394283610_3	19	19	19
259333891_1	31	20	34	259323199_7	22	22	22
259323199_7	22	22	21	183413733_0	16	17	16
260566720_1	26	16	27	7770188_0_r	31	31	31
183413733_0	21	27	27	7744301_0	18	22	18
7770188_0_r	31	31	31	83144692_0_r	12	15	12
7740026_0	29	33	31	259314448_1	32	32	32
259314448_1	33	32	32	7740026_3_r	35	35	35
259899754_0	31	34	36	259617265_1	32	32	32
608662037_8_r	17	16	23	7770185_2	27	26	27
83144692_0_r	7	21	18	7782325_5	37	36	37
7778900_3_r	30	30	30	259899754_0	36	34	36
394283610_3	15	16	19	7740026_0	33	33	33
119882420_4	47	47	47	7778900_3_r	30	30	30
7770185_2	16	18	27	260566003_0	36	40	36
7782325_5	36	36	36	608662037_8_r	17	15	17
259323200_2	46	48	44	259314445_1	35	34	35
260566003_0	37	37	37	259970324_1_r	26	26	26
7744893_0_r	17	25	23	7744134_0	35	24	35

260513234_1	26	33	33	260513234_1	33	19	33
7744134_0	32	30	33	259885808_1	33	32	33
259314445_1	34	34	34	7744893_0_r	20	22	20
259970324_1_r	26	26	26	107920507_14	36	37	36
7744295_23	47	47	47	259336961_0	36	35	36
259336961_0	34	36	36	323899401_8	49	49	49
259885808_1	31	29	28	119882420_4	47	47	47
608654955_0	44	44	44	260566007_0_r	32	32	32
165419574_0	47	47	47	7782325_7_r	37	35	37
323899401_8	49	47	49	165419574_0	47	47	47
259333883_0_r	44	45	45	323899401_11_r	48	47	48
107920507_14	33	33	35	648168632_0_r	46	47	46
7782325_7_r	31	34	35	323899401_18	47	47	47
260566007_0_r	32	32	32	259323200_2	46	48	46
323899401_11_r	48	47	48	48689129_3	45	45	45
259333882_3_r	46	43	43	165419545_19_r	48	46	48
203055723_4	43	42	43	173180101_5	29	29	29
48689129_3	45	45	45	608654955_0	44	44	44
165419545_15	47	47	47	259311989_2	38	38	38
203055723_1	39	40	42	48689134_0	34	30	34
173180101_1	34	34	34	7744295_23	48	48	48
648168632_0_r	47	46	45	48689143_1	46	46	46
173180101_5	29	29	29	173180101_1	34	34	34
203055723_10	39	39	39	48688394_2	47	46	47
173180101_0	35	36	34	259338307_0	42	43	42
7744295_2	48	48	48	174194202_7_r	45	47	45
323899401_18	47	48	47	173180101_0	35	34	35
165419545_14	46	46	46	203055723_1	42	42	42
259365070_2	47	46	47	174194212_4	39	36	39
259365070_28	27	25	32	203055723_4	42	43	42
174194202_7_r	47	47	47	7744295_2	48	48	48
174194212_4	47	49	48	7782325_1_r	28	27	28
48689134_0	30	33	18	259617249_0_r	43	44	43
259311989_2	38	38	38	203055723_10	39	39	39
259492955_1_r	41	44	42	165419545_15	47	47	47
7782325_1_r	18	23	25	259333883_0_r	45	45	45
165419545_8	47	46	47	165419545_14	46	46	46
48689143_1	45	46	45	259617233_0_r	49	47	49
7775257_2_r	46	46	46	259492955_1_r	47	45	47
259365070_47	44	44	44	318475224_11_r	44	47	44
259617233_0_r	46	47	49	259333882_3_r	41	41	41
129230175_3	44	45	45	106664406_0	46	46	46
259310836_13_r	44	46	46	165419545_8	47	47	47

165419545_19_r	44	46	48	174194202_8	14	27	14
174194202_8	23	13	26	165419545_5	36	34	36
48688394_2	45	45	46	106664313_0_r	49	49	49
259365070_40	32	35	37	259365070_47	44	44	44
165419545_5	23	34	36	259310836_13_r	47	46	47
106664313_0_r	49	49	49	7775257_2_r	46	46	46
259617249_0_r	45	46	45	259365070_28	30	24	30
129230176_2	44	32	40	259365070_40	31	34	31
106664406_0	46	46	46	259365070_2	46	43	46
318475224_11_r	47	47	47	129230176_2	44	44	44
259338307_0	29	35	36	129230175_3	32	45	32

Table A6: Speed data for 4 PM to 5 PM and 5 PM to 6 PM

Link ID	Speed (mph) in scenario			Link ID	Speed (mph) in scenario		
	1	2	3		1	2	3
7779547_1_r	25	25	25	7740932_2	27	27	27
7764464_16	14	13	10	637330666_4	20	25	25
637330666_4	27	24	27	7764464_16	15	17	16
165419497_7_r	7	8	13	165419497_7_r	8	17	14
7740932_2	26	27	27	394283610_3	17	19	19
259883863_1	13	27	15	7779547_1_r	25	25	25
260566720_1	27	27	27	259311994_2	29	32	33
259323199_7	22	22	22	259883863_1	4	22	18
259314439_3	26	28	34	259323199_7	21	6	22
7743601_12	25	17	26	7743601_12	25	23	20
259311994_2	25	34	20	7770584_0_r	6	9	14
7770584_0_r	13	9	18	260566720_1	27	26	27
260003382_0	29	26	37	7740932_0	23	27	27
394283610_3	18	19	19	83144692_0_r	7	5	7
259318944_1	23	28	32	7770185_2	25	21	27
592215806_4_r	32	35	36	259314439_3	15	32	24
7770185_2	22	25	27	260003382_0	18	32	21
7740932_0	25	27	23	259318944_1	23	19	29
259333888_0	20	22	20	183413733_0	14	21	21
7742120_1_r	11	27	17	259970298_0	27	32	34
259333891_1	9	14	25	259333891_1	12	11	10
7770188_0_r	31	15	31	259333888_0	10	17	14
83144692_0_r	3	4	9	7770188_0_r	31	31	31
7782154_2_r	11	21	24	608662037_8_r	16	17	19
7740026_0	27	24	33	7740026_0	24	28	30
260513234_1	33	18	13	259314448_1	32	31	32
183413733_0	11	16	15	259899754_0	21	28	33
7744301_0	13	16	19	7782154_2_r	5	12	20
608662037_8_r	20	15	21	7742120_1_r	2	4	5
259970298_0	33	34	34	7744134_0	10	10	15
7740026_3_r	32	34	34	592215806_4_r	37	37	37
7744134_0	18	18	22	259970324_1_r	6	3	4
259899754_0	15	23	26	260513234_1	4	13	10
259314448_1	31	32	32	7744301_0	7	14	14
259970324_1_r	26	26	26	259885808_1	14	19	26
7778900_3_r	30	30	30	7744893_0_r	4	5	11
259617265_1	30	28	32	7778900_3_r	29	30	30
119882420_4	45	46	47	260566003_0	30	35	38
7782325_5	36	36	37	7740026_3_r	29	31	33

260566003_0	28	39	40	119882420_4	45	46	47
7744893_0_r	6	6	12	323899401_8	49	49	49
259885808_1	12	14	27	7782325_7_r	3	2	14
259314445_1	34	34	33	259617265_1	26	27	25
259323200_2	48	47	47	7782325_5	35	36	35
7782325_7_r	14	19	31	259314445_1	34	34	34
259336961_0	33	34	36	259336961_0	31	32	35
259311989_2	38	38	38	260566007_0_r	3	19	32
107920507_14	24	29	31	648168632_0_r	9	44	47
323899401_8	49	48	49	259311989_2	39	38	38
173180101_5	29	29	29	259365070_47	3	44	44
648168632_0_r	26	42	44	323899401_11_r	44	46	46
174194202_7_r	45	47	47	173180101_5	29	29	29
259338307_0	36	31	40	608654955_0	41	44	44
608654955_0	44	44	44	174194202_7_r	46	47	47
323899401_11_r	46	46	47	7782325_1_r	3	3	3
173180101_1	34	34	34	323899401_18	47	47	48
260566007_0_r	10	32	32	173180101_1	34	34	34
7782325_1_r	3	6	12	259492955_1_r	44	42	43
173180101_0	30	33	32	259338307_0	32	35	37
323899401_18	47	47	48	174194202_8	19	11	16
48688394_2	46	45	45	173180101_0	31	28	31
48689129_3	45	44	45	259323200_2	36	40	37
7744295_23	48	47	48	174194212_4	37	33	24
259617249_0_r	42	40	35	107920507_14	6	18	29
165419574_0	47	47	47	48689129_3	45	45	45
48689134_0	14	21	18	259617249_0_r	35	36	36
174194212_4	40	44	43	48688394_2	45	47	46
48689143_1	43	45	46	48689134_0	13	13	17
174194202_8	8	9	17	259365070_28	9	7	6
165419545_19_r	48	47	48	259365070_40	13	27	23
259365070_47	12	44	44	318475224_11_r	42	45	47
259492955_1_r	40	42	44	129230176_2	15	41	39
318475224_11_r	47	47	45	106664313_0_r	48	45	48
7744295_2	41	47	48	7744295_23	44	40	48
203055723_4	43	43	43	259365070_2	32	26	25
259365070_28	8	7	20	259617233_0_r	18	32	45
165419545_15	47	47	46	165419545_19_r	40	40	48
203055723_10	39	39	39	165419545_15	47	47	47
203055723_1	42	42	42	7744295_2	38	48	46
106664313_0_r	48	46	48	165419545_5	9	22	33
165419545_14	46	44	46	106664406_0	5	9	26
259333883_0_r	41	45	45	259310836_13_r	38	45	40

259333882_3_r	22	31	32	203055723_1	32	42	42
259365070_2	29	27	28	165419545_14	46	46	46
259365070_40	16	21	36	259333882_3_r	17	20	23
106664406_0	8	26	42	203055723_4	43	43	37
259310836_13_r	36	41	37	203055723_10	39	39	39
259617233_0_r	16	39	39	259333883_0_r	45	45	45
165419545_8	47	47	47	129230175_3	13	45	45
129230176_2	35	41	43	7775257_2_r	12	46	46
165419545_5	22	32	29	165419574_0	47	47	47
7775257_2_r	46	46	45	165419545_8	47	46	47
129230175_3	24	37	41	48689143_1	40	42	45

APPENDIX B

TRAVEL TIME CALCULATED FROM MATSIM OUTPUT

Table B1: Travel time data for 7AM to 8 AM

Link ID	Travel time (sec) in scenario		
	1	2	3
7744301_0	7	7.5	9.9
7743601_12	11.15	12	11
259311994_2	9	9	9
7782154_2_r	10	13.19	10
592215806_4_r	9	9	9
7779547_1_r	9	9.08	9
259617265_1	4	3.74	4
7740026_3_r	17.7	17.84	17.5
7770584_0_r	25.35	25.1	22
7740932_2	21	21	21
7764464_16	12.67	16.94	10.06
260003382_0	10.09	15.53	9
7740026_0	5.57	6	7.19
165419497_7_r	16.96	11.33	18.13
259333888_0	14.57	12	12.12
259883863_1	5	7.93	9.3
637330666_4	8.67	8.17	8
259333891_1	10.5	15.66	16.19
394283610_3	39	39	39
260566720_1	14.14	11	17.17
259336961_0	34.3	34.15	35.64
259318944_1	9	9	9
183413733_0	8.06	8.89	11.23
259323199_7	4.31	4.17	4.41
7778900_3_r	4	4.48	4.03
7740932_0	26.91	27.05	27.1
259314439_3	16.36	9	12.58
7770188_0_r	4	4	4
119882420_4	10	10	10
259970298_0	8	8	7.73
83144692_0_r	23.94	16.69	14.48
608662037_8_r	5.92	6.15	5.67
260566007_0_r	4	4	4
259314448_1	4	4	4
260566003_0	13.5	13.87	13.82
259970324_1_r	5.07	5.11	5.04
7782325_5	3	3	3
7782325_7_r	9	9.24	9.38
7770185_2	9.43	7.02	7.02

259323200_2	3	3	3
7742120_1_r	3.33	4.24	3
259314445_1	3	3	3
259333883_0_r	5.11	5	5
259899754_0	12	13.02	13.86
260513234_1	3.02	3	3
7744295_23	4	4	4
608654955_0	4	4	4
7744893_0_r	12.15	14.17	12
259885808_1	36.37	37.36	40.26
107920507_14	31.65	30.53	32.11
7782325_1_r	6.77	7	6.68
165419574_0	3	3	3
259333882_3_r	6.26	6.35	6.1
203055723_10	4	4	4
203055723_4	3.09	3	3
323899401_11_r	14	14.1	14
323899401_8	5.08	5	5
48689129_3	3	3	3
7744134_0	26.56	23.67	22
203055723_1	6	6.02	6
165419545_15	5.08	5	5
165419545_14	6	5.94	6
648168632_0_r	7.09	7.29	7.43
259365070_2	5.79	6.04	6.05
7744295_2	25	25	25
259311989_2	3	3	3
48689134_0	4.51	4.63	5.74
48689143_1	14.37	14.11	14.23
174194212_4	3.05	3.15	3
173180101_5	4	4	4
173180101_0	16.69	16.81	16.79
173180101_1	10.03	10	10
174194202_7_r	5	5	5.09
7775257_2_r	9	9	9
165419545_8	15.09	15	15
259365070_28	2.76	3.16	3.36
129230175_3	3.19	3	3
165419545_19_r	6.13	6	6
259310836_13_r	8.14	8.11	8.13
323899401_18	13	12.99	13.1
165419545_5	4.03	3.31	3
259617233_0_r	7.03	7.13	7.84

259617249_0_r	7.12	7.59	7.92
106664406_0	6	6	6
259492955_1_r	11.11	10.9	10.21
48688394_2	7.44	7.2	7.24
106664313_0_r	14	14	14
259365070_40	3.27	3.17	3.1
259365070_47	3	3	3
174194202_8	6.49	3.33	4.84
318475224_11_r	10	10	10
259338307_0	4.66	5.02	4.66
129230176_2	35.13	20.15	19.43

Table B2: Travel time data for 8 AM to 9 AM and 3 PM to 4 PM

Link ID	Travel time (sec) in scenario			Link ID	Travel time (sec) in scenario		
	1	2	3		1	2	3
259311994_2	9	11	9	592215806_4_r	9	9	9
7743601_12	11.94	12	12	259311994_2	9	9	9
7782154_2_r	11.19	10	10.83	7740932_2	21	21	21
592215806_4_r	9	9	9	7764464_16	10	18	10.09
7740932_2	21	21	21	7779547_1_r	11.19	9	9
165419497_7_r	12.89	10.88	14.63	637330666_4	8.68	8.4	8
7779547_1_r	9	9	9.11	165419497_7_r	16.96	18.76	9.45
7770584_0_r	26.39	24.89	22	7743601_12	12	12	11.95
259333888_0	14.57	17.28	13.78	259318944_1	12.08	10.96	10.94
637330666_4	8.62	8.52	8.22	259314439_3	11.18	12.23	9
259314439_3	17.9	9	9	7740932_0	29.78	27	26.95
7764464_16	11.43	10.08	16.24	7782154_2_r	13.03	11.68	10.65
259883863_1	8.87	13.38	5.05	259333888_0	16.58	14.17	13.37
259318944_1	14.37	11.06	9	259883863_1	5.21	5.23	5.06
7744301_0	8.44	8.14	8.17	7770584_0_r	48.25	32.56	25.17
259617265_1	3.97	3.83	3.95	259970298_0	8.22	8	8
7740932_0	27.14	27	27.09	260566720_1	11.08	21.42	11
259970298_0	7.97	8	8	7742120_1_r	3	3	3
7740026_3_r	17.28	17.17	17.35	260003382_0	9.41	11.46	9
7742120_1_r	3.94	5.25	4.88	259333891_1	15.95	13.44	9
260003382_0	13.08	8.56	9	394283610_3	39.37	39	39.08
259333891_1	10.37	15.97	9.68	259323199_7	4.51	4.31	4.24
259323199_7	4.34	4.36	4.42	183413733_0	14.42	14	14.84
260566720_1	11.54	19.26	11.24	7770188_0_r	4	4	4
183413733_0	11.7	9	9	7744301_0	8.44	7.78	9.6
7770188_0_r	4	4	4	83144692_0_r	40.76	23.94	31.69
7740026_0	6.83	6	6.41	259314448_1	3.78	4	4
259314448_1	3.93	3.97	4	7740026_3_r	19.53	17.38	17.23
259899754_0	13.88	12.71	12	259617265_1	4.11	4	4
608662037_8_r	6.78	7.46	5	7770185_2	7.15	7.22	7
83144692_0_r	51.04	17.28	20.26	7782325_5	3.04	3	2.9
7778900_3_r	4	4	4	259899754_0	17.83	12.64	12.08
394283610_3	49.47	46.28	39	7740026_0	6.05	5.93	5.97
119882420_4	10	10	10	7778900_3_r	4.02	4	4
7770185_2	11.36	10.2	6.98	260566003_0	14.1	12.67	13.98
7782325_5	3	3	3	608662037_8_r	5	7.93	6.83
259323200_2	3.15	3	3.27	259314445_1	3	3	2.92
260566003_0	13.68	13.79	13.87	259970324_1_r	5.03	5.05	5
7744893_0_r	18.14	12.47	13.9	7744134_0	34.94	33.17	22.55

260513234_1	3.92	3.03	3	260513234_1	3	5.15	3
7744134_0	24.41	26.09	24.01	259885808_1	36.11	36.78	35.18
259314445_1	3	2.98	3	7744893_0_r	31.32	14	15.67
259970324_1_r	5.04	5.02	5.04	107920507_14	31.27	29.15	30.1
7744295_23	4.03	4.08	4.09	259336961_0	35	35.67	34.94
259336961_0	36.22	34.9	34.76	323899401_8	5	5	5
259885808_1	37.51	40.47	41.57	119882420_4	10.07	10	10
608654955_0	4	4	4	260566007_0_r	4	4	4
165419574_0	3	3	3	7782325_7_r	11.12	9.49	9
323899401_8	5	5.23	5	165419574_0	3	3	3
259333883_0_r	5.11	5	5	323899401_11_r	14.37	14.32	14
107920507_14	32.95	32.78	30.84	648168632_0_r	7.08	7	7.14
7782325_7_r	10.51	9.64	9.37	323899401_18	13	12.92	13
260566007_0_r	4	4	4	259323200_2	3.17	3	3.12
323899401_11_r	14	14.09	14	48689129_3	3	3	3
259333882_3_r	6.18	6.57	6.6	165419545_19_r	6.04	6.17	6
203055723_4	3	3.1	3	173180101_5	4	4	4
48689129_3	3	3	3	608654955_0	4.05	4	4
165419545_15	5	5	5	259311989_2	3	3	3
203055723_1	6.47	6.25	6.07	48689134_0	5.68	4.31	3.88
173180101_1	10	10	10.08	7744295_23	4.38	4	4
648168632_0_r	7	7.19	7.35	48689143_1	14.91	14.22	14.35
173180101_5	4	4	4	173180101_1	10	10	10
203055723_10	4	4	4	48688394_2	7.23	7.23	7.09
173180101_0	16.98	16.32	17.08	259338307_0	4.37	4.19	4.23
7744295_2	25.14	25	25	174194202_7_r	5.49	5	5.28
323899401_18	12.97	12.9	13.07	173180101_0	17.22	17.08	17.04
165419545_14	6	6	6	203055723_1	6	5.99	6
259365070_2	5.87	6	5.9	174194212_4	3.05	4.09	3.75
259365070_28	2.78	2.99	2.37	203055723_4	3.07	3	3.08
174194202_7_r	5	5	5	7744295_2	25	25.13	25.39
174194212_4	3.12	3	3.08	7782325_1_r	13.07	7.05	6.79
48689134_0	4.41	3.93	7.11	259617249_0_r	7.7	7.68	7.77
259311989_2	3	3	3	203055723_10	4	4	4
259492955_1_r	10.55	9.88	10.26	165419545_15	4.97	4.95	5
7782325_1_r	10.53	8.15	7.66	259333883_0_r	5.01	5	5
165419545_8	15	15.23	15	165419545_14	6	5.99	6
48689143_1	14.54	14.31	14.54	259617233_0_r	7.79	7.2	7
7775257_2_r	9	9	9	259492955_1_r	10.54	9.76	9.21
259365070_47	3	3	3	318475224_11_r	10	10	10.72
259617233_0_r	7.46	7.28	7.03	259333882_3_r	7.43	6.9	6.9
129230175_3	3.06	3	3	106664406_0	8.57	6.02	6
259310836_13_r	8.4	8.1	8.14	165419545_8	15	15	15

165419545_19_r	6.45	6.22	6	174194202_8	5.05	3.3	6.36
174194202_8	3.92	6.64	3.34	165419545_5	3.77	3.14	3
48688394_2	7.31	7.38	7.15	106664313_0_r	14	14	14
259365070_40	3.54	3.17	3	259365070_47	3	3	3
165419545_5	4.65	3.16	3	259310836_13_r	8.29	8.02	8
106664313_0_r	14	14	14	7775257_2_r	9	9	9
259617249_0_r	7.39	7.34	7.42	259365070_28	4.18	3.1	2.5
129230176_2	14.9	20.61	16.19	259365070_40	5.76	3.32	3.66
106664406_0	6.08	6	6	259365070_2	8.01	6.41	6.06
318475224_11_r	10	10	10	129230176_2	14.69	14.92	14.76
259338307_0	6.17	5.15	5	129230175_3	3.38	3	4.24

Table B3: Travel time data for 4 PM to 5 PM and 5 PM to 6 PM

Link ID	Travel time (sec) in scenario			Link ID	Travel time (sec) in scenario		
	1	2	3		1	2	3
7779547_1_r	9.15	9	9	7740932_2	21.12	21	21
7764464_16	12	13.1	16.71	637330666_4	11	8.57	8.71
637330666_4	8	9.1	8	7764464_16	11.38	10.08	11
165419497_7_r	29.57	28.39	16.68	165419497_7_r	25.9	12.72	15
7740932_2	21.63	21	21.14	394283610_3	43.77	39.02	39
259883863_1	10.57	5	9.14	7779547_1_r	9.14	9.11	9
260566720_1	11	10.96	11	259311994_2	11.14	10.21	9.92
259323199_7	4.33	4.31	4.21	259883863_1	34.21	6.05	7.68
259314439_3	12.7	11.65	9.57	259323199_7	4.57	15.62	4.34
7743601_12	12.17	18.29	12	7743601_12	12.49	13.35	15.81
259311994_2	13.3	9.73	16.64	7770584_0_r	67.76	46.81	28.79
7770584_0_r	32	44.15	22	260566720_1	11	11.39	11.07
260003382_0	11.39	12.52	8.97	7740932_0	32.18	27.38	27.37
394283610_3	40.83	39.04	39.08	83144692_0_r	49.76	73.17	56.79
259318944_1	13.98	11.4	10.2	7770185_2	7.3	8.79	7
592215806_4_r	10.43	9.46	9.21	259314439_3	22.37	10.29	13.57
7770185_2	8.59	7.34	7	260003382_0	18.16	10.17	15.71
7740932_0	29.49	27.63	32.05	259318944_1	13.79	16.8	11.04
259333888_0	20.88	19.08	20.55	183413733_0	17.16	11.71	11.62
7742120_1_r	9.9	4.04	6.51	259970298_0	10.13	8.38	8
259333891_1	35.93	22.65	13.17	259333891_1	26.5	29.63	34.29
7770188_0_r	4	7.98	4	259333888_0	43.09	24.06	28.86
83144692_0_r	111.4	95.05	39.2	7770188_0_r	4	4	4
7782154_2_r	30.45	16	14.27	608662037_8_r	7.34	6.96	6.09
7740026_0	7.33	8.33	6	7740026_0	8.32	7.12	6.66
260513234_1	3.02	5.42	7.98	259314448_1	3.97	4.15	4
183413733_0	22.6	15.35	15.85	259899754_0	20.28	15.54	13.16
7744301_0	13.22	10.83	8.92	7782154_2_r	64.32	28.67	17.09
608662037_8_r	5.72	7.86	5.59	7742120_1_r	52.09	30.37	22.24
259970298_0	8.24	7.98	8	7744134_0	76.98	78.97	51.81
7740026_3_r	18.63	17.71	18	592215806_4_r	9	9	9
7744134_0	44.22	44.98	36.55	259970324_1_r	22.06	48.82	29.82
259899754_0	28.45	18.86	16.96	260513234_1	28.06	7.41	10.5
259314448_1	4.19	3.98	4	7744301_0	23.12	12.42	12.19
259970324_1_r	5.03	5.01	5.04	259885808_1	81.52	62.93	44.3
7778900_3_r	4	4	4	7744893_0_r	70.52	58.25	29.93
259617265_1	4.18	4.54	4	7778900_3_r	4.1	4	4
119882420_4	10.49	10.22	10	260566003_0	17.21	14.33	13.42
7782325_5	2.99	3	2.9	7740026_3_r	21.12	19.33	18.22

260566003_0	17.91	13.14	12.58	119882420_4	10.45	10.28	10
7744893_0_r	53.24	50.41	26.9	323899401_8	5	5	5
259885808_1	94.01	85.02	43.55	7782325_7_r	122.66	183.94	24.01
259314445_1	2.98	2.99	3.04	259617265_1	4.97	4.68	5.18
259323200_2	3	3.07	3.08	7782325_5	3.06	3	3.1
7782325_7_r	23.27	17.68	10.75	259314445_1	3	2.99	3
259336961_0	37.5	36.35	34.95	259336961_0	40.33	38.52	35.74
259311989_2	3	3	3	260566007_0_r	40.15	6.67	4.03
107920507_14	46.31	37.47	34.65	648168632_0_r	34.89	7.48	7
323899401_8	5	5.1	5	259311989_2	2.99	3	3
173180101_5	4.02	4	4	259365070_47	51.25	3	3
648168632_0_r	12.82	7.8	7.44	323899401_11_r	15.34	14.65	14.38
174194202_7_r	5.22	5	5	173180101_5	4	4	4
259338307_0	5.02	5.77	4.51	608654955_0	4.28	4	4
608654955_0	4	4	4	174194202_7_r	5.1	5	5
323899401_11_r	14.39	14.58	14.15	7782325_1_r	69.84	61.71	56.73
173180101_1	10	10	10.03	323899401_18	12.96	13.18	12.73
260566007_0_r	12.99	4	4	173180101_1	10.15	10.04	10
7782325_1_r	65.37	32.86	15.65	259492955_1_r	9.9	10.36	10.16
173180101_0	19.38	18.08	18.58	259338307_0	5.58	5.09	4.83
323899401_18	12.97	13.03	12.85	174194202_8	4.68	7.71	5.55
48688394_2	7.16	7.4	7.33	173180101_0	18.84	21.15	18.68
48689129_3	3	3.04	3	259323200_2	3.97	3.64	3.87
7744295_23	4.01	4.02	4	174194212_4	4.01	4.41	6.19
259617249_0_r	8	8.44	9.56	107920507_14	193.42	58.99	37.45
165419574_0	3	3	3	48689129_3	3.02	3	3
48689134_0	9.33	6.28	7.18	259617249_0_r	9.59	9.4	9.23
174194212_4	3.7	3.36	3.44	48688394_2	7.32	7.12	7.26
48689143_1	15.29	14.64	14.23	48689134_0	10.12	9.69	7.5
174194202_8	10.96	9.36	5.24	259365070_28	8.61	10.58	11.74
165419545_19_r	6	6.07	6	259365070_40	8.44	4.18	4.9
259365070_47	11.12	3	3	318475224_11_r	11.29	10.55	10
259492955_1_r	10.87	10.34	9.95	129230176_2	43.31	15.75	16.53
318475224_11_r	10	10.19	10.59	106664313_0_r	14.29	15.09	14.3
7744295_2	29.53	26.03	25.39	7744295_23	4.35	4.75	4
203055723_4	3.04	3.03	3	259365070_2	8.59	10.6	10.96
259365070_28	9.41	11.44	3.87	259617233_0_r	19.47	10.75	7.58
165419545_15	5	4.99	5.07	165419545_19_r	7.15	7.23	6
203055723_10	4	4	4	165419545_15	5	5	5
203055723_1	6	6	6	7744295_2	31.67	25.24	26.63
106664313_0_r	14.25	14.91	14.29	165419545_5	11.95	4.89	3.28
165419545_14	6	6.32	5.99	106664406_0	53.05	30.14	10.75
259333883_0_r	5.51	5.02	5	259310836_13_r	9.89	8.36	9.41

259333882_3_r	13.25	9.06	8.82	203055723_1	7.89	6	6.03
259365070_2	9.54	10.26	9.95	165419545_14	6	6	6
259365070_40	6.93	5.45	3.09	259333882_3_r	16.75	14.23	12.41
106664406_0	34.86	10.52	6.58	203055723_4	3.04	3	3.5
259310836_13_r	10.27	9	10.04	203055723_10	4	4	4
259617233_0_r	20.79	8.75	8.88	259333883_0_r	5.01	5	5
165419545_8	15.03	15	15	129230175_3	10.46	3	3
129230176_2	18.55	15.84	15.14	7775257_2_r	34.77	9	9
165419545_5	4.89	3.35	3.67	165419574_0	3	3	3
7775257_2_r	9	9	9.19	165419545_8	15	15.14	15
129230175_3	5.71	3.66	3.25	48689143_1	16.33	15.73	14.54