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Mobility-as-a-Service: Assessing Performance and Sustainability Effects of an Integrated Multi-Modal Simulated Transportation Network

Mohamed El-Agroudy
University of Central Florida

MOBILITY-AS-A-SERVICE: ASSESSING PERFORMANCE AND SUSTAINABILITY EFFECTS OF AN INTEGRATED MULTI-MODAL SIMULATED TRANSPORTATION NETWORK

By

MOHAMED AMR EL-AGROUDY
B.Eng. in Civil Engineering (2017)
McGill University, Montreal, Canada

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ABSTRACT

Advances in information technology services have seen profound impacts on the state of transport services in the urban traffic environment. Mobility-as-a-Service (MaaS) represents the digital consolidation of users, operators, and public-private managing entities to provide totally comprehensive, integrated trip-making services. Users now enjoy extra flexibility for trip-making with new modal alternatives such as micro-mobility (e.g Lime Bikes, Spin Scooters) and rideshare (e.g. Lyft, Uber). However, current knowledge on the performance and interactive effects of these newer alternative modes is vague if not inconsistent. As such, these effects were studied through micro-simulation analysis of a multi-modal urban corridor in Orlando, Florida. D-Optimal experimental designs are generated to evaluate the hard performance and sustainability effects of five (5) modes: personal vehicles, bus transit, rideshare, walking, and micro-mobility.

Bus transit demonstrates the lowest impact per person-trip on a route-level (i.e. travel time, queuing), while significantly enhancing network-level performance factors such as average delay and travel speed. For instance, a relatively minor eight (8) percent increase in transit share resulted in a 15.5 percent decrease in average delay through the network. Moreover, the route-level impacts of transit decrease to zero as the network approaches congestion. Conversely, rideshare demonstrates significant adverse effects across all performance measures, worsening in more congested conditions, while walking and micro-mobility effects are found to vary and are dictated mainly by their interactions with other sidewalk and roadway users. Furthermore, curbside facilities

such as lay-bys also demonstrated substantial roadway performance impacts. Lastly, various cost analyses are used to demonstrate the potential cost-efficiency of even the most cutting-edge transit-focused services in terms of project budgeting and externalities. Discussion of the findings provided valuable insights for street-and-city-level multi-modal planning design, as well as the broader operational implications of autonomous technologies taking on a greater role in the transportation service industry.

To all whose efforts paved the way for us to make it this far, and all who may benefit from the small step forward that is my contribution. Look to the future and charge on!

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EXECUTIVE SUMMARY

In the context of mobility and transit engineering, the emergence of new technologies has provided engineers with tomorrow's solutions to today's problems. Enhanced connectivity and information services have resulted in the rise of a new breed of transportation alternatives, such as rideshare (Uber, Lyft, etc.) and micro-mobility (Lime bike-share, Spin scooter-share). Mobility-as-a-Service (MaaS) is a concept that seeks to fully unify service with information to provide optimal travel solutions from a holistic framework that combines multi-modal private and public alternatives. Current research on existing MaaS applications has shown promising results in encouraging multi-modal trip planning and increasing transit ridership, however, the impacts on network performance have not been explored in-depth. This research aims to comprehensively quantify the benefits or detriments of different modes in a MaaS network in terms of performance and sustainability factors. A VISSIM model of I-Drive in Orlando was developed to reflect the existing conditions of a multi-modal transit corridor during a typical weekday PM peak hour. Alternative MaaS scenarios are analyzed by implementing ride-share and micro-mobility as alternative modes in addition to three existing modes: personal vehicles, transit, and walking. Varied modal splits are tested according to three (3) multi-level experimental designs under D-Optimality criteria. Several network-level and route-level performance measures were analyzed including average network delay, speed, total queuing, transit stop queuing, sidewalk travel time, and vehicular travel time along I-Drive. A practical benefit-cost analysis was also conducted comparing the costs of traditional capacity improvement

projects with MaaS-oriented transit improvement projects in terms of externalities, operating costs, capital investment, and costs-over-time.

Analysis and statistical modeling of network-level factors found significant effects and interactions across all modes. Generally, transit was found to have major benefits for improving network-level factors relative to other modes. For instance, in congested conditions, increasing the transit modal share by eight (8) percent resulted in a 15.5% decrease in average delay throughout the network. Rideshare was found to have significant adverse network-level impacts while the roles of the walking and micro-mobility modes are less pronounced and dictated by their interactions. Route-level performance measures also suggest that rideshare represented the heaviest load per person on roadway capacity. Notably, transit was found to have no effect on transit stop queuing and interacts with vehicular demand such that adding transit capacity does not affect vehicular travel times at high congestion levels, suggesting the potential for transit to improve throughput in congested conditions. The impacts of infrastructure were also considered for queuing effects at shared rideshare-transit stops; on average, stops with lay-bys were found to enjoy over 1200% reduced spill-over queuing. Finally, the benefit-cost analysis demonstrates the cost-effectiveness of MaaS-oriented infrastructure and transit improvements per-mile and over time. Several transit improvement project cost estimates were compared with traditional lane build scenarios using real-world data. Despite the relatively high capital investment, the costs per-person-mile of added capacity were found to be at least 11.7 times cheaper for even the most expensive, cutting-edge transit improvements. Furthermore, operating costs and externalities for

transit improvements were also found to be cheaper over time than the costs and externalities of vehicle ownership and maintenance. These findings lay the groundwork for standardizing efficient, conscious, and sustainable MaaS implementation in terms of modal focus, infrastructure requirements, and capacity utilization. Overall, the research findings were very encouraging, demonstrating the potential of MaaS for cost-effective congestion relief with strong implications for enhancing the practice of multi-modal transportation planning in Florida.

CHAPTER 1 : INTRODUCTION

1.1 Background: Mobility-as-a-Service (MaaS)

Trends in urbanization and advancement of technology have resulted in major shifts in the urban transportation framework. The combination of transportation services and personal information systems has already seen the growth of an entirely new market in ride-sharing and micro-mobility (bike-share or scooter-share) services, such as Uber, Lyft, or Lime. Public and personal transit has also seen integration with apps like Google Maps that provide the user with transit schedules, route times, route pricing, alternative routes, and live traffic conditions. The end goal is to provide commuters sustainable and effective transportation services with the convenience of a unified payment platform. Two of the most cutting-edge technology-based solutions to fixing urban traffic congestion have been the promises of electric self-driving vehicles and, as a counter to private vehicle ownership, the promises of more integrated public transportation networks. While fully autonomous vehicle implementations have been shown to improve throughput and capacity (Gružauskas, 2018; Kloostra and Roorda, 2019), it has also been found that substantial performance and environmental improvements may be realized through more cost-effective, integrated shared-use transportation systems, which may also take advantage of the technological advances in big data collection and autonomous vehicles (Ramboll, 2019; Zhang, 2015; Nikitas et al., 2017). While the economic and societal benefits of such systems have been explored in depth, performance effects of such integrated networks have seen much less attention. The

following work aims to explore the performance effects of such integrated transit systems and the effects of individual modes through microsimulation analysis of multiple multi-modal scenarios in a MaaS network.

In general, widespread private vehicle ownership has been found to be problematic given future projections on issues such as emissions, congestion, economy, and safety (Hao et al., 2011a). Public transit offers a more efficient solution for moving more people with less resources. It is found that in developing countries like China, transit capacity (in terms of buses) increases with the urban population in prefecture-level cities (Hao et al., 2011b). In particular, public transit capacity sees major increases at population levels exceeding two million. Furthermore, for a long time it has been known that public transit spending carries a higher return on investment in terms of economic growth and throughput (Aschauer, 1991). These studies are suggestive of the potential for a shift leading away from private ownership towards shared transportation solutions. Cities around the world are beginning to move their public transportation services to the cloud, with integration of shared services such as transit apps, parking apps, city-bikes, electric scooters, and carpooling networks. Furthermore, urbanization trends are shifting towards better use of land (i.e. building upwards versus building outwards) as more of the world's population is expected to live and work in urbanized areas in the coming decades (Cohen, 2006). These kinds of landscapes will also allow for shorter trip distances and relying on density for adequate provision of service; as such, shared multi-modal transportation systems such as MaaS are expected to see much more attention as these urbanization trends are realized.

1.2 Research Questions

The following questions are posited to more clearly direct the research methodology and analysis.

1.2.1 From the Literature

- What are the major components in a MaaS network and how do they effect the individual trip making process?
- What does the current knowledge body say on the performance effects of various modes of transportation?
- Which measures of network performance should be targeted in the analysis?
- What are the features of successful multi-modal applications, and how does the Orlando transportation system compare?
- Which analysis techniques are most suited to addressing performance effects?

1.2.2 From the Experiment

- How is performance effected by various modes on a microscopic basis (i.e. effects that can be observed on the individual level)?
- How is performance effected by various modes on a network-wide basis (i.e. effects that aggregate performance across the entire network of users)?
- How do various modes interact in terms of performance effects?
- How can MaaS components be implemented most effectively to reduce externalities and improve performance?

CHAPTER 2 : LITERATURE REVIEW

2.1 MaaS: General Overview of Components and Benefits

Mobility as a Service represents a relatively novel concept in the urban transportation landscape that seeks to improve transportation services through efficient integration of existing travel modes. Effective MaaS implementations can provide affordable solutions and quality of life improvements for many of the inconveniences associated with public transit. In the context of the Orlando urban transportation framework, MaaS components have long been considered one of the leading solutions to Orlando's congestion issues (though not particularly under the guise of MaaS, see section 2.2).

To date, the majority of studies on MaaS focus on the challenges of implementation, such as funding, partnerships, and social challenges for changing attitudes towards a connected multi-modal transportation system (Holmberg et al., 2016). For example, a significant challenge for implementation is the deployment of a digitized buying/subscription process, one of the essential pre-requisites for developing an attractive MaaS network. Another major challenge is the design of the network; how should roadway design accommodate multiple modes to create a network that is both sustainable and convenient for customers? A study by Zhou and Sperling (2001) notes the negative effects of multiple modes interacting at traffic lights. Emissions were observed at intersections in Shanghai under a variety of infrastructure and traffic conditions. While pollutant concentrations were expectedly higher at intersections (and much higher at streets under elevated roadways), state-of-the-practice emissions

models were consistently underpredicting pollution levels at these locations. The higher-than-expected pollution levels were attributed delays and erratic flows as a result of mixed-use roadways for bicycles, compact vehicles, and regular cars, highlighting the importance of multi-modal oriented design. There has also been much investigation into the policy-framework and commercial perspective of which players should take the lead in such implementations (i.e. What role does the public sector play in facilitating a successful MaaS network? What incentives are there for private entities? How should policy be designed around these partnerships?) (Li and Voege, 2017; Sochor et al., 2015).

While each of these challenges may warrant an entire dedicated study, very little attention has been given to the design aspect of MaaS networks and how performance and sustainability factors may be optimized through proper implementations. The Orlando transportation network represents a unique challenge due to its mixture of land-uses, population groups, and the existing transportation infrastructure which heavily favors personal vehicle usage. As such, I-Drive is chosen in this study as a prime candidate for such an implementation due to the existing multi-modal environment in addition to some of the elements of a MaaS network, such as the I-Ride information services. MaaS-like considerations for improving the Orlando transportation network have been made in the past, despite the less-than-optimal existing transportation framework.

2.2 Examples of MaaS Implementations in Florida

In Florida, MaaS components are seeing major growth in connecting travel information and service. Intelligent Transportation Systems (ITS) have seen major developments in improving network performance and safety through traveler information systems and limited access facility management in Orlando (such as E-Pass) (Abou-Senna 2016; Al-Deek et al., 1997; Al-Deek et al. 1993; Kanafani and Al-Deek, 1990). These applications have led to improvements in reducing network delay, lowering accident rates, and improving emergency response times. Such ITS applications represent several major components of MaaS networks: big data processing, information management and distribution, and automated payment collection. As early as 2000, the potential of ITS in MaaS-like implementations has been discussed for the benefits of improving connectivity at a local and regional level (Grovdahl and Hill, 2000).

Notably, the work discusses the need for implementing alternative transportation modes accessibly and safely. Accessibility concerns are a major consideration for the benefit of certain groups in society that may not easily take advantage of ITS, but are contributors nonetheless. For instance, low-income, minority, and elderly groups may be more reliant on public transportation services and walking/biking facilities due to the financial and physical stress of owning and maintaining personal automobiles. A significant number of these services already exist in Florida to cater to these demographics and others, but are typically limited in capacity and reach. Examples include theme park shuttles for Universal and Disney, I-Ride, dedicated campus shuttles for universities including UCF and USF, and county-wide park-n-ride services such as

implemented by the Pinellas Suncoast Transit Authority (PSTA). Furthermore, many these services are augmented via traveler information systems and apps that can update users on schedules and bus timings in real-time. The combination of these components is an important first step in implementing a comprehensive MaaS network. However, many of these examples represent independent local entities. Implementing MaaS in scale is an entirely different challenge that will require both public and private involvement.

The National Center for Transit Research addresses some of the concerns for large-scale implementation in the following referenced report on high speed rail in the Orlando-Tampa corridor. Several aspects critical to MaaS are discussed in terms of connectivity (Gregg and Begley, 2011). A well-connected transportation network is crucial in being able to implement MaaS effectively. As such, the report elucidates on the characteristics of successful transit connections that facilitate easier multi-modal inter and intra city travel. Examples of such characteristics include:

- Operation along moderately dense suburban corridors that connect land use mixes that consist of all-day trip generators
- The necessity of serving traditional markets such as low-income, blue collar neighborhoods
- The linking of suburban transit services (local circulators) to the broader regional network
- Economically viable services that can adapt fleets to customer demand
- The necessity of private-public sector cooperation and community involvement

Regardless of these considerations, the more popular traditional approach to regional and local transportation planning in central Florida has been to simply add more lane capacity to meet anticipated demand, further exacerbating the popularity of personal automobile usage. This is largely due to induced traffic; as congestion rises and reaches equilibrium, demand self-regulates as users divert routes or modes to avoid congested roadways (Victoria Transport Policy Institute [VTPI], 2013). Once capacity is added, demand will increase to reach a new equilibrium. As such, anticipated demand is often overestimated as the traditional planning approach assumes that lanes must be added to meet demand. Furthermore, this approach often results in further externalities such as downstream congestion where capacity is inadequate. However, new initiatives to encourage multimodal alternatives have been set to present a conceptual year 2040 multimodal network for Orange County, Florida (Orange County Government, 2020). By Phase 3 of the initiative, specific corridors will have been identified for multimodal implementation, the transition process, funding options, and future alternatives to the current planning approach. Such an initiative is promising in the potential future implementation of a MaaS network in Florida, however, several states and countries around the world have already seen success with more comprehensive applications.

2.3 Examples of MaaS Implementations Around the World

In general, Nordic European Countries have been on the cutting-edge of real world MaaS implementation. Helsinki, Finland has been the leader in pioneering a fully realized MaaS application, Whim, which achieves multimodal integration at the

convenience of a single fare or even monthly subscription. Recent analysis of data collected over the first year since the app has been deployed has demonstrated the notable success and benefits of such systems (Ramboll, 2019). One of the major challenges outlined in the report is the first-mile-last-mile problem; the multi-leg trip challenge of getting from the trip origin to a major transit line, and then from the end of the transit leg to the destination. It is found that Whim users are much more likely to take multimodal trips compared to the general population, and more likely to engage in sustainable mobility patterns such as the combination of transit and bikeshare. These effects are major benefits in reducing the impact of car dependency and traffic congestion. Furthermore, public transit is highlighted as the backbone of the Whim network, with transit contributing to 73% of Whim trips, compared to 48% on average for a non-Whim user. Impressively, this increase in transit share was achieved after only one year of app deployment. While the wider Orlando driving landscape is quite different to the Helsinki network, these findings are highly encouraging in the potential for MaaS to quickly become a disruptive technology.

Another example of European innovation in the MaaS field is the information service provider, MOBiNET, which is working to build the foundation for MaaS services to be implemented on a larger, international scale, with trip planning, payment management, and pan-European traveler identity management (European Commission, 2020). The aim of MOBiNET is to provide a harmonized communications platform between businesses and users to allow optimal creation, deployment, and operation of mobility services at the local and regional level, on a Europe-wide platform. While MOBiNET is

still in the pilot stages, such an extensive platform is essential to facilitating and streamlining the communication process between service providers and users on a large scale. ITS Europe (also known as ERTICO) is a similar partnership aiming at bringing together private and public entities to facilitate safer and more efficient multi-modal travel. The partnership currently includes 120 companies from various industries, including service providers, transportation sector, researchers, public authorities, mobile network operators, and vehicle manufacturers (ITS Europe, 2020). Notably, the group includes some of the biggest players in the transportation game, including Volkswagen (the largest car manufacturer in the world) and the BMW group. To capture the attention of such industry giants reflects the rapidly growing exposure of MaaS as a viable solution. This comes as no surprise, as research continues to demonstrate that MaaS has the potential to be a win-win solution for all parties involved. The following figure 2.1 highlights some of the benefits to public institutions, private entities, and individual travelers.

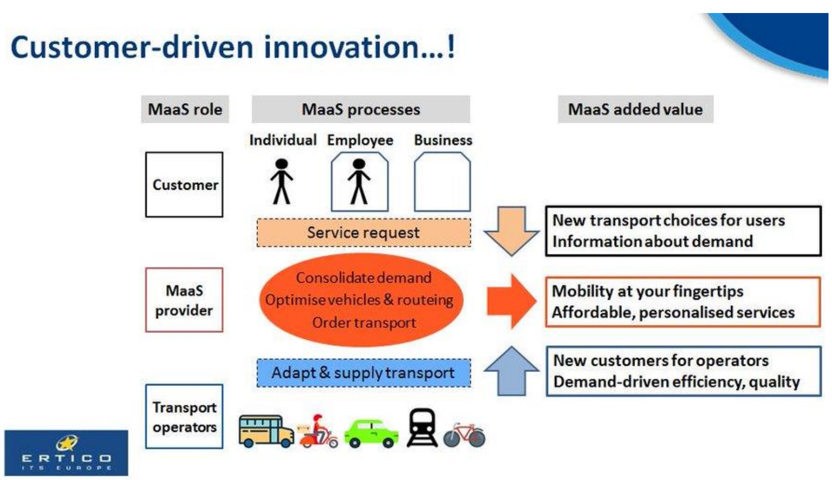


Figure 2. 1 Roles, Processes, and Value Components of MaaS Partnership

Source: ITS Europe (ERTICO, 2017)

Globally recognized ride-hailing services such as Uber represent another example of MaaS components in action. As mentioned before, the PSTA park-n-ride program is one example of a transit service with technologically augmented information systems. In addition to this, the PSTA has also partnered with Uber to launch the TD Late Shift program (Uber Blog, 2016). The program aims to reduce the financial stress of transportation for low-income users by allowing up to 23 free rides per month. These kinds of programs further highlight the potential for public-private MaaS partnerships to provide multi-modal solutions that are affordable and accessible.

2.4 Benefits and Detriments: Costs, Externalities, and Network Performance of Different Vehicular Modes

The effects of modal share on network performance have seen attention mainly in the conversation of shifting the transportation modal share to have higher transit ridership and less for personal vehicles. This effort to shift to transit comes as no surprise, given the high benefit to cost ratios of transit, along with its other positive effects on economic, social, and environmental factors. For instance, the American Economic Association (Parry et al., 2007) outlines the kinds of externalities associated with personal vehicle uses, including performance measures such as traffic congestion, as well as safety and sustainability measures such as traffic accidents and pollutants. The Victoria Transportation Policy Institute (2019) goes further at identifying the externalities in terms of vehicle type (personal vehicle, passenger, transit user, compact vehicle, etc.) and traffic condition (urban peak, urban midday, rural, etc.). For example,

the externality and operating costs for personal vehicles in typical urban peak traffic conditions is estimated to be roughly $1.814 per vehicle-mile of personal auto mobile usage. On the other hand, transit comes out to $27.483 per bus-mile, suggesting that transit costs are less at roughly 15 passengers per bus or higher.

In addition to the lower externalities and costs, transit has been found to have exceptionally high positive impacts on network performance. Another study by the American Economic Association (Anderson, 2014) observed the effects of ceasing transit service on highway delay. The study demonstrates that transit riders are more likely to be users with commutes that take them along severely congested routes, suggesting that users naturally gravitate towards transit as a way of reducing their own stress from traffic congestion. Data from a strike in 2003 by Los Angeles transit workers was used to determine this impact in terms of delay. The results were remarkably higher than expected, with highway delay increasing by 47 percent when transit services are ceased, due to the shift away from transit. Data from Los Angeles County (Los Angeles County Government, 2017) finds that transit users accounted for roughly six (6) percent of the total modal share in 2017. It is highly remarkable that a perceivably minor six (6) percent shift in modal share can result in a 47 percent increase in highway delay. A number of studies analyze the factors behind these effects such as roadway space requirements, induced congestion due to lane building, transit infrastructure, and the other mentioned effects such as delay, travel time, and costs (Litman, 2013; Adler, 2016; Adler, 2019). While the consensus is that transit provides the highest returns on investment, there is not much research in terms of interactions between several modes.

Furthermore, rideshare services such as Uber are only beginning to be considered for the effects on performance and it is difficult to find studies that demonstrate these effects in clear quantifiable terms. As such, the consensus on the effects of rideshare is quite inconsistent. While the long-term expectation is that increasing rideshare market penetration will reduce the need for personal vehicles, and thus lanes and parking space, this theory is mainly based on the benefits of pooling: multiple users and trips with a single vehicle (Shaheen, 2018). This represents a valid benefit to rideshare services but can also be construed as the natural outcome of more efficient vehicle usage. Conversely, several studies have concluded that rideshare servicers actually contribute to higher congestion levels and vehicle-miles travelled (VMT) (Schaller, 2017; Henao, 2017). Another study by Erhardt et. Al (2019) examines a counterfactual scenario of traffic share in San Francisco using real world application programming interface (API) data from two rideshare service providers. The study finds that rideshare has the most significant effect on congestion, with real-world weekday vehicle hours of delay increasing by 62% with ridesharing versus an estimated 22% without. Furthermore, Tirachini et. Al (2018) find that unless these services can substantially increase occupancy rates (i.e. pooling), VMT and congestion would increase. Other behavioral and political aspects have been explored as well, for example, surveyed rideshare adopters were reported to generally participate in more sustainable mobility choices and are more physically active (Das, 2020). However, a study by Clewlow and Mishra (2017) finds that using rideshare services results in a six (6) percent drop in bus transit use among adopters in major American cities. Interestingly, both studies find no

relationship between rideshare use and car ownership, suggesting that the theorized benefits in parking space reduction have yet to be realized. It is concluded that the substitutive and complementary effects of combining rideshare and transit are highly dependent on the quality and quantity of available public transit services. Most of these studies focus on empirical and survey data methods, and thereby suffer from subjective bias and lack of controls (various factors can influence the behavioral attitudes towards rideshare, e.g. public transit quality). As such it is difficult to come to a consensus on the effects of rideshare, thus, the proposed research effort aims to examine these newer mode options as well as the interactions between them in a comprehensive manner, observing both microscopic and network level effects.

2.5 Multi-Modal Transportation Network Analysis

2.5.1 Quality/Level of Service Handbook

The Quality/Level of Service Handbook (QLOS Handbook, 2020) is the Florida Department of Transportation's (FDOT) standard for determining how transportation network performance is measured. This is essential to planning and design activities in determining the best course of action for optimization of services and mitigation of externalities such as traffic congestion. Much of this section will focus specifically on transit services in Orlando, as this constitutes one of Orlando's greatest weaknesses in moving to a sustainable transportation system. Chapter 3 of the handbook outlines the main principles behind QLOS analysis. These are outlined by the four dimensions of mobility:

- Quality of travel: Traveler satisfaction with a facility or service
- Quantity of travel: Magnitude of use of a facility or service
- Accessibility: Ease in which travelers can engage in desired activities
- Capacity utilization: Quantity of operations relative to capacity

The handbook's main focus revolves around the first and fourth dimensions. It is important to distinguish between Quality of Service and Level of Service. Quality of Service represents a more qualitative analysis of transportation systems. This type of measurement scheme focuses on user perception of the operation of a facility or service. Level of Service represents a more quantitative analysis whereby the performance can be graded according to objective measures such as delay, traffic density, and average speed, all of which also have a significant impact on the user's perspectives of how the transportation system is running. This began in 1965 when the Highway Capacity Manual (HCM) originally introduced a grading scheme (LOS grades) as a way of communicating performance to the general public and how it is affected by operations and design.

Chapter 7 of the QLOS handbook provides several examples of qualitative measures which can be used to assess the LOS of other modes of transportation. These factors do not represent hard performance measures but rather features of the network which affect user perception and comfort. These variables are typically for use in the LOSPLAN software, so there aren't necessarily any thresholds provided in the handbook. However, generally acceptable ranges are provided in some cases. Furthermore, the handbook does not necessarily include thresholds or methods for determining QOS, but the following

factors can be inferred to impact QOS in some ways. Three of the variables that haven't been previously discussed are bus stop amenities, bus stop type, and passenger loads. Bus stop amenities scores bus stops based on how equipped they are for passenger comfort. Excellent scores are given to stops with shelters, and benches. Good scores are given to stops with shelters only. Fair scores are given to stops with benches only. Poor scores are given to stops without shelters or benches.

2.5.2 Transit Capacity and Quality of Service Manual

The Transit Capacity and Quality of Service Manual (TCQSM, 2017) is another resource widely accepted as the most complete manual for assessing transit performance. The TCQSM combines the aforementioned capacity concepts (borrowing from the HCM) as well as the qualitative service factors, such as environment data and reliability. QOS analysis focuses on the following factors:

- Transit availability: Is transit service an option for a given trip?
- Transit comfort and convenience: If transit service is an option, how attractive is it to potential passengers?

These areas can be broken down into several other smaller scale factors, with particular attention given to the availability factor. The factors are:

Spatial Availability

- Pedestrian Access
- Walking Distance to Transit
- Pedestrian Environment
- Street Patterns

- Americans with Disabilities Act (ADA) Considerations

Bicycle Access

- Integrating Bicycles with Transit
- Bicycles on Transit
- Bicycle Access Trip Lengths

Automobile Access

- Park-and-Ride (Combined parking and transit services)

Temporal Availability

- Frequency
- Passenger Arrival Patterns
- Service Span
- Information Availability
- Capacity Availability

Other factors that capture comfort and convenience measures include:

- Passenger Loading
- Reliability
- Travel Time
- Safety and Security
- Cost
- Appearance and Comfort

2.6 Transportation Micro-Simulation Software: VISSIM

2.6.1 Macro vs. Microscopic Traffic Simulation

Traffic simulation modelling has become one of the most effective tools for analysis of transportation facilities and networks. Before modern advances in computing power, the most popular traffic planning and operations relied on deterministic methods such as manual computation via Highway Capacity Manual (HCM) procedures or simplistic methods such as travel demand models. While these methods are valuable in their application of transportation theory, they are too complex to be efficient and lack many of the capabilities of computerized models. For instance, the HCM is useful in understanding theory and calculating measures of performance such as capacity, delay, queuing, density, and more. However, these procedures are difficult to apply to analysis of a large network and cannot always account for evolving driver behavior and new operational strategies, and are best applied in small-scale or isolated facilities. Travel demand modelling can better model larger networks but also suffers the inflexibility in handling different driver behavior and strategies.

Simulation modelling takes advantage of the computing power available in the modern age to extend these analyses to larger networks with the ability to observe how distinct subnetworks may impact each other. Macroscopic modelling is the most simplistic of traffic simulation models, basing the interactions between subnetworks on the basic deterministic measures of flow, density, and speed (on a segment basis). Microscopic modelling offers the most accurate and high-fidelity solution to analyzing networks and designs by simulating individual vehicles with various driver behavior characteristics

and vehicle by vehicle interactions (see the following figure 2.2). They are also more flexible in being able to design around a variety of geometric configurations and operational strategies, however they suffer the shortcomings of being time-consuming, costly, and difficult to calibrate to real life scenarios. Mesoscopic models combine the properties of both micro and macroscopic modelling tools, but still lack the accuracy and fidelity of microscopic models.

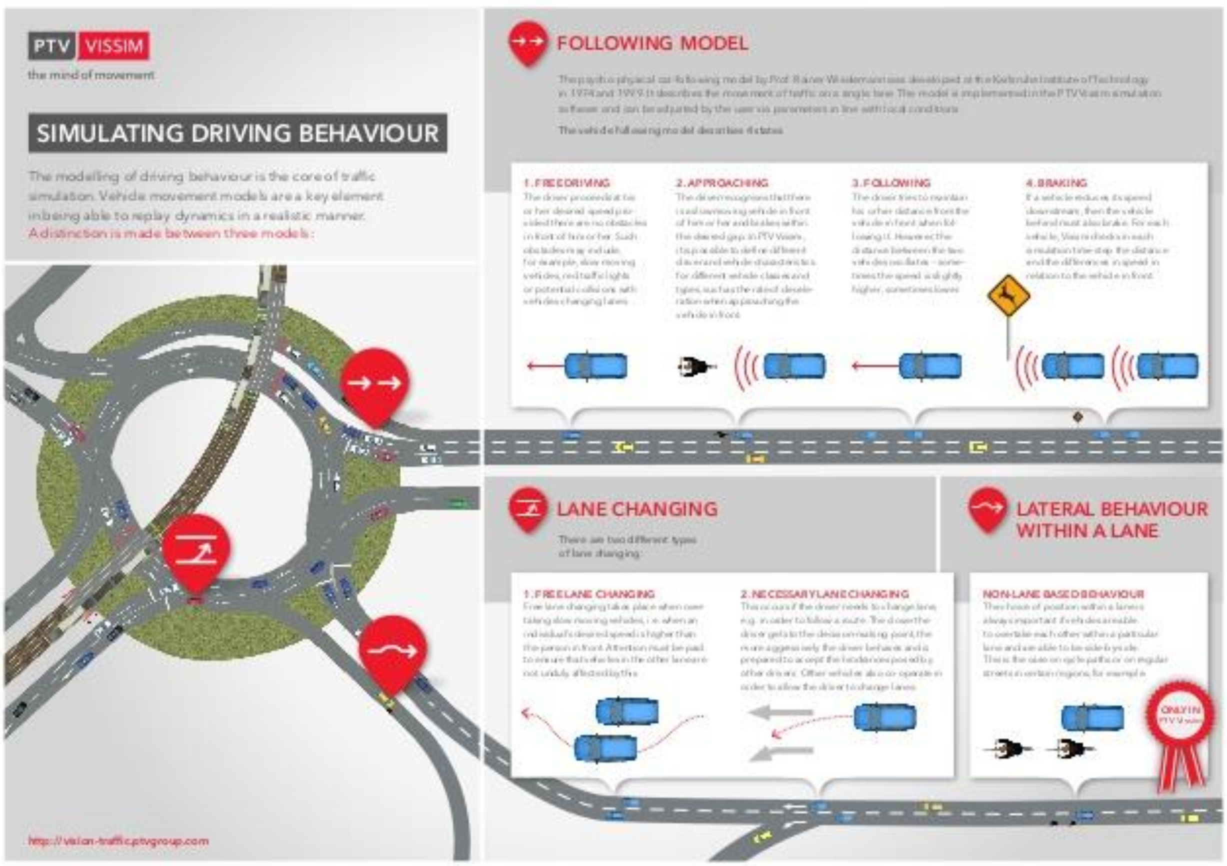


Figure 2. 2: Infographic on VISSIM Driver Behavior and Interaction

Source: PTV VISSIM (vision-traffic.ptvgroup.com) (2020)

Considering the smaller size of the chosen corridor and the operational MaaS strategies to be tested, it is apparent that microsimulation is the most effective method for

modelling of I-Drive. While it may be time consuming to model and calibrate, the requirements for developing the different scenarios involving origin and destination specific routing in addition to cyclist and transit options will benefit from the flexibility of microsimulation. The following sections describe the capabilities of a specific microsimulation software, VISSIM, for modelling motorized vehicles, rideshare, public transit, and bicycles.

2.6.2 Motorized Vehicles in VISSIM

The main benefit to using VISSIM for the selected corridor is the ability to alter specific network and driver characteristics and evaluate the desired measures over the entire network. Furthermore, VISSIM allows for seamless integration with other modes of transportation such as transit and micro-mobility. This will prove valuable in modelling portions of the network where pedestrians, vehicles, and cyclists interact, while simultaneously simulating bus scheduling on fixed routes. Furthermore, VISSIM allows for simulation of other behavioral effects such as deceleration and lane changing aggression, to model a situation that is specific to regional characteristics of drivers.

2.6.3 Public Transit in VISSIM

It is also important to consider the impact of transit operations to the surrounding traffic. An important aspect to consider is the delay caused by a bus stopping to pick up and drop off passengers. This delay is considered as a function of the transit demand, and VISSIM allows multiple options for modelling the dwell time based on either a normal distribution, a user defined distribution, or by an explicit function of passenger

demand. This is affected by the boarding and alight times per passenger, the time for opening and closing doors, and whether boarding and alighting are sequential or simultaneous (depends on the design of bus and number of entrances and exits).

As the main goal of the project will be to determine the performance effects in a MaaS network across multiple modes, the third option for calculating dwell time will be extremely valuable as the planned alterations to the mode split will have a significant impact on both vehicle and passenger demand. The changes to vehicle demand itself will impact performance, but also impact passenger demand, which will impact dwell time, which in turn will impact bus and vehicle performance. VISSIM provides a flexible platform to evaluate the culmination of all these effects.

The ability to simulate buses with fixed schedules and how they interact with the other modes will be crucial. Furthermore, the flexibility in geometric design that VISSIM offers may allow for testing of alternative configurations for bus routing. Namely, Bus Rapid Transit (BRT) lanes offer a solution to the impact of buses on congestion and vice versa, and also has the potential to encourage use of public transit. BRT lanes are lanes separate from the regular use traffic lanes and run undisturbed by regular traffic.

VISSIM is valuable as the simulation model will allow direct observation of how the transit configuration will interact with regular commuters and the integrated rideshare services offered by MaaS. For example, the regular configuration may cause backups as the rideshare drivers must temporarily stop in the right lanes to drop-off and pick-up travelers. In the BRT configuration, the separation of the transit lines from the roadway may allow for drop-off lanes separate from the regular traffic. This design concept is

known as Kiss-and-Go lanes and is similar to the designs implemented in airports for taxi services.

Regarding LOS analysis, the FDOT QLOS Handbook (2013) only measures transit performance and facilities quality through scheduling frequency and bus stop amenities. As these features are only influenced by design and planning, bus LOS alone does not reflect the performance effects of a MaaS network, but rather the design and planning aspects. Fortunately, VISSIM can make more specific evaluations on measures such as capacity utilization, emissions, and travel speed (which will be affected by the mode split and configuration, allowing for optimized scheduling).

2.6.4 Cyclists (Bikeshare) in VISSIM

Analysis of cyclist performance is one of the key benefits of using VISSIM as the software is capable of simulating behavior that is reflective of real-life. Similarly as with transit evaluation, cyclist LOS scores are based mostly on design features. It may be valuable to investigate how alternative transit configurations may impact LOS, but it is also important to use the evaluation tools provided by VISSIM to calculate other measures of cyclist performance such as stops and travel time.

2.6.5 Calibration and validation

As previously mentioned, the accuracy and power that comes with micro-simulation also comes with the cost of significant time and effort. Besides the time required to model the geometries and collect the data, micro-simulation analysis requires validation by comparing the simulated outputs to real life measures of performance, to ensure a

base model that is true to life. Once a validated model has been established, then design changes and traffic projections can be altered to investigate the impacts. Two major parameters are typically chosen for use in calibration: segment volumes and travel time (or speed) (FDOT, 2019). Segment volumes are readily available from the FDOT or Orange County websites and can be calibrated in the model by altering inflows and outflows to minor intersections, commercial, and residential areas. Travel time/speed may be adjusted by simply altering the speed decisions or vehicle type properties. Furthermore, behavioral features such as driver deceleration and lane changing aggression may be useful to alter to ensure that the model is representative of regional driver characteristics which may affect the previously mentioned performance measures. The aim is to create a balance between the properties such that segment volumes and average travel time/speed match up with real-life conditions before investigating alternative mode splits and configurations.

2.6.6 Summary of Micro-Simulation Methods for a MaaS Network

The review on the capabilities of VISSIM micro-simulation software make it clear that it would be the ideal software for modelling the base network and making design and operational changes. Customized routing and vehicle types allow for simulation of integrated rideshare and micro-mobility. The transit features will also allow for modelling of transit and it’s impacts on congestion and vice versa. The geometric flexibility furthers these capabilities by allowing testing of various configurations and optimization of services. All of this will be built on a foundation of a calibrated and validated base scenario to ensure that the evaluations are accurate and true to life. While

macroscopic modelling may be valuable in evaluating larger networks, the selected corridor is feasible to be modelled in a microsimulation environment. Furthermore, macroscopic models can only evaluate on a segment-level and will not account for the effects of different design configurations or be used to simulate integrated rideshare through customized routing that is precise to the lane-level. Therefore, micro-simulation offers the most powerful tool to simulating these effects.

CHAPTER 3 : INTERNATIONAL DRIVE TRANSPORTATION NETWORK AND MODAL ALTERNATIVES

3.1 International Drive: Population and Land Use

The corridor of International Drive from Pointe Plaza Ave to W Sand Lake Blvd is selected as the analysis network due to the existing multi-modal structure which accommodates pedestrians, vehicles, and transit. I-Drive is also a major tourist hub, therefore the demand for alternate modes like transit and rideshare are already in place. It is also home to significant hospitality and commercial intensity and sees major demand during PM peak hours and weekend peak hours. Furthermore, I-Drive represents a major pedestrian hotspot in Orlando due to the available commercial and restaurant activities. As such, it is a prime candidate for testing the effects of MaaS implementations in congested settings. The flexibility offered by VISSIM allows testing across various modal shares and congestion levels. See APPENDIX B for maps.

3.2 Public Transit: Lynx

Lynx bus transit services the corridor both Northbound (NB) and Southbound (SB). Three lines serve NB (lines 8, 38, and 42) while two lines serve SB (lines 8 and 42). Note that line 8 is a circulator line. See the following excerpt from the Lynx system map (figure 3.1) for more detailed route information. Ridership, boarding, and alighting data indicate that Lynx serves secondary to I-Ride, the more popular tourism-focused transit servicer on I-Drive.

Figure 3. 1 I-Drive Corridor on the Lynx System Map

Source: Lynx (golynx.com) (2020)

3.3 I-Ride

I-Ride represents a much smaller operation than Lynx, with lines only serving the International Drive area. However, I-Ride still enjoys significant popularity as evidenced by the ridership data (see APPENDIX A). I-Ride lines often operate at or above capacity during peak hours and are also augmented by the I-Ride GPS information system that allows users to 'track the trolley' directly from their phones. While I-Ride has two main lines, red and green, the corridor of interest is only served by I-Ride red. See the

following excerpt from the I-Ride system map for detailed route information (figure 3.2).

Figure 3. 2 I-Drive Corridor on the I-Ride System Map

Source: I-Ride Trolley (internationaldriveorlando.com/iride-trolley/) (2020)

Note on vehicles and transit: While I-Drive represents a moderately urban and multi-modal corridor, the overall transportation network in Orlando is still heavily vehicle-reliant. Public transit is majorly neglected due to the lack of quality stops; shelters are rare and accessible information services and air conditioning outside of bus stops are non-existent. As such, it is important to note that the following experiment is a sensitivity analysis, and effective capacity utilization of transit in reality will depend on planning and design.

CHAPTER 4 : DEVELOPMENT OF BASE NETWORK SIMULATION IN VISSIM

4.1 Data Collection

The following subsections describe the sources and procedures used in gathering the necessary data. The raw full data sets as well as screenshots can be found in the APPENDIX. Furthermore, a changelog for the VISSIM model is included in APPENDIX C to describe the 'building' process, challenges, and solutions.

4.2 Network Geometry: Vehicles and Pedestrians

Network geometry represented the simplest form of input. As VISSIM has built-in integrated mapping services (mapped to scale), building the network geometry is simply a matter of overlaying the roadway and sidewalk components on the map. See APPENDIX B for a screenshot of the roadway and pedestrian area layout.

4.3 Signalization Inputs

Signalization inputs were retrieved directly from Orange County Florida (OCFL) Traffic Operations. The most recent signal study on I-Drive was used for up to date signalization data as well as traffic volumes and turning movement counts. As several of the signals are based on adaptive systems, the actual signalization inputs to VISSIM were chosen to reflect traffic conditions as well as timing thresholds for pedestrian

crossings based on the adaptive signal plans. See APPENDIX D for the raw and adjusted (input) signalization data.

4.4 Vehicle Compositions and Inputs

As previously mentioned, vehicular data was collected as part of the I-Drive signal study from OCFL Traffic Operations. This includes turning movement counts, roadway flows, and heavy vehicle percentages. These data are input to VISSIM via volume inputs, routing decisions, and vehicle compositions. See APPENDIX E for the turning movement count sheets.

4.5 Driver Behavior

Driver behavior was adjusted to reflect real world conditions and was mainly altered in the calibration stage to achieve realistic results. The changes were minimal and mainly revolved around producing more predictive lane changing behavior. This was achieved by using the Weidemann 99 car following model (built-in) and increasing the look ahead and look back distances (so drivers are more likely to preemptively change lanes). From the perspective of the analyst, the resulting vehicular behavior was more accurate to real-life conditions than the default behaviors.

4.6 Transit Inputs

Transit inputs included four main components:

1. Bus scheduling and routing: Retrieved directly from the Lynx and I-Ride websites
2. Transit stop locations: Retrieved via aerial maps
3. Occupancy data: Retrieved directly from Lynx and I-Ride data centers
4. Boarding and Alighting data: For Lynx, this data was available directly from the public Lynx GIS site. Boarding and alighting data for I-Ride was estimated by interpolating the figures for Lynx based on ridership.

See APPENDIX F for the raw detailed transit data.

4.7 Pedestrian Inputs

Pedestrian inputs were also retrieved from OCFL Traffic Operations as the count data also included pedestrian crossing activity. For pedestrian activity in between intersections, three field visits were performed to collect pedestrian flowrates on the major sections of I-Drive. Any missing data were interpolated to ensure flow continuity. See APPENDIX G for data and calculations.

4.8 Calibration and Validation

4.8.1 Segment Flowrate Calibration

Flowrate data was retrieved from a traffic impact study conducted by VHB on I-Drive. Directional flowrates for 16 points in the network were provided. The simulation model

was adjusted several times via routing decisions and volume inputs on minor pathways in order to satisfy several criteria based on matching the observed conditions to the simulated conditions. See the following presentation slide describing the calibration criteria (figure 4.1).

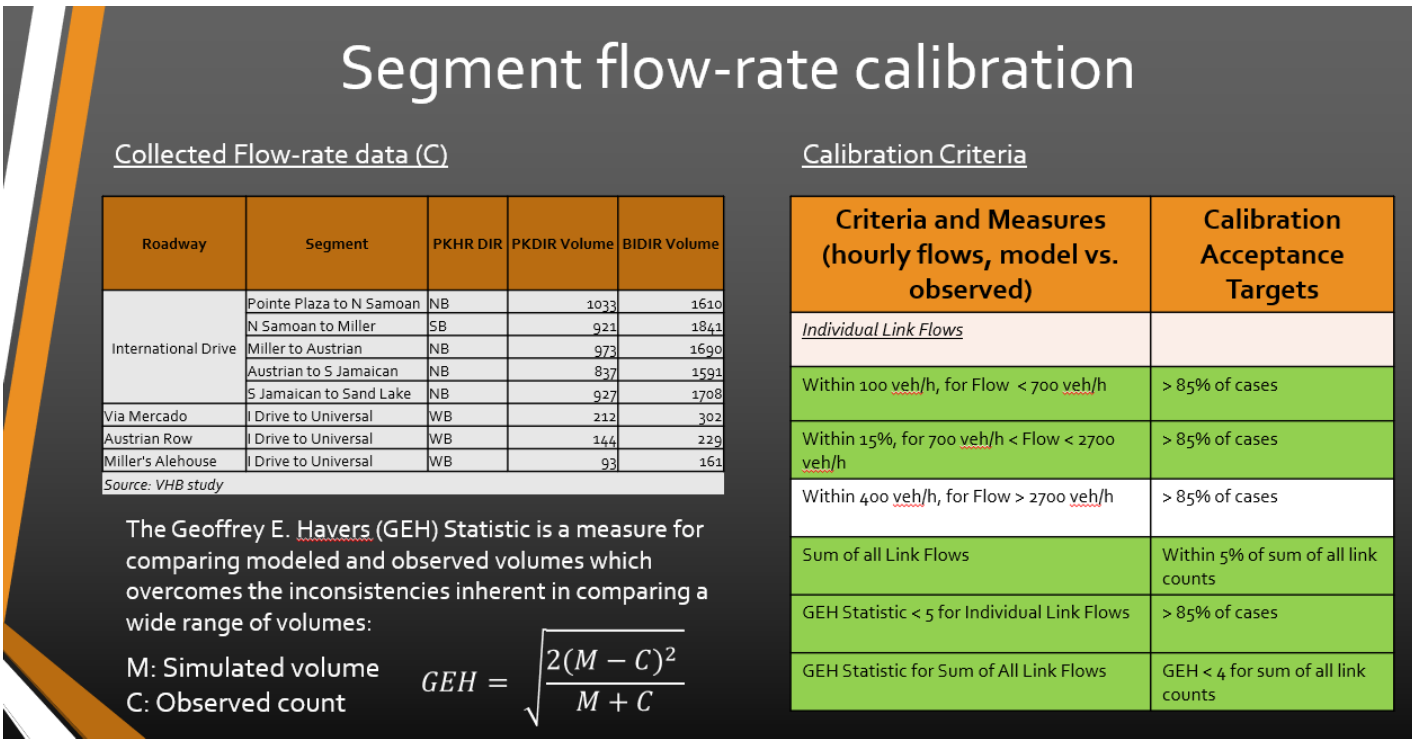


Figure 4. 1 Segment Flowrate Calibration Criteria

Sources: VHB Study, FHWA Traffic Analysis Toolbox Vol. 3: Guidelines for Applying Traffic Microsimulation Modelling Software (2004), and FDOT Traffic Analysis Handbook: A Reference for Planning and Operations (2014)

4.8.2 Travel Time Calibration

Travel time data was retrieved via a field visit to I-Drive during a typical weekday PM peak hour. The floating car method is used to collect an observed travel time measurement. As with segment flowrates, these are checked against certain criteria to validate the simulation. See the following figure 4.2.

Calibration of Travel Time and Reasonableness

Criteria and Measures (model vs. observed)	Calibration Acceptance Targets
Travel times Journey times along corridor NB and SB Within 15% (or 1 min, if higher) [Floating car runs]	>85% of targets
Individual Link Speeds Visually Acceptable Speed-Flow Relationship	To analyst's satisfaction
Bottlenecks Visually Acceptable Queuing	To analyst's satisfaction

Figure 4. 2 Calibration Criteria for Travel Times and Bottlenecks

Sources: VHB Study, FHWA Traffic Analysis Toolbox Vol. 3: Guidelines for Applying Traffic Microsimulation Modelling Software (2004), and FDOT Traffic Analysis Handbook: A Reference for Planning and Operations (2014)

CHAPTER 5 : DESIGN OF EXPERIMENT AND DEVELOPMENT OF ALTERNATIVE SCENARIOS

5.1 Response Variables: Measures of Performance and Sustainability

First, it is important to note that traffic performance measures often correlate with measures of sustainability. Per the literature review, it is clear that smooth traffic flow characteristics in general correlate with lower emissions levels in addition to the time and money savings. In order to comprehensively assess the impacts of different modes, several typical traffic performance measures were selected and separated into network-level and route-level variables. As the interactions between modes are uncertain (see sections 2.3 – 2.4), it is possible that performance effects may impact the network as a whole, while also having effects localized to the route-level (e.g. queuing behavior at transit stops, travel time along scheduled transit routes). The following subsections describe the selected performance measures.

5.1.1 Route-Level Performance Measures

- Vehicular Travel Time (VTT, seconds): The average time for vehicles to travel the length of I-Drive between W Sand Lake Rd and Pointe Plaza Ave (NB and SB measurements) during the analysis period. This is computed in VISSIM by averaging the travel times of any simulated vehicles that traversed the full length of I-Drive during the analysis period.

- Sidewalk Travel Time (STT, seconds): The average travel time for sidewalk users (pedestrians and cyclists) to travel from Pointe Orlando (Pointe Plaza Ave intersection) to Castle Hotel (S Austrian Ct intersection). This is computed similarly as with variable VTT.
- Transit Stop Queuing (Q, number of queued vehicles): The total number of simulated vehicles that enter the queue state at transit stop 11 (shared by transit and rideshare) during the analysis period. Transit stop 11 serves SB, does not feature a lay-by, and is located roughly 30 ft upstream of the Via Mercado intersection stop-bar. This stop was selected as the mentioned characteristics implied that queuing behavior there could be the most sensitive to changes in modal share.

  Note on Queuing: A simulated vehicle in VISSIM is recorded in the queue state when its speed drops below 3.1 mph and has a headway of less than 65.6 ft to the vehicle downstream. A vehicle exits the queue state once it accelerates past 6.2 mph. In VISSIM, queue measurements do not capture scheduled vehicle stops, therefore rideshare and transit stops are not captured and VISSIM measures only the spillover queue of unscheduled vehicles. Queuing also represents a major sustainability aspect; recall Zhou and Sperling's (2001) findings that the erratic starting and stopping due to interacting modes resulted in underestimating emissions at intersections. Research by Coelho et. Al. (2005) also concludes that the greatest percentage of emissions for stopped vehicles are released during acceleration back to cruising speed.

5.1.2 Network-Level Performance Measures

- Average Delay (DELAY, seconds): The average delay experienced by simulated vehicles over the analysis period. This is computed in VISSIM by computing the total delay to vehicles in the network and dividing by the total number of vehicles in the network.
- Average Speed (SPEED, mph): The average speed of simulated vehicles over the analysis period. This is computed in VISSIM by averaging the average speeds of every simulated vehicle.
- Total Stops (TQ, number of queued vehicles): The total number of times a simulated vehicle enters the queue state during the analysis period. The queue state is defined similarly as with variable Q.

5.2 Design Variables: Modal Share

The following independent (input) variables and ranges were selected to test a variety of modal shares on and off the roadway. In order to also capture performance effects over a range of traffic conditions (e.g. smooth flow, near capacity, congestion), demand (D) is also chosen as a variable to represent the total persons per hour input to the network. The values of each of the four modal inputs represent the persons per hour input for that mode. 'Persons per hour' is chosen over the traditional 'vehicles per hour' measure to ensure all modes can be measured in consistent units. It is also worthwhile to note that 'persons per hour' represents a more precise and practical measurement of flowrate, especially when considering multiple modes.

- Demand (D, 12,706 to 16,477 persons per hour): The total flow of persons input to the network including personal vehicles, transit users, rideshare uses, pedestrians, and bikeshare (micro-mobility) users.
- Transit (T, 671 to 1,943 persons per hour): The total flow of persons entering the network on buses plus the flow of all boarding passengers. Note, boarding passengers may be pedestrians or cyclists, as in a true MaaS network. The ratio is of pedestrian to cyclist boarding passengers is determined by the ratio of W to M.
- Rideshare (R, 0 to 678 persons per hour): The total flow of persons assigned to rideshare lines. Due to lack of rideshare data, it is assumed that any existing rideshare is captured in the base validated model and R represents additional flow.
- Walking (W, 1,375 to 2,750 persons per hour): The total flow of pedestrians in the network, not including boarding passengers.
- Micro-Mobility (M, 0 to 1,000 persons per hour): The total flow of bikeshare users in the network, not including boarding passengers.

Note on occupancy: In order to convert between persons flow and vehicle flow, vehicular modes are each given an occupancy ratio. For vehicles and rideshare, a ratio of 1.58 persons per vehicle is used (Florida Department of Transportation, 2011). For transit, this ratio increases by level, ranging from 15 persons per entering bus to 45 persons per entering bus (with a maximum occupancy of 60 passengers). At the highest transit level, frequency is doubled and boarding is

tripled. Input values for mid-range transit levels are interpolated based on entering occupancy, frequency, and boarding.

Note on interpretation: The base scenario is represented by the lowest level of each variable (Base Scenario ~ D[12,706], T[671], R[0], W[1,375], M[0]). Each person per hour increase in the modal variables (T, R, W, M) represents a person per hour switch from a vehicle. For example, for every 158 persons per hour added to any mode, 100 personal vehicles per hour are removed (equivalent to 158 persons per hour). Therefore, D can be modelled independently of the other input variables (this is necessary for generating the Design of Experiment, see section 5.3). The effect of D simply represents the average effect of all modes, and not specifically the effect of personal vehicles. The effects of personal vehicles can still be analyzed by assigning another variable (V = D – T – R – W – M).

5.3 JMP Statistical Analysis Software: Experimental Designs

Four basic components are necessary for generating experimental designs. Sections 5.1 and 5.2 discuss the three most important components: the dependent (response) variables, the independent (explanatory) variables, and the variable units. From there, a randomized set of scenarios can be generated to observe the effects of varying the values of the independent variables. In experimental situations with several independent continuous variables, this poses several challenges in which classical factorial designs do not apply (e.g. need to capture nonlinear effects, standard fractional factorial design requires too many runs, factors include mixture components as well as other variables)

(National Institute of Standards and Technology, 2020). D-Optimal designs provide multiple options to address these issues depending on the experiment objective.

The design selection process for this work was iterative. In other words, information from the first design was used to influence the objectives for the second design, and likewise with the third design. This is a common narrowing-down process when dealing with a design space that is initially very large. For instance, capturing quadratic effects requires at least three (3) levels per variables. Under a full factorial design, this would require $n = 3^k$ scenario runs, where k is the number of independent variables. This translates to 243 scenarios for a full factorial, or 81 scenarios for a half factorial. Due to the considerable time investment requires to design, run, and extract data from each scenario, classical designs were not appropriate. On the other hand, D-Optimal designs selectively pick a limited number of treatment scenarios to satisfy the specific objective of the experiment. This is achieved by maximizing the D-Efficiency, calculated as the determinant of the information matrix based on the design matrix. In JMP this can be done through the built-in Design of Experiment platform. Based on the selected design, the maximum number of scenarios and levels are decided on by the user, in addition to other parameters such as variable constraints. The software then generates random treatment sets and calculates the D-Efficiency for each set until a maximum D-Efficiency is found. This provides the user with the optimal treatment set for achieving the experiment objective.

Typically, screening designs are popular in the early stages of experimentation on multiple independent variables. As recently as 2011, a new type of screening design was

introduced that could estimate up to quadratic and second-order effects without confounding. Bradley Jones, the co-inventor of Definitive Screening Designs (DSDs) describes the usefulness of DSDs:

"As the name suggests, DSDs are screening designs. Their most appropriate use is in the earliest stages of experimentation when there are a large number of potentially important factors that may affect a response of interest and when the goal is to identify what is generally a much smaller number of highly influential factors.

Since they are screening experiments, I would use a DSD only when I have four or more factors. Moreover, if I had only four factors and wanted to use a DSD, I would create a DSD for six factors and drop the last two columns. The resulting design can fit the full quadratic model in any three of the four factors.

DSDs work best when most of the factors are continuous. That is because each continuous factor has three levels, allowing an investigator to fit a curve rather than a straight line for each continuous factor." (JMP Blog, 2016)

Dr. Jones also elaborates on some of the conditions for a DSD to be appropriate, many of which apply to the MaaS experiment:

1. Factors should be independent of each other
2. Ideally, factors should be continuous or limited to being two-level categorical
3. The DSD should not be run as a split-plot design
4. Cubic terms are confounded with main effects, therefore a DSD is not appropriate if the a priori model has higher than second-order effects

By including D as an independent variable (as opposed to V which would not vary independently with other modes), a DSD treatment set can be generated with confidence. Again, V can still be assigned a variable and analyzed, but D is selected for the purposes of scenario design. Furthermore, by adding two (2) 'dummy factors' and using JMP's 'augment design' feature, several scenarios are added to further increase the power of the design. The final DSD included 20 total scenarios with two (2) center-points (center-points are scenarios with every variable set to the middle level, these are useful for being able to capture pure error so that lack-of-fit testing can be performed).

From the results of the first experiment, it was decided to further investigate the effects of R and T for potential interactions, and further strengthening of the dataset. For this, a response-surface design is chosen for its power in capturing quadratic and second-order effects. Due to the smaller number of factors, it was possible to run a design that covered the entire design space (effectively a full factorial design). The final Response-Surface design included 11 total scenarios with three (3) center-points.

Finally, D and T were selected as the last factors to scrutinize for interactions. A full factorial design is used with five (5) levels per variable (interpolating existing levels to add levels 1.5 and 2.5 for each variable) to ensure even more power for the final statistical modelling with quadratic effects and interactions. The final full factorial design included 26 total scenarios with two (2) center-points

5.4 Distribution of New Trips

Accurately capturing the effects of each mode required that realistic travel patterns were maintained as much as possible. Therefore, trips from alternate modes that replace personal vehicle trips were distributed to maintain flow continuity and balance by adjusting input volumes and routing. For instance, as transit lines run directly NB and SB on I-Drive, personal vehicles are removed and routed such that the persons-per-hour flow on I-Drive remains constant with the addition of new transit trips. The same is done for rideshare routes. For W and M users, new trips are distributed evenly based on existing travel patterns, and similarly, the associated personal vehicle trip removals are distributed evenly by existing travel patterns.

5.5 Micro-Mobility Modelling

Several options were considered for modeling of M. VISSIM allows a good level of flexibility in modeling cyclists. There are options to model cyclists as vehicles that interact and travel on the roadway with other cars, but this option does not allow travel along pedestrian routes or interactions with pedestrians outside of crosswalks. In order to capture the interactions between pedestrians and vehicles at crosswalks, cyclists are instead modelling as pedestrians with adjusted speed, behavior, and 3D model parameters to simulate realistic cyclist, pedestrian, and vehicle interactions.

5.6 Rideshare Modelling

Due to lack of any current and applicable rideshare data, the base scenario assumes that rideshare effects are captured in the regular flow of vehicles. Modeled rideshare behavior differs from regular vehicles through slightly lower speed distributions (rideshare drivers are more likely to drive slowly due to potential unfamiliarity, or actively seeking passengers), routing, and pick-up/drop-off activity. Additional rideshare volume is simulated by modeling multiple modified transit lines with various origins, destinations, and pick-up/drop-off activities within and outside of the network. Six (6) rideshare routes are modeled in total. The modified transit vehicle models are adjusted to reflect the regular variety of personal vehicles on the road, and speed is adjusted to reflect the slightly lower speed distribution. Pick-up and drop-off activity is shared with four (4) of the transit stops, as would be typical of a true MaaS network. The transit stops are selected to cover a variety of locations and stop infrastructure (such as Lay-Bys). Note that rideshare levels are relatively low to avoid overloading transit stops. The volumes were chosen based on sensitivity analysis and picking a reasonable flow that would not result in total gridlock under congested conditions.

CHAPTER 6 : STATISTICAL ANALYSIS, MODELING, AND BENEFIT-COST OF MODAL ALTERNATIVES

The following chapter describes the results of the analysis in order of experiment to reflect how the results guided the thought process behind experiment selection and analysis of performance measures. Several modeling techniques are used to pick and refine models that agree with findings, theory, and common sense. A practical benefit-cost analysis is also included at the end of the chapter. For a synthesis of the key findings in simplified terms, see section 7.1.

6.1 Experiment 1 – Definitive Screening Design (D, T, R, W, M)

The purpose of the initial experiment was to determine which response variables and which modes may possibly be correlated, and to identify potential interactions. Due to the limited dataset and inconclusive results, comprehensive statistical modeling was not carried out at this stage. See the following table 6.1 for the variable levels (three levels per variable) and treatment set.

Table 6. 1 Experiment 1 Definitive Screening Design

Scenario	D	T	W	R	M	Name				
1	14592	671	1375	0	0	D2	R1	T1	W1	M1
2	16477	671	2750	0	0	D3	R1	T1	W3	M1
3	12706	1943	2750	339	0	D1	R2	T3	W3	M1
4	12706	671	2750	678	500	D1	R3	T1	W3	M2
5	12706	1943	1375	678	1000	D1	R3	T3	W1	M3
6	14592	1943	2750	678	1000	D2	R3	T3	W3	M3
7	16477	671	2063	678	1000	D3	R3	T1	W2	M3
8	16477	1307	2750	678	0	D3	R3	T2	W3	M1
9	16477	1943	2750	0	1000	D3	R1	T3	W3	M3
10	16477	1943	1375	0	500	D3	R1	T3	W1	M2
11	12706	671	2750	0	1000	D1	R1	T1	W3	M3
12	12706	1943	2063	0	0	D1	R1	T3	W2	M1
13	12706	1307	1375	0	1000	D1	R1	T2	W1	M3
14	14592	1307	2063	339	500	D2	R2	T2	W2	M2
15	12706	671	1375	678	0	D1	R3	T1	W1	M1
16	16477	1943	1375	678	0	D3	R3	T3	W1	M1
17	16477	671	1375	339	1000	D3	R2	T1	W1	M3
18	14592	1307	2063	339	500	D2	R2	T2	W2	M2
19	12706	671	1375	0	1000	D1	R1	T1	W1	M3
20	12706	671	2750	678	1000	D1	R3	T1	W3	M3

6.1.1 Effects of Demand

Performance results of demand were as expected: generally higher levels of demand correlate with higher delay, higher travel times, lower speeds, and more queuing. This is consistent with general flow theory. See the following figures 6.1 and 6.2.

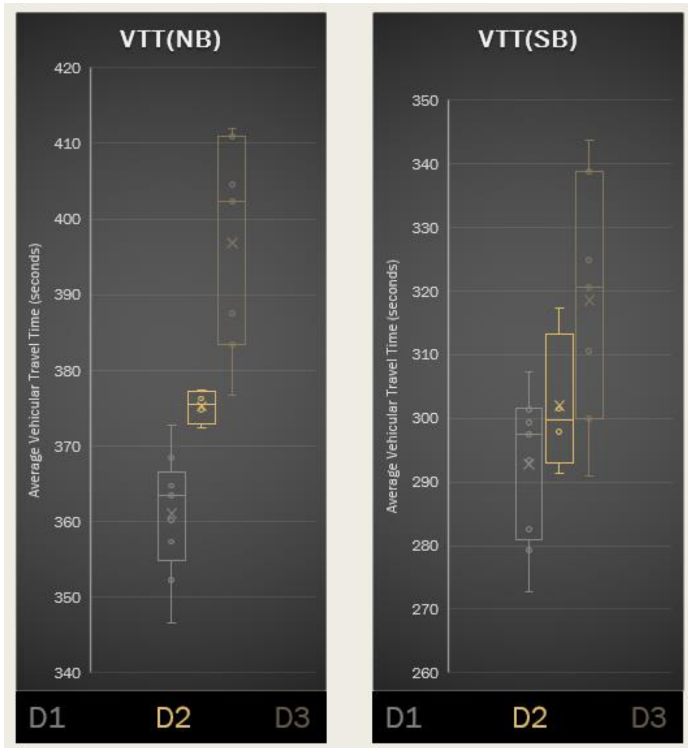


Figure 6. 1 Effects of Demand on VTT

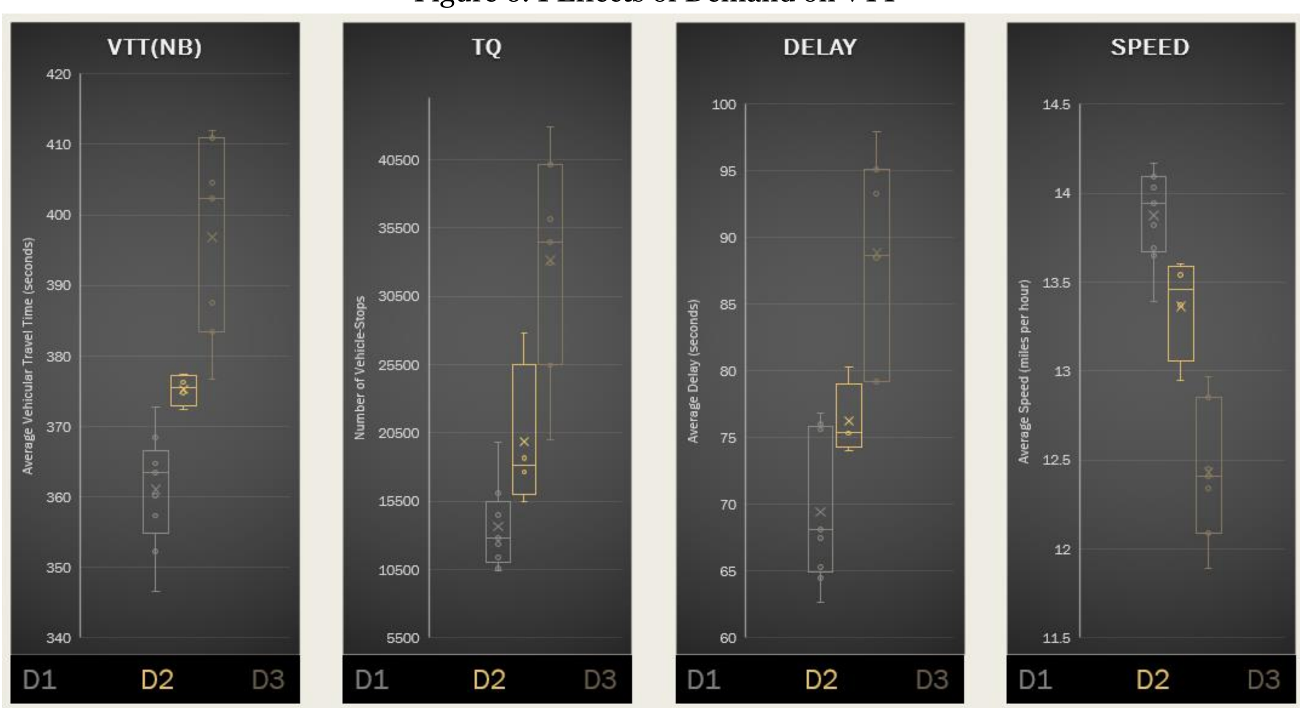


Figure 6. 2 Effects of Demand on Q, TQ, DELAY, and SPEED

6.1.2 Effects of Transit

At first glance, transit appears to worsen VTT, however, it is important to note the inconsistency between NB and SB. Further, the error bars for VTT were quite large, suggesting that the perceivable effect may just be noise. Surprisingly, variable Q does not exhibit any apparent response to changes in transit level, indicating that increased transit frequency does not affect queuing at transit stops. See figure 6.3.

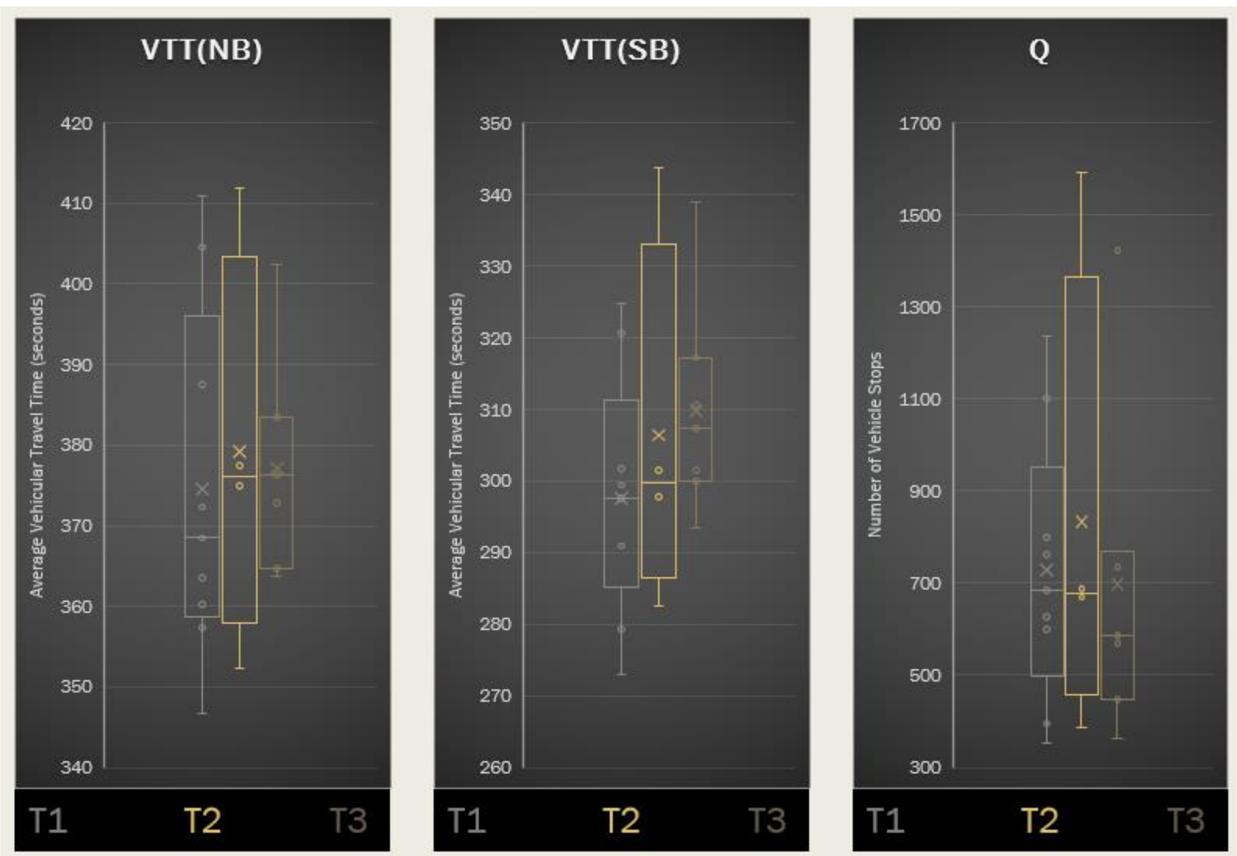


Figure 6. 3 Effects of Transit on VTT and Q

Despite the inconclusive results on the route-level variables, the network-level variables demonstrated notable benefits (see figure 6.4) . As such, it was decided that route-level transit effects required further experimentation.

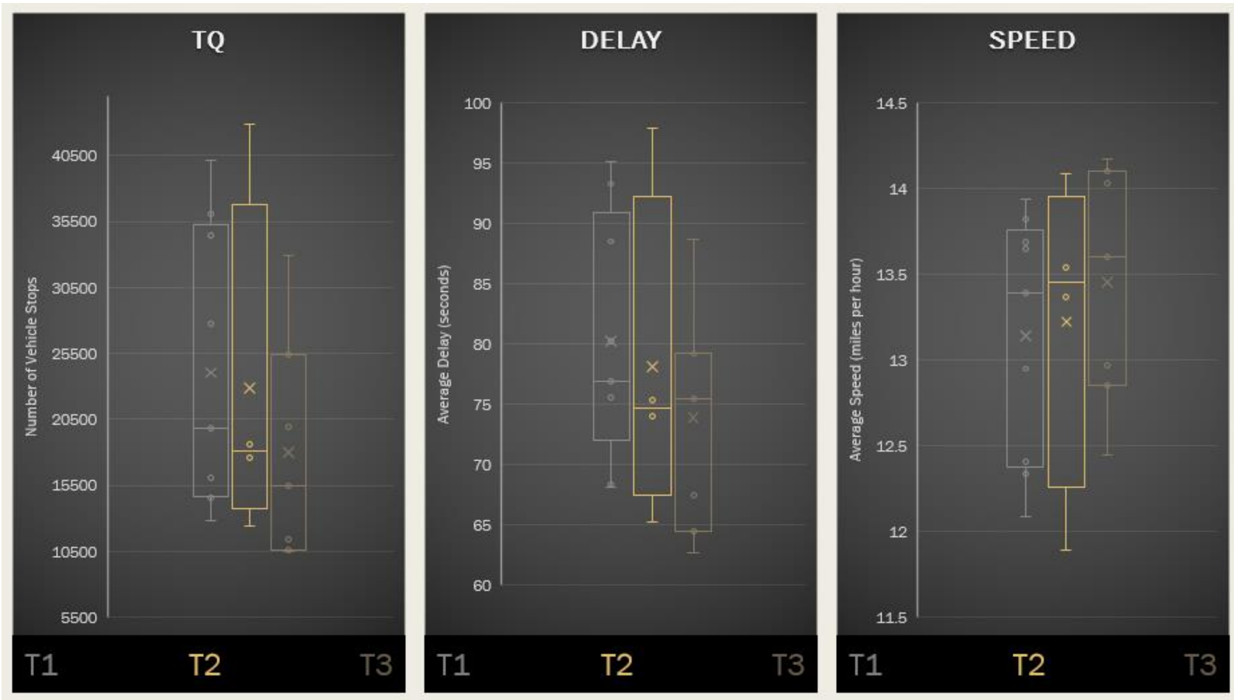


Figure 6. 4 Effects of Transit on TQ, DELAY, and SPEED

6.1.3 Effects of Rideshare

For VTT measurements, rideshare shows very similar behavior as with transit. Notably, the error bars are smaller than those for transit and the increase in VTT is more pronounced. This also lines up with the route-level effect of Q, implying that rideshare causes significant adverse effects at the route level. Looking at the network-level measures, rideshare shows opposite effects to transit, with lowered SPEED and notable increases to TQ and DELAY. It is worthwhile to note that rideshare volumes are relatively low (maximum of 678 persons per hour on rideshare vs. 1943 persons per hour on transit). As such, the findings are suggestive that rideshare represents the heaviest load per person on roadway capacity. See figures 6.5 and 6.6.

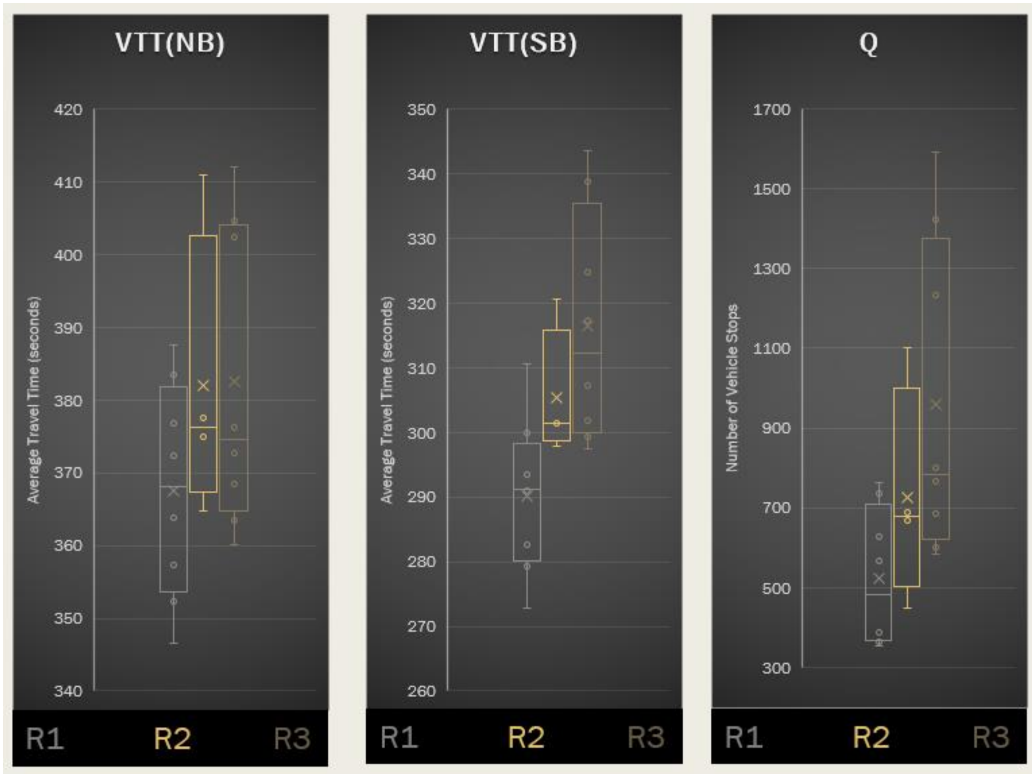


Figure 6. 5 Effects of Rideshare on VTT and Q

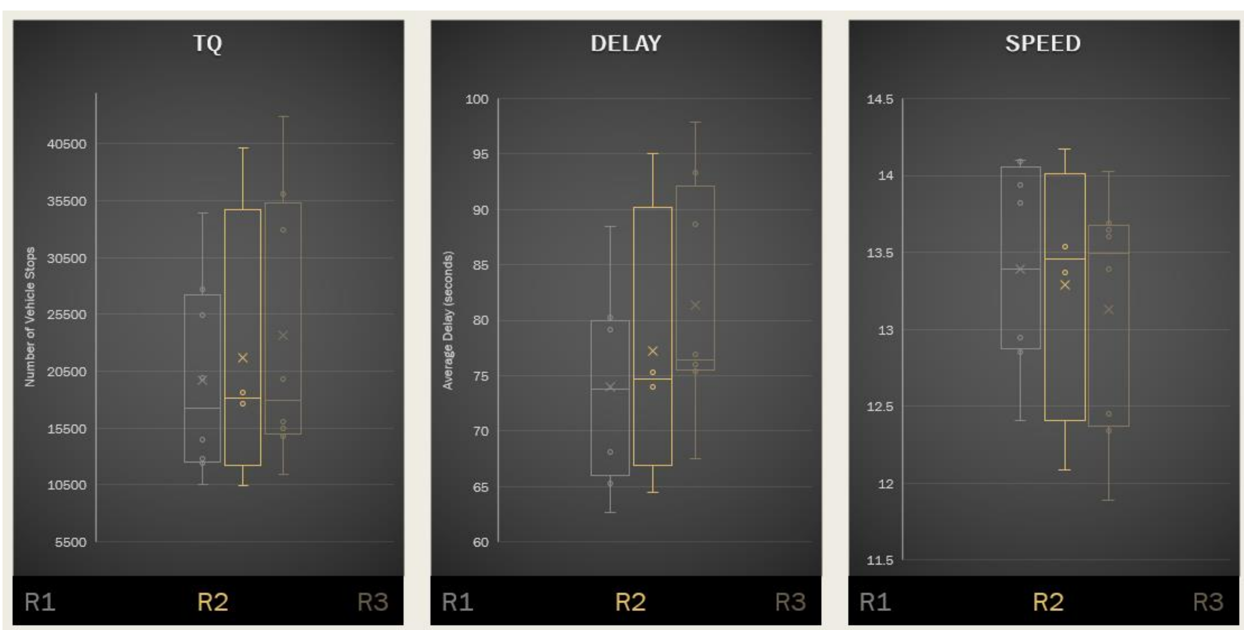


Figure 6. 6 Effects of Rideshare on TQ, DELAY, and SPEED

6.1.4 Effects of Walking

Unsurprisingly, it was difficult to notice any effects for walking other than on STT. See figure 6.7. The majority of responses did not exhibit any noticeable increase or decrease.

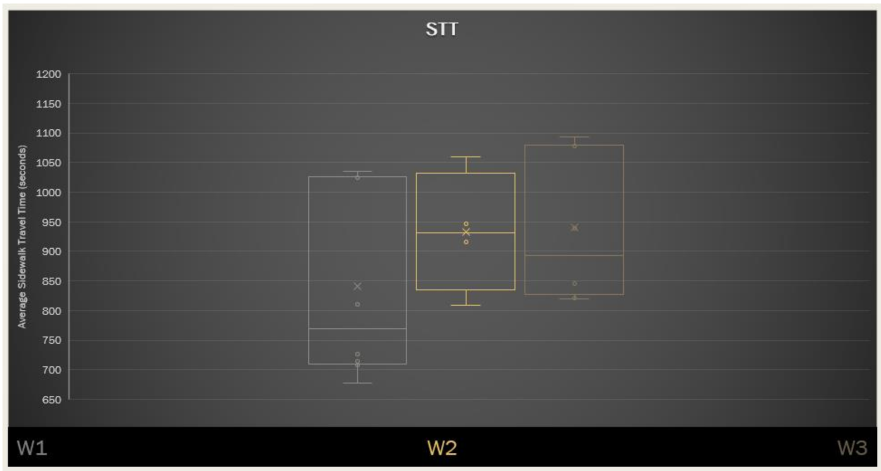


Figure 6. 7 Effects of Walking on STT

6.1.5 Effects of Micro-Mobility

Similarly to W, micro-mobility did not seem to have any effect on roadway variables. On the other hand, STT enjoyed major reductions with increasing levels of M. See the following figure 6.8.

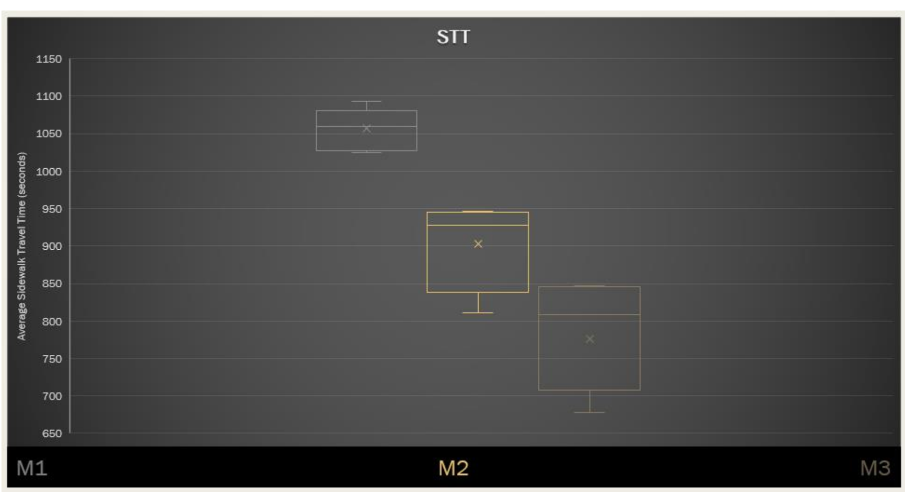


Figure 6. 8 Effects of Micro-Mobility on STT

6.1.6 Potential Interactions

Due to the large number of overlapping effects, it was difficult to determine interactions at this stage. Linear regression models were attempted to explain the interactions described in the previous sections, however, it was difficult to find consistent models with good diagnostics that agreed with the findings and common sense. Therefore, potential interactions were identified by partitioning the data and observing the changes. For instance, the following figure 6.9 demonstrates the effect of increasing transit by demand. Only scenarios with zero rideshare are considered to try and isolate the T*D interaction. It appears that, in general, transit gives better performance measures at higher demand levels. Notably, a relatively small eight (8) percent increase in transit modal share at demand level 3 (D3) resulted in a major 34.1% reduction in network vehicle stops, and a 10.5% decrease in average delay (increased to a 15% reduction when comparing individual scenarios D3T1 vs. D3T3).

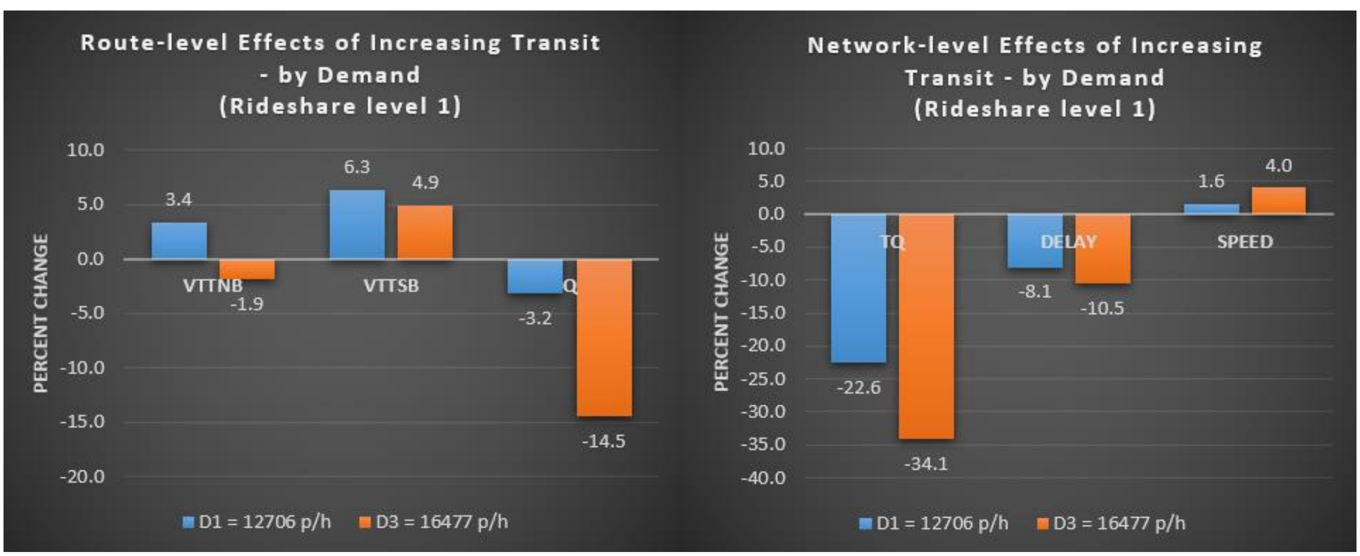


Figure 6. 9 Effects of Increasing Transit - by Demand (Zero Rideshare)

Similarly, the same analysis was carried out to observe the effects of transit in high rideshare scenarios, see the following figure 6.10. Interestingly, the interaction effect observed earlier that showed transit performing better at higher demand levels was found to be the opposite when observing the same changes at high rideshare levels. At this stage, it was impossible to say with certainty whether a T*D interaction existed. The differences between figures 6.9 and 6.10 could indicate that only a T*D interaction exists, or it could indicate a second possible T*R interaction.

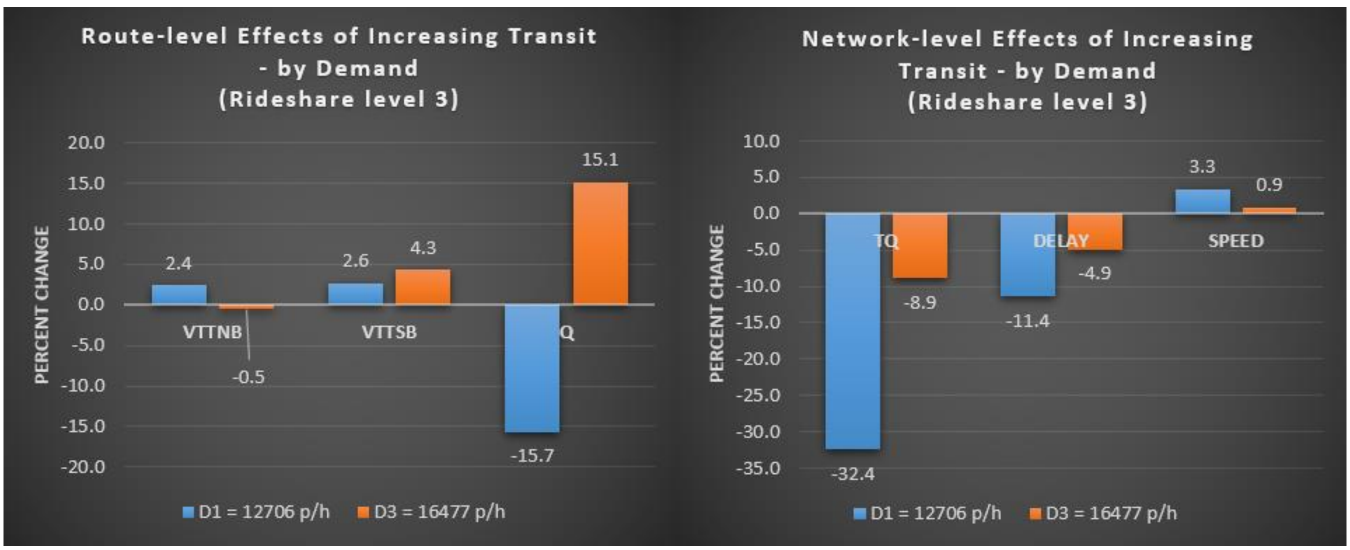


Figure 6. 10 Effects of Increasing Transit – by Demand (High Rideshare)

Rideshare was also analyzed by looking at the percent changes in performance measures between scenarios with and without rideshare, and again, there appeared to be a very strong R*D interaction indicating that rideshare performs worse at higher demand (the opposite to transit). However, the effects of rideshare at Demand level 2 (14,592 persons/hour) did not line up with the rest of the data. Upon closer observation of D2 level scenarios, the inconsistency was attributed to lack of scenarios (only four [4]

scenarios at D2) and lack of variety (see the following table 6.2). It was concluded that the possible R*T, R*D, and T*D interactions required more observations to verify.

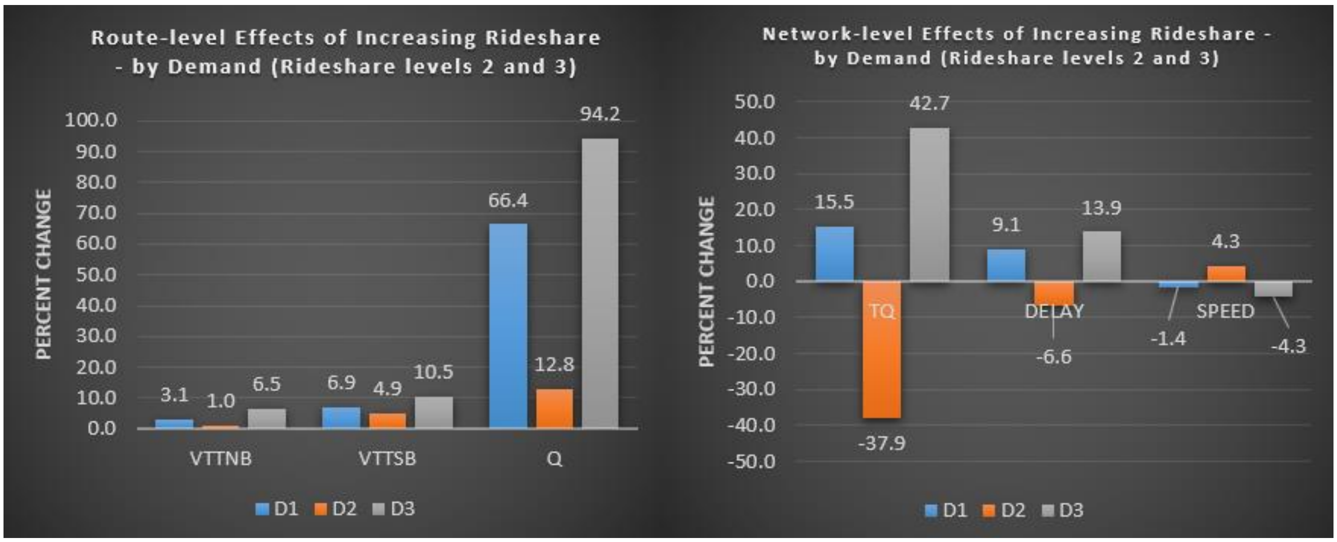


Figure 6. 11 Effects of Increasing Rideshare – by Demand

Table 6. 2 Limited Scenarios and Variety at Level D2

Scenario	D	T	W	R	M	Name				
1	14592	671	1375	0	0	D2	R1	T1	W1	M1
14	14592	1307	2063	339	500	D2	R2	T2	W2	M2
18	14592	1307	2063	339	500	D2	R2	T2	W2	M2
6	14592	1943	2750	678	1000	D2	R3	T3	W3	M3

6.2 Experiment 2 – Response Surface Design/Full Factorial (T, R)

A response surface design was generated using only the variables T and R. Similarly as with the DSD, the response surface design assigns three levels per variable. Due to the

small number of variables, the generated design essentially mimicked a full factorial with an additional center point. The following table 6.3 describes the variable levels and treatment set.

Table 6. 3 Experiment 2 Response Surface Design

Scenario	R	T	Name	
21	339	1307	R2	T2
22	678	671	R3	T1
23	0	671	R1	T1
24	678	1307	R3	T2
25	0	1307	R1	T2
26	339	1307	R2	T2
27	339	1943	R2	T3
28	0	1943	R1	T3
29	678	1943	R3	T3
30	339	671	R2	T1

6.2.1 Effects on Vehicular Travel Time

Analysis of the R and T effects showed right away that rideshare demonstrates the heaviest detriments to travel time, while the effect of transit is still unclear. Two possible explanations exist: the effect of transit on travel time is negligible (i.e. charting VTT vs. transit shows a horizontal line) or a quadratic effect exists in which the effect on travel time is minimized at transit level 2. See figure 6.12 and note the local minimums for each curve. It is possible that the minimums represent a threshold at which the effect of transit changes from reducing travel time to increasing travel time. However, there was no clear and consistent increase/decrease of travel time, the former was considered as the more likely possibility. In order to determine which explanation was correct, two (2)

statistical models on VTT were developed using only the dataset from experiment 2. See figures 6.13 and 6.14. The statistical models indicate that the first consideration is more statistically significant (figure 6.14); transit does not have an effect on VTT at level D2, however rideshare demonstrates a clear and significant linear effect. Furthermore, the quadratic models are inconsistent in their parameter effects, the effects in the linear model match up more closely between NB and SB.

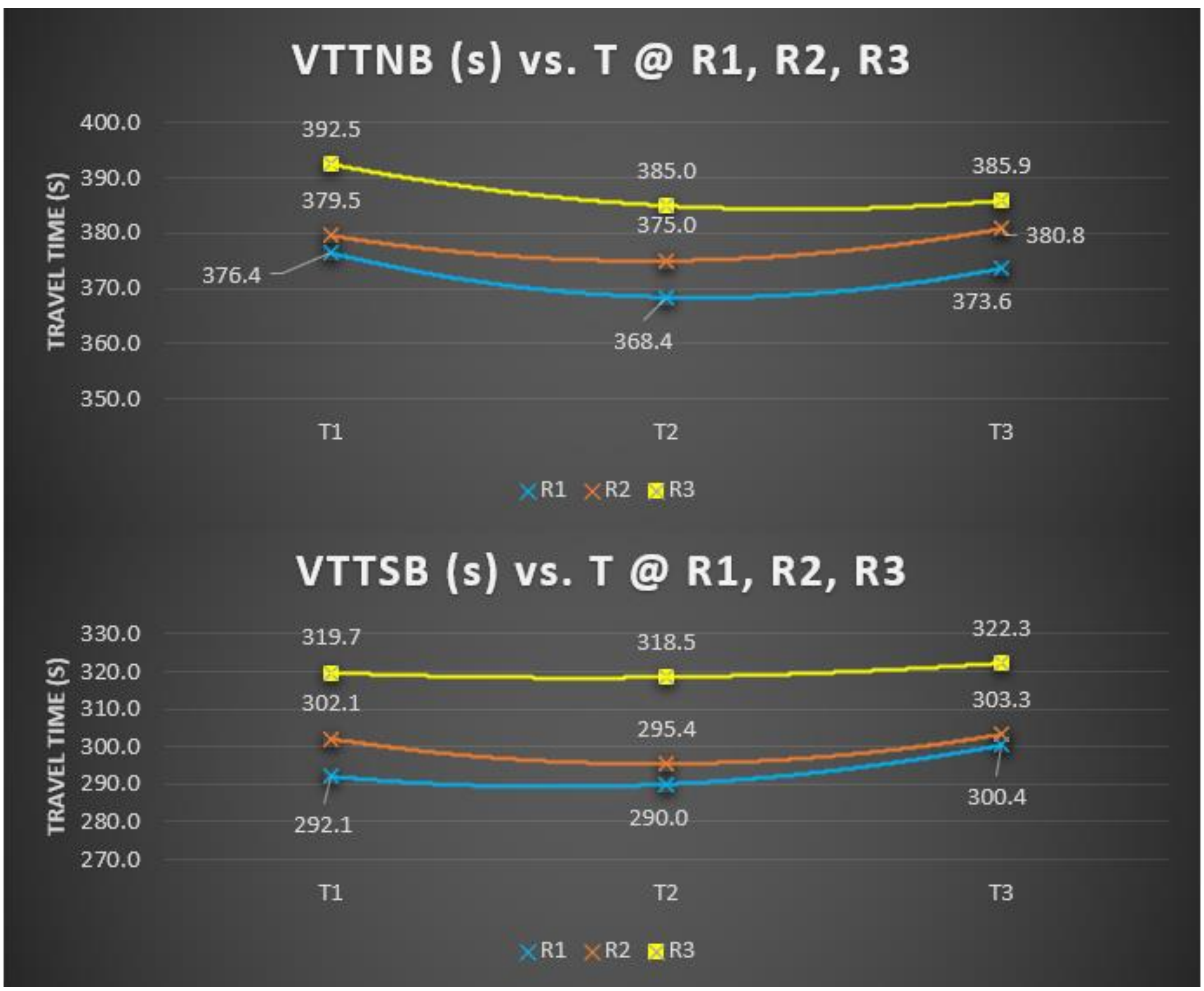
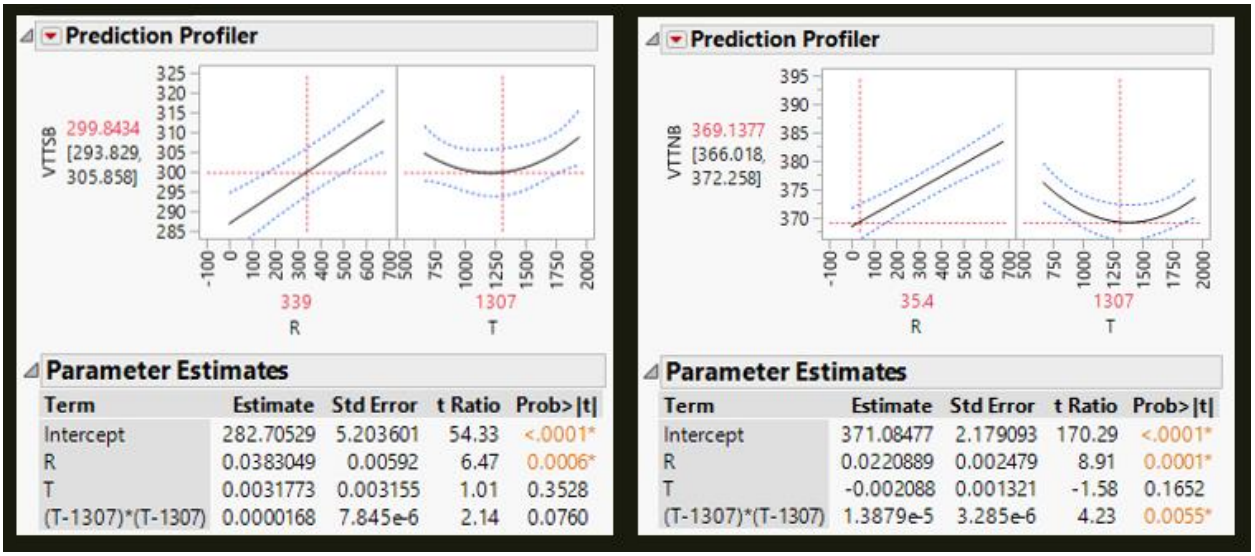


Figure 6. 12 Effects of Transit and Rideshare on VTT



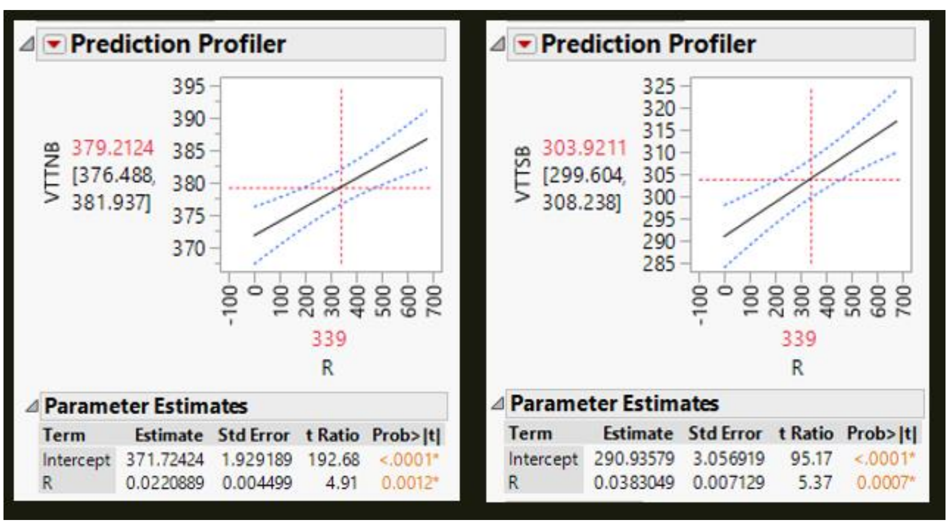
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	282.70529	5.203601	54.33	<.0001*
R	0.0383049	0.00592	6.47	0.0006*
T	0.0031773	0.003155	1.01	0.3528
(T-1307)*(T-1307)	0.0000168	7.845e-6	2.14	0.0760

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	371.08477	2.179093	170.29	<.0001*
R	0.0220889	0.002479	8.91	0.0001*
T	-0.002088	0.001321	-1.58	0.1652
(T-1307)*(T-1307)	1.3879e-5	3.285e-6	4.23	0.0055*

Figure 6. 13 Quadratic VTT models for Transit and Rideshare – Experiment 2



Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	371.72424	1.929189	192.68	<.0001*
R	0.0220889	0.004499	4.91	0.0012*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	290.93579	3.056919	95.17	<.0001*
R	0.0383049	0.007129	5.37	0.0007*

Figure 6. 14 Linear VTT models for Transit and Rideshare – Experiment 2

6.2.2 Effects on Average Delay and Speed

The effects for delay and speed are quite consistent with the results from part 1. In general, transit appears to have notable positive network-level performance effect with rideshare having adverse network-level impacts. See the following figure 6.15.

Figure 6. 15 Effects of Transit and Rideshare on DELAY and SPEED

6.2.3 Queuing Analysis – Experiment 2

Recall from experiment 1 that transit appeared to have no effect on queuing at transit stops yet had notable effects on the total number of stops in the network. The results from experiment 2 verify the effect on TQ, but surprisingly also show an effect for Q. See figure 6.16. Upon further inspection of vehicle queues, it was found that certain stops enjoyed significantly lower queuing. This revealed that stops with lay-bys (LB) experienced significantly better queuing performance. In this context, a lay-by represents any sort of exclusive bay or lane that removes the transit vehicle from the general flow of traffic. This observation makes sense as the presence of a lay-by prevents any scheduled vehicles from impeding the flow of traffic during boarding and alighting. Interestingly, the reduction effect of transit seen in figure 6.16 acts the opposite way when a lay-by is present, indicating a potential T*LB interaction (see figure 6.17 vs. 6.16). As such, it was decided to perform another queuing analysis in the next experiment.

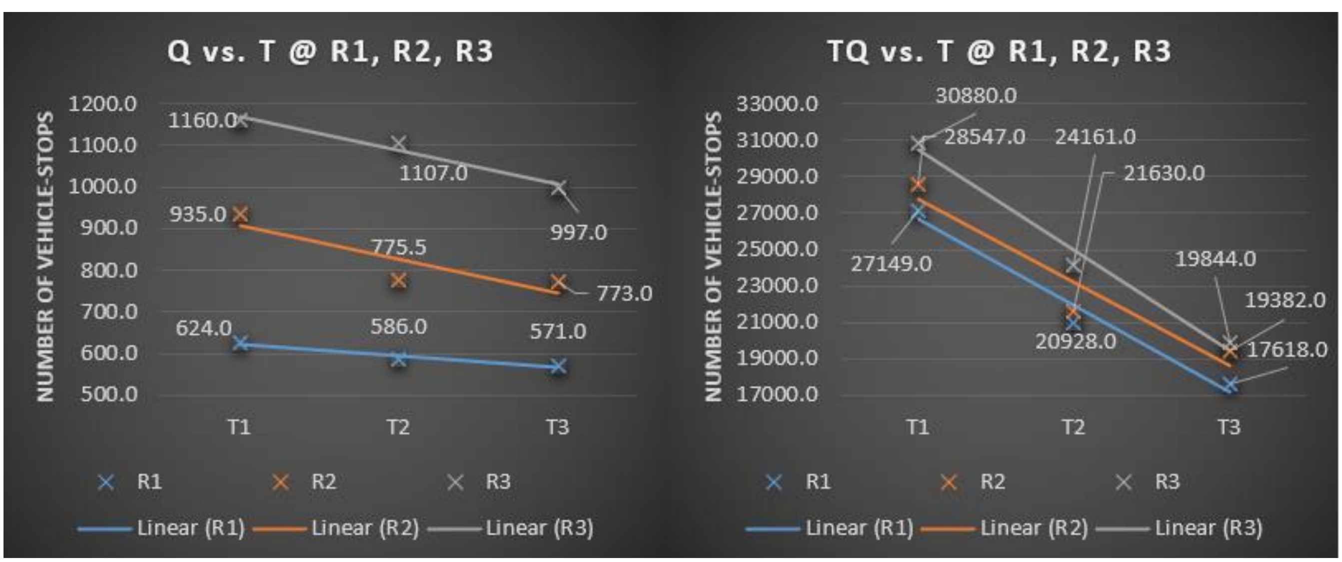


Figure 6. 16 Effect of Transit and Rideshare on Q and TQ

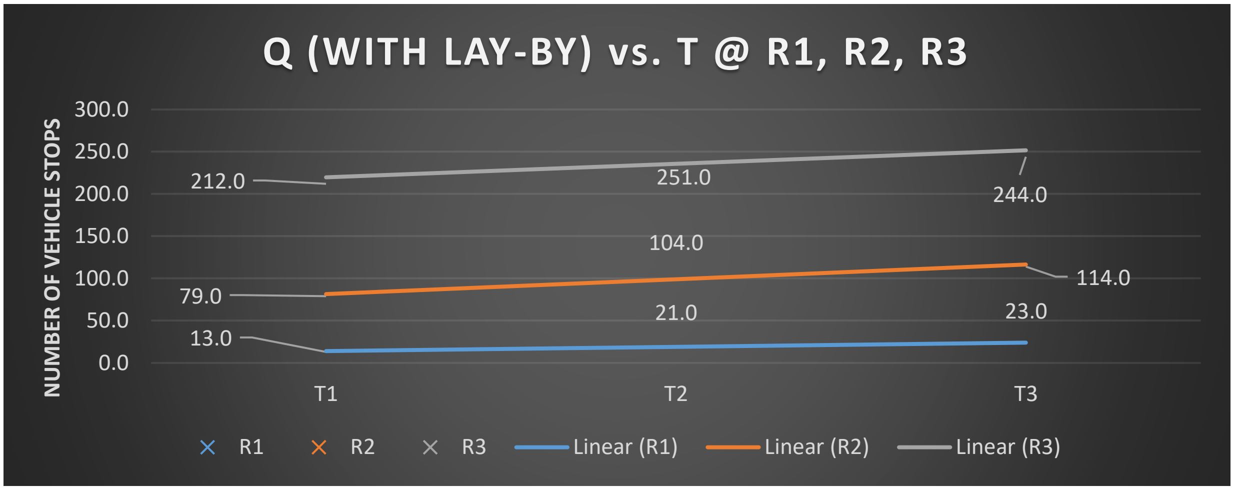


Figure 6. 17 Effect of Transit on Q – with Lay-By

6.3 Experiment 3 Full Factorial (D, T)

The purpose of the final experiment was to add more intermediate levels in order to verify a consistent travel time model that captures the effects of personal vehicles, transit, and rideshare. Furthermore, a second queuing analysis was performed to verify queuing effects. A full factorial design is selected for the most comprehensive analysis. See the following table 6.4.

Table 6. 4 Experiment 3 Full Factorial

Scenario	D	T	Name	
31	16477	1943	D3	T3
32	15534	987	D2.5	T1.5
33	15534	1623	D2.5	T2.5
34	12706	987	D1	T1.5
35	12706	1623	D1	T2.5
36	15534	1302	D2.5	T2
37	12706	1943	D1	T3
38	13649	1943	D1.5	T3
39	13649	1302	D1.5	T2
40	16477	987	D3	T1.5
41	13649	671	D1.5	T1
42	15534	1943	D2.5	T3
43	15534	671	D2.5	T1
44	14591	1302	D2	T2
45	12706	671	D1	T1
46	13649	1623	D1.5	T2.5
47	14591	1943	D2	T3
48	12706	1302	D1	T2
49	16477	1302	D3	T2
50	13649	987	D1.5	T1.5
51	16477	1623	D3	T2.5
52	16477	671	D3	T1
53	14591	1623	D2	T2.5
54	14591	671	D2	T1
55	14591	987	D2	T1.5

6.3.1 Consistent VTT Model

Visualizing the data for the VTT effect of transit on NB and SB starts to answer some questions as to the D*T interaction. In the peak direction (NB), increasing transit appears to have slight reduction effects on VTT, while SB effects show the opposite. See figures 6.18 and 6.19. This is suggestive of a negative D*T interaction. As the input variables D and T are macroscopic and reflect the inputs to the whole network, new

route-level variables were selected for modelling. The new variables, VD, TD, and RD represent the persons per hour directional flowrate entering I-Drive; VTTNB and VTTSB are both assigned to a single variable VTT. A block factor, Direction, is added to capture any nuisance effects that differ between NB and SB (such as lane configurations, capacity, transit stop infrastructure, etc.). Finally, the dataset for the model is expanded to use data from all three experiments. Combining datasets is typically inappropriate unless the experiments are reasonably similar. As the experiments all use the same variables, and results are based off simulation, it was determined that the full dataset is appropriate to use.

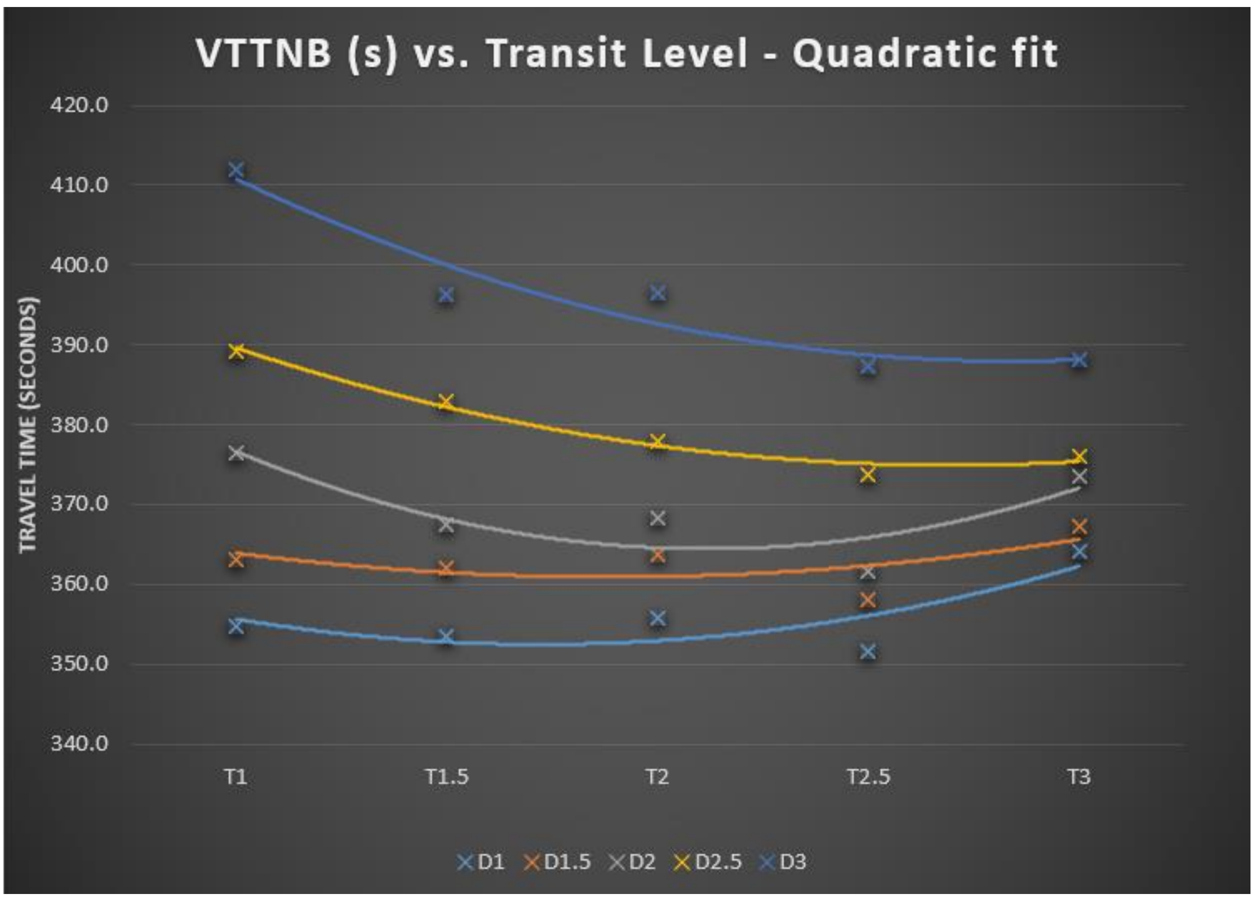


Figure 6. 18 Effects of Transit and Demand on VTTNB

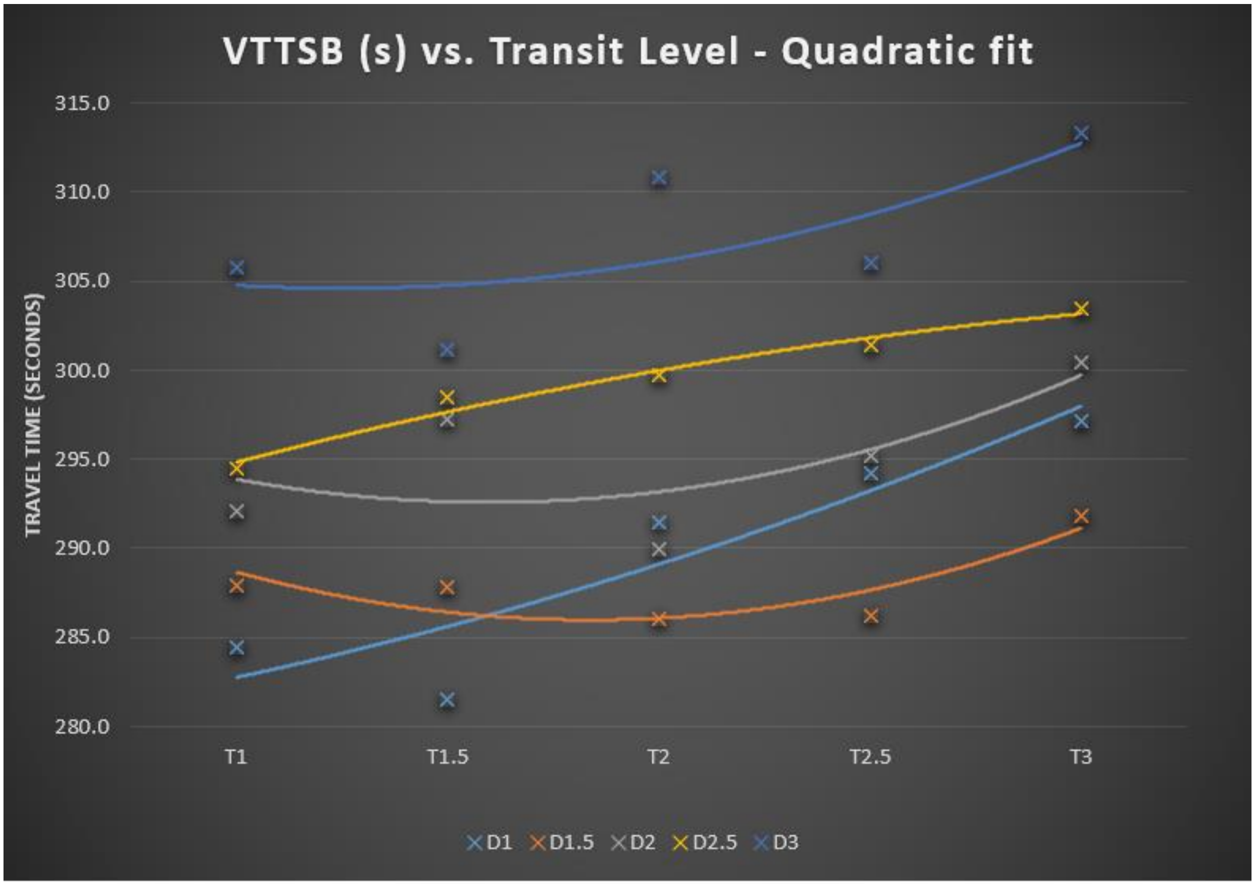


Figure 6. 19 Effects of Transit and Demand on VTTSB

Several steps are taken to ensure a final model that is consistent and passes diagnostics (ANOVA Test, Lack of Fit Test):

1. Filtering for outliers: Three (3) different methods are used to filter for outliers. First, outliers are filtered by observing the normal distributions in JMP and excluding data that fall out of range. Second, outliers are filtered by plotting the distributions of studentized residuals and excluding data that falls out of range. See figure 6.20. Finally, the actual residual plots are looked at and any remaining outliers are removed. In total, 15 outliers are removed. At this stage, the model

passed ANOVA testing, but still found a Lack of Fit significant to 0.43%. Removing outliers did not appear to enhance the ANOVA diagnostics but had a very minor effect on improving lack of fit (up to 1.7% significance). Parameter effects remained mostly unchanged after filtering.

2. Improving Lack of Fit (LoF): As the current dataset only included two (2) centerpoints in total, pure error appeared to be quite small relative to residual error, resulting in a significant lack of fit. In order to verify the pure error, two (2) additional centerpoints are added to experiments 2 and 3, then simulated to output VTT measurements.
3. AICc checking: In situations where two or more theoretically valid models must be compared, the Akaike information criterion (AICc) is used. The criterion is used to compare the probability of minimizing information loss between two models. In general, models with lower AICc values are more likely to minimize information loss.
4. Alternative types of models: Several other models are tested to determine if there could be a better fit. The tested alternatives included log, quadratic, and exponential transformations of input and output variables, as well as generalized linear models with various link functions. The only variable transform that turned up a satisfying model was to use log transformations on the directional flowrate inputs. While the model effects came out to be the same, some of the parameter effects were less significant. Furthermore, the log-transform model suffered lower significance in ANOVA testing. Generalized linear models turned

up very similar results to the original linear regression; this is likely due to the nature of the data (VTT was already normally distributed, and the variables were also continuous).

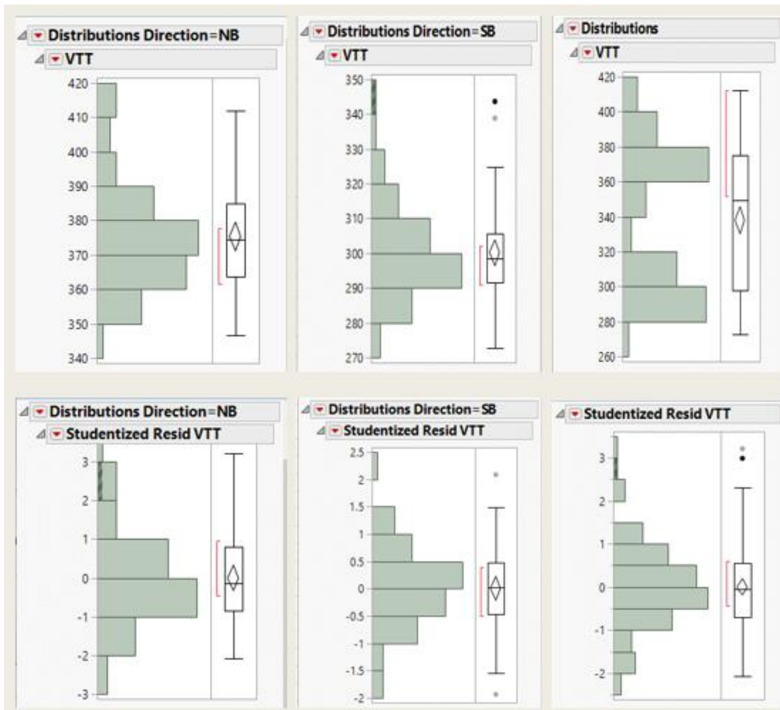


Figure 6. 20 Distributions of VTT and Studentized Residuals – Filtering of Outliers

As such, the basic linear regression model with one categorical block variable 'Direction' was chosen as the ideal model. The model demonstrates exceptional diagnostics for both parameter effects and prediction. Furthermore, the effects agreed with the observations, common sense, and general flow theory. The D*T and D*R interactions mentioned earlier were verified as well as first-order and quadratic effects. See the following figure 6.21 for a demonstration of the D*T and D*R interactions. Note how the effect of transit becomes less steep at higher demand levels while the effect of rideshare becomes steeper. Figure 6.22 includes the model parameter estimates, ANOVA testing, R^2, Lack-

of-Fit testing, and residual plot. The model interpretation will be further discussed in the performance effects synthesis, section 7.1.

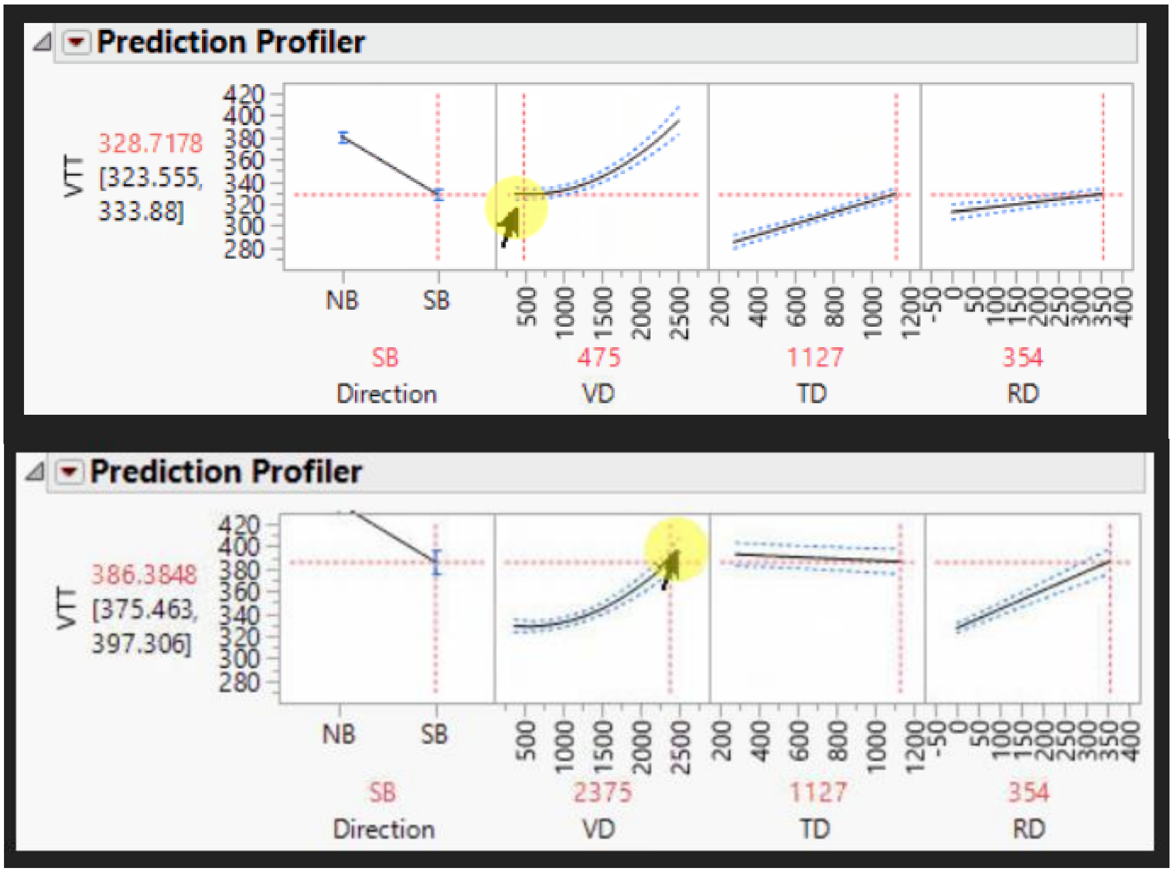


Figure 6. 21 D*T and D*R Interactions

Observing the prediction profilers above, the top profiler shows the linear parameter effects of TD and RD at low vehicular volumes. At these low volumes, TD and RD have very similar effects, however, as VD is increases (see bottom profiler), the effect of transit is reduced to zero (line is horizontal), while the effects of rideshare become worse. This was consistent with the inferences from figures 6.11, 6.18, and 6.19.

Summary of Fit

RSquare	0.988853
RSquare Adj	0.987995
Root Mean Square Error	4.295279
Mean of Response	333.1817
Observations (or Sum Wgts)	99

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	148930.08	21275.7	1153.192
Error	91	1678.90	18.4	Prob > F
C. Total	98	150608.98		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	81	1552.3609	19.1649	1.5146
Pure Error	10	126.5361	12.6536	Prob > F
Total Error	91	1678.8971		0.2424
				Max RSq
				0.9992

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	258.40424	3.613732	71.51	<.0001*
Direction[NB]	26.240501	0.682843	38.43	<.0001*
VD	0.0342871	0.00163	21.03	<.0001*
TD	0.0170042	0.002076	8.19	<.0001*
RD	0.1169462	0.005679	20.59	<.0001*
(VD-1582.45)*(VD-1582.45)	1.7484e-5	2.148e-6	8.14	<.0001*
(VD-1582.45)*(TD-620.379)	-3.116e-5	3.54e-6	-8.80	<.0001*
(VD-1582.45)*(RD-82.7172)	6.3978e-5	1.113e-5	5.75	<.0001*

Effect Tests

Residual by Predicted Plot

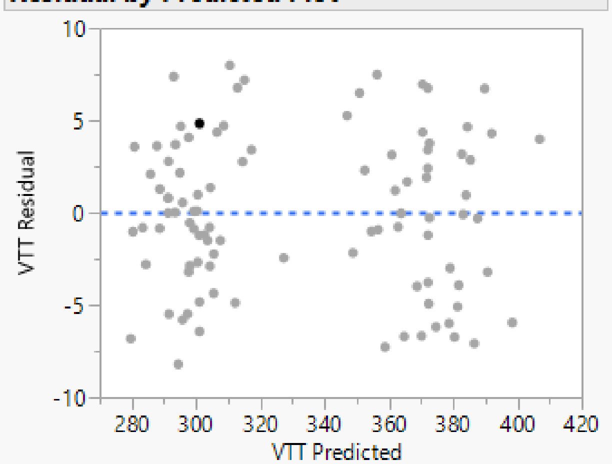


Figure 6. 22 Final Selected VTT Regression Model

6.3.2 Queuing Analysis – Experiment 3

So far, analysis suggests that three factors have potential effects on transit stop queuing: T, R, and Lay-By (L). Further investigation into the effect of lay-bys reveals staggering improvements to queuing performance. As demonstrated in the following figure 6.23, transit stops with lay-bys enjoy an over 1200% reduction in spillover queuing, on average. The 'L' factors on the x-axis represent stops with lay-bys.

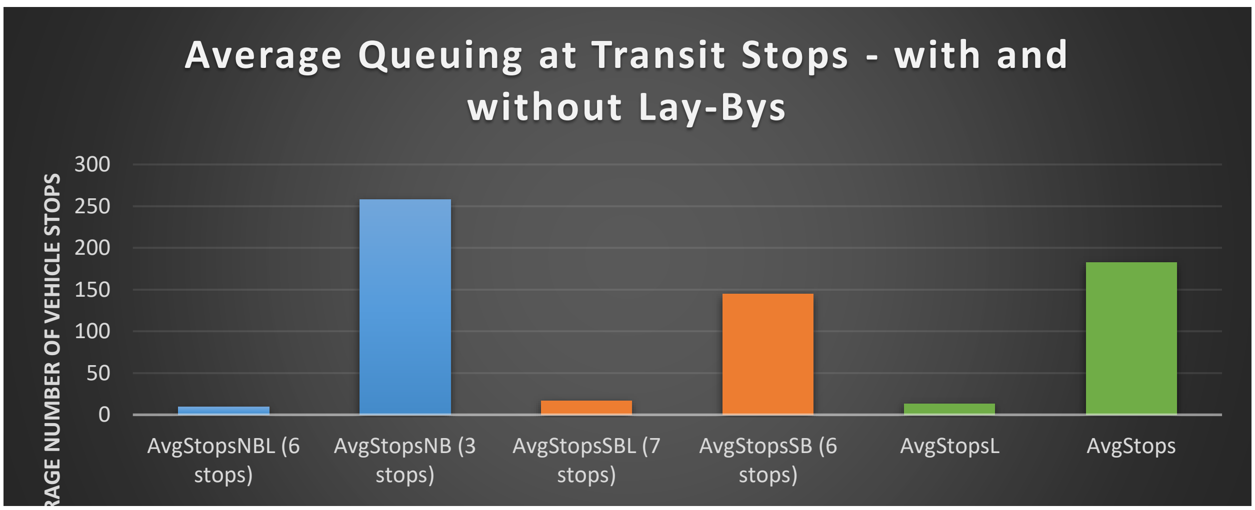


Figure 6. 23 Comparison of Queuing at Stops with and without Lay-Bys (Q)

To determine whether transit does exhibit an effect on average transit stop queuing, the following charts are plotted to see if any pattern is apparent, but there does not appear to be an obvious relationship between Q and T or D. The different ranges of the data only indicate an effect of LB. See figure 6.24. Furthermore, statistical modelling verifies there is no significant relationship between D, T, directional D and T, and average or total transit queuing stops. The only model that consistently predicted significant effects only included R and LB (categorical: lay-by) as variables. See figure 6.25.

Note the inconsistencies between the two-period moving average trendlines and data callouts for scenarios at Demand level 2.

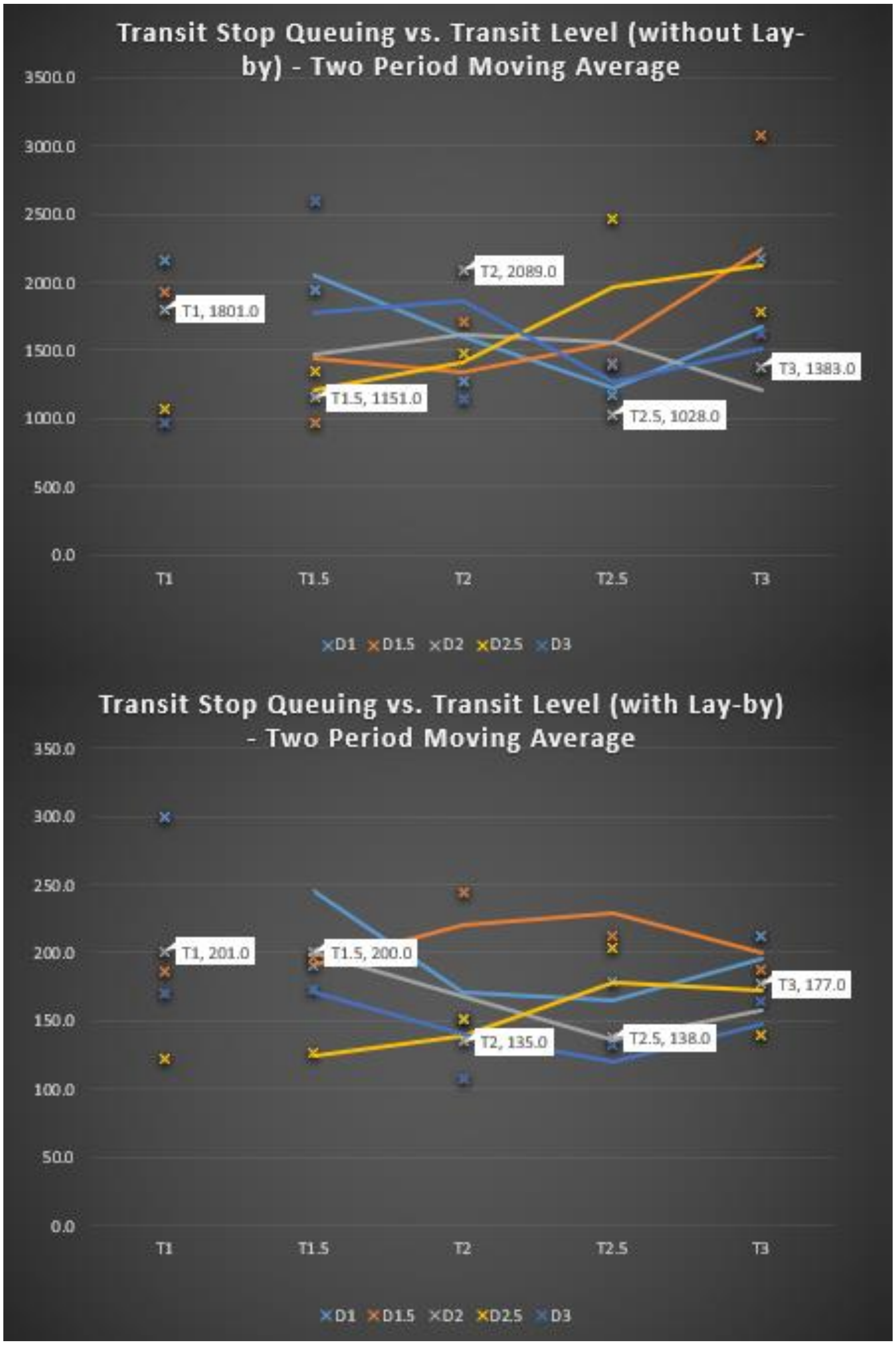


Figure 6. 24 Transit Stop Queuing vs. Transit Level by Demand (Q)

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	652.65	32.94737	19.81	<.0001*
R	0.5243363	0.065525	8.00	<.0001*
LB	-713.9	34.4124	-20.75	<.0001*

Figure 6. 25 Regression on Average Transit Stop Queuing (Q)

Total queuing was also modelled to verify the previous assertions that transit significantly reduces total queuing in the network while rideshare increases queuing. V is used instead of D to achieve significant parameter effects. The model verifies that rideshare has the strongest effect on increasing queuing while regular vehicles have a less pronounced effect. Transit is shown to have the only effect to reduce total queuing in network. See figure 6.26. R^2, ANOVA, and LoF testing show good diagnostics.

Summary of Fit

RSquare	0.924837
RSquare Adj	0.919593
Root Mean Square Error	1853.601
Mean of Response	20664.83
Observations (or Sum Wgts)	47

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	1817862884	605954295	176.3629
Error	43	147740985	3435836.9	Prob > F
C. Total	46	1965603869		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	41	147055935	3586730	10.4714
Pure Error	2	685051	342525	Prob > F
Total Error	43	147740985		0.0909
				Max RSq
				0.9997

Parameter Estimates

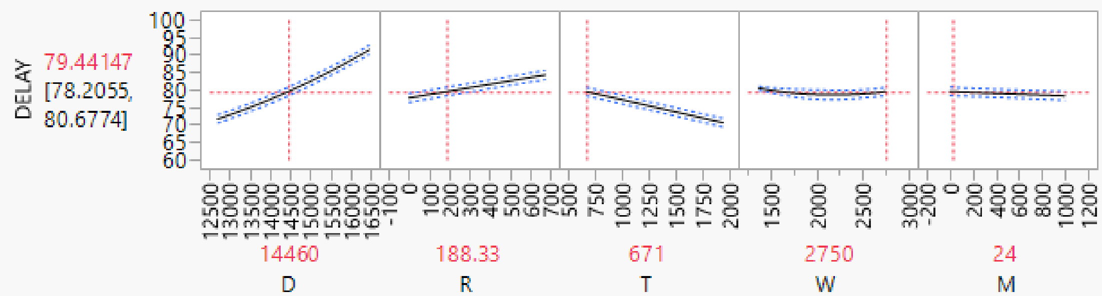
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-21211.44	2241.317	-9.46	<.0001*
R	4.7865828	1.035877	4.62	<.0001*
T	-2.019467	0.544207	-3.71	0.0006*
V	3.926076	0.176898	22.19	<.0001*

Figure 6. 26 Regression on Total Queuing in Network (TQ)

6.3.3 Average Delay and Speed Modeling

Regression modeling of average delay (DELAY) and speed (SPEED) is carried out to verify the previous assumptions that T improves network-level factors and R has adverse effects. Both models agree on these assumptions but also show significant effects for walking and micro-mobility. While M shows a decreasing effect to delay, as expected due to the removal of personal vehicles, W displays a more interesting effect. Increasing walking level is beneficial up to level 2. Increased walking levels beyond level 2 result in worsened network performance. This implies that a threshold exists at walking level 2, at which the added vehicular delay from conflicts due to additional pedestrians outweighs the delay savings of removing vehicles. See the following figures 6.27 and 6.28. Note that while the quadratic effect of W is only significant to 12%, it was judged to be valid based on the DELAY model findings and the issue of vehicle-pedestrian conflicts mentioned above.

Prediction Profiler



Summary of Fit

RSquare	0.981944
RSquare Adj	0.979072
Root Mean Square Error	1.148912
Mean of Response	76.17488
Observations (or Sum Wgts)	52

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	3158.6489	451.236	341.8452
Error	44	58.0800	1.320	**Prob > F**
C. Total	51	3216.7289		<.0001*

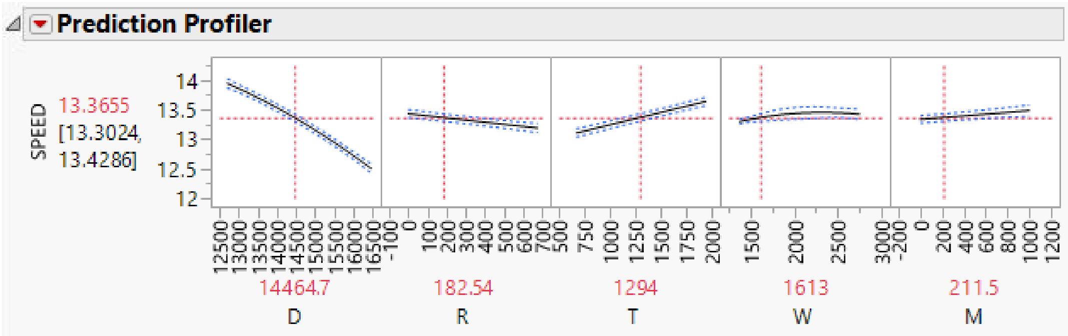
Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	41	51.635549	1.25940	0.5863
Pure Error	3	6.444436	2.14815	**Prob > F**
Total Error	44	58.079985		0.8192
				Max RSq
				0.9980

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	13.011976	2.338291	5.56	<.0001*
D	0.0051618	0.000122	42.27	<.0001*
R	0.0097664	0.000641	15.23	<.0001*
T	-0.006998	0.000316	-22.17	<.0001*
W	-0.003306	0.001189	-2.78	0.0080*
M	-0.00127	0.000523	-2.43	0.0193*
(D-14464.7)*(D-14464.7)	3.8787e-7	1.067e-7	3.63	0.0007*
(W-1613.02)*(W-1613.02)	2.9139e-6	1.334e-6	2.18	0.0343*

Figure 6. 27 Regression on DELAY



Summary of Fit

RSquare	0.975096
RSquare Adj	0.971134
Root Mean Square Error	0.093767
Mean of Response	13.27685
Observations (or Sum Wgts)	52

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	15.147383	2.16391	246.1134
Error	44	0.386863	0.00879	**Prob > F**
C. Total	51	15.534246		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	41	0.30498209	0.007439	0.2725
Pure Error	3	0.08188066	0.027294	**Prob > F**
Total Error	44	0.38686275		0.9803
				Max RSq
				0.9947

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.896888	0.190838	93.78	<.0001*
D	-0.000376	0.00001	-37.74	<.0001*
R	-0.00036	5.234e-5	-6.88	<.0001*
T	0.0004204	2.576e-5	16.32	<.0001*
W	0.0002474	0.000097	2.55	0.0144*
M	0.0001486	4.267e-5	3.48	0.0011*
(D-14464.7)*(D-14464.7)	-2.692e-8	8.711e-9	-3.09	0.0035*
(W-1613.02)*(W-1613.02)	-1.741e-7	1.089e-7	-1.60	0.1169

Figure 6. 28 Regression on SPEED

6.3.4 Sidewalk Travel Time Modeling

Finally, sidewalk travel time (STT) is considered for modeling based on W and M. As previously inferred, higher W levels correlate to higher STTs, while higher M levels result in notably reduced travel times. Interestingly, the model reveals quadratic effects as well as a positive interaction between W and M; at higher levels of M, the positive effect of W is more pronounced. Notably, the W*M interaction suggests that higher micro-mobility volumes adds to walking delays, likely due to conflicts between pedestrians and cyclists. Figure 6.29 includes the model as well as a demonstration of the W*M interaction.

Summary of Fit

RSquare	0.987655
RSquare Adj	0.983247
Root Mean Square Error	17.97382
Mean of Response	899.1219
Observations (or Sum Wgts)	20

Analysis of Variance

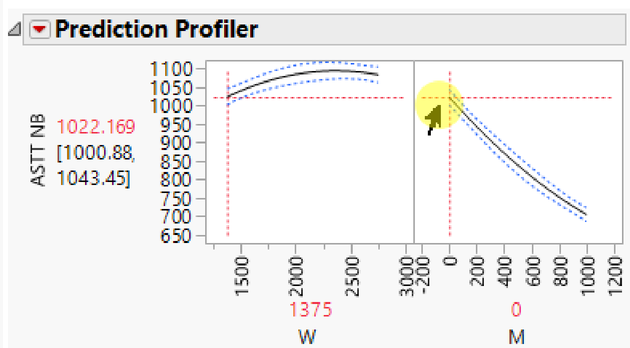
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	361855.61	72371.1	224.0187
Error	14	4522.82	323.1	**Prob > F**
C. Total	19	366378.43		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	3	1929.1142	643.038	2.7272
Pure Error	11	2593.7031	235.791	**Prob > F**
Total Error	14	4522.8174		0.0949
				Max RSq
				0.9929

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	907.36192	18.43864	49.21	<.0001*
W	0.0719399	0.006538	11.00	<.0001*
M	-0.271451	0.0099	-27.42	<.0001*
(W-2062.6)*(W-2062.6)	-7.189e-5	0.000023	-3.13	0.0073*
(W-2062.6)*(M-550)	5.1465e-5	1.41e-5	3.65	0.0026*
(M-550)*(M-550)	0.0001005	4.339e-5	2.32	0.0361*



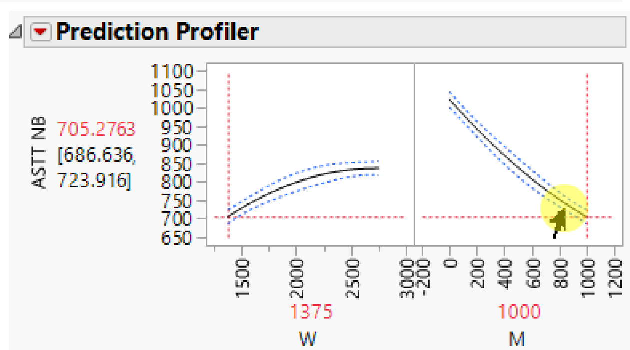


Figure 6. 29 Regression on STT

6.4 Benefit-Cost and Capacity Improvement Analysis

To measure the cost of using a transportation mode, it is necessary to account for multiple factors and externalities, such as operating costs, cost of ownership, crash damages, congestion, parking, pollution, and more. The Victoria Transport Policy Institute (2019) took these factors ,and others including land-use intensity, into account to calculate the costs per vehicle-mile of using different kinds of vehicles. As such, the cost savings for regular vehicles were calculated as $1.814 per vehicle-mile of auto reduction. To measure transit costs, several methods are used to find a reasonable cost that aligns with previous research and real-world budget data.

- Method 1: Using the Lynx Comprehensive Annual Financial Report (2018) – Cost/Vehicle-Mile (CPVM) is computed by plotting Total Operating Expenses against Total Vehicle-Miles Travelled
- Method 2: Using the same report, the CPVM is calculated by finding the cost versus utility of adding an additional peak vehicle (considering number of peak vehicles instead of TVMT)
- Method 3: VTPI also includes a cost for transit, equating to $27.483 per vehicle-mile
- Method 4: Conservative method – add the average of methods 1 and 2 (considered as operating expense) to method 3 (consider as externalities)

The following table 6.5 describes the benefit-cost calculations. Data is normalized to represent the cost over the 1.39 miles of I-Drive that is being analyzed. These findings are generally in the lower end of the range of B/C ratios found in Philadelphia (8.33), Memphis (19.96), Tennessee (3.4), and Roanoke (3.9) (Skolnik and Schreiner, 1998). It is important to note that these findings are highly dependent on capacity utilization. In other words, if transit fails to attract auto-drivers, the cost savings would be greatly reduced.

Table 6. 5 Benefit-Cost Ratios of Transit vs. Personal Vehicle Use

(in cents)	Cost savings of removing one car user (B)	Cost of adding one transit user (C)	B/C
B/C(1) =	159	19.1	8.32
B/C(2) =	159	20.3	7.83
B/C(3) =	159	60.3	2.64
B/C(4) =	159	80	1.99
Average =		44.9	5.2

In order to analyze the costs in more practical terms, project expenses are estimated and compared with traditional lane build expenses. The following table demonstrates the cost of adding one lane in each direction, using two methods outlined in the Orange County FL Impact Fee Update (2012).

Table 6. 6 Project Costs of Lane Build Alternative

Immediate cost (Capital investment):						
Cost-Per-Lane-Mile Improvement Calculations:	N-Lanes	CPLM	Segment Length (mi)	Project Cost	Capacity Improvement (pph)	Cost/additional person-trip on I-Drive (over 1.39 miles)
Traditional method (additional lanes)	2	3,744,000	1.39	$ 10,408,320.00	1422	$ 7,319.49
Historical method (total new lanes)	6	2,028,000	1.39	$ 16,913,520.00	1422	$ 11,894.18
AVERAGE				$ 13,660,920.00		$ 9,606.84
(Source: OC Impact Fee update 2012)						

To estimate the improvement costs of transit projects, three levels of improvement are considered for their costs. Project components are described in the following list and cost estimates are retrieved from a paper by Hess et. Al. (2005), which assesses the project costs and components for several bus transit services in America. It is important to note that one advantage of transit improvements is that improvements can be gradually phased in at reasonable over-time costs, compared to the immediate capital

investment required for a lane build project. The following list describes the components for each level of transit improvement:

- Level 1 Improvement: Purchase Tier 3 buses (articulated low-floor coaches at approximately $435,000 per bus) only
- Level 2 Improvement: Purchase Tier 2 buses (articulated buses at approximately $848,500 per bus), Total Renovation of Stops/Stations, Signal Priority/SPAT, Bus Arrival Information, ROW Improvement
- Level 3 Improvement: Purchase Tier 1 buses (diesel/electric articulated 60-foot buses at $1.2 million per bus), Construct HOV, Total Renovation of Stops/Stations, Signal Priority, Bus Arrival Information, ROW Improvement, Property Acquisition (per mile)

Detailed figures on component costs can be found in APPENDIX H or in the paper by Hess et. Al. (2005). The following figure 6.30 describes the immediate costs necessary for each type of project. It is important to note that while the lane-build scenario only adds capacity over 1.39 miles, fleet expansion would effectively add the same capacity (+1,422 persons/hour) to 52.62 miles of transit routes as the additional buses would serve more than just the 1.39 mile segment on I-Drive. Therefore, if the costs are considered on a per mile basis, which is a more effective measure of return on investment, it is shown that the cost of even the most cutting-edge transit improvement project is dwarfed by the costs of a lane-build scenario. See figure 6.31. Furthermore, operating costs and externalities can be considered via project expense timelines. The following figures 6.32 and 6.33 describe the cost breakdowns over time and

demonstrate the superior cost efficiency per mile of high-level transit improvements. The transit improvement timeline accounts for a gradual increase in fleet size to meet projected demand as it comes. Detailed spreadsheets can be found in APPENDIX H.

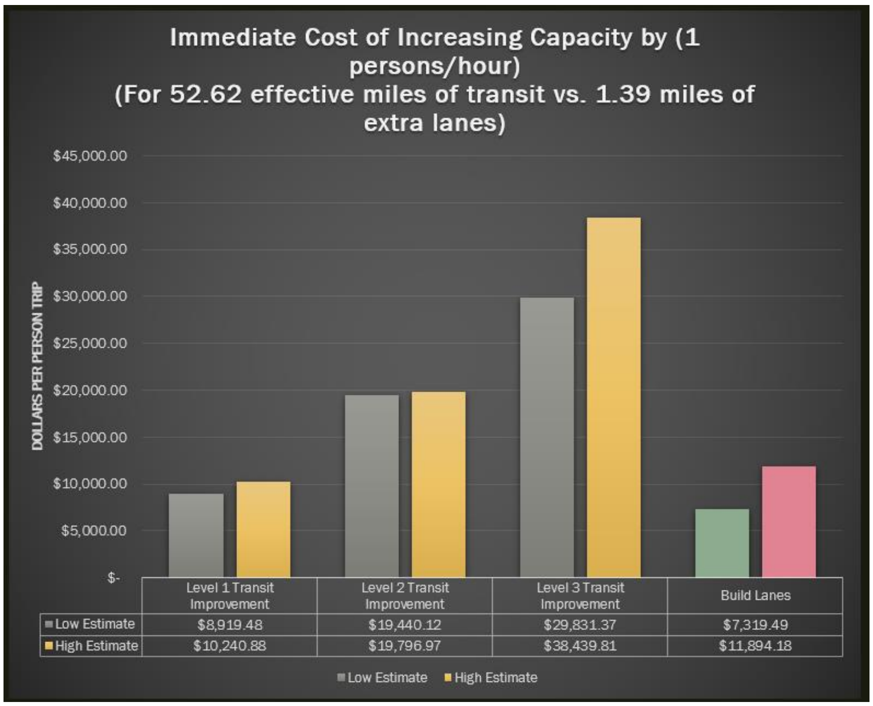


Figure 6. 30 Comparison of Capital Investments for Different Capacity Improvements

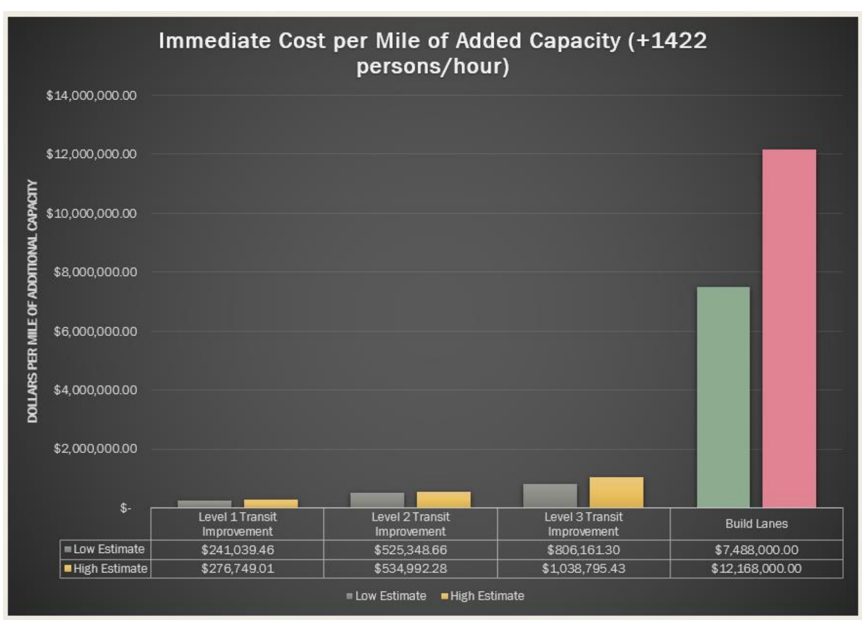


Figure 6. 31 Cost Comparison per Mile of Additional Capacity

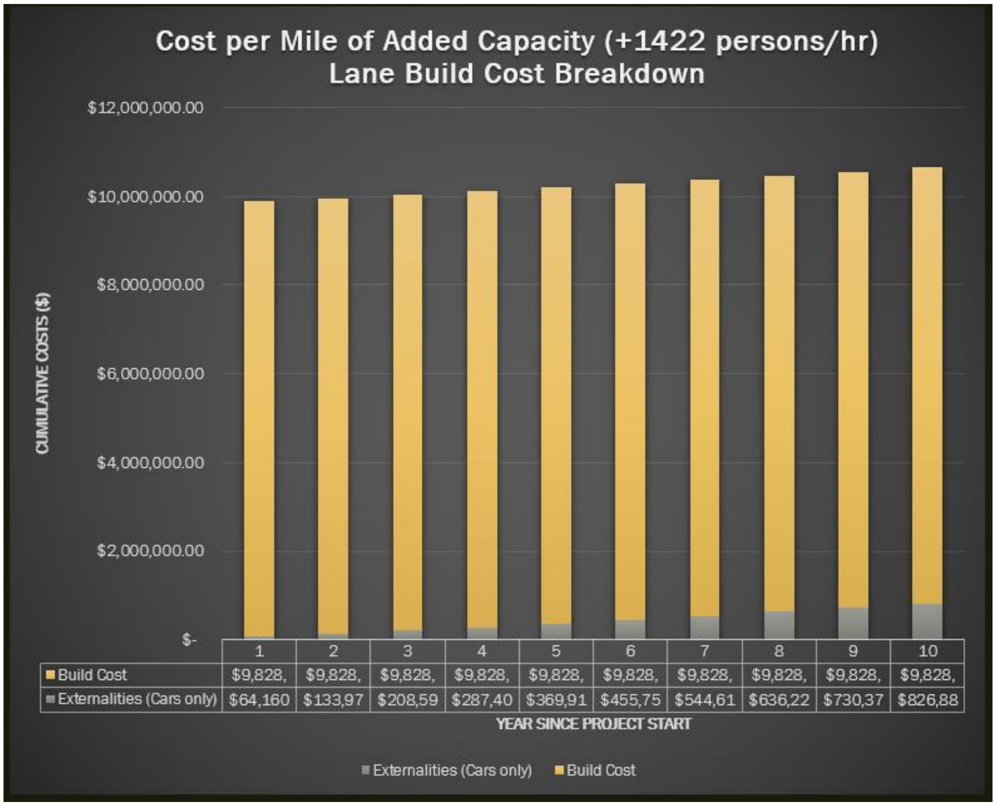


Figure 6. 32 Project Expense Timeline for Lane Build

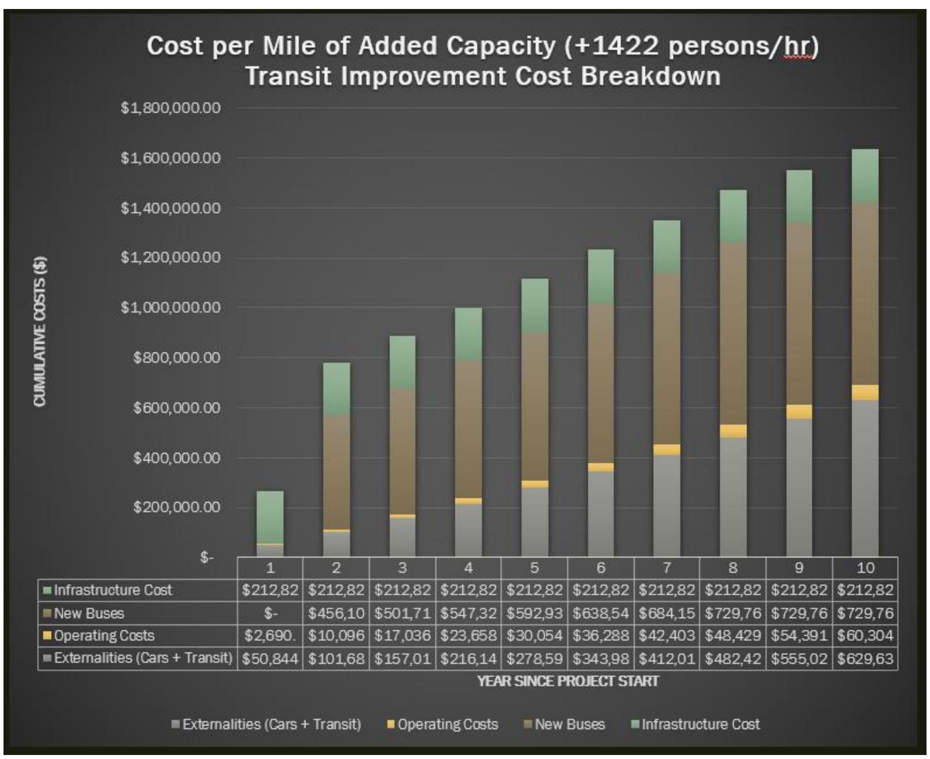


Figure 6. 33 Project Expense Timeline for Transit Level 3 Improvement

CHAPTER 7: CONCLUSIONS

The final chapter of this work aims to synthesize the key findings and describe the implications of applying MaaS to the network of study. The research effort was successful in identifying the relevant performance effects of various modes, some beneficial and some detrimental. Furthermore, other considerations were taken into account including the impacts of certain infrastructure and the costs of transit-oriented improvements versus traditional lane-oriented improvements. Overall, the research findings were very encouraging, demonstrating the potential of MaaS for cost-effective congestion relief with strong implications for enhancing the practice of multi-modal transportation planning in Florida.

7.1 Key Findings

The following list describes the key findings for each factor and the implications as far as MaaS network planning and design:

1. TRANSIT (T): In general, transit is found to have significant positive impacts to overall network-level performance factors, such as DELAY and SPEED. For instance, using the full dataset to estimate the effect of transit in congested settings reveals a stark 15.5% decrease in average delay throughout the network as a result of a relatively small 8% increase in transit modal share (i.e. shifting from personal vehicles). Considering route-level factors, transit also appears to perform best in congested environments. As demonstrated by the D*T interaction, additional transit capacity does not appear to increase vehicular

travel time in congested settings, with only marginal impacts in less congested settings. As such, it is important that MaaS networks are built around transit as the backbone of any integrated multi-modal service. This is also consistent with the findings of the Whim study (Ramboll, 2019), which showed that MaaS users use transit at a significantly higher rate than the regular population.

2. RIDESHARE (R): The effects of rideshare are to be expected, as rideshare essentially represents a less efficient vehicle on the roadway. This is due to the generally lower speed distribution and the pickup/dropoff activities of rideshare users. One positive aspect of rideshare is more trips per vehicle, which may eventually allow for less total vehicles on the road. However, even at low modal shares of four (4) percent, rideshare demonstrates significant adverse effects on the roadway network, despite the minor one-to-one shift away from personal vehicles. Across all route-level and network-level performance factors, rideshare consistently performs the worst. Transit stop queuing (Q) in particular suffers majorly due to the spillover queues caused by rideshares picking up or dropping off passengers. As such, curbside infrastructure is a necessary consideration for accommodating high rideshare volumes.
3. INFRASTRUCTURE: The research effort revealed that infrastructure had a surprisingly strong effect on influencing queuing at transit stops. While this is to be expected, the sheer magnitude of the effects reveal just how effectively performance can be improved with the addition of lay-bys. Simply removing transit and rideshare vehicles from the general traffic flow has unprecedented

sustainability and performance benefits. As rideshare still has significant effects to increasing queuing, separate considerations must be made for rideshare infrastructure. These improvements may be in the form of designated pick-up/drop-off zones (also known as kiss-and-go lanes) that prevent rideshare users from blocking the traffic flow and provide a safe space for rideshares to await boarding. Overall, the infrastructure analysis highlighted the importance of ensuring that scheduled vehicles do not impede traffic flow during boarding and alighting.

4. COSTS: As described in the previous chapter, both operating costs and capital investments for transit are significantly lower than costs for traditional lane builds. This agrees with current literature and also highlights the benefit of transit improvements over lane builds. While a lane build will only serve a limited length of roadway at a high cost, investments into transit automatically result in much more widespread improvement of service. By simply expanding the transit fleet, buses can be directed to either serve new areas or enhance capacity (in persons per hour) in already congested areas.
5. WALKING AND MICRO-MOBILITY (W and M): The findings on walking and micro-mobility see that the two modes go hand in hand. Sidewalk Level of Service is a field that has not seen much attention in terms of capacity analysis, however the results here demonstrate that high volumes of walkers can indeed have a significant effect on both sidewalk delay as well as vehicular delay. Furthermore, while micro-mobility can make non-vehicular travel much more attractive, there

is always the challenge of safety and conflicts, as proven by the W*M interaction. Not only would micro-mobility increase the delay for other walkers, but the increase in pedestrian-cyclist conflicts also poses a safety issue.

7.2 Implications for Future Direction

First, it is important to disclaim that the research effort and conclusions expressed in this paper address a very limited set of environmental factors and conditions. While these insights are valuable in tackling urban congestion, the performance aspects of MaaS are not studied in the context of a broader regional network. However, the findings may still be extrapolated to help direct research on the practical application and regional impacts of MaaS. The following discussion focuses on the functional aspects of implementing MaaS in terms of utilization, costs, connectivity, and technological advancement.

One major consideration that requires attention is the capacity utilization factor; how to maximize funding and return on investment by bolstering transit popularity. A major issue for Lynx in Orlando is the lack of ridership, which stems from generally poor stop/station infrastructure and infrequent service in most areas. As such, the cost analysis considered the most cutting-edge improvements that are likely to win some more popularity among commuters. Higher quality buses, stops, and information services are all crucial to providing a service that is perceivably reliable and effective. It is extremely important to address the capacity utilization issue quickly as falling ridership represents a severe threat to transit services. According to the Lynx Operating

Budget, system generated funds account for only 24.5 percent of the budget while the remaining expenses fall entirely on county, city, state, and federal funding. The continued drop in Orlando's transit ridership fuels a vicious cycle of lesser funding due to lesser ridership, thereby resulting in even less funding and so forth. Successful MaaS networks are typically able to answer the financial issues through diversified funding sources (such as the variety of public-private partnerships that fund European MaaS services like Whim and ERTICO) and operators (combining services from private and public entities).

Diversification of operators also serves another crucial purpose: multi-modal connectivity. A major obstacle for transit-dependent users is the lack of options for connecting to the transit network from a trip origin. MaaS provides an opportunity to address the lack of connectivity by utilizing multiple modes to serve different roles in moving users through the different levels of the network. For instance, though it was found that rideshare is generally detrimental in congested conditions, it is certainly naïve to conclude that the role of rideshare must be totally limited. In terms of regional connectivity, rideshare may offer solutions to many of the challenges of MaaS, namely the first-mile-last-mile issue. The first-mile-last-mile issue addresses the challenges of mode-choice for the starting and ending legs of multi-modal trip making, where transit generally serves the major intermediate legs of journeys. In areas where congestion is not a major concern, such as suburban connector networks, it may be more effective to concentrate rideshare services with the main purpose of moving passengers to the closest available transit hubs. Transit services can also be concentrated in higher traffic

areas to reap the throughput and performance benefits that transit enjoys even in congested conditions. This would limit exposure of rideshare vehicles to heavy traffic conditions, thereby limiting the adverse performance impacts of rideshare demonstrated in a congested network like the I-Drive corridor.

Furthermore, attention must be given to the wider-reaching, long-term effects of rideshare, including reduced personal vehicle ownership and all of the benefits that come with it, such as more free space (as parking requirements become less), less congestion in the long-term, and overall emissions. The fast-evolving progress in Connected Automated Vehicles (CAVs) is also likely to be a major turning point in rideshare popularity and effectiveness. As costs for vehicle automation systems continue to fall, the cost-effectiveness to the rideshare user will eventually outpace car ownership. Once costs fall in line, the average commuter may be more willing to forgo their traditional transportation modes to take advantage of the convenience and flexibility offered by multi-modal MaaS services.

In terms of MaaS system connectivity, it is important to note is the potential of data-driven, automated redeployment. CAVs will be able to utilize large datasets in real-time to dynamically respond to travel patterns in different peak periods and reposition accordingly, resulting in faster response times and less fuel wastage. Both rideshare and transit services will be able to benefit from the rapidly falling costs of automation. As automated transit and information services become more prevalent, less staffing will be needed for driving, scheduling, route mapping, and fleet management. The findings set forth in this research may be particularly useful in the programming of these automated

transit operations. The parameter effects for rideshare and transit modes can be implemented with traffic data shared between public and private CAV operators to automate fixed-route (transit) optimization and fleet positioning (rideshare). This further demonstrates the potential of private-public partnerships to implement MaaS most effectively.

Finally, the effects of walking and micro-mobility open questions into optimizing connectivity at the microscopic level for both sidewalk travel modes as well as roadway travel modes. Features like transit stops, curbs, and lay-bys represent the main interface between pedestrians, cyclists, small vehicles, and transit. As such, reducing conflicts at this interface can be extremely valuable in performance and sustainability terms by improving the general smoothness of users interacting and switching from mode to mode. Possible areas for research on curbside management are separation techniques (differentiating 'wheels from heels'), sidewalk pavement widening in high-volume areas, kiss-and-go lanes, micro-mobility deployments, and lay-bys. In short, these findings and discussions have major implications for transforming the traditional practice of lane-build focused transportation planning. Further research will be crucial in applying these performance analyses to optimize multi-modal transportation planning in expansive, suburb-heavy cities like Orlando.

APPENDIX A: I-RIDE RIDERSHIP REPORT FY 2020

I-RIDE TROLLEY RIDERSHIP FY 2020 @ MAY 2020

RIDERSHIP MONTH	BUDGET FY 20	ACTUAL FY 20	VAR. to Budget	% Var.	ACTUAL FY 19	Var. to last year	% Var.
Oct-19	125500	123229	-2271	-1.81%	124620	-1391	-1.12%
Nov-19	115000	110939	-4061	-3.53%	114729	-3790	-3.30%
Dec-19	87000	88145	1145	1.32%	86377	1768	2.05%
Jan-20	63000	68260	5260	8.35%	63973	4287	6.70%
Feb-20	68500	71357	2857	4.17%	68316	3041	4.45%
Mar-20	85800	39229	-46571	-54.28%	85881	-46652	-54.32%
Apr-20	128700	0	-128700	-100.00%	128725	-128725	-100.00%
May-20	116000	0	-116000	-100.00%	116265	-116265	-100.00%
total	789500	501159	-288341	-36.52%	788886	-287727	-36.47%

PASSES MONTH	BUDGET FY 20	ACTUAL FY 20	VAR. to Budget	% Var.	ACTUAL FY 19	Var. to last year	% Var.
Oct-19	$ 57,298	$ 52,663	$ (4,635)	-8.09%	$ 52,148	$515	0.99%
Nov-19	$ 38,500	$ 45,846	$ 7,346	19.08%	$ 48,240	($2,394)	-4.96%
Dec-19	$ 31,868	$ 39,847	$ 7,979	25.04%	$ 38,951	$896	2.30%
Jan-20	$ 26,170	$ 37,719	$ 11,549	44.13%	$ 31,375	$6,344	20.22%
Feb-20	$ 27,132	$ 35,362	$ 8,230	30.33%	$ 32,496	$2,866	8.82%
Mar-20	$ 42,343	$ 10,703	$ (31,640)	-74.72%	$ 56,618	($45,915)	-81.10%
Apr-20	$ 48,902	$ -	$ (48,902)	-100.00%	$ 69,400	($69,400)	-100.00%
May-20	$ 59,048	$ -	$ (59,048)	-100.00%	$ 77,777	($77,777)	-100.00%
total	$ 331,261	$ 222,140	$ (109,121)	-32.94%	$ 407,005	$ (184,865)	-45.42%

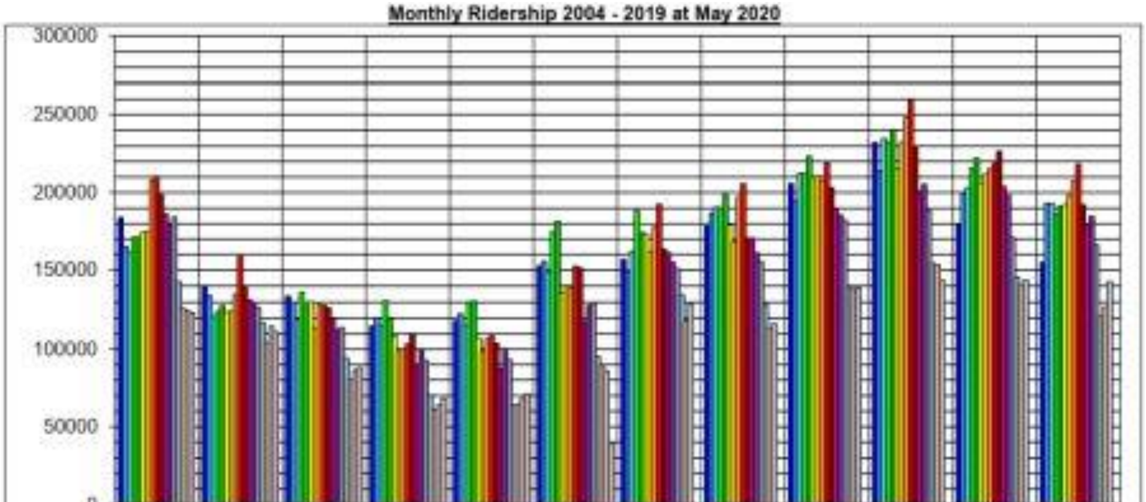
FAREBOX MONTH	BUDGET FY 20	ACTUAL FY 20	VAR. to Budget	% Var.	ACTUAL FY 19	Var. to last year	% Var.
Oct-19	$ 50,202	$ 41,284	$ (8,918)	-17.76%	$ 44,880	$ (3,596)	-8.01%
Nov-19	$ 43,515	$ 39,733	$ (3,782)	-8.69%	$ 43,451	$ (3,718)	-8.56%
Dec-19	$ 36,952	$ 37,102	$ 150	0.41%	$ 33,813	$ 3,289	9.73%
Jan-20	$ 28,453	$ 28,793	$ 340	1.19%	$ 27,660	$ 1,133	4.10%
Feb-20	$ 29,017	$ 30,348	$ 1,331	4.59%	$ 26,905	$ 3,443	12.80%
Mar-20	$ 40,712	$ 15,595	$ (25,117)	-61.69%	$ 33,929	$ (18,334)	-54.04%
Apr-20	$ 42,386	$ -	$ (42,386)	-100.00%	$ 46,422	$ (46,422)	-100.00%
May-20	$ 43,274	$ -	$ (43,274)	-100.00%	$ 39,911	$ (39,911)	-100.00%
total	$ 314,511	$ 192,855	$ (121,656)	-38.68%	$ 296,971	$ (104,116)	-35.06%

COMBINED	BUDGET FY 19	ACTUAL FY 19	VAR. to Budget	% Var.	ACTUAL FY 18	Var. to last year	% Var.
FARES	$ 645,772	$ 414,995	$ (230,777)	-35.74%	$ 703,976	$ (288,981)	-41.05%

* Ceased operations on March 22, 2020 due to the Coronavirus (COVID 19)

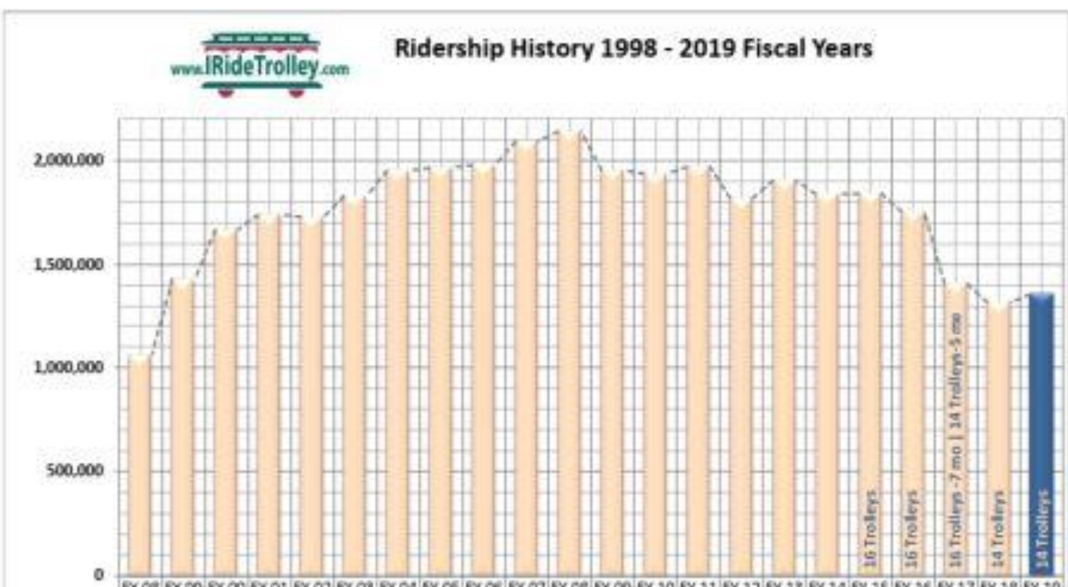
Based on operating 14 trolleys per day

Monthly Ridership 2004 - 2019 at May 2020



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
FY 04	184121	136675	133439	114930	118158	152806	157035	178498	205896	232241	179254	155112
FY 05	165319	133802	130359	120025	122749	155807	148362	186986	195069	214135	199209	193336
FY 06	162170	120800	119302	115811	115777	148256	162410	190681	212258	234779	203119	193080
FY 07	171128	123859	135968	130949	130174	174755	188373	190141	212071	232512	215688	186045
FY 08	171030	127677	127635	119891	130823	181378	174359	198466	223178	240676	221874	191238
FY 09	174280	123674	130535	108527	107264	135807	173331	179240	209972	214991	206191	192118
FY 10	174704	124370	113676	99687	98762	140277	161829	168491	213664	232834	211684	198209
FY 11	208052	134704	128533	100130	106334	138694	177612	197066	208013	248238	215241	207302
FY 12	210347	158754	127924	103347	108307	152628	192600	205681	218927	260062	218521	218154
FY 13	198558	139384	126409	109219	103896	151595	163810	170676	203110	228841	226724	192216
FY 14	186288	131843	119495	90041	87542	117686	161199	170537	189558	201092	203798	179481
FY 15	180155	128736	112686	99570	100413	127895	155188	161169	185980	205305	198227	184845
FY 16	184182	126611	113880	92855	93296	128742	151053	155576	182237	188275	171111	166306
FY 17	142790	117139	94444	70211	64065	95422	134532	128863	139346	154423	145737	121096
FY 18	126060	104410	80797	61264	64780	89727	118037	113853	137804	153536	140920	127164
FY 19	124620	114729	88377	63973	68316	85881	128725	116265	138921	143772	143635	142867
FY 20	123229	110839	88145	68260	71357	39229	0	0				

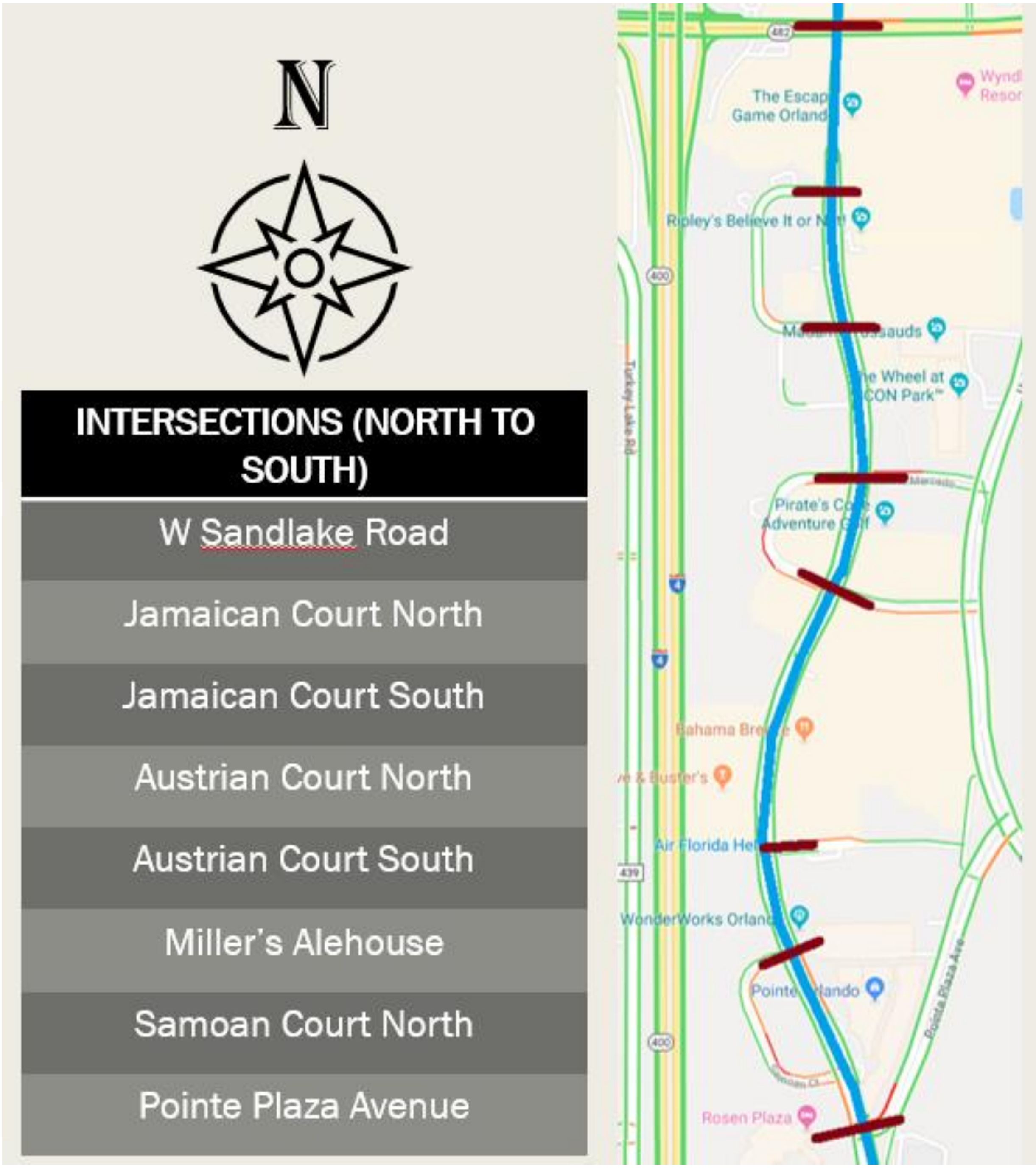
Ridership History 1998 - 2019 Fiscal Years



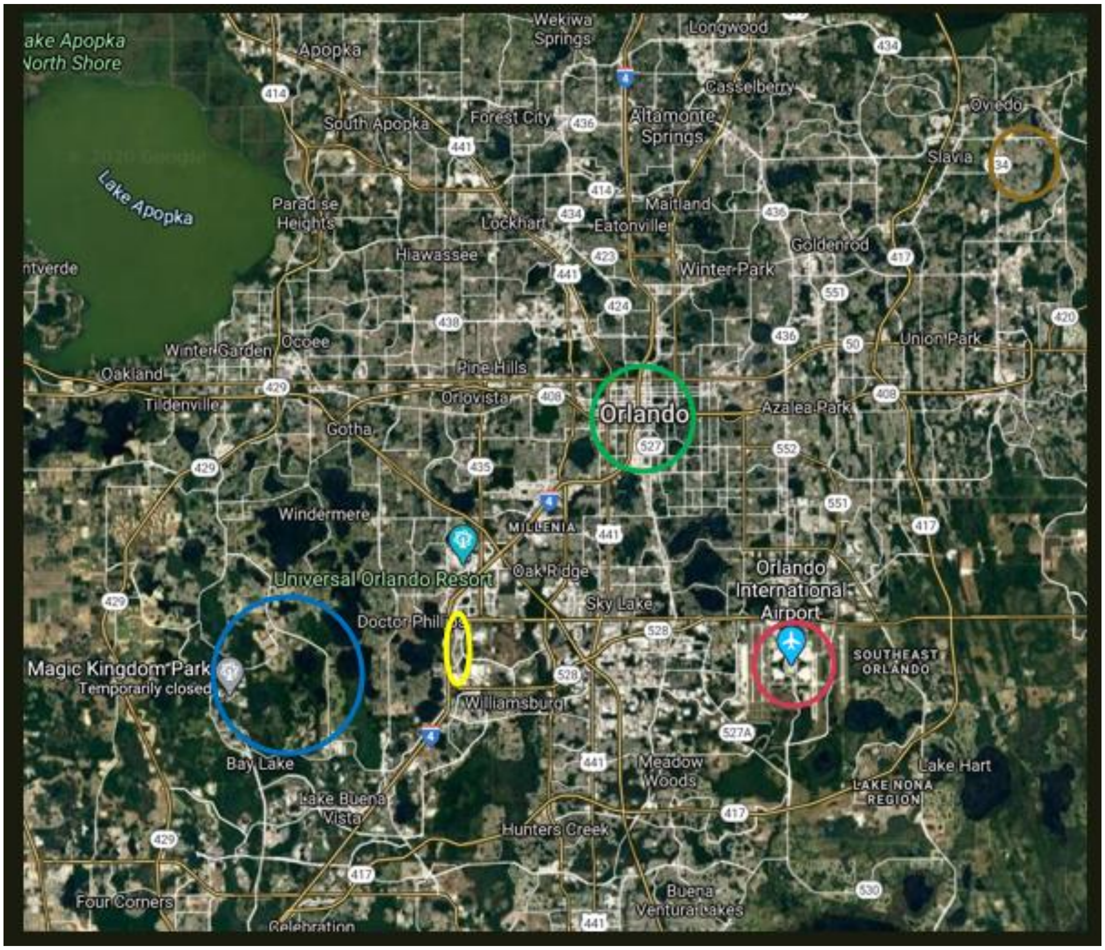
	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15	FY 16	FY 17	FY 18	FY 19
Series1	1,06	1,43	1,66	1,74	1,72	1,82	1,95	1,96	1,97	2,09	2,13	1,95	1,93	1,96	1,81	1,90	1,83	1,83	1,75	1,40	1,31	1,35

APPENDIX B: MAPS AND VISSIM NETWORK SCREENSHOTS

Network intersection map (Google Maps)



Regional network map (Google Maps)



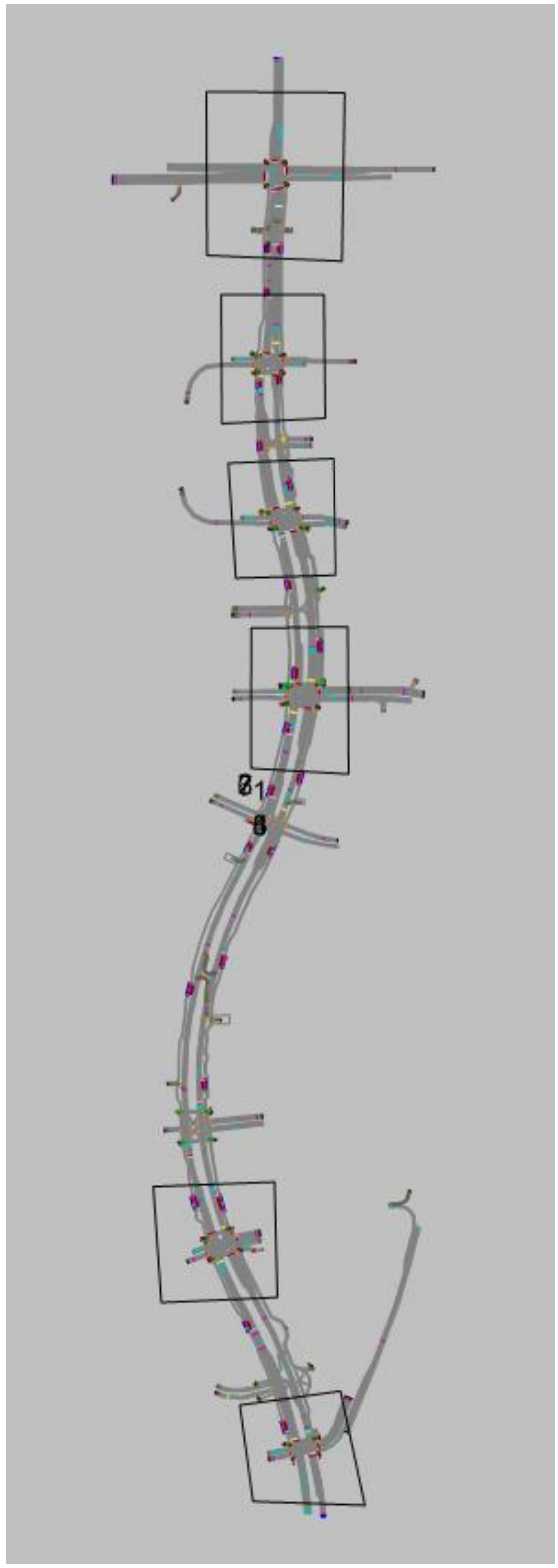
Regional Network

I-Drive acts as a major attractor for commercial and tourism uses.

Points of interest:

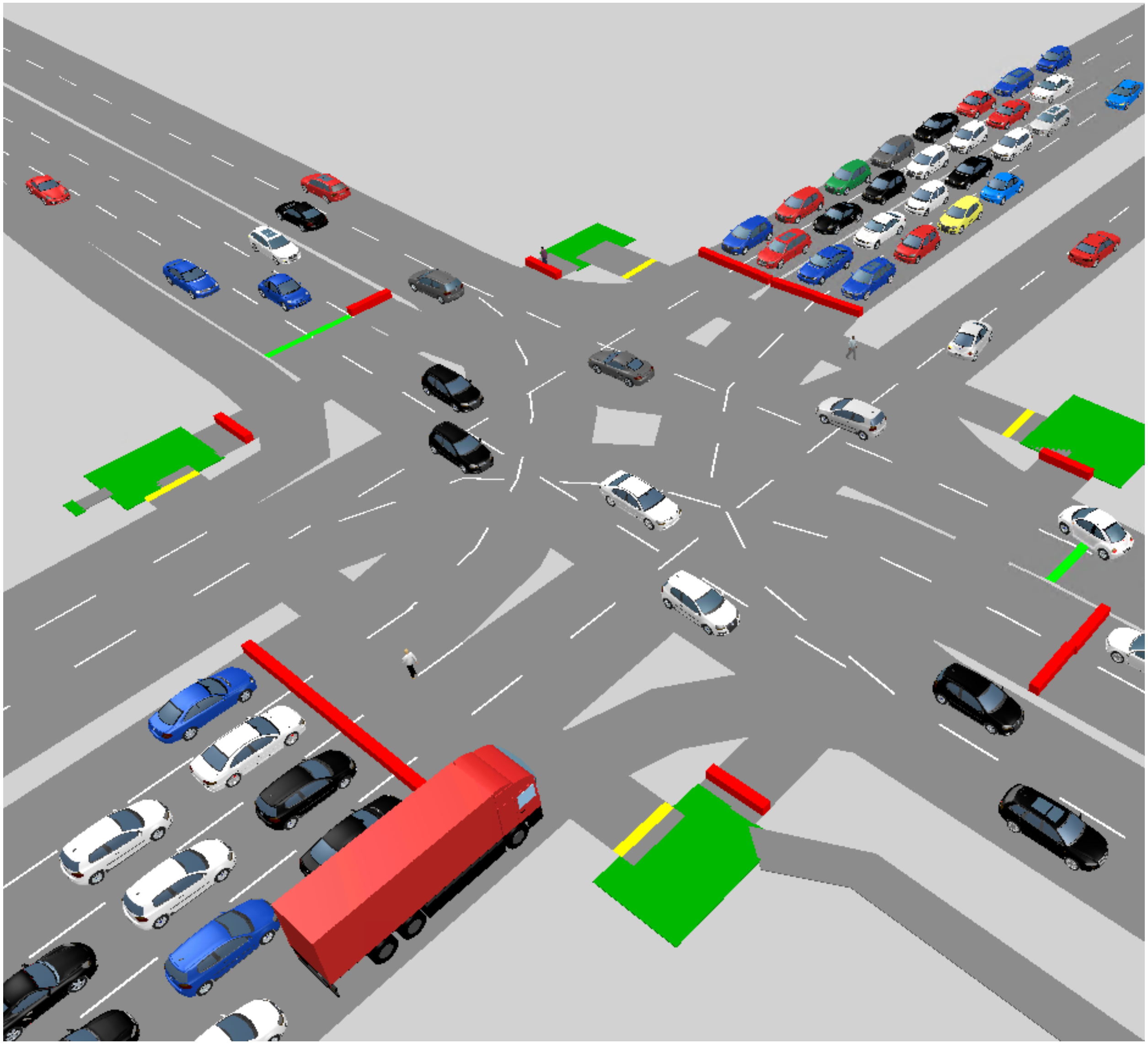
- Study corridor (International Drive)
- Airport
- Theme parks
- Central business district
- UCF!

Network overview in VISSIM

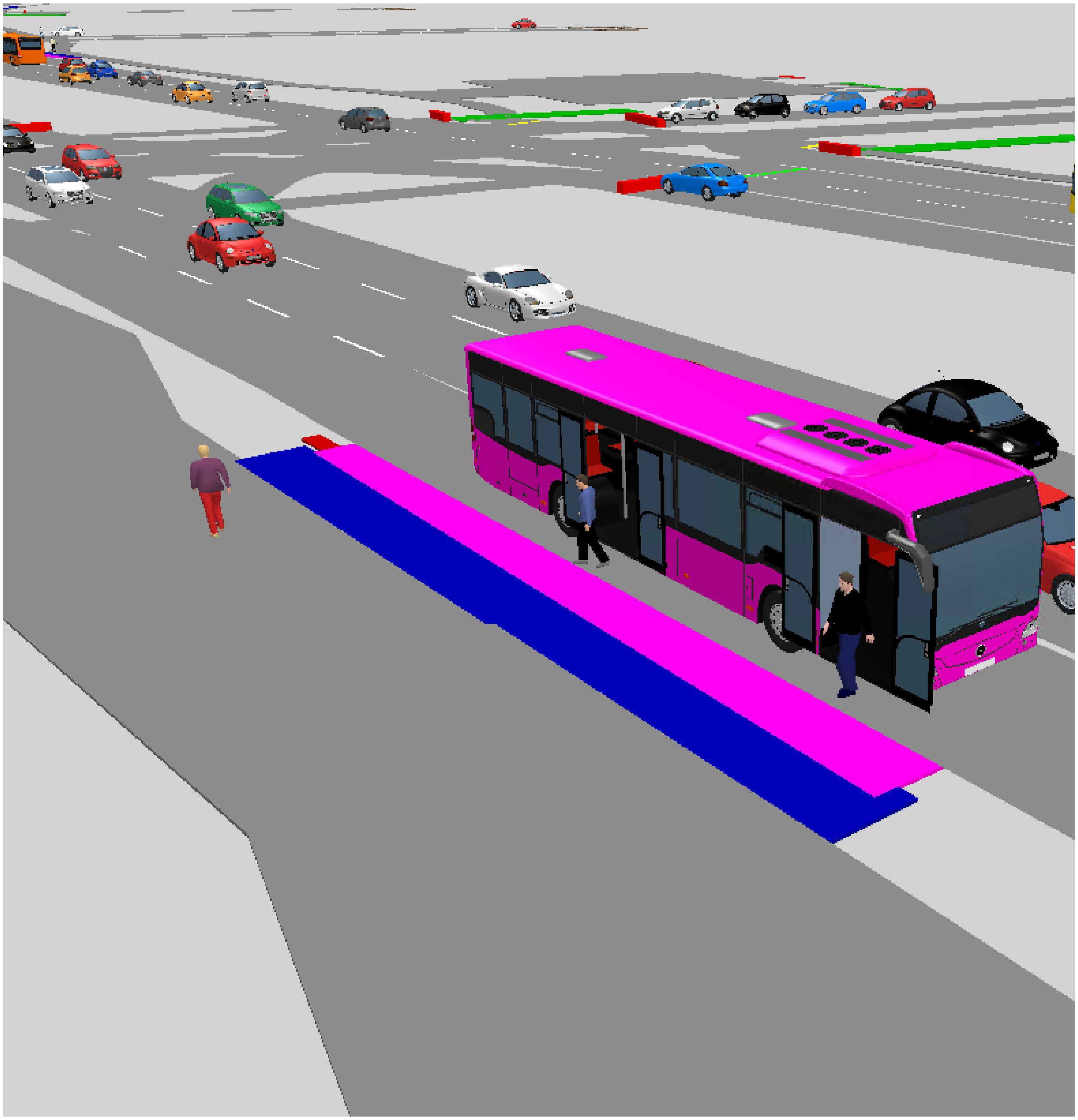


VISSIM 3D screenshots

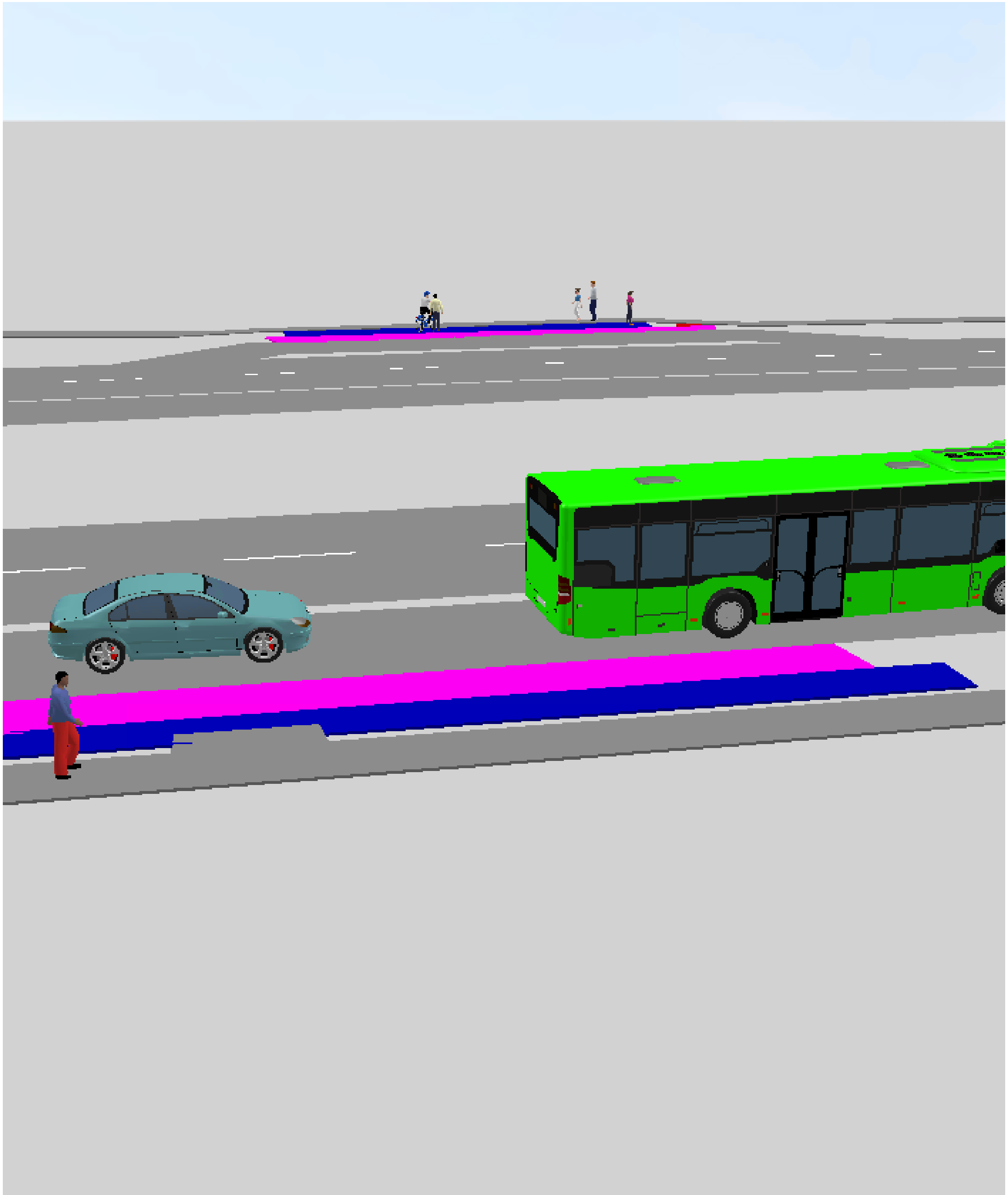
I-Drive and Sand Lake Rd intersection



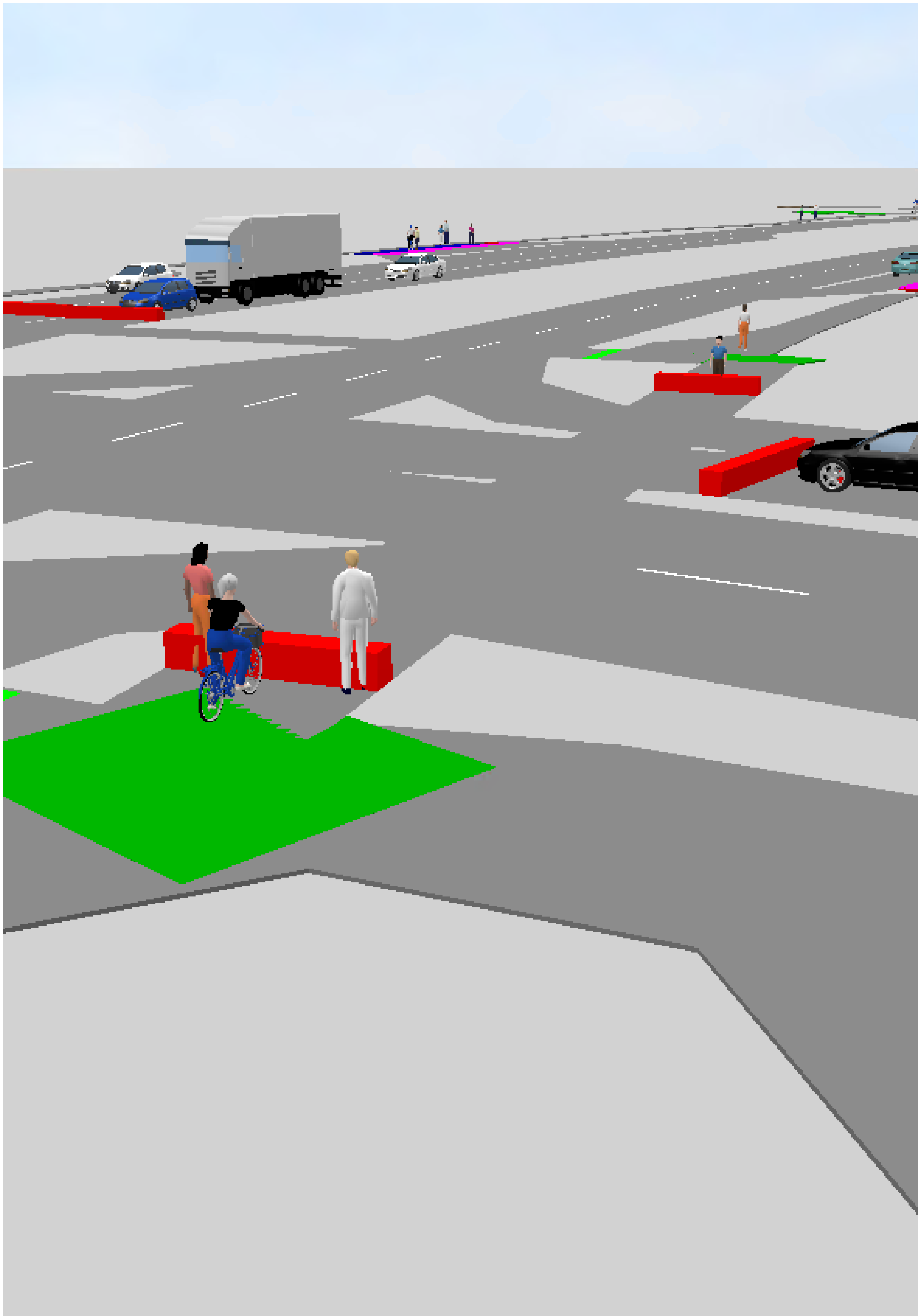
Transit Drop-Off



Shared Rideshare-Transit Stop



Pedestrians and cyclists waiting at intersection



APPENDIX C: VISSIM MODEL CHANGELOG

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VISSIM MODEL CHANGELOG
_______________________________________________________________________________________________________________________________

v0.0 - Basic inputs for sandlake road, main issue is that the vehicles are changing lanes close to the intersection causing backups
v0.1 - Experimented with no lane changes allowed near intersection, also changed undetermined conflict areas, worse results
v0.2 - Experimented with shorter 'no lane change' zones and conflict areas, no results
v0.3 - Started from scratch (sandlake), strictly followed best practices for link design, issue is still present but not as bad
v0.4 - Adjusted driver behavior parameters: changed minimum look-ahead to 800 ft, minimum look-back to 200 ft, set maximum deceleration values
for own and trailing to the most aggressive recommended settings (-12 and -8 ft/s2), enabled co-operative lane change (set to default values)
slight improvements only
v0.5 - Changed car following model to Wiedemann 99 from Wiedemann 74, major improvements
v0.6 - Changed cooperative lane change>maximum collision distance from 10 s to 5 s, further improvements, still few vehicles on the NB and SB
making last second lane change decisions
v0.7 - Tried restricting lane changes near the intersection at various distances, worse performance, revert to v0.6 which has the best performance
v0.8 - Changed the maximum wait time for diffusion, more vehicles are removed (31 vs 22 but this is still acceptable) but last second lane changes
seem to be reduced. Briefly, near the end of the simulation there appeared to be some backups from vehicles in the exclusive right turn lanes making
last second lane changes for the NB and EB approaches. Overall this version seems realistic from observation alone.
_______________________________________________________________________________________________________________________________

v1.0 - Jamaican Ct N constructed, major issue is that vehicles going EBR on sandlake are backed up because all the vehicles in the exclusive right lane are
attempting to go through as vehicles are changing lanes close to the intersection, again
v1.1 - Problem solved - by removing the right lane from the EB segment approaching the intersection and modelling the exclusive right as a connector pulled
back to the previous segment. No more lane changes or unrealistic backups, this also reduced the number of diffused vehicles. However, still some vehicles
attempting to make left lane changes too close to the stopline. Consider using this treatment again if queueing issues re-emerge.
v1.2 - Jamaican Ct S constructed, pulled back the link and routing decision for Sandlake EB, also gave I-Drive SB @ Sandlake the same treatment as in v1.1.
Further reduction in diffused vehicles (from 41 to 29) and no more unrealistic queuing on Sandlake EB. Noted that there are backups due to the geometry
of I-Drive SB @ Sandlake, however this is still realistic
v1.3 - Constructed Via Mercado - same backing up issue for vehicles going NBL and SBL. Consider using the treatment used for Sandlake
v1.4 - Adjusted geometry at Via Mercado, reduction of diffused vehicles from ~110 to 40
v1.5 - Adjusted Jamaican Ct S, reduction of diffused vehicles from 40 to 20
v1.6 - Further adjustments to I-Drive NB @ via mercado and routing @ Jamaican S, reduction of diffused vehicles to 11
v1.7 - Construction of Austrian CT S/Austrian row, diffused vehicles still at 11
v1.8 - Construction of Miller's/AF intersection
v1.9 - Construction of Samoan Ct N, diffused vehicles down to 5 (somehow)
v1.10 - Construction of Pointe Plaza, added inflows for the intersections EB and WB, diffused vehicles up to 31
v1.11 - Correction of some signal timing plans. To reduce diffused vehicles on Via Mercado WB (LT and TH), the connectors were pulled back, however, this
caused overlapping of the connectors due to the shared LT-TH lane, causing vehicles to stack, assigning conflict zones to prevent overlap worsened the issue.
Furthermore almost no vehicles were using the leftmost lane at Via Mercado WB. To resolve this, the configuration was changed from 1 exclusive RT +
1 shared TH-LT + 1 exclusive LT to 1 exclusive RT + 1 exclusive TH + 1 exclusive LT. Vehicle behavior seems realistic, unknown why there are two LTs at this
intersection as the WBLT volumes are relatively low (LT/TH/RT = 37/45/148). Added any remaining inflows. Diffused vehicles down to 8
_______________________________________________________________________________________________________________________________

v2.0 - Construction of inlets/outlets for calibration inbetween major intersections ****NEEDS REVISION****

POINTE PLAZA AVE
-Samoan Ct S (C)
SAMOAN CT N
-Air Florida/Miller's Ale House (C)
-Austrian Ct S (C)
AUSTRIAN CT N
-ICON Park (C)
JAMAICAN CT S
-Ripley's (C)
JAMAICAN CT N
-Walgreen's/Harley Davidson (C)
SANDLAKE RD
```

v2.1 - Added the I-Ride Red line NB and stops, fixed Austrian Ct S (It was modelled as signalized but there aren't any signals in reality)
v2.2 - Added I-Ride Red line SB and stops, adjusted conflict areas at bus stops
v2.3 - Added Lynx 8, 38, 42 NB and 8, 42 SB

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v3.0 - Construction of pedestrian areas and crossings at major intersections
v3.1 - Added pedestrian flows and routing at intersections
v3.2 - Pedestrian signalization and conflict areas established
v3.3 - Adjusted stop lines for RTOR to be compatible with crosswalks
v3.4 - Bus departure time inputs for Lynx routes
v3.5 - Bus departure time inputs for I-Ride routes, major bug with Sandlake Western Crosswalk, pedestrians aren't passing through signals (208 vehicles diffused + vehicle flow incomplete)

Analysis period is taken as the average PM Peak across the intersections (start times):

Pointe Plaza - 5:30 (5.5)
Samoan N - 5:30 (5.5)
Austrian N - 5:45 (5.75)
Jamaican S - 5:45 (5.75)
Jamaican N - 6:00 (6)
Sandlake - 4:45 (4.75)

AVERAGE ~ 5:30 (5.54)

Simulation period starts 15 minutes prior to allow warmup - 5:15 PM

v3.6 - Resolved pedestrian bug by adjusting signal timing
v3.7 - Increased diffusion time to 45 s, minimal effect, diffused vehicles up to 8 (still very minor, most likely due to the extended simulation period)
Added Platform edges, data requested for boarding/alighting.
Added waiting areas for pedestrians, adjusted signal timing on all intersections to allow for safe pedestrian crossing (v_ped = 3.5 ft/s)
Increased diffusion time to 80 s, diffused vehicles down to 3! Staggered bus departure times by 1-2 minutes on the SB lines to avoid bus clustering which caused additional bugs
v3.8 - Set up data collection nodes for major intersections and queue counters for intersection approaches and bus stops (6 nodes and 64 queue counters)
v3.9 - Adjusted routes so regular vehicles stop using lay-bys, split link sections for flow-rate measurement, set up travel time measurements
v3.10 - Placeholder inputs for alighting and boarding pedestrians at transit stops, still awaiting data
v3.11 - Data for alighting/boarding has been received, input sidewalks
v3.12 - Conflict areas for sidewalks and pedestrian inputs
v3.13 - Fixed bugs for November presentation (diffused vehicles back down to 3, no more backups), input pedestrian spawns and terminations for field visit, inputs for UJ spawns, route and volume adjustments for Sandlake SB peds
v3.14 - Made route and volume adjustments for UJ NB/SB peds, need to be double check intersection ped counts
v3.15 - Made bus route/stop adjustments and input relative flows for boarding at each stop, input alighting percentages and occupancy numbers
v3.16 - Fixed pedestrian routing, now all areas are either walkable, origin areas, or destination areas. Input boarding volumes. Checked simulation to ensure realistic queuing and behavior.

UNCALIBRATED MODEL COMPLETION

CALIBRATION

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v4.0 - Adjusted pedestrian routes and areas to be able to count pedestrians entering and exiting the TAZs
v4.1 - Adjusted bus stops to be able to count transit users entering and exiting the TAZs, added links to count vehicles entering and exiting TAZs
v4.2 - CAL2N adjusted
v4.3 - Don't forget to name the TAZ inflows/outflows, Austrian S routing and inputs adjusted, need to make adjustments to Miller's
v4.4-v4.16 Calibration of segment flowrates, speed, and entering/exiting ratios
v4.17 - Routes for data collection on non-personal-vehicle modes established, rideshare routes established

APPENDIX D: RAW AND ADJUSTED SIGNALIZATION DATA

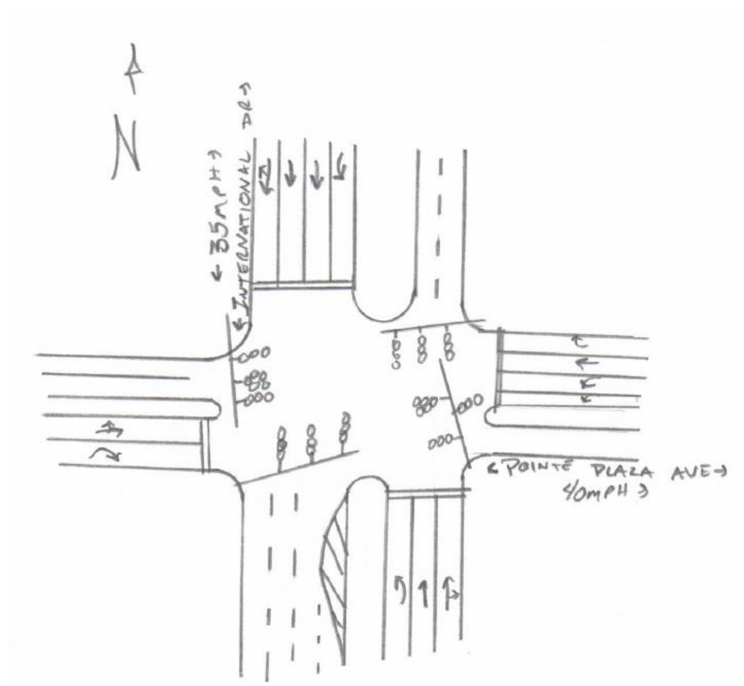
Raw Signalization Data

Intersection: International Dr & Pointe Plaza Av						Node:	356
Equipment: Eagle			CDI:		CDO:	Date:	09/25/19

BASIC TIMING

Phase	1	2	3	4	5	6	7	8
Direction	SBL	NB		EB	NBL	SB		WB
Min Green (sec)	8	15		8	8	15		5
Vehicle Gap (sec)	1.5	3.0		2.0	1.5	3.0		2.0
Max Green 1 (sec)	15	45		15	15	45		15
Max Green 2 (sec)	15	45		15	15	45		15
Yellow (sec)	4.1	4.0		3.5	4.0	4.1		4.4
All-Red (sec)	2.0	2.0		2.4	2.0	2.0		2.0
Walk (sec)		7		7		7		
Flash Don't Walk (sec)		27		36		25		

1	2	4	8
5	6		

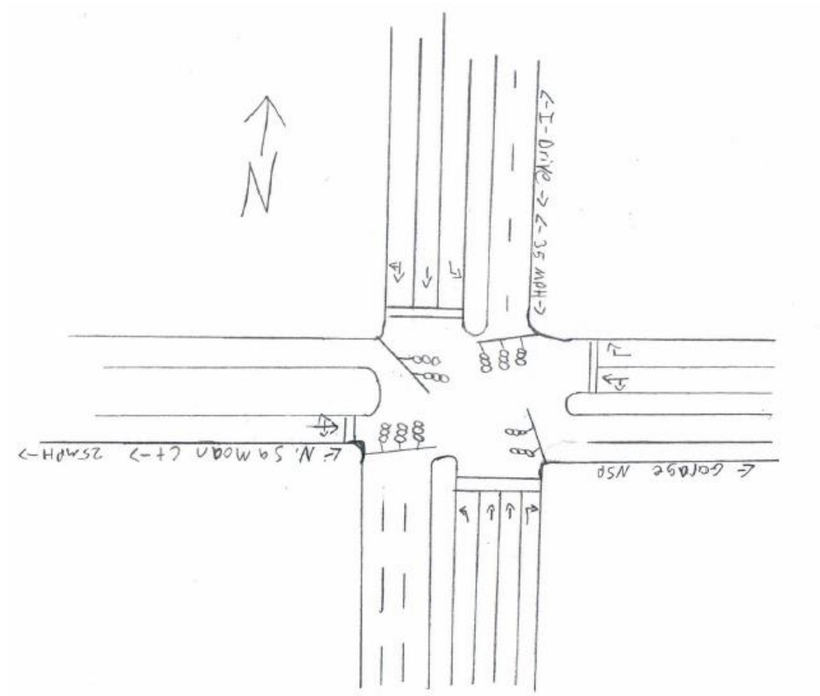


Location: International Dr & Samoan Ct N							Node:	307
Equipment: Eagle			CDI:		CDO:		Date:	09/25/19

BASIC TIMING

Phase	1	2	3	4	5	6	7	8
Direction	SBL	NB		EB	NBL	SB		WB
Min Green (sec)	5	15		5	5	15		5
Vehicle Gap (sec)	1.5	3.0		1.5	1.5	3.0		1.5
Max Green 1 (sec)	14	45		15	14	45		15
Max Green 2 (sec)	14	45		15	14	45		15
Yellow (sec)	4.0	4.0		3.4	4.0	4.0		3.4
All-Red (sec)	2.0	2.0		3.7	2.0	2.0		3.2
Walk (sec)		7		7		7		7
Flash Don't Walk (sec)		29		39		15		30

1	2	4	8
5	6		

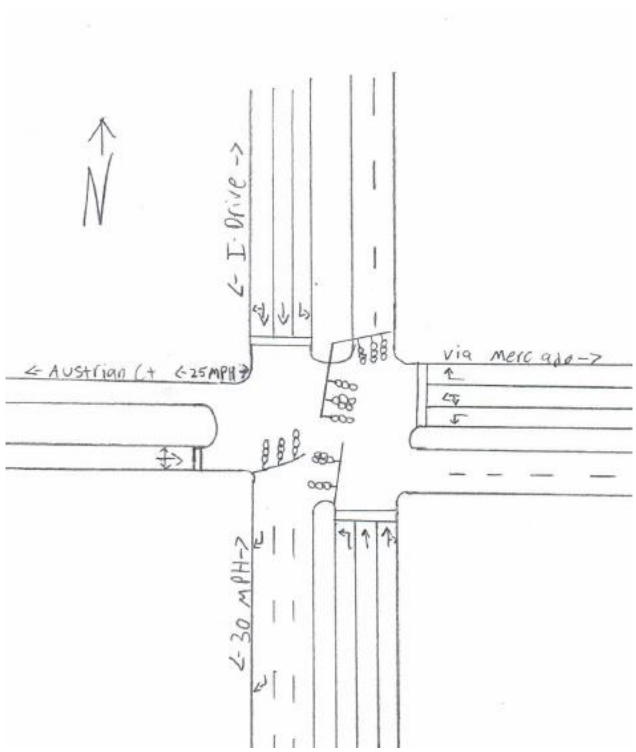


Location: International Dr & Austrian Ct - Via Mercado							**Node:**	**309**
Equipment: Eagle		*SCOOT N22213*	**CDI:**		**CDO:**		**Date:**	**09/25/19**

BASIC TIMING

Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Direction	SBL	NB		EB	NBL	SB		WB
Min Green (sec)	5	14		5	5	14		5
Vehicle Gap (sec)	2.0	3.5		2.7	2.0	3.5		2.7
Max Green 1 (sec)	15	50		50	15	50		50
Max Green 2 (sec)	15	50		50	15	50		50
Yellow (sec)	4.0	4.0		3.4	4.0	4.0		3.4
All-Red (sec)	2.0	2.0		3.5	2.0	2.0		3.5
Walk (sec)		7		7		7		7
Flash Don't Walk (sec)		27		15		16		14

1	2	4	8
5	6		

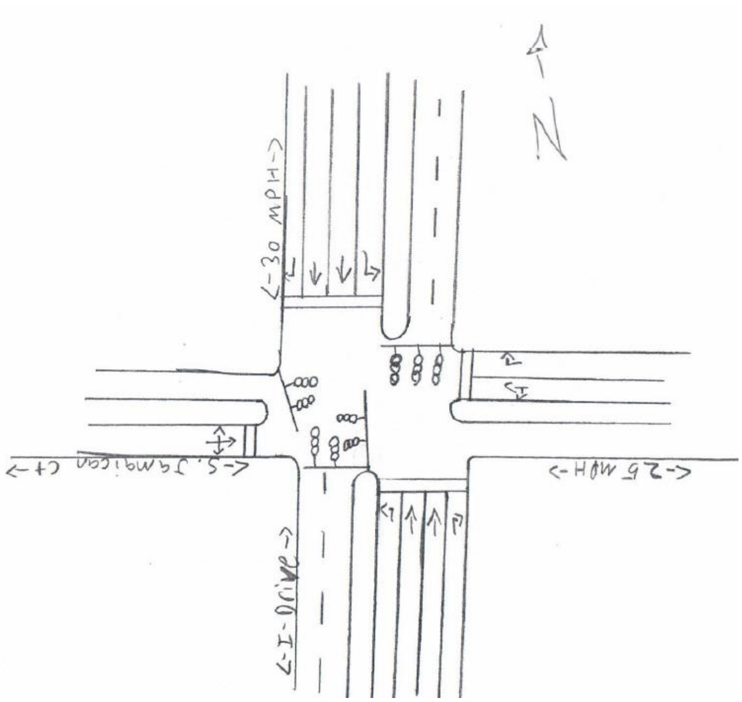


Intersection: International Dr & Jamaican Ct South				Node:	310
Equipment: Eagle	SCOOT NODE 22111	CDI:	CDO:	Date:	09/25/19

BASIC TIMING

Phase	1	2	3	4	5	6	7	8
Direction	SBL	NB		EB	NBL	SB		WB
Min Green (sec)	5	15		5	5	15		5
Vehicle Gap (sec)	3.0	3.0		3.0	3.0	3.0		3.0
Max Green 1 (sec)	15	50		50	15	50		50
Max Green 2 (sec)	15	50		50	15	50		50
Yellow (sec)	4.0	4.0		3.4	4.0	4.0		3.4
All-Red (sec)	2.0	2.0		3.2	2.0	2.0		3.5
Walk (sec)		7		7		7		7
Flash Don't Walk (sec)		23		37		21		37

1	2	4	8
5	6		

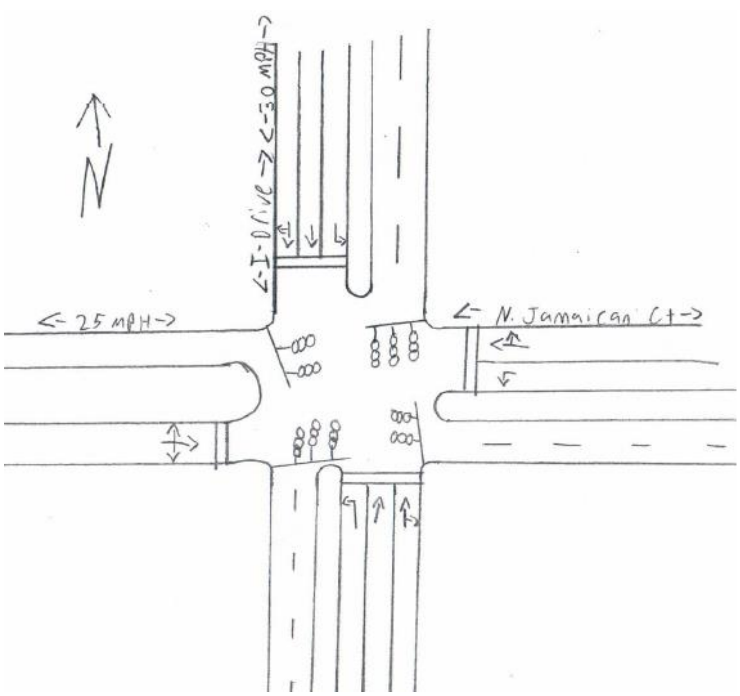


Intersection: International Dr & Jamaican Ct North				Node:	308
Equipment: Eagle	SCOOT	CDI:	CDO:	Date:	06/18/16

BASIC TIMING

Phase	1	2	3	4	5	6	7	8
Direction	SBL	NB		EB	NBL	SB		WB
Min Green (sec)	5	15		5	5	15		5
Vehicle Gap (sec)	3.0	3.0		3.0	3.0	3.0		3.0
Max Green 1 (sec)	15	50		50	15	50		50
Max Green 2 (sec)	15	50		50	15	50		50
Yellow (sec)	4.0	4.0		3.4	4.0	4.0		3.4
All-Red (sec)	2.0	2.0		3.3	2.0	2.0		2.7
Walk (sec)		7		7		7		7
Flash Don't Walk (sec)		17		30		15		31

1	2	4	8
5	6		

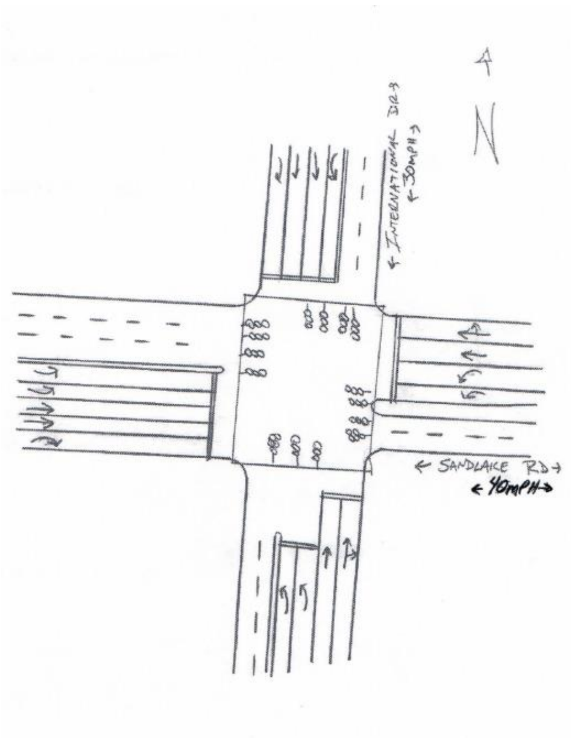


Location: Sand Lake Rd & International Dr				Node:	147
Equipment: Eagle	SCOOT N20141	CDI:	CDO:	Date:	09/25/19

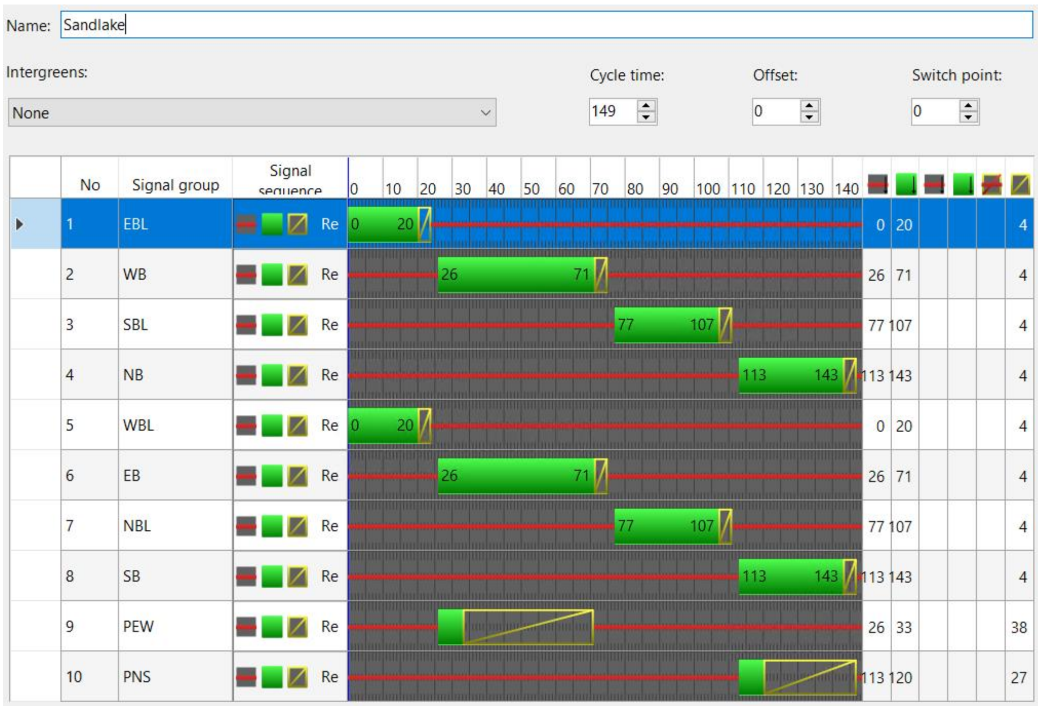
BASIC TIMING

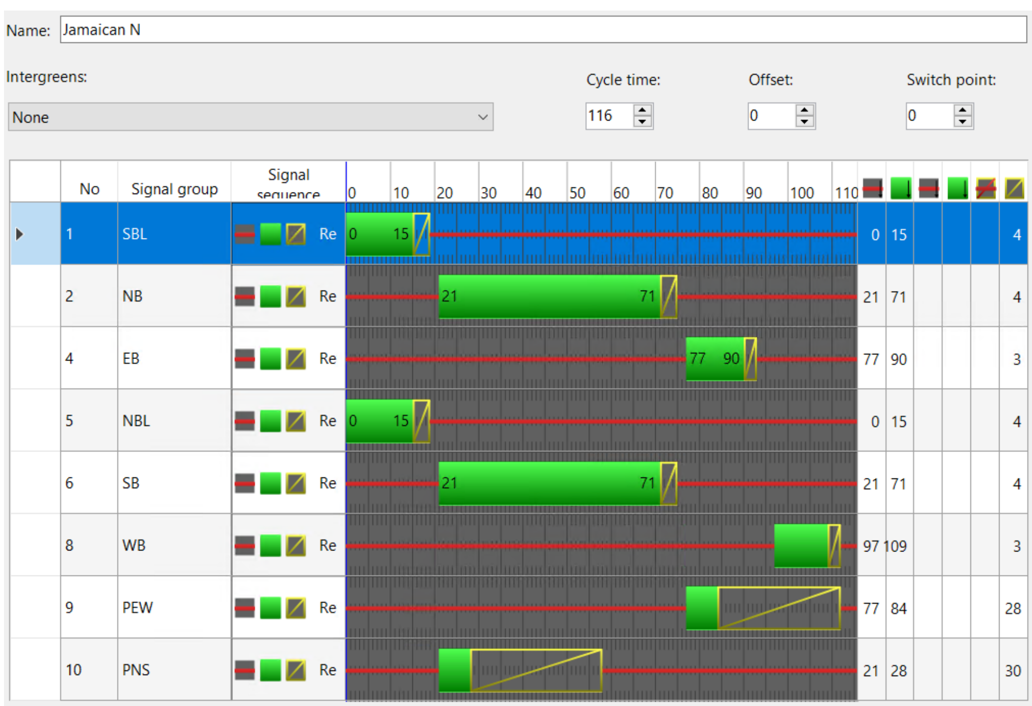
Phase	1	2	3	4	5	6	7	8
Direction	EBL	WB	SBL	NB	WBL	EB	NBL	SB
Min Green (sec)	5	15	5	5	5	15	5	5
Vehicle Gap (sec)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Max Green 1 (sec)	20	45	15	25	20	45	25	25
Max Green 2 (sec)	20	45	15	25	20	45	25	25
Yellow (sec)	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
All-Red (sec)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.3
Walk (sec)		7		7		7		7
Flash Don't Walk (sec)		39		27		40		28

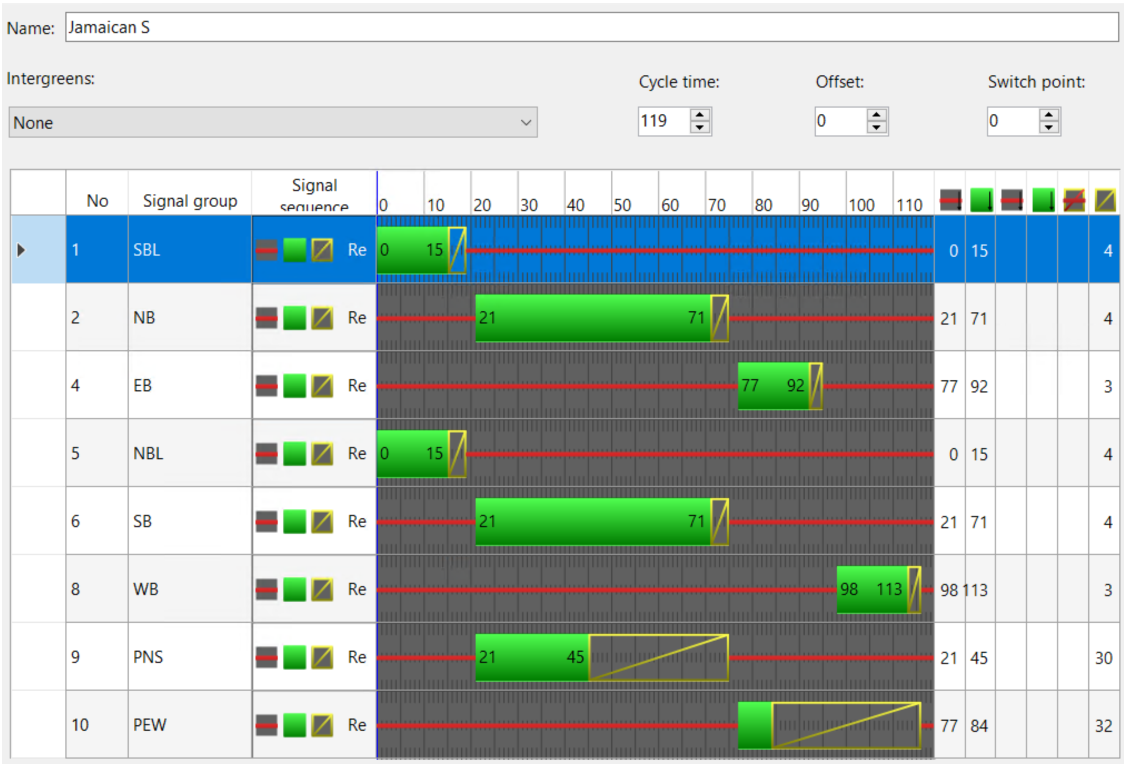
1 2	3 4
5 6	7 8

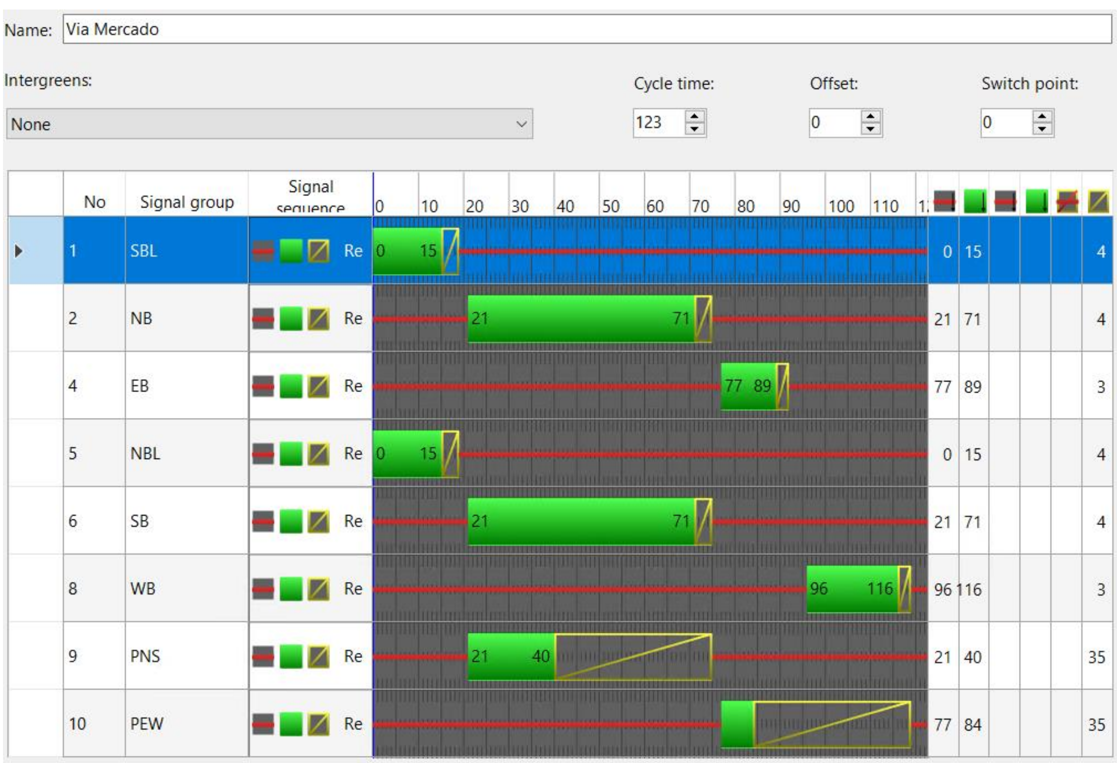


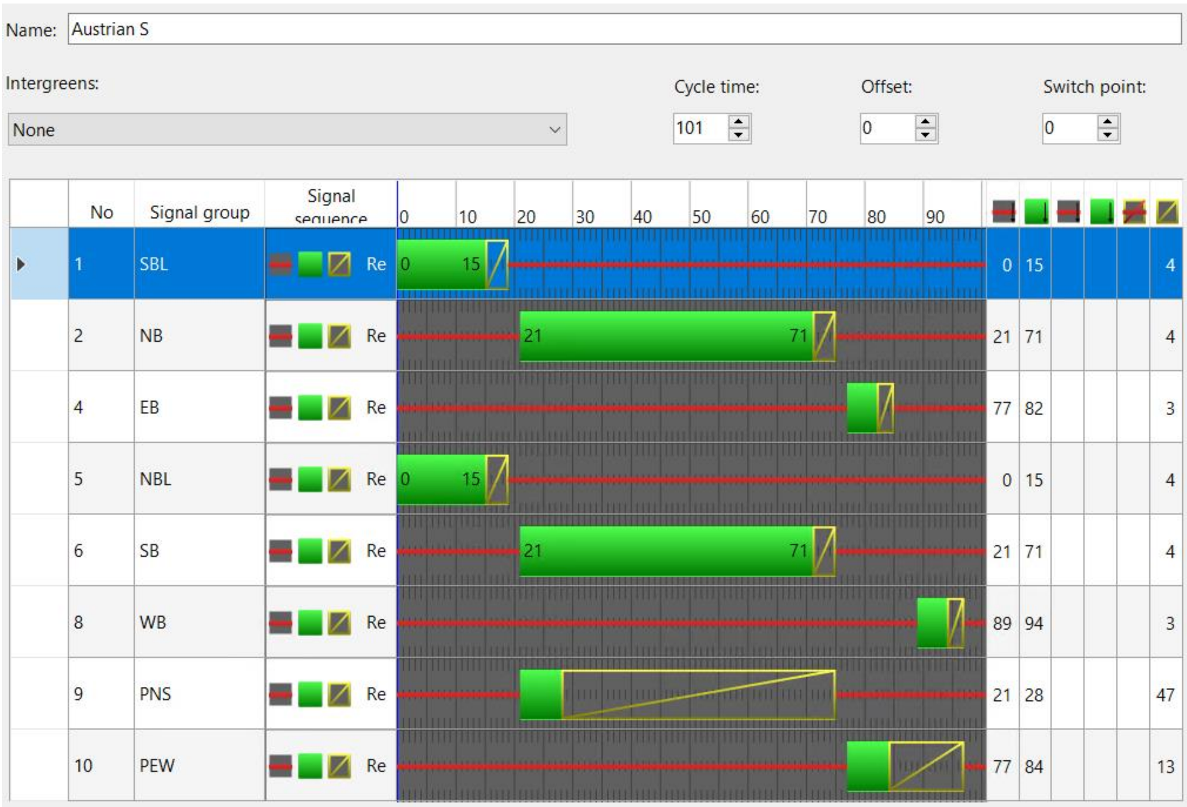
Adjusted Signalization Data

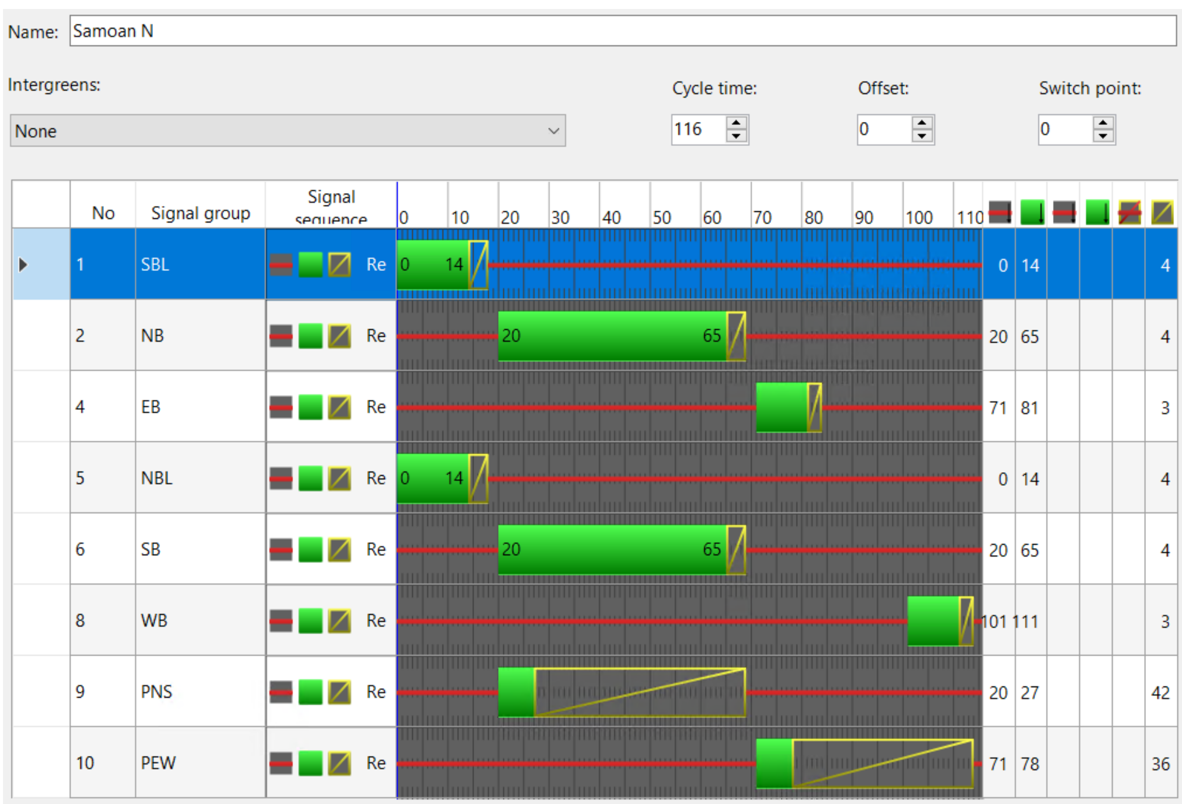


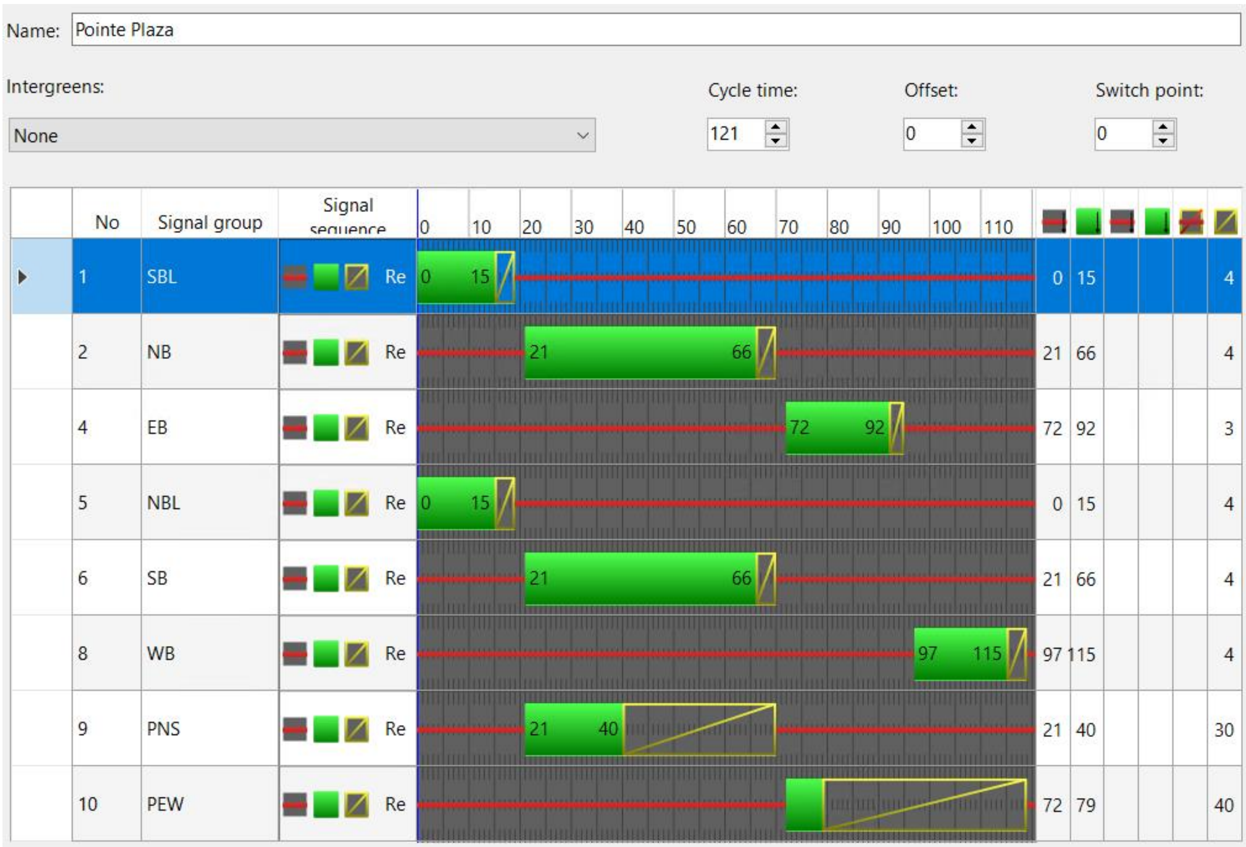



Name: Jamaican S
Intergreens: None
Cycle time: 119
Offset: 0
Switch point: 0
No | Signal group | Signal sequence
1 SBL Re 0 15 4
2 NB Re 21 71 4
4 EB Re 77 92 3
5 NBL Re 0 15 4
6 SB Re 21 71 4
8 WB Re 98 113 3
9 PNS Re 21 45 30
10 PEW Re 77 84 32


Name: Via Mercado
Intergreens: None
Cycle time: 123
Offset: 0
Switch point: 0
No | Signal group | Signal sequence
1 SBL Re 0 15 4
2 NB Re 21 71 4
4 EB Re 77 89 3
5 NBL Re 0 15 4
6 SB Re 21 71 4
8 WB Re 96 116 3
9 PNS Re 21 40 35
10 PEW Re 77 84 35


Name: Austrian S
Intergreens:
None
Cycle time:
101
Offset:
0
Switch point:
0
No
Signal group
Signal sequence
0 10 20 30 40 50 60 70 80 90
1 SBL Re 0 15 0 15 4
2 NB Re 21 71 21 71 4
4 EB Re 77 82 3
5 NBL Re 0 15 0 15 4
6 SB Re 21 71 21 71 4
8 WB Re 89 94 3
9 PNS Re 21 28 47
10 PEW Re 77 84 13


Name: Samoan N
Intergreens:
None
Cycle time:
116
Offset:
0
Switch point:
0
No
Signal group
Signal sequence
0 10 20 30 40 50 60 70 80 90 100 110
1 SBL Re 0 14 0 14 4
2 NB Re 20 65 20 65 4
4 EB Re 71 81 3
5 NBL Re 0 14 0 14 4
6 SB Re 20 65 20 65 4
8 WB Re 101 111 3
9 PNS Re 20 27 42
10 PEW Re 71 78 36


Name: Pointe Plaza
Intergreens: None
Cycle time: 121
Offset: 0
Switch point: 0
No
Signal group
Signal sequence
0 10 20 30 40 50 60 70 80 90 100 110
1 SBL Re 0 15 0 15 4
2 NB Re 21 66 21 66 4
4 EB Re 72 92 72 92 3
5 NBL Re 0 15 0 15 4
6 SB Re 21 66 21 66 4
8 WB Re 97 115 97 115 4
9 PNS Re 21 40 21 40 30
10 PEW Re 72 79 40

APPENDIX E: VEHICULAR TURNING MOVEMENT COUNTS

Time	NB	SB	EB	WB	Total

POINTE PLAZA AVE (L TH R)

Peak Hour Analysis From 05:00 PM to 06:45 PM - Peak 1 of 1
Peak Hour for Entire Intersection Begins at 05:30 PM

05:30 PM	6	**258**	**2**	**266**	7	108	2	117	2	3	4	9	**44**	**4**	23	71	**463**
05:45 PM	7	257	2	266	6	**114**	2	**122**	3	2	2	7	28	3	21	52	447
06:00 PM	5	219	1	225	**11**	99	2	112	5	2	3	10	41	3	29	**73**	420
06:15 PM	**8**	222	1	231	9	104	**3**	116	**6**	**5**	**5**	**16**	37	0	**33**	70	433
Total Volume	26	956	6	988	33	425	9	467	16	12	14	42	150	10	106	266	1763
% App. Total	2.6	96.8	0.6		7.1	91	1.9		38.1	28.6	33.3		56.4	3.8	39.8		
PHF	.813	.926	.750	.929	.750	.932	.750	.957	.667	.600	.700	.656	.852	.625	.803	.911	.952
Cars	26	927	6	959	33	408	9	450	16	12	14	42	140	10	105	255	1706
% Cars	100	97.0	100	97.1	100	96.0	100	96.4	100	100	100	100	93.3	100	99.1	95.9	96.8
Trucks	0	29	0	29	0	17	0	17	0	0	0	0	10	0	1	11	57
% Trucks	0	3.0	0	2.9	0	4.0	0	3.6	0	0	0	0	6.7	0	0.9	4.1	3.2

SAMOAN CT N

Peak Hour Analysis From 05:00 PM to 06:45 PM - Peak 1 of 1
Peak Hour for Entire Intersection Begins at 05:30 PM

05:30 PM	7	157	21	185	14	90	**5**	109	**21**	**1**	**5**	**27**	**7**	0	7	14	335
05:45 PM	5	**186**	**23**	**214**	14	**99**	4	**117**	12	0	4	16	4	0	2	6	**353**
06:00 PM	**10**	156	18	184	**15**	88	3	106	9	0	2	11	7	0	**11**	**18**	319
06:15 PM	3	159	22	184	5	95	3	103	3	0	2	5	5	0	4	9	301
Total Volume	25	658	84	767	48	372	15	435	45	1	13	59	23	0	24	47	1308
% App. Total	3.3	85.8	11		11	85.5	3.4		76.3	1.7	22		48.9	0	51.1		
PHF	.625	.884	.913	.896	.800	.939	.750	.929	.536	.250	.650	.546	.821	.000	.545	.653	.926
Cars	25	633	83	741	48	359	15	422	43	1	12	56	23	0	24	47	1266
% Cars	100	96.2	98.8	96.6	100	96.5	100	97.0	95.6	100	92.3	94.9	100	0	100	100	96.8
Trucks	0	25	1	26	0	13	0	13	2	0	1	3	0	0	0	0	42
% Trucks	0	3.8	1.2	3.4	0	3.5	0	3.0	4.4	0	7.7	5.1	0	0	0	0	3.2

AUSTRIAN CT N/ VIA MERCADO

Peak Hour Analysis From 05:00 PM to 06:45 PM - Peak 1 of 1
Peak Hour for Entire Intersection Begins at 05:45 PM

05:45 PM	**9**	179	14	**202**	7	98	2	107	4	4	3	11	**15**	**15**	**47**	**77**	**397**
06:00 PM	1	142	8	151	5	**106**	3	114	**6**	**8**	1	15	9	9	40	58	338
06:15 PM	5	149	**16**	170	9	102	**7**	118	2	2	0	4	10	6	37	53	345
06:30 PM	6	**182**	5	193	**11**	106	2	**119**	6	5	**8**	**19**	13	5	24	42	373
Total Volume	21	652	43	716	32	412	14	458	18	19	12	49	47	35	148	230	1453
% App. Total	2.9	91.1	6		7	90	3.1		36.7	38.8	24.5		20.4	15.2	64.3		
PHF	.583	.896	.672	.886	.727	.972	.500	.962	.750	.594	.375	.645	.783	.583	.787	.747	.915
Cars	21	635	41	697	32	399	14	445	17	18	12	47	46	35	147	228	1417
% Cars	100	97.4	95.3	97.3	100	96.8	100	97.2	94.4	94.7	100	95.9	97.9	100	99.3	99.1	97.5
Trucks	0	17	2	19	0	13	0	13	1	1	0	2	1	0	1	2	36
% Trucks	0	2.6	4.7	2.7	0	3.2	0	2.8	5.6	5.3	0	4.1	2.1	0	0.7	0.9	2.5

JAMAICAN CT S

Peak Hour Analysis From 05:00 PM to 06:45 PM - Peak 1 of 1
Peak Hour for Entire Intersection Begins at 05:45 PM

05:45 PM	7	169	30	206	17	**200**	18	235	16	1	5	22	**15**	**11**	23	**49**	512
06:00 PM	5	178	27	210	18	188	15	221	17	1	**7**	25	7	6	24	37	493
06:15 PM	5	174	19	198	27	142	10	179	**18**	**2**	7	**27**	9	3	19	31	435
06:30 PM	**8**	**232**	**35**	**275**	**33**	181	**23**	**237**	17	0	4	21	9	2	**26**	37	**570**
Total Volume	25	753	111	889	95	711	66	872	68	4	23	95	40	22	92	154	2010
% App. Total	2.8	84.7	12.5		10.9	81.5	7.6		71.6	4.2	24.2		26	14.3	59.7		
PHF	.781	.811	.793	.808	.720	.889	.717	.920	.944	.500	.821	.880	.667	.500	.885	.786	.882
Cars	24	733	111	868	95	699	66	860	68	4	23	95	40	22	92	154	1977
% Cars	96.0	97.3	100	97.6	100	98.3	100	98.6	100	100	100	100	100	100	100	100	98.4
Trucks	1	20	0	21	0	12	0	12	0	0	0	0	0	0	0	0	33
% Trucks	4.0	2.7	0	2.4	0	1.7	0	1.4	0	0	0	0	0	0	0	0	1.6

JAMAICAN CT N

Peak Hour Analysis From 05:00 PM to 06:45 PM - Peak 1 of 1
Peak Hour for Entire Intersection Begins at 06:00 PM

06:00 PM	2	219	4	225	12	226	**29**	267	12	1	0	13	6	2	6	14	519
06:15 PM	**7**	207	7	221	23	219	20	262	17	1	2	20	10	2	**17**	**29**	532
06:30 PM	3	**227**	**12**	**242**	18	188	16	222	11	0	5	16	**11**	**3**	14	28	508
06:45 PM	2	218	9	229	**24**	**246**	25	**295**	**18**	**3**	**6**	**27**	6	2	15	23	**574**
Total Volume	14	871	32	917	77	879	90	1046	58	5	13	76	33	9	52	94	2133
% App. Total	1.5	95	3.5		7.4	84	8.6		76.3	6.6	17.1		35.1	9.6	55.3		
PHF	.500	.959	.667	.947	.802	.893	.776	.886	.806	.417	.542	.704	.750	.750	.765	.810	.929
Cars	14	849	32	895	77	866	87	1030	56	5	13	74	33	9	52	94	2093
% Cars	100	97.5	100	97.6	100	98.5	96.7	98.5	96.6	100	100	97.4	100	100	100	100	98.1
Trucks	0	22	0	22	0	13	3	16	2	0	0	2	0	0	0	0	40
% Trucks	0	2.5	0	2.4	0	1.5	3.3	1.5	3.4	0	0	2.6	0	0	0	0	1.9

SAND LAKE RD

Peak Hour Analysis From 02:00 PM to 05:45 PM - Peak 1 of 1
Peak Hour for Entire Intersection Begins at 04:45 PM

04:45 PM	162	**110**	33	**305**	**29**	99	82	210	43	237	131	411	30	214	**16**	260	1186
05:00 PM	153	104	**46**	303	21	**110**	99	**230**	50	**251**	143	**444**	29	208	15	252	**1229**
05:15 PM	**167**	95	39	301	29	90	**105**	224	53	237	106	396	30	203	9	242	1163
05:30 PM	132	95	36	263	24	92	100	216	**60**	224	**149**	433	**34**	**240**	6	**280**	1192
Total Volume	614	404	154	1172	103	391	386	880	206	949	529	1684	123	865	46	1034	4770
% App. Total	52.4	34.5	13.1		11.7	44.4	43.9		12.2	56.4	31.4		11.9	83.7	4.4		
PHF	.919	.918	.837	.961	.888	.889	.919	.957	.858	.945	.888	.948	.904	.901	.719	.923	.970

Cars	2470	1667	709	4846	535	1494	1842	3871	1077	6036	2350	9463	529	4714	366	5609	23789
% Cars	98.9	95.6	98.3	97.7	99.8	95.3	99.1	97.7	99	98.5	99.2	98.7	97.4	98.2	99.2	98.2	98.2
Trucks	28	76	12	116	1	73	17	91	11	92	18	121	14	88	3	105	433
% Trucks	1.1	4.4	1.7	2.3	0.2	4.7	0.9	2.3	1	1.5	0.8	1.3	2.6	1.8	0.8	1.8	1.8

APPENDIX F: TRANSIT ALIGHTING AND BOARDING DATA

Location	Operator(ID)	Alighting-Monthly	Boarding-Monthly	Alighting-Daily	Boarding-Daily	Alighting-PK	Boarding-PK	Occupancy	Alighting %	Notes
1	Lynx (1)			74	137	8	16	43	0.20	
	I-Ride (18)	4071	4338	152	162	17	18	43	0.40	Occupancy is 80% of total capacity @ 54 persons/trolley
2	I-Ride (17)	1018	2428	38	91	4	10	44	0.10	
3	Lynx (2)			23	60	3	7	50	0.05	
	I-Ride (16)	997	1121	37	42	4	5	50	0.08	
4	I-Ride (15)	1053	1326	39	50	4	6	51	0.09	
5	Lynx (3)			21	46	2	5	54	0.04	
6	I-Ride (14)	1139	1185	43	44	5	5	52	0.09	Data is missing for this stop, interpolated for Alighting/Boarding monthly and occupancy
7	Lynx (4)			43	116	5	13	57	0.09	
	I-Ride (12)	1224	1044	46	39	5	4	52	0.10	Data is taken from August instead of April, the data for this stop for April shows extremely low numbers, perhaps due to equipment malfunction, interpolated
8	I-Ride (11)	942	545	35	20	4	2	51	0.08	
9	Lynx (5)			33	62	4	7	65	0.06	
Average								51.0988469		
Lynx occupancy = roughly 15 (43 split between 3 lines)										

Location	Operator(ID)	Alighting-Monthly	Boarding-Monthly	Alighting-Daily	Boarding-Daily	Alighting-PK	Boarding-PK	Occupancy	Alighting %	Notes
1	Lynx (1)			112	23	13	3	43	0.30	
2	I-Ride (11)	1015	1810	38	68	4	8	43	0.10	
3	Lynx (2)			51	5	6	1	33	0.18	
4	I-Ride (12)	1196	1452	45	54	5	6	46	0.11	
5	Lynx (3)			65	13	7	1	28	0.27	
	I-Ride (13)	784	1077	29	40	3	5	47	0.07	
6	I-Ride (14)	2848	2282	107	85	12	10	49	0.25	
7	Lynx (4)			27	3	3	0	25	0.12	
8	I-Ride (15)	1485	1300	56	49	6	6	46	0.14	
9	Lynx (5)			30	6	3	1	22	0.15	
10	Lynx (6)			45	7	5	1	19	0.26	
	I-Ride (17)	1545	1682	58	63	7	7	46	0.14	
11	Lynx (7)			91	24	10	3	15	0.68	
	I-Ride (18)	5244	2813	196	105	22	12	46	0.48	
12	I-Ride (19)	569	597	21	22	2	3	36	0.07	
13	Lynx (8)			46	6	5	1	8	0.69	
	I-Ride (20)	661	814	25	30	3	3	36		
Average								34.591567		
Lynx occupancy = roughly 22 (43 split between 2 lines)										

Estimating occupancy from total ridership and total roundtrips for I-Drive		
16 trolleys total		
5 trolleys make 8 roundtrips each		
11 trolleys make 7 roundtrips each		
Trolley has 54 person capacity		
Total roundtrips per day =	117	
Total ridership for April 2016 =	151053	
Total monthly capacity =	189540	
Average occupancy ratio = Monthly ridership/monthly capacity =		0.796945
Average occupancy for I-Ride per line = 0.8*54 = roughly 43 persons		
Assume the same for Lynx, but split between 2 lines (SB) and 3 lines (NB)		

Daily factor:	(Daily demand)*(Daily factor) = PK Hr demand
Study number	PK Hr split (Daily factor)
1	0.077
2	0.15
3	0.085
4	0.1425
Average	0.1136

Monthly factor:	(Monthly demand)*(Monthly factor) = Daily demand	
Study number	Weekday-weekend ratio	Weekday split (Monthly factor)
4	1.073	0.0339
5	2.5	0.0397
6	2	0.0385
Average		0.0374

Total monthly demand = 22(average weekday demand) + 8*(average weekend demand)*

(Total monthly demand)/(average weekday demand) = 1/(monthly factor) = 22 + (8/Weekday-weekend ratio)

Monthly factor = (1/(22+8/Weekday-weekend ratio))

TRANSIT PEAK HOUR RIDERSHIP ESTIMATES FROM DAILY/MONTHLY VOLUMES

CASE STUDY 1: Pendyala (2002)

23% of total daily transit trips occur in a PM Peak hour period (3:30 PM to 6:30 PM), or roughly 7.7% in a single hour. This study was conducted across multiple cities (several of which are in Florida)

Table 7. Mode Choice Model Output Summary

	Daily Model	Sum of Time Periods		AM Peak Period	Off-Peak Period	PM Peak Period
Linked Transit Trips	25,719	25,807	100%	3,483	16,504	5,820
Unlinked Transit Trips	36,150	36,358	101%	4,939	23,174	8,245
Auto Linked Trips	2,611,499	2,611,097	100%	385,048	1,681,595	544,454
Overall Transit Share	1.0%	1.0%		0.9%	1.0%	1.1%

Table 8. Percentage of Daily Transit Trips by Time of Day

	Observed %	Model %
AM Peak Period	14%	13%
Off-Peak Period	63%	64%
PM Peak Period	23%	23%

CASE STUDY 2: UDOT (2000)

The Long Range Transit Analysis (WFRC) found that 15% of people are using transit in the peak hour.

Results of Model Run. The results of the mode choice model runs for 2020 with this transit network show that there would be approximately 11,500 boardings in the North Corridor in a 24-hour period (a boarding is one person getting on a transit vehicle). These results are shown in Table 2-6 (Transit Use in 2020). The directional split (how many people traveling in one direction versus the other during peak period) is 80 percent one way and 20 percent the other; during the evening rush hour, 80 percent of people on transit are leaving downtown. WFRC has indicated that, of all of the people on transit during a 24-hour period, 15 percent are using it during the p.m. peak hour. This contrasts with the highway analysis, where it is assumed that, in a 24-hour period, only nine percent of the people are on the highway during the peak hour.

Table 2-6
TRANSIT USE IN 2020

	Daily Trips		
Transit Mode	*Regional*	*North Corridor*	*Peak Hour Trips*
Bus	119,224	10,650	1,275
Light Rail	32,559	0	0
Commuter Rail	1,927	850	105
Total	153,710	11,500	1,380

Source: WFRC, March 1998

CASE STUDY 3: Polzin et. Al. (2002)

The Nationwide Personal Transportation Survey (NPTS) in 1995 found that 25.37% of total trips occur in a PM Peak hour period (3:00 PM to 6:00 PM), or 8.45% in one hour.

TABLE 1 Service Availability Weighted by Temporal Distribution of Travel Demand

Time of Day	Percent of Total Trips[a]	Route 1 (Same for Route 2)		
		Frequency (Runs/h, f)	Time Coverage Per Run (t min)	Temporally Weighted Service Availability (M)
0:01-1:00	0.49%	0	0	0
1:01-2:00	0.23%	0	0	0
2:01-3:00	0.15%	0	0	0
3:01-4:00	0.11%	0	0	0
4:01-5:00	0.32%	0	0	0
5:01-6:00	0.98%	0	0	0
6:01-7:00	**2.99%**	**2**	**10**	**0.599**
7:01-8:00	7.39%	2	10	1.478
8:01-9:00	5.87%	2	10	1.174
9:01-10:00	4.48%	2	10	0.895
10:01-11:00	4.91%	2	10	0.982
11:01-12:00	6.00%	2	10	1.200
12:01-13:00	6.71%	2	10	1.354
13:01-14:00	5.99%	2	10	1.198
14:01-15:00	6.83%	2	10	1.365
15:01-16:00	8.72%	2	10	1.744
16:01-17:00	8.23%	2	10	1.645
17:01-18:00	8.42%	2	10	1.683
18:01-19:00	6.87%	2	10	1.374
19:01-20:00	5.06%	2	10	1.012
20:01-21:00	3.75%	2	10	0.749
21:01-22:00	2.77%	2	10	0.554
22:01-23:00	1.67%	0	0	0
23:01-24:00	0.99%	0	0	0
Total	100%			**18.466**[b]

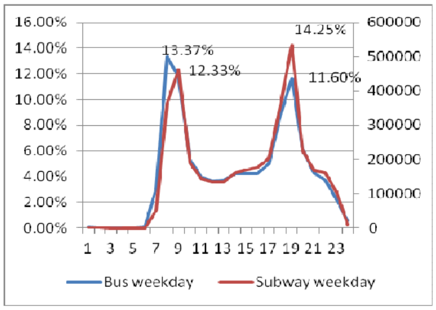
[a]Weekday travel

[b]See Equation 2.

CASE STUDY 4: Shi and Lin (2012)

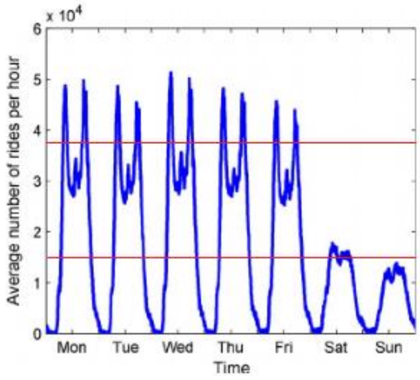
Data collected from the Shenzhen company in China found that the ratio of weekday trips to weekend trips was 1.073 (3750487/3496259) over 2 days, which is quite low. It was also found that 14.25% of trips occur in the peak hour between 5:00 PM and 6:00 PM.

	Weekday	Weekend
Subway trips	940541	989094
Bus trips	3750487	3496259
Total	4691028	4485353



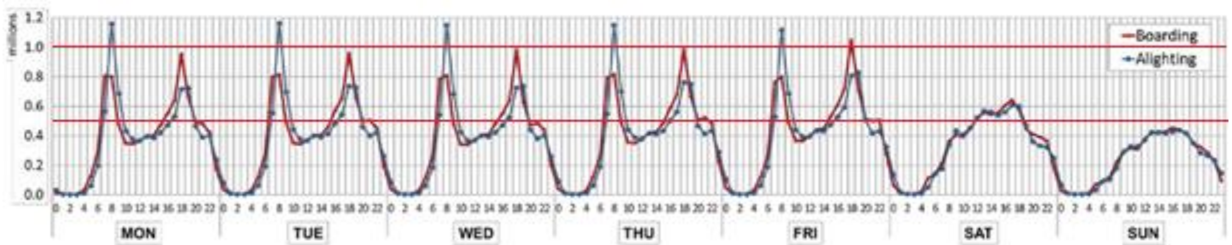
CASE STUDY 5: Foell et. Al. (2015)

Data collected from one of the largest bus operators in Lisbon, Portugal found that 21% of daily trips occur in the PM Peak period between 4:30 PM and 7:30 PM, or 7% per hour on average. It was also found that the ratio between average weekday trips and average weekend trips was high (a rough visual inspection finds a ratio of 3.75/1.5 = 2.5 times higher usage on a weekday compared to a weekend). Over 61 days, 24,257,353 bus rides were recorded.



CASE STUDY 6: Kim et. Al. (2018)

Transit data from the Korean public transit system in Seoul shows that the ratio between average weekday and weekend trips was also quite high, at roughly 2 (1 million/0.5 million). Data was collected for about 20 million records daily on average (or 10 million trips daily).



APPENDIX G: PEDESTRIAN COUNTS (RAW DATA)

Intersection	Corner	2HR Count N/S	2HR Count E/W	1HR avg N/S	1HR avg E/W
Sandlake	SW	32	41	16	21
	NW	26	21	13	11
	NE	21	31	11	16
	SE	16	21	8	11
Jamaican N	SW	20	6	10	3
	NW	25	18	13	9
	NE	68	22	34	11
	SE	63	5	32	3
Jamaican S	SW	14	4	7	2
	NW	29	2	15	1
	NE	89	10	45	5
	SE	79	13	40	7
Via Mercado	SW	15	3	8	2
	NW	27	42	14	21
	NE	118	22	59	11
	SE	110	0	55	0
Samoan N	SW	20	25	10	13
	NW	44	71	22	36
	NE	149	50	75	25
	SE	166	14	83	7
Pointe Plaza	SW	27	0	14	0
	NW	14	30	7	15
	NE	51	10	26	5
	SE	74	0	37	0

Crossing (North to South)	Volume EB	Volume WB	Volume NB	Volume SB	Volume EB	Volume WB	Volume NB	Volume SB
SandLake				13				11
Jamaican N								
Jamaican S								
Uncle Julio's			14	22			113	50
Via Mercado								
Austrian S								
Miller's Ale House	16		49	28		7	51	42
South xwalk	16					7		
Samoan N								
Samoan S								
Churros and Co	13		47	42		3	79	16
South xwalk	42					6		
Pointe Plaza			14				37	
	West side				East side			

APPENDIX H: BENEFIT-COST AND CAPACITY IMPROVEMENT ANALYSES

B/C analysis to represent the benefit of a single user switching to transit in monetary terms of the cost of transit improvement (cost) and cost reduction of personal automobile costs and externalities (benefit)

This analysis demonstrates the value of a vehicle user switching to transit in terms of annual cost savings (e.g. It is X times cheaper to use transit)

B/C ratio = Cost savings/ Cost of transit operation

Cost savings = 1.814$ per vehicle-mile of auto reduction

7280 ft equals 1.39 mi

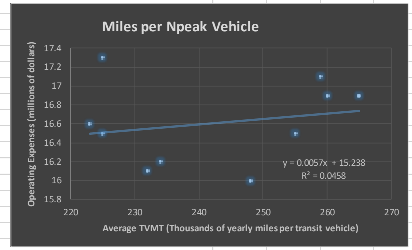
therefore cost savings = 1.814*1.39 equals 2.52$ per vehicle of auto reduction on I-Drive

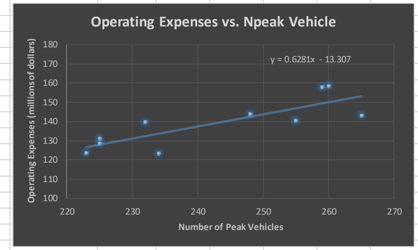
equals 1.59$ per person of auto reduction on I-Drive

Cost of transit operation

Per vehicle operating expenses will be calculated using Npeak vehicles, Transit VMT (TVMT) vs. operating expenses

Year	N	OE (mil dollars)	Total TVMT (mil miles)	TVMT/N (thousands of miles per vehicle)
2009	234	123.3	16.2	69.2
2010	223	123.7	16.6	74.4
2011	225	128.8	16.5	73.3
2012	225	131.1	17.3	76.9
2013	232	139.7	16.1	69.4
2014	248	144	16	64.5
2015	255	140.4	16.5	64.7
2016	265	143.4	16.9	63.8
2017	259	157.8	17.1	66.0
2018	260	158.5	16.9	65.0





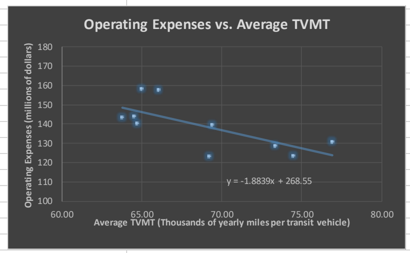
TVMT/N is the unit cost per transit-vehicle-mile

Total TVMT = ∑TVMT(i) where the value of I represents each bus (summing vehicle miles for each bus)

therefore, total TVMT = N*(AVG TVMT)

AVG TVMT = (total TVMT)/N

YEAR	AVG TVMT (thousand miles per vehicle)	Total TVMT (mil yearly miles)	OE (mil dollars)
2009	69.23	16.2	123.3
2010	74.44	16.6	123.7
2011	73.33	16.5	128.8
2012	76.89	17.3	131.1
2013	69.40	16.1	139.7
2014	64.52	16	144
2015	64.71	16.5	140.4
2016	63.77	16.9	143.4
2017	66.02	17.1	157.8
2018	65.00	16.9	158.5
Avg	68.73		



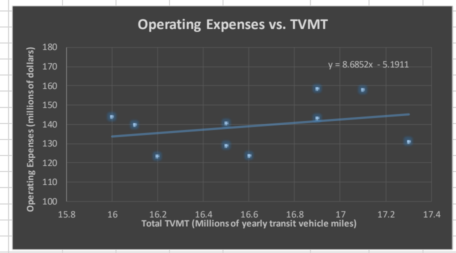


Figure1 indicates that operating expenses decrease by 1.9k per additional vehicle mile per bus (higher bus utilization = cheaper cost/vehicle-mile)

Figure2 indicates that operating expenses increase by 8.7 dollars per vehicle mile 8.7*1.39 = 12.1 dollars per bus on I-Drive

Method 1: Cost/Vehicle-Mile = OE/TVMT

Transit Level	Frequency	Delta frequency	Delta cost = cost per bus on I-Drive (1.39 mi) *delta frequency
T1	20	0	0
T1.5	25	5	60.5
T2	30	10	121
T2.5	35	15	181.5
T3	40	20	242

Transit Level	Npersons	Delta persons	Delta cost	Cost of adding one person to transit on I-Drive
T1	671	0	0	0
T1.5	987	316	60.5	0.191455696
T2	1302	631	121	0.191759113
T2.5	1623	952	181.5	0.190651261
T3	1943	1272	242	0.190251572
AVG				$ 0.19 per person

(in cents)	Cost savings of removing one car user (B)	Cost of adding one transit user (C)	B/C
B/C(1) =	159	19.1	8.32
B/C(2) =	159	20.3	7.83
B/C(3) =	159	60.3	2.64
B/C(4) =	159	80	1.99
Average =		44.9	5.2

These findings are generally in the lower end of the range of B/C ratios found in Philadelphia (8.33), Memphis (19.96), Tennessee (3.4), and Roanoke (3.9)

Also note, as the units are per person on I-Drive, these findings are dependent on the capacity utilization of transit systems. These findings are also based on annualized costs (e.g. the assumption is that most of the infrastructure is in place and only additional vehicles are needed).

Method 2: Cost/Vehicle-Mile by calculating cost and utility of adding an additional peak vehicle

Cost of Additional Peak Vehicle = 0.628 M$ per peak vehicle

Thousand Miles per Additional Peak Vehicle (on Average) = 68.73 thousand miles per peak vehicle

Cost of an additional Vehicle-Mile = $ 9.24 /Vehicle-Mile

Cost of an additional Bus on I-Drive = 9.24*1.39 = $ 12.84 /Bus on I-Drive

AVG cost of adding one person to transit (extrapolating from method 1) = $ 0.203 per person

Method 3: Using the Cost/Vehicle from the VTPI study

Cost/Bus-mile = $27.483

Cost of an additional Bus on I-Drive = 27.483*1.39 = $ 38.20 /Bus on I-Drive

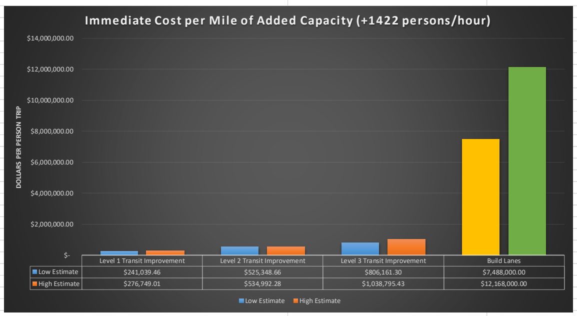
AVG cost of adding one person to transit (extrapolating from method 1) = $ 0.603 per person

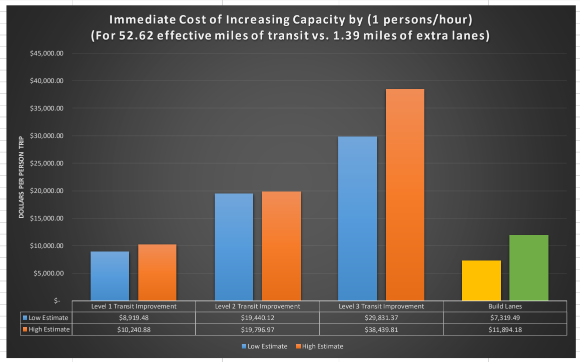
Cost of Traditional Capacity Improvement Project										
			Effective miles of added capacity by transit							
4 Lane Directional MSV for I-Drive:	1790	vph	Route	L (mi)	N-buses current	N-buses future	Added Capacity (pph)	Capacity*miles	Effective miles @ 1453 added capacity	
4 Lane Directional MSV in persons demand :	2828	pph	I-Drive (all lines)	1.39	28	60	1453	2019.392		
			Lynx 8	70.02	12	26	623	43596.45257		
6 Lane Directional MSV for I-Drive:	2690	vph	Lynx 38	27.1	5	11	259	7030.514286		
6 Lane Directional MSV in persons demand :	4250	pph	Lynx 42	64.4	6	13	311	20048.64		
			I-Ride Red	13.92	5	11	259	3611.245714		
(Source: VHB I-Drive study)								76306.24457	52.62	
Immediate cost (Capital investment):										
Cost-Per-Lane-Mile Improvement Calculations:	N-Lanes	CPLM	Segment Length (mi)	Project Cost	Capacity Improvement (pph)	Cost/additional person-trip on I-Drive (over 1.39 miles)				
Traditional method (additional lanes)	2	3,744,000	1.39	$ 10,408,320.00	1422	$ 7,319.49				
Historical method (total new lanes)	6	2,028,000	1.39	$ 16,913,520.00	1422	$ 11,894.18				
				$ 13,660,920.00		$ 9,606.84				
(Source: OC Impact Fee update 2012)										
Annual cost (Externalities):	Annual cost/additional person-trip (from B/C)									
	$ 1.59									
Cost of Transit Improvement Project										
	Cost/Bus (thousands of $)		Lynx Route	Freq	L (miles)	Route time IN (min)	Route time OUT (min)	Buses IN	Buses OUT	Nbuses
San Jose (HOV)	465	435 Avg	8	4	36.4	98	88	6.5	5.9	12
Vancouver (HOV)	405		38	4	28.49	78		5.2	0	5
Los Angeles (HOV)	848.5		42	2	33.59	88	83	2.9	2.8	6
Cleveland (Electric/Diesel Busway)	1200		Total							23
	Fleet (buses)		I-Ride route time (min) =	50						
I-Ride Red serves at 6 bus/hr frequency	5		I-Ride route length (mi) =	16.7						
Adding Lynx Fleet	28		Assume 20 mph Avg							
Extrapolating to 40 bus/hr (double capacity)	56		Total Bus routes length (mi) =	185.17						
Additional fleet needed to double capacity	28									
Additional fleet needed to match lane build capacity	32									
Immediate cost (Capital investment):										
Level 1 Improvement: Purchase Tier 3 buses only										
	Average	Low Price (thousands of dollars)	High Price (thousands of dollars)							
Total cost (thousands of dollars) = Nbuses*CostPerBus =	13920	12960	14880							
Capacity Improvement in pph =	1453	1453	1453							
Total Cost/Additional person-trip (over 52.62 effective miles) =	$ 9,580.18	$ 8,919.48	$ 10,240.88							
Total Cost/Additional person-trip on I-Drive (1.39 miles) =	$ 253.07	$ 235.62	$ 270.52							
Level 2 Improvement: Purchase Tier 2 buses, Total Renovation of Stops/Stations, Signal Priority/SPAT, Bus Arrival Information, ROW Improvement										
	Average	Low Price (thousands of dollars)	High Price (thousands of dollars)	Inventory Detail	Average	Low cost (thousands of dollars)	High cost (thousands of dollars)			
Cost of buses (thousands of dollars) =	848.5			32 buses	27152	27152	27152			
Stop/Station Renovation (thousands of dollars per stop) =	47.5	38	57	22 stops	1045	836	1254			
Signal Priority/SPAT (thousands of dollars per mile) =	91.5	83	100	1.39 miles	127.185	115.37	139			
Bus Arrival Information (per stop) =	8	6	10	22 stops	176	132	220			
ROW Improvement (per mile) =	8	8		1.39 miles	5.56	11.12	0			
Totals					28505.745	28246.49	28765			
Total cost (thousands of dollars) =	28505.745	28246.49	28765							
Capacity Improvement in pph =	1453	1453	1453							
Total Cost/Additional person-trip (over 52.62 effective miles) =	$ 19,618.54	$ 19,440.12	$ 19,796.97							
Total Cost/Additional person-trip on I-Drive (1.39 miles) =	$ 518.24	$ 513.53	$ 522.95							
Level 3 Improvement: Purchase Tier 1 buses, Construct HOV, Total Renovation of Stops/Stations, Signal Priority/SPAT, Bus Arrival Information, ROW Improvement, Property Acquisition (per mile)										
	Average	Low Price (thousands of dollars)	High Price (thousands of dollars)	Inventory Detail	Average	Low cost (thousands of dollars)	High cost (thousands of dollars)			
Cost of buses (thousands of dollars) =	1200			32 buses	38400	38400	38400			
Stop/Station Renovation (thousands of dollars per stop) =	292.5	135	450	22 stops	6435	2970	9900			
Signal Priority/SPAT (thousands of dollars per mile) =	917	34	1800	1.39 miles	1274.63	47.26	2502			
Bus Arrival Information (per stop) =	53	53	53	22 stops	1166	1166	1166			
ROW Improvement (per mile) =	1376.5	253	2500	1.39 miles	1913.335	351.67	3475			
Property Acquisition (per mile) =	295	295	295	1.39 miles	410.05	410.05	410.05			
Totals					49599.015	43344.98	55853.05			
Total cost (thousands of dollars) =	49599.015	43344.98	55853.05							
Capacity Improvement in pph =	1453	1453	1453							
Total Cost/Additional person-trip (over 52.62 effective miles) =	$ 34,135.59	$ 29,831.37	$ 38,439.81							
Total Cost/Additional person-trip on I-Drive (1.39 miles) =	$ 901.72	$ 788.02	$ 1,015.42							

Total Project Costs/Additional Persons Capacity	Level 1 Transit Improvement	Level 2 Transit Improvement	Level 3 Transit Improvement	Build Lanes
Low Estimate	$ 8,919.48	$ 19,440.12	$ 29,831.37	$ 7,319.49
High Estimate	$ 10,240.88	$ 19,796.97	$ 38,439.81	$ 11,894.18
Cost per Additional mile of added capacity				
Low Estimate	$ 241,039.46	$ 525,348.66	$ 806,161.30	$ 7,488,000.00
High Estimate	$ 276,749.01	$ 534,992.28	$ 1,038,795.43	$ 12,168,000.00
Person-mile Cost of level 3 transit as a percent of cost of lane-build =	10.0			
Using the Level 3 transit option is 90% cheaper per person-mile of added capacity!				

Annual cost (Operating costs + externalities):	Annual cost/additional person-trip (from B/C)
	$ 0.80

Year	Transit Annual cost/additional person-mile	Cars Annual cost/additional person-mile	AADT	Transit Cumulative OC (Includes non-transit externalities)	Cars Cumulative OC		Buses needed to meet Demand	Cost of new buses per mile (k$)	Fixed transit costs per mile(k$)	Fixed lane build costs per mile (k$)
1	$ 0.58	$ 1.14	56090	$ 53,534.34	$ 64,160.50	1	28	$ -	$ 212.83	$ 9,828.06
2	$ 0.58	$ 1.14	61031	$ 111,784.42	$ 133,972.79	1.191	48	$ 456.10	$ 212.83	$ 9,828.06
3	$ 0.58	$ 1.14	65236	$ 174,047.63	$ 208,594.78	1.382	50	$ 501.71	$ 212.83	$ 9,828.06
4	$ 0.58	$ 1.14	68895	$ 239,803.84	$ 287,403.09	1.573	52	$ 547.32	$ 212.83	$ 9,828.06
5	$ 0.58	$ 1.14	72135	$ 308,652.38	$ 369,917.55	1.764	54	$ 592.93	$ 212.83	$ 9,828.06
6	$ 0.58	$ 1.14	75042	$ 380,275.14	$ 455,756.89	1.954	56	$ 638.54	$ 212.83	$ 9,828.06
7	$ 0.58	$ 1.14	77678	$ 454,413.39	$ 544,611.02	2.145	58	$ 684.15	$ 212.83	$ 9,828.06
8	$ 0.58	$ 1.14	80088	$ 530,852.55	$ 636,222.78	2.336	60	$ 729.76	$ 212.83	$ 9,828.06
9	$ 0.58	$ 1.14	82310	$ 609,411.82	$ 730,375.47	2.527	60	$ 729.76	$ 212.83	$ 9,828.06
10	$ 0.58	$ 1.14	84369	$ 689,936.73	$ 826,883.98	2.718	60	$ 729.76	$ 212.83	$ 9,828.06

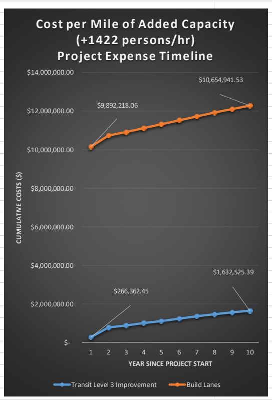


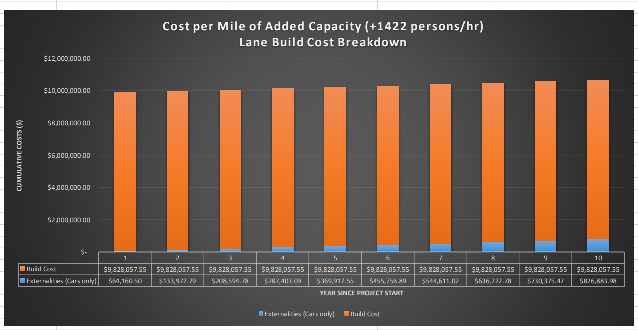


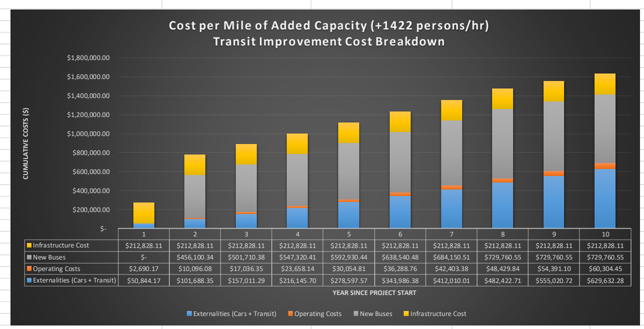
Year	Transit Level 3 Improvement	Build Lanes
1	$ 266,362.45	$ 9,892,218.06
2	$ 780,712.87	$ 9,962,030.34
3	$ 888,586.12	$ 10,036,652.33
4	$ 999,952.35	$ 10,115,460.64
5	$ 1,114,410.93	$ 10,197,975.11
6	$ 1,231,643.73	$ 10,283,814.44
7	$ 1,351,392.01	$ 10,372,668.57
8	$ 1,473,441.21	$ 10,464,280.34
9	$ 1,552,000.48	$ 10,558,433.03
10	$ 1,632,525.39	$ 10,654,941.53

Year	Externalities (Cars only)	Build Cost
1	$ 64,160.50	$ 9,828,057.55
2	$ 133,972.79	$ 9,828,057.55
3	$ 208,594.78	$ 9,828,057.55
4	$ 287,403.09	$ 9,828,057.55
5	$ 369,917.55	$ 9,828,057.55
6	$ 455,756.89	$ 9,828,057.55
7	$ 544,611.02	$ 9,828,057.55
8	$ 636,222.78	$ 9,828,057.55
9	$ 730,375.47	$ 9,828,057.55
10	$ 826,883.98	$ 9,828,057.55

Year	Externalities (Cars + Transit)	Operating Costs	New Buses	Infrastructure Cost
1	$ 50,844.17	$ 2,690.17	$ -	$ 212,828.11
2	$ 101,688.35	$ 10,096.08	$ 456,100.34	$ 212,828.11
3	$ 157,011.29	$ 17,036.35	$ 501,710.38	$ 212,828.11
4	$ 216,145.70	$ 23,658.14	$ 547,320.41	$ 212,828.11
5	$ 278,597.57	$ 30,054.81	$ 592,930.44	$ 212,828.11
6	$ 343,986.38	$ 36,288.76	$ 638,540.48	$ 212,828.11
7	$ 412,010.01	$ 42,403.38	$ 684,150.51	$ 212,828.11
8	$ 482,422.71	$ 48,429.84	$ 729,760.55	$ 212,828.11
9	$ 555,020.72	$ 54,391.10	$ 729,760.55	$ 212,828.11
10	$ 629,632.28	$ 60,304.45	$ 729,760.55	$ 212,828.11







LIST OF REFERENCES

Abou-Senna, H. (2016). Congestion pricing strategies to investigate the potential of route diversion on toll facilities using en-route guidance. Journal of Traffic and Transportation Engineering (English Edition), 3(1), 59-70.

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.

Adler, M., Liberini, F., Russo, A., & van Ommeren, J. N. (2019). The congestion relief benefit of public transit: evidence from Rome.

Aftabuzzaman, M., Currie, G., & Sarvi, M. (2010). Evaluating the congestion relief impacts of public transport in monetary terms. Journal of Public Transportation, 13(1), 1.

Al-Deek H., and Kanafani A., (1990). A Simple Model for Route Guidance Benefits. Institute of Transportation Studies. University of California, Berkeley.

Al-Deek H., Ishak S., and Radwan A., (1993). The Potential Impact of Advanced Traveler Information Systems (ATIS) on Accident Rates in an Urban Transportation Network. Department of Civil and Environmental Engineering, University of Central Florida.

Al-Deek H., Mohamed A., and Radwan A., (1997). Operational Benefits of Electronic Toll Collection: Case Study. Journal of Transportation Engineering November/December 1997.

Anderson, M. L. (2014). Subways, strikes, and slowdowns: The impacts of public transit on traffic congestion. American Economic Review, 104(9), 2763-96.

Ahn, K., Rakha, H., Trani, A., & Van Aerde, M. (2002). Estimating vehicle fuel consumption and emissions based on instantaneous speed and acceleration levels. Journal of transportation engineering, 128(2), 182-190.

Aschauer, D. A. (1991). Transportation spending and economic growth: the effects of transit and highway expenditures.

Arnott, R., & Small, K. (1994). The economics of traffic congestion. American scientist, 82(5), 446-455.

Barrett, M. (2011). Bus Rapid Transit: Chicago's New Route to Opportunity. Metropolitan Planning Council. Retrieved from 'https://www.metroplanning.org/uploads/cms/documents/brt_report_20110817_reva.pdf'

Bruun, E. (2005). Bus Rapid Transit and Light Rail. Transportation Research Record: Journal of the Transportation Research Board, 1927(1), 11–21. doi:10.1177/0361198105192700102

Clewlow, R. R., & Mishra, G. S. (2017). Disruptive transportation: The adoption, utilization, and impacts of ride-hailing in the United States.

Coelho, M. C., Farias, T. L., & Rouphail, N. M. (2005). Measuring and modeling emission effects for toll facilities. Transportation Research Record, 1941(1), 136-144.

Cohen, B. (2006). Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. Technology in society, 28(1-2), 63-80.

Cortes C. E., Burgos V., Fernandez R. (2010) Modelling passengers, buses, and stops in traffic micro-simulation: review and extensions. Retrieved from 'https://onlinelibrary.wiley.com/doi/pdf/10.1002/atr.110'

Das, V. (2020). Does Adoption of Ridehailing Result in More Frequent Sustainable Mobility Choices? An Investigation Based on the National Household Travel Survey (NHTS) 2017 Data. Smart Cities, 3(2), 385-400.

Dave, (2018). Saving lives: The Lyft and Uber Effect on Drunk Drivers. Rideshare Central. Retrieved from 'https://ridesharecentral.com/saving-lives-the-lyft-uber-effect-on-drunk-driving'

Dimitrov S., Ceder A. A., Chowdhury S., Monot M. (2015) Modeling the interaction between buses, passengers and cars on a bus route using a multi-agent system. DOI: 10.1080/03081060.2017.1314504

European Commission. (2017). Europe-Wide Platform for Cooperative Mobility Services. Retrieved from
'https://cordis.europa.eu/project/id/318485'

ERTICO. (2017, March 22). Jacob Bangsgaard presenting #mobilityasaservice at #MaaSMarket conference - Focusing on the user #mobilityasaservice #MaaS [Tweet]
'https://twitter.com/ERTICO/status/844561601139216390?s=20'

Fagnant D., and Kockelman K., (2015). Operations of a Shared Autonomous Vehicle Fleet for the Austin, Texas Market. Transportation Research Record (2015) Retrieved from
'http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.431.1531&rep=rep1&type=pdf'

Fagnant D., and Kockelman K., (2016). Dynamic Ride Sharing and Fleet Sizing for a System of Shared Autonomous Vehicles in Austin, Texas. Transportation 45: 1-16 (2016) Retrieved from
'http://www.ce.utexas.edu/prof/kockelman/public_html/TRB15SAVswithDRSinAustin.pdf'

Florida Department of Transportation (FDOT). (2011). Florida Transportation Trends and Conditions. Retrieved from
'https://www.fdot.gov/docs/default-source/planning/trends/tc-report/behavior.pdf'

Florida Department of Transportation (FDOT). (2013). FDOT Quality/Level of Service Handbook. Retrieved from
'https://www.fdot.gov/planning/systems/documents/sm/default.shtm'

Florida Department of Transportation (FDOT). (2014). FDOT Traffic Analysis Handbook: A Reference for Planning and Operations. Retrieved from
'https://www.fdot.gov/planning/systems/programs/sm/traffic/default.shtm'

Federal Highway Administration (FHWA). (2004). Traffic Analysis Toolbox Vol. 3: Guidelines for Applying Traffic Microsimulation Modelling Software (2004). Federal Highway Administration, US Department of Transportation.

Federal Highway Administration (FHWA). (2009). Federal Highway Administration National Household Travel Survey 2009. Federal Highway Administration, US Department of Transportation.

Foell, S., Phithakkitnukoon, S., Kortuem, G., Veloso, M., & Bento, C. (2015). Predictability of public transport usage: a study of bus rides in Lisbon, Portugal. IEEE Transactions on Intelligent Transportation Systems, 16(5), 2955-2960.

Gregg, R., & Begley, J. T. (2011). Enhancing the connectivity of high speed rail in the Orlando-Tampa corridor with local public transportation systems: issues and opportunities (No. 2117-77928-00). National Center for Transit Research (US).

Grovdahl, D. L., & Hill, E. T. (2000). Regional planning and intelligent transportation systems: Effects on land use and society. ITE journal, 70(3), 34-38.

Gružauskas, V., Baskutis, S., & Navickas, V. (2018). Minimizing the trade-off between sustainability and cost effective performance by using autonomous vehicles. Journal of Cleaner Production, 184, 709-717.

Hao, H., Wang, H., & Ouyang, M. (2011a). Comparison of policies on vehicle ownership and use between Beijing and Shanghai and their impacts on fuel consumption by passenger vehicles. Energy Policy, 39(2), 1016-1021.

Hao, H., Wang, H., & Yi, R. (2011b). Hybrid modeling of China's vehicle ownership and projection through 2050. Energy, 36(2), 1351-1361.

Henao, A. (2017). Impacts of Ridesourcing-Lyft and Uber-on Transportation Including VMT, Mode Replacement, Parking, and Travel Behavior. University of Colorado at Denver.

Hensher, D. A. (2006). Integrating accident and travel delay externalities in an urban speed reduction context. Transport Reviews, 26(4), 521-534.

Hess, D. B., Taylor, B. D., & Yoh, A. C. (2005). Light Rail Lite or Cost-Effective Improvements to Bus Service? Transportation Research Record: Journal of the Transportation Research Board, 1927(1), 22–30. doi:10.1177/0361198105192700103

Holmberg, P. E., Collado, M., Sarasini, S., & Williander, M. (2016). Mobility as a Service-MaaS: Describing the framework.

I-Ride Trolley. (2020). System Map. Retrieved from
'https://www.internationaldriveorlando.com/iride-trolley/'

ITS Europe. (2020). ERTICO. Retrieved from
'https://ertico.com/'

Kain, J. F., & Liu, Z. (1999). Secrets of success: assessing the large increases in transit ridership achieved by Houston and San Diego transit providers. Transportation Research Part A: Policy and Practice, 33(7-8), 601-624.

Kanafani A., and Al-Deek H. (1990). A Simple Model for Route Guidance Benefits, Institute of Transportation Studies. University of California, Berkeley.

Kim, M. K., Kim, S., & Sohn, H. G. (2018). Relationship between spatio-temporal travel patterns derived from smart-card data and local environmental characteristics of Seoul, Korea. Sustainability, 10(3), 787.

Kloostra, B., & Roorda, M. J. (2019). Fully autonomous vehicles: analyzing transportation network performance and operating scenarios in the Greater Toronto Area, Canada. Transportation planning and technology, 42(2), 99-112.

Li, Y., & Voege, T. (2017). Mobility as a service (MaaS): Challenges of implementation and policy required. Journal of transportation technologies, 7(2), 95-106.

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

Litman, T. (2013). Smarter congestion relief in asian cities. Transport and Communications Bulletin for Asia and the Pacific, 82(1).

Litman, T. (2014). Congestion evaluation best practices. In International Transportation Economic Development Conference. Sheraton Dallas Hotel, Dallas, USA (pp. 1-20).

Litman T., (2018). Autonomous Vehicle Implementation Predictions Implementations for Transport Planning. Victoria Transport Policy Institute. Retrieved from
'https://www.vtpi.org/avip.pdf'

Loeb B., Kockelman K., and Liu J., 2018. Shared Autonomous Electric Vehicle (SAEV) Operations Across the Austin, Texas Network with Charging Infrastructure Decisions. Transportation Research Part C: Emerging Technologies, Volume 89, April 2018, Pages 222-233 (2018) Retrieved from
'https://www.sciencedirect.com/science/article/pii/S0968090X18300627?via%3Dihub' Accessed March 15th, 2019

County of Los Angeles. (2017). Commute Mode Share in LA County (2005-2017). Open Data. Retrieved from
'https://data.lacounty.gov/Transportation/Commute-Mode-Share-in-LA-County-2005-2017-/y7mn-ys78'

Lynx. (2020). Lynx System Map. Retrieved from
'https://www.golynx.com/resources/pdf/System-Map-121414.pdf'

Lynx. (2018). Comprehensive Annual Financial Report for years ended September 30, 2018 and 2017. Retrieved from
'https://www.golynx.com/resources/pdf/System-Map-121414.pdf'

Manjunatha P., Viortisch P., Mathew T. V. (2013) Methodology for Calibration of VISSIM in Mixed Traffic. Retrieved from
'https://pdfs.semanticscholar.org/c429/eb783aefdc06f88d611cf3534c014cd82cac.pdf'

Ge, Q., & Menendez, M. (2012). Using VISSIM to model traffic in the city of Zürich. In IVT-Alumni-Seminar: Verkehrsingenieurtag 2012. ETH Zürich, Institut für Verkehrsplanung und Transportsysteme (IVT).

Dowling, R. G., & Reinke, D. (2008). Multimodal level of service analysis for urban streets (Vol. 128). Transportation Research Board.

Nikitas, A., Kougias, I., Alyavina, E., & Njoya Tchouamou, E. (2017). How can autonomous and connected vehicles, electromobility, BRT, hyperloop, shared use mobility and mobility-as-a-service shape transport futures for the context of smart cities?. Urban Science, 1(4), 36.

Parry, I. W., Walls, M., & Harrington, W. (2007). Automobile externalities and policies. Journal of economic literature, 45(2), 373-399.

Pendyala, R. M. (2002). Time of Day Modeling Procedures for Implementation in FSUTMS (No. RPWO No. 8,).

Pickrell, D. H. (1989). Urban rail transit projects: forecast versus actual ridership and costs. Final Report (No. UMTA-MA-08-9021-89-1). United States. Urban Mass Transportation Administration.

Pinellas Suncoast Transit Authority. (2020). Direct Connect PSTA. Retrieved from 'www.psta.net/riding-psta/directconnect/'

Pinellas Suncoast Transit Authority. (2020). PSTA Brings Together Uber and Taxi to get People on the Bus. Retrieved from 'www.masstransitmag.com/alt-mobility/shared-mobility/car-sharing/press-release/12296934/'

Polzin, S. E., Pendyala, R. M., & Navari, S. (2002). Development of time-of-day–based transit accessibility analysis tool. Transportation Research Record, 1799(1), 35-41.

Orange County Government Florida. (2020). Policy and Public Involvement. Retrieved from 'https://www.orangecountyfl.net/TrafficTransportation/PublicInvolvementMeetings.aspx#.XnV-C6hKhPY'

Palmer, K., Dessouky, M., & Zhou, Z. (2008). Factors influencing productivity and operating cost of demand responsive transit. Transportation Research Part A: Policy and Practice, 42(3), 503-523.

PTV Vision. (2011). VISSIM 5.30-05 User Manual. Retrieved from 'http://www.et.byu.edu/~msaito/CE662MS/Labs/VISSIM_530_e.pdf'

Ramboll Consulting. (2019). Whimpact: Insights from the world's first Mobility-as-a-Service system. Retrieved from 'https://ramboll.com/-/media/files/rfi/publications/Ramboll_whimpact-2019' Accessed March 26th, 2019

Richtel, M. 2014. Distracted Driving and the Risks of Ride- Hailing Services Like Uber. The New York Times. Retrieved from 'https://bits.blogs.nytimes.com/2014/12/21/distracted-driving-and-the-risks-of-ride-hailingservices-like-uber/'

Sale, J. E., & Green, B. (1979). Operating Costs and Performance of American Public Transit Systems. Journal of the American Planning Association, 45(1), 22–27. doi:10.1080/01944367908976935

Schaller, B. (2017). Unsustainable? The growth of app-based ride services and traffic, travel and the future of New York City. Schaller Consulting.

Shaheen S. (2018) Shared Mobility: The Potential of Ridehailing and Pooling. In: Sperling D. (eds) Three Revolutions. Island Press, Washington, DC

Shi, X. Y., & Lin, H. F. (2012). Research on the Temporal Distribution of Public Trips in Developed City in China: In the Case of Shenzhen. Applied Mechanics and Materials, 209-211, 624–627. doi:10.4028/www.scientific.net/amm.209-211.624

Skolnik, J., & Schreiner, R. (1998). Benefits of Transit in Small Urban Areas: A Case Study. Transportation Research Record: Journal of the Transportation Research Board, 1623(1), 47–56. doi:10.3141/1623-07

Sochor, J., Strömberg, H., & Karlsson, I. M. (2015). Implementing mobility as a service: challenges in integrating user, commercial, and societal perspectives. Transportation research record, 2536(1), 1-9.

Institute of Transportation Engineers (ITE). (2019). Traffic and Transit Impact Studies State of the Practice 2019

Transportation Research Board (TRB). (2017). Transit Capacity and Quality of Service Manual 2013. The National Academies of Sciences Engineering Medicine Retrieved from
‘http://www.trb.org/Main/Blurbs/169437.aspx’

Tindale, S. (2012). Orange County Transportation Impact Fee Update Final Report. Tindale-Oliver and Associates Inc. Retrieved from
‘https://www.orangecountyfl.net/Portals/0/Library/Traffic-Transportation/docs/Roadway%20Impact%20Fee%20Update.pdf’

Uber Advanced Technologies Group (ATG). (2018). Advanced Technologies Group. Retrieved from
‘https://uber.app.box.com/v/UberATGSafetyReport’

Utah Department of Transportation (UDOT). (2000). Legacy Parkway Final Environmental Impact Statement and Section 4(f), 6(f) Evaluation. Retrieved from ‘https://www.google.com/books/edition/Legacy_Parkway_Project_Construction_from/HLs1AQAAMAAJ?hl=en&gbpv=1&dq=Legacy+Parkway+Project,+Construction+from+I-215&printsec=frontcover’

Van Woensel, T., Creten, R., & Vandaele, N. (2001). Managing the environmental externalities of traffic logistics: The issue of emissions. Production and Operations Management, 10(2), 207-223.

Zhang, W., Guhathakurta, S., Fang, J., & Zhang, G. (2015). The performance and benefits of a shared autonomous vehicles based dynamic ridesharing system: An agent-based simulation approach. In Transportation Research Board 94th Annual Meeting (No. 15-2919).

Zhou, H., & Sperling, D. (2001). Traffic emission pollution sampling and analysis on urban streets with high-rising buildings. Transportation Research Part D: Transport and Environment, 6(4), 269-281.