INTELLIGENT LANE UTILISATION TO IMPROVE FREIGHT TRANSPORTATION MOBILITY ON ARTERIALS

SOHA S SAIYED

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Abstract

The increase in commodity flow and just-in-time pickup/delivery activities in urban areas have increased truck traffic on urban roadways, which raises safety and operational concerns. The governing agencies are planning to improve the efficiency by adopting the Intelligent Lane Utilisation (ILU) tactics along the highways and major arterials. Truck only lane and truck lane restriction tactics were selected to carry out the analysis for this study.

The objective of this study is to evaluate the effectiveness of selected ILU tactic on arterial roadways with significant truck traffic. The study used two approaches, Approach I (fixed traffic demand) carried out microsimulation analysis. Whereas Approach II (changed traffic demand) carried macrosimulation analysis and result of the analysis was used as an input for the microsimulation analysis. The findings indicate that success of ILU tactic depends on various factors such as the number of lanes and the link length between major intersections, etc.

DEDICATION

To my loving parents and brother Saif Ali

without your love, support, patience, and understanding

this work would not be possible.

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CHAPTER 1. INTRODUCTION

This thesis explores intelligent lane utilisation to improve freight transportation mobility across major arterials in Greater Toronto and Hamilton area. The study performs analysis using macrosimulation and microsimulation to estimate benefits of intelligent lane utilisation tactics on Derry road and Highway 50 in the Region of Peel in southern Ontario.

1.1. Research Overview

Moving goods is vital to keeping retail stores stocked, to ensuring that manufacturers receive the components they need for manufacturing, and to delivering finished products to markets. The health of a city's economy depends on moving goods, and moving goods depends on excellent logistics. The goods movement system can be divided into two parts: 1) regional, i.e., goods moving in and out of a metropolitan area, and 2) local, i.e., goods moving within a metropolitan area (RPA, 2016). Various modes may be used to transfer goods, for example, air, rail, water, and road (Rodrigues, 2020).

Air and water transportation may be used for long-distance goods movement with rail typically used for heavy and/or bulk commodities travelling long distances, normally greater than 650 kms (The Canadian Encyclopedia, 2014). Once the goods reach a major gateway such as an airport, rail terminal or a port, they are transported to logistics facilities (warehouses or distribution centres) for processing and then forwarded to their final destinations.

Trucks are particularly important for transferring goods to local vendors. Almost everything we use each day (food for dinner, clothes purchased in stores or online, etc.) has used trucks to travel some part of the journey to us. In urban areas, trucks are used to pick up and deliver large quantities of goods. As trucks are long, wide, heavy, and tall, they face some limitations. For example, trucks cannot make sharp turns, and they need longer stopping distances than passenger cars. Due to sheer size, trucks also impose challenges for other vehicles travelling on the same roadways. For instance, large trucks may obscure signs and signals for the vehicle following them (Mwakalonge, 2012).

The daily and weekly travel time pattern for trucks and the passenger vehicles are different and truck drivers prefer to avoid commuting time periods (AM and PM peak hours) with heavy passenger vehicle traffic. However, the truck drivers are limited as to when they can travel. The constraints are imposed by hours-of-service regulations, maritime terminal operating hours, neighborhood curfews and union-negotiated hours of operation (Vilain and Wolfrom, 2001).

The congestion of trucks directly affects the quality of life in most cities. Issues such as the impact of trucks on congestion cannot be ignored. For more than past three decades, traffic congestion has become a prominent problem in urban areas, a problem that not only affects commuters, but also hinders the economic growth and prosperity of congested areas. Congestion is one of the main causes of gas emissions throughout the globe (Yan, 2010). It also results in wasted time and energy (fuel consumption) that add significantly to the cost of truck and passenger transportation (Mekky, 2007).

1.1.1. Importance of Freight Movement in Canada

According to the US Bureau of Transportation Statistics (BTS, 2020), trucks account for 70% of the total monetary value, 60% of the total weight, and 34% of the ton-miles of total freight moved from Canada to the United States. It is reported that approximately 57% ($325 billion) of the trade between Canada and the United Sates is handled by heavy commercial trucks (Transport Canada, 2012). In 2017, approximately 11 million two-way truck movements were recorded at the land-border crossings between Canada and the United Sates, representing $387 billion in imports and exports (Transport Canada, 2018). Of all the Canadian provinces, Ontario has the highest level of trade interaction with the United States through land border crossings. Almost 80% of Ontario's exports go to the United States. Of all the goods transported, 87% of merchandise exports are manufactured goods, with the automotive industry alone accounting for more than 35% (Anderson, 2015).

Freight trucking companies in Ontario account for approximately 42% of the companies throughout Canada (Anis, 2019). Ontario's Highway 401 is one of the busiest corridors in all of North America. The corridor not only services Toronto, the largest metropolitan area in Canada, but also facilitates the movement of goods between Canada and the United States (Transport Canada, 2018). A large percentage of the goods from the Greater Toronto and Hamilton Area (GTHA) is transported to various American cities such as Chicago IL, Columbus OH, Nashville TN, etc. (Gingerich, et al., 2016; Transport Canada, 2016). **Figure 1** shows the GTHA.

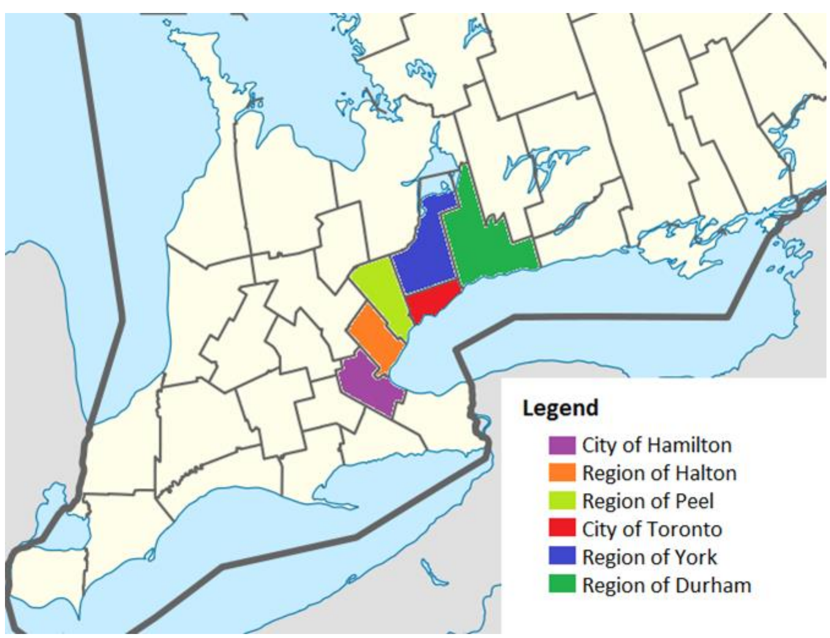


Figure 1: Greater Toronto and Hamilton Area, southern Ontario (Metrolinx, 2008)

The Peel Region is the most significant centre in Ontario in terms of goods movements. It is estimated that $1.8 billion worth goods move through the Peel Region daily and that these goods movements generated $49 billion worth of annual Gross Domestic Product (GDP): 6.3% of provincial GDP and 3.2% of federal GDP in 2014 (Goods Movement Economic Impact Analysis Report, 2015. In 2016, 25,024 Peel businesses were involved in transportation and warehousing (LEPC, 2016). These businesses depend on major arterials of the region. This research studied two major arterials in Peel, Derry Road (also known as Regional Road 5) and Highway 50. These two study corridors were selected because they are near Toronto Pearson International airport (Canada's largest airport) and also connect to CN Brampton (CN's largest intermodal facility), and CP Vaughan Intermodal Terminals (CP's largest intermodal rail facility). The airport and intermodal rail facility terminals create high daily truck traffic volumes. **Figure 2**Error! Reference source not found. shows the dense network of 400 series highways in or near Peel and the location of the three major freight transportation generators mentioned.

Figure 2: Peel Region's Transportation Infrastructure (Region of Peel, 2017)

Reducing truck travel time by improving the flow of trucks along major truck routes in GTHA can be viewed as a promising way to promote the sustainable growth of the regional economy. The value of time (VOT) for commercial vehicles has been neglected largely because it is particularly challenging to assess. Rudra and Roorda (2014) noted two main reasons for the difficulties:

1. Several factors may affect travel choices made by commercial vehicles, in contrast to passenger transport where travel choices are generally made by the driver alone.
2. Private firms resist releasing confidential information that may affect their competitiveness within the industry.

VOT for commercial vehicles is the marginal benefit that a driver derives from a unit reduction in the amount of time necessary to move a particular quantity of goods from an origin to a destination. (Zamparini and Regianni, 2007). Delivery time is the amount of time from a) the moment in which there is an arrangement between a shipper and a carrier regarding the consignment of specific goods and b) the time the goods arrive to the customer. Transportation time includes all logistics operations (loading, unloading, travelling, warehousing, etc.) between the origin and destination. Travel time refers to the time used to move goods from an origin to a destination (Zamparini and Regianni, 2007).

1.1.2. Potential Solution to Improve Travel Time

According to the 2017 goods movement strategic plan published by the Region of Peel, Ontario government agencies generally agree that the surface infrastructure in the Region must be improved (Region of Peel, 2017) to reduce the freight travel time. Examples of operational level tactics for reducing freight travel time include off-peak hour delivery, and optimizing transport routes using advanced technology (e.g., route choice-based GPS and other software).

This thesis investigates the potential for intelligent lane utilisation (ILU) as a promising engineering solution for improving truck flows on targeted roadway corridors. Under ILU, a lane is operated with a special management scheme applied to a particular type of vehicle such as buses or trucks. These management schemes may include lane use restriction or tolls which smoothes traffic flow, vehicle throughput or both. ILU that targets trucks is loosely known as truck friendly measures (Goodin, 2006) and are commonly implemented to achieve improvements in the operational conditions of freight movement along highways (e.g., improving traffic speed, reducing pollution and improving safety). In the United States, examples of ILU corridors for trucks, emergency vehicles and transit vehicles include the SR 91 Express Lanes in Orange County, CA, the I-15 FasTrak Express Lanes in San Diego, CA, and the I-10 Houston, TX.

Transportation Association Canada (TAC, 2014) has identified seven different types of ILU tactics (i.e., high occupancy vehicles, toll lanes, high occupancy toll, exclusive lanes, reversible lanes, temporary use of shoulder lanes and multifaceted lanes). These options require appropriate traffic control devices (e.g., roadway marking) and may involve expensive construction costs for measures such as raised medians. Peel Region's "Action 5: Research truck-only lanes and implement a pilot project" is one of five strategic infrastructure improvements in their goods movement strategic plan (Region of Peel, 2017. Kriger (2016), however, examined United States' applications of ILU tactics and reported that physically separated truck lanes options do not generate benefits that exceed the costs of implementation. He suggested a pilot project to gather traffic flow data to determine whether ILU can be broadly implemented across the GTHA in Ontario.

To understand the impact of ILU tactics, transportation engineers often use macrosimulation and microsimulation models to study the movement of traffic on roadways and to understand possible solutions for freight movement (Rodrigues, 2014). Example studies include the I-81 in VA, SR-60 in CA, and the I-35 in Dallas, TX. These studies used microsimulation modelling with varying objectives and scopes (Roorda, et.al., 2010). Freight demand forecasting models generally use a macrosimulation model to assess network performance (Damodaran, 2012; Roorda, et.al., 2010). However, macrosimulation and microsimulation need to be used together for a city/region wide network where a macrosimulation model can investigate changed traffic demand due to the implementation of ILU tactics, and a microsimulation model can investigate the detailed impact on vehicle-to-vehicle integration and traffic control (e.g., traffic signals). The use of both the macro- and microsimulation models can help to provide a holistic understanding of the impact of ILU tactics on potential time saving benefits for freight movement on study corridors.

1.2. Research Goals and Objectives

The goal of this research is to evaluate the impact of selected ILU tactics on freight mobility (travel time savings) on the selected study corridors (Derry Road and Highway 50 in the Region of Peel). We investigated travel time changes by using both a macro- and a microsimulation model. The study has four objectives:

1. Conduct a literature review to identify the most appropriate type of ILU tactics in our study corridors. The review investigates North American jurisdictions currently using or planning to use ILU tactics on their roadways.
2. Calibrate a macrosimulation model to estimate changes in traffic demand (light, medium and heavy trucks, and passenger cars upon implementation of ILU tactics.

3. Use outcomes from macrosimulation model (updated traffic demand) to develop microsimulation model in order to evaluate the operational impact (in terms of travel time changes) of ILU on the targeted study corridors.
4. Evaluate ILU tactics to determine the best approach for freight travel time savings on the study corridors.

To achieve these objectives, the study's first step is to review the literature on managed lane tactics. Topics include high occupancy vehicle lanes, urban truck lanes, and other strategies which will help understand ILU's possible impact on travel time changes. The study then acquires and amalgamates the data required to calibrate and develop the macrosimulation and microsimulation models. The work required is divided into two approaches, the Approach I assume fixed traffic demand and performs a microsimulation analysis using the collected data. The Approach II considers changed traffic demand due to implementation of ILU techniques, hence, performs a macrosimulation analysis to obtain changes in traffic volume and uses it as input for microsimulation analysis. The study uses VISSIM software for microsimulation analysis and EMME for macrosimulation analysis. The study concludes with recommendations for future research. **Figure 3** shows the workflow for the thesis.

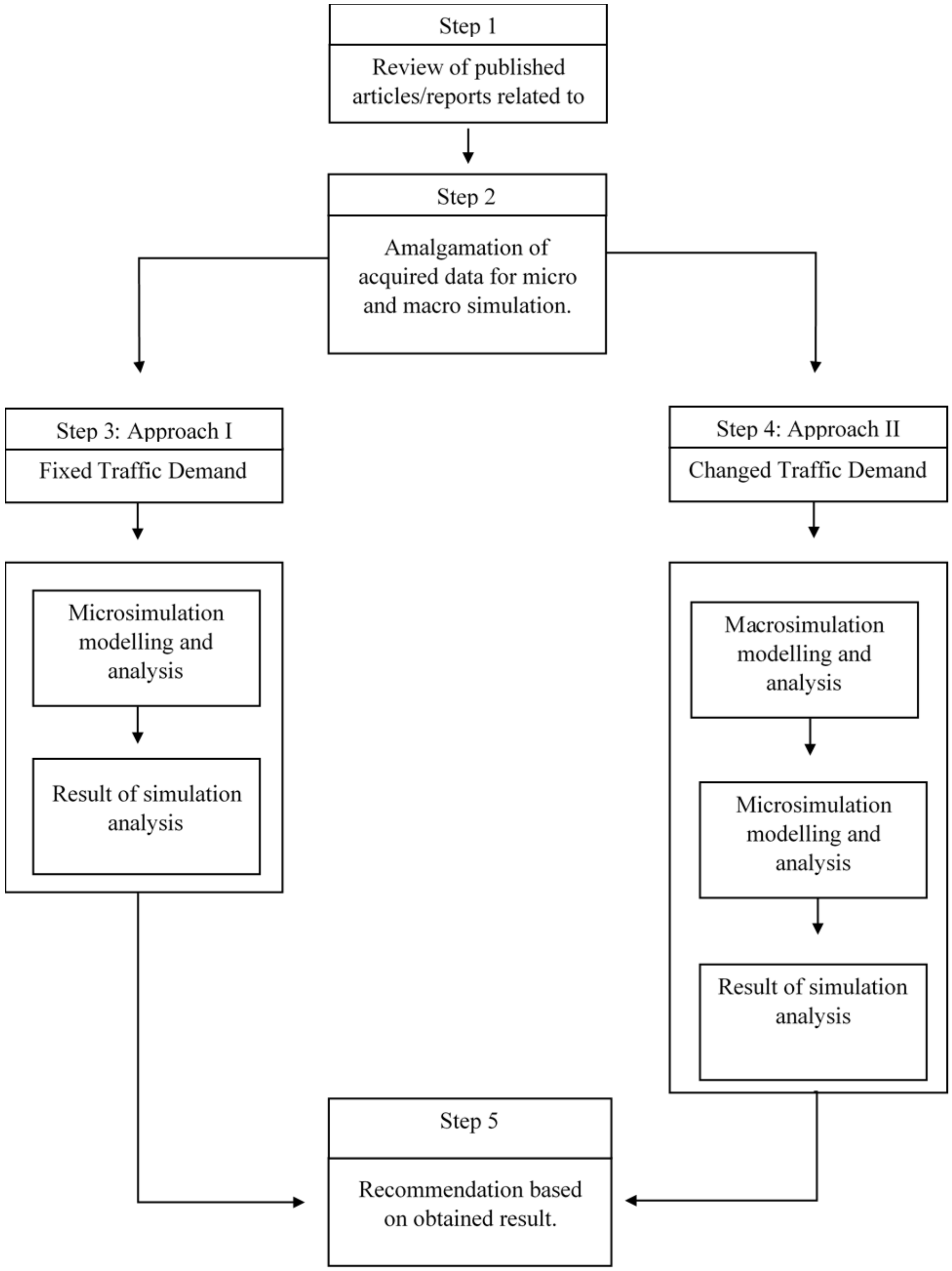


Figure 3: Research Structure

1.3. Anticipated Benefits of the Research

The results of this study are expected to help transportation authorities to identify potential ILU tactics for improving freight mobility along the two study corridors and possibly also along other corridors in the GTHA. Note that it is the first time that ILU tactics have been investigated on arterial roadways in North America as such tactics have been implemented elsewhere on freeways only. The study will help Regional municipalities in Ontario to improve mobility on urban arterial roadways. The research will also contribute to the growth of the economy in the region and indeed Canada by suggesting techniques that can improve goods movement.

Trucks occupying the middle lane often move more slowly than passenger vehicles and introduce safety challenges for passenger vehicles especially for the ones wishing to overtake slow moving trucks. Traffic can be affected for miles as passenger vehicles try to change lanes and manoeuvre past the trucks. This study does not focus on measuring safety impact, but the separation of lanes via ILU tactics is expected to enhance traffic safety particularly for passenger cars.

1.4. Research Scope

The scope of this research is limited to estimating the impact of various ILU tactics in terms of improving travel times along the two study corridors. The study's main focus is on freight mobility, but the study also considers travel time changes for passenger vehicles.

The study focuses on Derry Road (9.22km) in Mississauga, ON and Highway 50 (11.02km) in Brampton, ON. These two corridors have major truck flows and are two of the most popular truck routes in the GTHA. As both study corridors pass through established urban areas (where widening for truck lanes would not be considered), this study considers specific ILU tactics that do not require substantial cross-sectional design changes. As a result, the ILU tactics investigated are limited to using an existing lane (e.g., the innermost or outermost lane) and no new lane construction is assumed. In addition, the truck only lane tactic was not implemented on the center lane of the study corridors as there are high chances of conflict with other types of vehicles while making lane changes near intersections where trucks can move into other lanes to make turning. The study considers both directions of traffic but investigates only one lane per direction for ILU tactics.

1.5. Structure of Thesis

This thesis contains in seven chapters. In **CHAPTER 2:** Literature Review, the results of an extensive literature review are presented in order to provide a basic information of Intelligent Lane Utilisation, their types, benefits and impediments. In **CHAPTER 3:** Study Data, the data used in this thesis is discussed in detail and information is provided on the Region of Peel study area located in Ontario, Canada. In **CHAPTER 4:** Macrosimulation model development the, EMME software parameters and the scenarios developed in the model are explained in detail. **CHAPTER 5:** Microsimulation model development the VISSIM software parameters and the model's calibration and Validation are discussed, along with this the scenarios developed in the model are explained in detail. In **CHAPTER 6:** Result of Simulation Analysis; the results from both the software's used for the analysis are discussed in terms of measure of performance. **CHAPTER 7:** Conclusion and Recommendations, the key findings of this thesis are summarized and recommendations for future technical and policy research are provided.

CHAPTER 2. LITERATURE REVIEW

Chapter 2 reviews studies published by government agencies, scientific journals and conference papers discussing the problems faced by trucks in relation to congestion (i.e., increased travel time) and possible solutions. This chapter discusses ILU tactics and the macro- and microsimulation models and their roles in the analysis of ILU tactics.

Section 2.1 discusses ILU for all vehicle types (cars, transit, carpools, taxis and/or trucks. Section 2.2 considers seven ILU tactics used. Section 2.3 discusses ILU tactics exclusively for trucks and includes both urban and rural settings. Section 2.4 discusses the macrosimulation and microsimulation approach for analysis.

2.1. Intelligent Lane Utilisation

The definition of ILU may vary from one agency to another. It can be explained as a dedicated lane for a particular transportation type of vehicle (e.g., buses or high occupancy vehicles (HOV)) separated from general-purpose lanes. The dedicated lanes provide a facility by which operations can be managed according to growing and changing needs. Management strategies include access control (Express lanes and Reversible lanes), vehicle eligibility (e.g., HOV lanes, truck lane restrictions, and off-peak use of HOV lanes by non-HOV vehicles) and varying pricing schemes for different vehicle types (Chrysler, 2016; FHWA, 2017). In general, these strategies are applied to manage travel demand for a better traffic flow as separate traffic streams can reduce traffic flow turbulence.

Figure 4 shows how access control, vehicle eligibility and pricing strategies can be implemented as part of ILU tactics (Texas Department of Transportation, 2020). On the left of the diagram are the three individual ILU strategies. The right on the diagram shows how more complex facilities can blend more than one of the strategies. **Figure 4** depicts that, as x-axis moves the lane management strategies are being added. For example, express lane considers access control only whereas busways considers both vehicle eligibility and access control. The multifaceted lanes considers three aspects (access control, vehicle eligibility, and pricing) altogether.

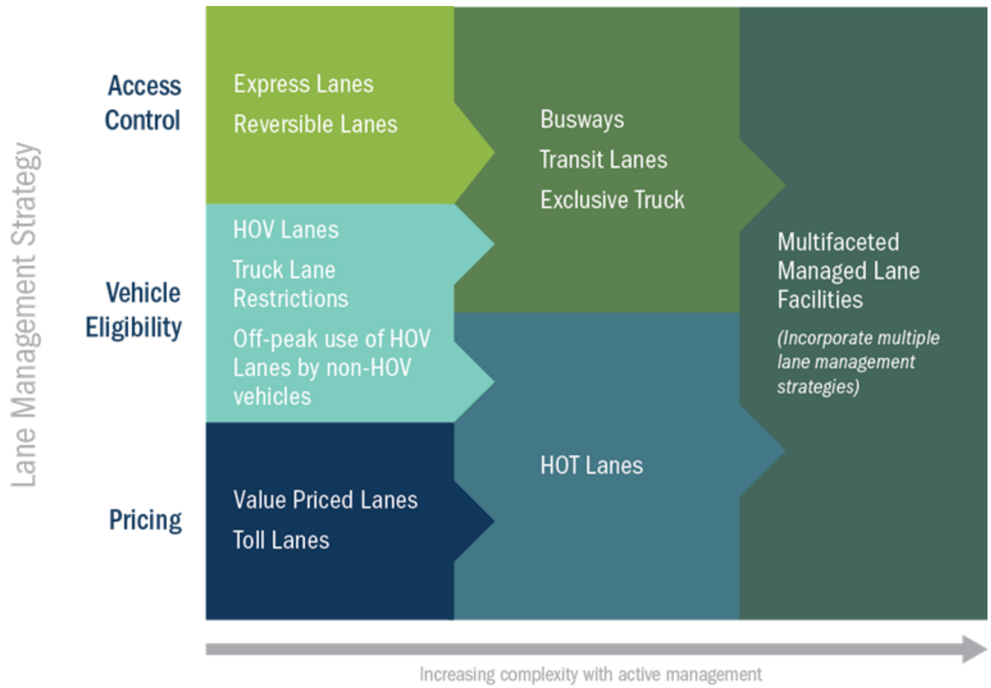


Figure 4: Intelligent Lane Utilisation Techniques (Texas Department of Transportation, 2020)

According to the FHWA (2008), ILU tactics are "highway facilities or a set of lanes where operational strategies are proactively implemented and managed in response to changing conditions of traffic flows." ILU tactics enhance the efficiency of roadways with the combination of various operational and design level adjustments. The key objectives of the ILU tactics are:

- the reduction in traffic congestion by increasing lane capacity;
- the savings of travel time and the production of more reliable trip times; and
- the improvement in air quality by reducing congestion which in turn reduces emissions.

The ILU concept has been also applied to maintain desired speed and to minimize lane change frequency along freeways and arterials (Moriarty and Langley, 1998; Wang and Liu 2005).

Increase in vehicle miles with limited expansion of roadway raises the possibility of serious traffic congestion. ILU tactics increase operational flexibility so that traffic operations can be managed efficiently over time as needs change. ILU tactics also improve mobility by providing viable travel options in congested corridors (FHWA, 2008).

2.2. Typical Intelligent Lane Utilisation Tactics

This section discusses seven ILUs: 1) High Occupancy Vehicle lanes, 2) Toll lanes, 3) High Occupancy Toll lanes, 4) Exclusive lanes, 5) Reversible lanes, 6) Temporary use of shoulder lanes, and 7) Multifaceted managed lane facilities.

2.2.1. High Occupancy Vehicle (HOV) Lanes

High-occupancy vehicle lanes provide a dedicated lane to vehicles with at least two passengers as an incentive to reduce the number of vehicle trips. The lanes are mostly used during peak travel hours when congestion is severe, and the time savings compared to the general travel lanes are the most significant (David Schrank & Tim Lomax, 2005). HOV lanes usually provide preferential treatment for transit, vanpools, carpools, and/or other designated vehicles by providing dedicated lanes for the designated vehicles to use (MTO,2020). The concept of HOV lane is to increase vehicle occupancy and allow more efficient movement of passengers. Most HOV facilities are a single lane adjacent to the general-purpose lanes. Some are separated from other traffic (FHWA, 2008). The City of Toronto's (2020) HOV network on arterials includes (but is not limited to):

- Don Mills Road/Overlea Boulevard/Pape Avenue - between Finch Avenue East and Danforth Avenue (27.2 km);
- Dundas Street West - between Etobicoke Creek and Aukland Road (5.0 km);
- Eglinton Avenue East - between Leslie Street and Cedar Drive (22.6 km); and

- Yonge Street - between Steeles Avenue and Bishop Avenue/Hendon Avenue (3.6 km).

The New Jersey turnpike has inner lanes designated as HOV lanes during peak periods between Interchanges 11 and 14 (51 km). (Transportation Framework Study, 2011).

Applications of HOV lanes have shown that the lanes help to improve average travel speed and reduce delay during peak hours leading to improvements in the reliability of the transportation system (Xu L,2005; Lipnicky and Burris, 2010). According to Urban Mobility Report (2005), the average travel time of 19 lanes with severe congestion in Texas (lane locations were not mentioned) declined by 20% after HOV lanes were implemented. These HOV lanes carried one-third of the peak direction passenger load and provided significantly higher speeds and more reliable travel times for HOV travellers than for travellers in congested main lanes.

2.2.2. Toll Lanes

Toll lane strategies can be used both to manage demand and to generate revenue (FHWA, 2017). Toll lanes can have variable road tolls, i.e., higher prices under congested conditions (in terms of time and/or location) and lower prices for less congested conditions. Toll lane strategies are applied to reduce peak-hour traffic volumes and improve traffic flow condition. The success of a toll lane depends on the geographic location of the roadway. A toll lane may do little to reduce congestion if alternative routes and modes are poor but may provide significant reductions in congestion if transportation alternatives (such as ridesharing, transit and telecommuting) are relatively attractive in which case a modest fee may cause a relatively large mode shift (TDM Encyclopedia, 2019).

In Ontario, the 407 Express Toll Route (407 ETR, 2020) begins at the junction of the Queen Elizabeth Way (QEW) and Highway 403 in Burlington, and travels 108.0 km across the Greater Toronto Area (GTA) to Brock Road in Pickering. Another example is the I-95 Express Toll Lanes

(ETLs) in northeastern Baltimore where four new toll lanes (two northbound and two southbound) have been implemented on the 12.8 km between Baltimore City Line and White Marsh Boulevard. Four general purpose lanes in each direction continue to remain toll free (Maryland Transportation Authority, 2015).

The capacity of the roadway is fixed, but traffic demand fluctuates over time and may result in congestion as supply and demand change (Lindsey and Verhoef, 2000). Road pricing may influence travellers to change their route and travel mode, but congestion pricing necessitates setting tolls that match the severity of congestion, i.e., tolls that vary according to time, location, type of vehicle, and current circumstances (e.g., accidents or bad weather) (Vickrey, 1963).

2.2.3. High Occupancy Toll (HOT) Lanes

HOT lanes are often proposed as a compromise between HOV lanes and a toll road. These lanes are generally free for HOVs like transit vehicles and carpools, but single occupancy vehicles have to pay a toll (TDM Encyclopedia, 2019). Some other types of vehicle, for example, hybrid vehicles, motorcycles and registered carpools, can be exempted. This ILU tactic allows drivers on roads with HOT lanes have the option of using the free general-purpose lanes.

Examples of HOT lanes include the US-290/ Northwest Freeway which has single lane in each direction separated by a median for 21.7 km from the Katy Freeway (I-10). The I-15 Express Lanes in San Diego, CA are another example. Here, two lanes separated by a moveable barrier are used as HOT lanes for 25.7 km between state Route 78 in Escondido and State Route 163 (FHWA, 2010). The SR-91 Express Toll Lanes in Orange County, CA provide an example of tolling. HOVs (three plus people) are offered a congestion-free alternative for 16.1 km on the innermost two lanes in each direction (Transportation Framework Study, 2011).

HOT lanes generate revenue for the local and state agencies. The revenue is generally used for maintaining the infrastructure (Lindsey, 2010). In theory, this revenue can create broad welfare gains (Safirova et al., 2004).

It is thought that higher HOT prices suggest higher levels of congestion and greater time savings for motorists using the HOT lanes (Liu et al., 2011b; Janson and Levinson 2014), but this explanation assumes a very clear behavioral response to price. **Figure 5** shows a HOT lane.

Figure 5: HOT lanes (FHWA, 2020)

2.2.4. Exclusive Lanes

Exclusive lanes can be provided for selected vehicle classes, usually buses or large trucks. The lanes provide possible travel time savings for the selected vehicle classes (as compared to traffic using the general-purpose lanes) (Xu L,2005). Exclusive lanes for buses provide an incentive for riders by decreasing delay. Exclusive lanes for trucks attempt to improve safety by reducing conflict between truck traffic and passenger car traffic.

Dedicated bus lanes are reserved exclusively for buses, often on major arterials. An example exclusive bus lane in the GTHA is the bus lane along the Yonge Street and Highway 7 corridors (VIVA Next, 2020). VIVA transit is known as a Bus Rapid Transit (BRT). These lanes used largely by express buses that have fewer stops along the bus route. The implementation of exclusive lanes requires certain operational improvement (e.g., bus signal priority) and special designs for bus stations (e.g., a middle lane bus station). It should be noted that not all exclusive bus lanes in GTA are designed for BRTs. Busways may be considered a cost-effective alternative to subways or light rail and are being implemented by a number of cities. Advantages of busways include flexibility and low construction costs (Wolshon and Lambert, 2004)

State Route 60 in California has an example of an exclusive truck lane implemented to reduce congestion and improve traffic flow. The lane is on a freeway, at grade, and runs from the I-710 to I-15 (35.4 km) (Urban Transportation Monitor, 2004). Exclusive lane for trucks is discussed in 2.3.

A survey of interviews with representatives of state departments of transportation and the commercial truck and bus industry in United State noted that exclusive lanes for trucks and buses had been considered by 17 percent of the highway agencies, exclusive lanes for buses by 20 percent of the highway agencies, and exclusive roadways for heavy vehicles by 3 percent of the highway agencies. However, few projects had been implemented (Harwood et al., 2003). **Figure 6** shows an exclusive bus lane.

Figure 6: Exclusive Bus Lane (York Region, 2014)

2.2.5. Reversible Lanes

Reversible lanes are usually implemented when there is limited or no available space (right-of-way) for highway to be widened. The lanes help to increase the capacity of the roadway during the AM and PM peak hours. Reversible lanes can be separated by concrete barriers which help to prevent traffic conflict with opposing traffic. They may also be separated by plastic pylons and jersey barriers. Reversible lanes may lead to an increased number of lanes in one direction for part of the day and an increased number of lanes in the opposite direction for a different part of the day.

A reversible lane system operates in Toronto on Jarvis Street from Queen Street to Isabella Street during the rush hours. The centre lane caters to northbound traffic from approximately 3:45 pm to 6:30 pm Monday to Friday. The same lane caters to southbound direction at all other times (City of Toronto, 2020). The East RL Thornton Freeway in Dallas, TX, has 8.2 km of reversible lanes for HOVs. Vehicles save 9 minutes in the morning and 4.5 minutes in the evening. The Thornton Freeway HOV lane has double the person carrying capacity of a freeway main lane. Its implementation led to bus passenger volumes increasing by 38% and carpools increasing by 300% (NHCRP, 2016 and Bain, 2001).

Moveable barrier technology can be divided into two categories: temporary and permanent. Temporary applications of moveable barrier technology generally result from a need to undertake maintenance, repair or construction work on busy highways. Permanent applications are typically associated with HOV facilities and the barrier is typically moved twice a day (out of peak hours). A review of permanent installations of moveable barriers around the world sent detailed questionnaires to 11 highway authorities (in the USA, Brazil, Australia and New Zealand). The result showed that 50% were located on heavily trafficked, high-capacity expressways and the other 50% on bridges. The value of reversible lanes is their ability to cater to growth in unbalanced travel demand and direction (e.g., morning and afternoon peak period traffic) (Bain, 2001). The East R L Thornton Freeway in Dallas reversible lanes are a good example of flexibility: the barrier is moved four times a day. **Figure 7** shows the geometric configuration of a typical reversible lane showing the moveable barrier in reversible lanes.

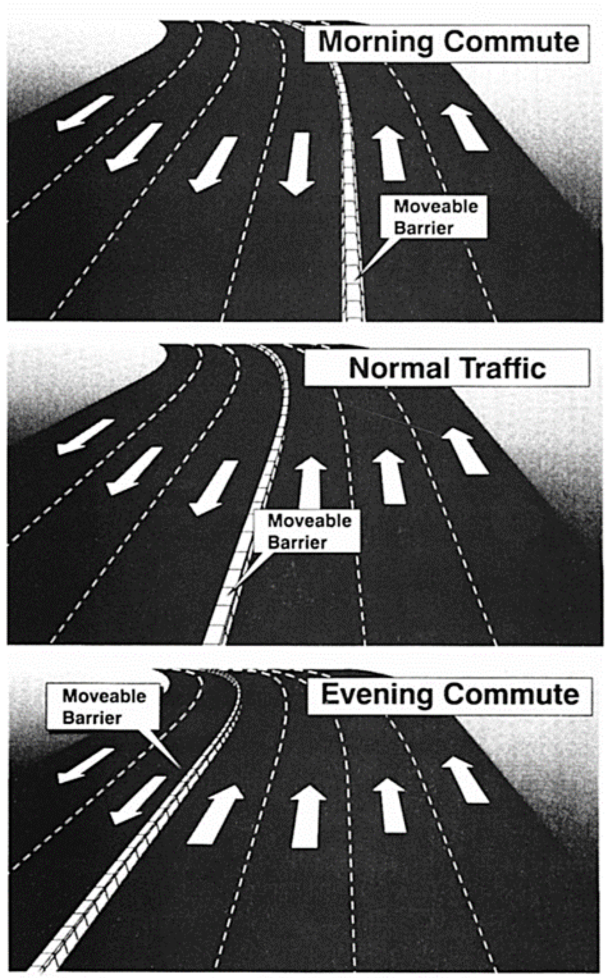


Figure 7: Reversible lanes (Bain, 2001)

2.2.6. Temporary Use of Shoulder Lanes

The right- or left-side shoulder lanes can be used as a dedicated lane for certain types of vehicle on a full- or part-time basis. The SR 29 in New Jersey, for example, has a part-time shoulder lane for cars travelling westbound during the morning peak period from Monday to Friday (FHWA, 2014). When a shoulder lane is used, there is no space for emergency stopping or for incident clearance. Outside the designated hours, the shoulder looks and operates like a normal shoulder (Washington DOT, 2007).

In some cases, shoulder use is restricted to authorized transit buses during peak hours. Montgomery County Maryland allowed temporary use of the shoulder lane by buses on a portion of US 29 to allow buses bypass queues at signalized intersections during construction work (FHWA, 2020).

A transit-only shoulder lane allows transit vehicles to use the shoulder under conditions and driving regulations specified to ensure the safety of the operation and all the freeway users (Kuhn, 2010). **Figure 8** shows a shoulder lane for buses.

Figure 8: Example of a bus shoulder lane (FHWA, 2020)

2.2.7. Multifaceted Managed Lane Facilities

Multifaceted managed lane facilities implement more than one type of ILU tactics simultaneously to achieve a high degree of operational benefits and flexibility (Florida DOT, 2020).

Figure 9: Multifaceted managed lanes (WSP, 2017)

Each lane of a roadway can be assigned a different purpose with different benefits. The example in **Figure 9** is on the SR-91 in Southern California. It includes an HOV lane, a toll lane, and normal lanes (WSP, 2017). Choosing this ILU tactic may reduce congestion for all vehicles by providing separate lanes for transit, licensed taxis and airport limousines to allow these vehicles to bypass congestion (TDM Encyclopedia, 2019).

The I15 Express Lanes in San Diego, California provides an eight-mile, two lane reversible facility from State Route 52 to State Route 56. The reversible lanes are separated from the main lanes by concrete barriers. Access is available only at the terminal. The lanes operate Monday through Friday southbound from 5:45 am to 11:00 am and northbound from 1:00 pm to 7:00 pm. The lanes originally operated as HOV lanes, but often had unused capacity. They were converted to HOT lanes for cars, but HOVs use the lanes free of charge (FHWA, 2004).

2.3. Exclusive Lane for Trucks

The ILU tactics discussed in Chapter 2.2 are for all vehicles on the roadway. This chapter discusses ILU tactics exclusively for trucks. ILU for trucks can be used to improve truck travel efficiency in both urban and rural areas. This is due to the daily and weekly travel time pattern for trucks and the passenger vehicles are different and it is obvious that the truck drivers prefer to avoid commuting periods with heavy passenger vehicle traffic. However, the truck drivers are limited as to when they can travel. The constraints are imposed by hours-of-service regulations, maritime terminal operating hours, neighborhood curfews and union-negotiated hours of operation, with the major constraint being the shippers hour in truck delivery time (Vilain and Wolfrom, 2001).

Trucks have been major source of revenue for a region hence the value of time for trucks is higher as compared to passenger car (Waters, 1993). Canadian trade volume extends to United States border. The mobility of freight movement across the border is vital for regional and national economies and cross-border business (Karim et al., 2009). Hence saving travel time for truck is considered to have more benefits as compared to saving travel time for passenger cars.

2.3.1. Truck Lane Restriction

Truck lane restriction is the most common approach to restricting trucks from using certain lanes (usually the left or centre lane) to improve roadway operations and reduce the number of collisions by reducing excessive lane changing, improving travel times, and reducing queue lengths and delays for passenger vehicles (Yang and Regan, 2007). Truck lane restriction increases the speed difference between cars and trucks on the roadway.

Truck lane restriction ensures that at least one lane can be used exclusively by other types of vehicle (e.g., passenger vehicles), but trucks restricted to a certain lane can use the other lane or lanes to overtake another vehicle and/or to enter or exit the section of roadway. Truck lane restriction can be designated for the full 24 hours or only for peak-hours depending on circumstances (FHWA, 2008).

Examples of truck lane restrictions on urban freeways include 15.7 km of the inner most lane of the I-10in Houston between Waco Street and Uvalde, 14.4 km of the IH 10 in San Antonio from Loop 410 to the IH 35, 127 km of the IH 35 in Austin from the Comal/Hays County line to the Williamson/Bell County line, and 19 kms of the IH 20 in Dallas from North Cedar Ridge Drive to the IH 45 (Texas A&M Transportation Institute, 2016).

Rahka et al. (2005) conducted a study of I 81 in Virginia using a traffic simulation model. The scenarios selected were related to the management of truck lanes and included extra lanes, truck-only lanes, physical separation of trucks, and the addition of climbing lanes. The objective was to investigate the efficiency and environmental and safety impact of each scenario. The maximum benefit for all three criteria was obtained when the trucks were restricted to the leftmost lane.

Hanscom (1990) conducted a study to evaluate the operational efficiency of truck lane restriction on multilane roadways. Three corridors were selected, two with three-lanes (trucks restricted from using innermost lane) in each direction and one with two-lanes (trucks restricted from using the outer lane) in each direction. The results showed that traffic congestion was reduced on the roadways with three lanes in each direction. The results were less reliable for the roadway for two lanes in each direction.

2.3.2. Truck Only Lanes

Truck only lanes are lanes that are designated for use by large trucks only. They are intended to improve operational conditions and alleviate congestion by separating slower-moving large trucks from faster-moving general traffic. The idea is not new, but it has been implemented only fairly recently and its application remains far more limited than truck lane restrictions (Fekpe, 2014). The approach is, however, becoming of much greater interest due to the recent challenges arising from increasing freight transportation activity.

In the United States, only a few states have implemented truck only lanes. In Los Angeles, CA, the northbound and southbound directions of the 1-5 at the State Route 14 split have truck only lanes. The lanes run 4 km in each direction and are designed to have trucks merge farther down to the general traffic at Route 99 (FDOT, 2015).

Other examples of truck only lanes include (Middleton et al., 2006):

- Intercity corridors (for example I-295 to I-95 in Jacksonville, FL for 14.9 km;
- General urban applications (for example, a 64 km truck lane on the I-75 from the Atlanta metro area to Macon); and
- Urban access routes to port and intermodal terminals (for example, the 29 km truck lane on the I-710 study in Southern California connects the Port of Long Beach and the Port of Los Angeles in the south to the SR-60 to the north and runs through 15 cities).

On the roadway, large trucks are limited to the outer lane while passenger vehicles are allowed to use the inner or outer lanes (FHWA, 2008). This may be because trucks are usually moving slowly due to heavy load as compared to the other traffic.

Truck only lanes can serve as an important step to improve congestion, these lanes do not only save travel time for trucks but also may save travel time for other traffic on the roadway. As passenger vehicles do not have to overtake trucks in passenger vehicle lanes, truck lanes can improve safety for passenger vehicles by, for instance, eliminating potential conflicts due to trucks' blind spots. In addition, trucks using a designated lane can travel as a fleet with tighter spaces between trucks and this may improve fuel efficiency (FindLaw, 2020). Truck lane design requires physical and or operational decisions regarding lane separation.

1. Physically Separated Truck Lanes

Figure 10 shows a roadway with two truck lanes and two general purpose lanes. In this case, the truck lanes are physically separated from the general-purpose lanes by a concrete barrier. Physically separated truck lanes require the construction of new lanes and/or the separation of existing lanes by concrete barriers, pylons, guardrails, grass medians, or grade separation.

Physically separated truck lanes provide a protected driving environment which helps to reduce the number of collisions between trucks and other vehicles by eliminating weaving and lane change interactions. Unfortunately, construction of physically separated truck only lanes is costly and access points are a major challenge as it is essential to minimize traffic flow disruption resulting from merging and weaving at access points. Physically separated truck lanes that impose a toll are known as truck only toll (TOT) lanes. The Lee Roy Selmon Expressway is an example of a TOT lane. The Expressway connects South Tampa near MacDill Air Force Base to Downtown Tampa and has toll lanes for 22.8 km (FDOT, 2013).

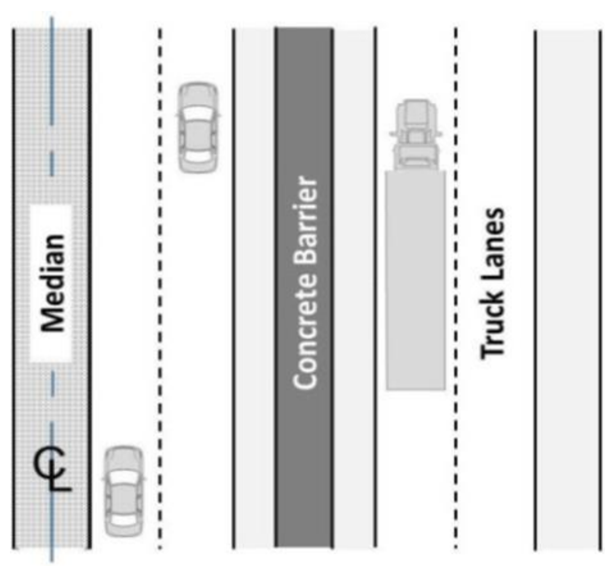


Figure 10: Physically Separated Truck Lanes (TAC, 2014)

2. Operationally Separated Truck Lanes

Operationally separated truck lanes refer to truck only lanes that are separated by rumble strips and/or appropriate paint striping and/or appropriate signage. This type of truck only lane is easy to design, inexpensive to construct, and relatively simple to remove if the desired effect is not achieved (TAC, 2014). Operationally separated truck lanes can encourage more trucks to use a roadway. If necessary, fees may be imposed creating a TOT lane. The toll can be imposed only during certain times of the day and with varying pricing options (HNTB Corporation, 2010).

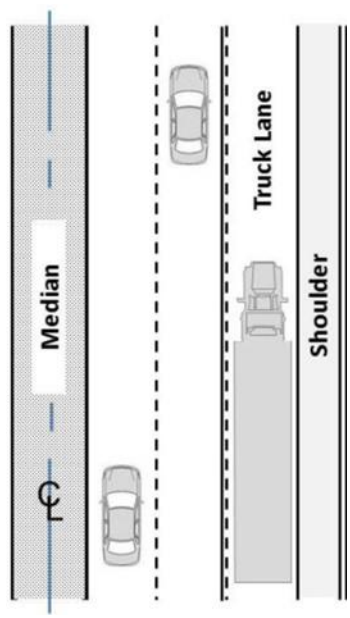


Figure 11: Operationally Separated Truck Lanes (TAC, 2014)

The I-680 Express Lanes in Alameda County, CA provide an example of operationally separated truck lanes. The lanes operate along a 22.5 km stretch of the I-680 from State Route 84 (south of Pleasanton) to State Route 237 (in Milpitas). The I-15 Express Lanes in San Diego, CA provide 32.1 km truck lane on State Route 78 in Escondido and State Route 163 in San Diego (CH2M Hill, 2012).

3. Physically Separated Truck Lanes versus Operationally Separated Truck Lanes

Factors affecting the type of separation selected for a truck lane include design specifications, cost, access, safety, congestion pricing operations, and public perception. The advantages and disadvantages of operationally and physically separated truck lanes are discussed by Georgia DOT (2010).

For operationally separated truck lanes, the advantages are:

- Inexpensive and fast to implement,
- Easy removal if unsuccessful, and
- Clear demarcation between lanes.

For operationally separated lanes, the disadvantages are:

- Lane separation easily ignored by driver,
- Frequent maintenance/replacement required for pylons, pavement marking and signage.

Georgia DOT (2010) noted that due to investment required to implement operationally separated lanes, operationally separated lanes are not well suited to HOT or a toll system.

For physically separated truck lanes, the advantages are:

- Improved safety for passenger cars due to the physical separation from trucks.

For physically separated truck lanes, the disadvantages are:

- Time required for construction,
- Possibility that vehicles will hit the concrete barrier and be damaged,
- Claustrophobia experienced by some drivers,
- General disbelief that such a complex and expensive system can be implemented.

Choice of physically or operationally separated truck lanes for study corridors

The two study corridors selected as this thesis's study roadways (Derry Road and Highway 50) pass through largely established urban areas in the City of Mississauga and the City of Brampton. As no additional right-of-way is available for adding an additional lane along either roadway, this study considers the application of operationally separated truck only lanes on the two study corridors.

2.4. Simulation Modelling Tools

Simulation models are a widely used tool for evaluating ILU tactics as analytical models cannot always solve real-world problems with varied and complex issues (Tuffin et. Al., 2007). This study uses two different levels of simulation modelling: 1) macrosimulation and 2) microsimulation. Different simulation models require different types of input and have different computational efficiency. Macrosimulation models are useful for evaluating network-wide transportation performance (e.g., traffic demand) associated with corridor improvements (e.g., adding lanes). Microsimulation models are useful for evaluating individual vehicles' travel performance (e.g., each vehicle's second-by-second travel trajectory) associated with different geometric or traffic control improvements. Successful implementation of ILU tactic requires using advanced modeling methods to achieve better assessment of the impacts of changes in traffic conditions and the impact of operation strategies. Simulation-based tools are most suitable for use in ILU modeling. These modelling tools make use of simulation to capture the dynamics of traffic flow in congested conditions (Shabanian, 2014). A variety of modeling approaches have been proposed to assess ILU technique implementations, these approaches range from high-level sketch planning tools or microsimulation modeling of individuals' behaviors and traffic operations (DeCorla-Souza and Whitehead, 2003; and Murray et al., 2001).

2.4.1. Macrosimulation

Macrosimulation models were originally developed to model traffic on distinct transportation sub networks such as freeway and arterial corridors, surface-street grid networks, and rural highways (Rodrigues, 2014). The models are mainly used as a transportation planning tool to forecast future peak-hour traffic volumes in future decades, the resulting traffic flows, and the impact of surface infrastructure improvements (Rodrigues, 2014). Macrosimulation models concentrate on estimating traffic volume at the aggregate level (i.e., the link level) (Brinckerhoff, 2006). The modelling relies on fundamental traffic flow relationships between speed, flow and density, and usually requires far less computational time than microsimulation (Alecsandru, 2006).

Macrosimulation models are not designed to estimate accurate traffic flow conditions for time periods of less than an hour, i.e., the models cannot be used for minute-by-minute or second-by-second analysis. The models are also not used to estimate lane the changing behaviour of individual vehicles in relation to changes in surface infrastructure. The simulation in a macrosimulation model occurs on a section-by-section basis rather than tracking individual vehicles (DOT California, 2014).

Various macrosimulation tools are popular in North America. They include TransCAD, CUBE, VISUM, and EMME (Heyns & Jaarsveld, 2017). This study uses EMME because EMME provides a very flexible modeling environment and uses efficient data handling procedures. All the data related to a transportation network's functional form and parameters and estimated travel demand are stored in the unified EMME database. EMME includes several additional useful features such as a matrix editor and powerful macro language (Mily Parveen, 2003). **Figure 12** shows a snapshot of EMME software.

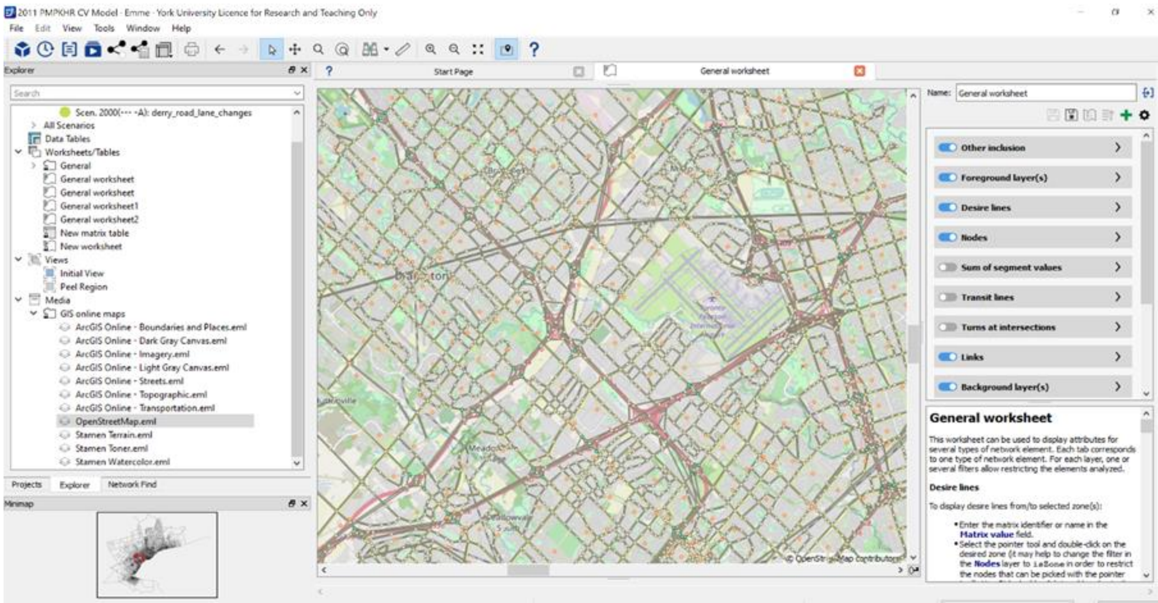


Figure 12: Snapshot of EMME software

EMME can estimate the potential impact of surface improvements associated with physically separated truck lanes or operationally separated truck lanes by changing link attributes accordingly. The software can also evaluate different ILU tactics such as the impact of varying tolls on truck only lanes (although this particular tactic is outside the scope of this thesis).

Past studies have used macrosimulation to accurately estimate traffic conditions (e.g., travel speed) as a function of different levels of demand brought about by different traffic demand management strategies including congestion pricing and managed lane tactics (FHWA, 2008). Shalaby (1999) used the TRANSYT-7F simulator to examine changes in performance measures of through buses and adjacent traffic following the introduction of reserved lanes for buses in an urban arterial in downtown Toronto.

Toledo et al. (2017) conducted a study on a real-time simulation-based control framework to determine the effect of different toll rates. They used a macroscopic simulation model to predict resulting flow conditions. The researchers obtained predicted travel times from a traffic flow model and iterated the model's travel time information until consistency.

2.4.2. Microsimulation

Microsimulations model detailed traffic characteristics, roadway network characteristics, and driving behaviour using hypothetical traffic and roadway scenarios. It is often more straightforward and cost-effective to investigate different traffic condition scenarios using microsimulation instead of direct observations of real-world traffic and roadway conditions especially as simulated traffic and roadway conditions may not even exist in the real world (Jayakrishnan, Cortes, et. al., 2003). Microsimulation models can respond to different operational level traffic control tactics and produce accurate measures-of-effectiveness (MOEs) that include capacity, queue length, delay in time, level-of-service (LOS), etc (Chien and Liu, 2002). The models are highly flexible. For example, they can: analyze different traffic behaviours (e.g., different speeds and travel times) for each separate lane of a segment; estimate separate results for passenger vehicles, transit, trucks, etc: and analyze traffic and transit operations for various lane configurations, vehicle compositions, traffic control strategies (Beacher, et. al., 2005).

Many microsimulation models are available. They include CORSIM, PARAMICS, VISSIM, AIMSUN, etc (Heyns & Jaarsveld, 2017). PTV VISSIM (hereafter VISSIM) was chosen for this thesis. The model can evaluate the impact of the selected ILU tactics for trucks. VISSIM generates many traffic measures including speed, density, travel time, and delay. The software's detailed travel behaviours are based on a car-following model developed by Wiedemann (Park and Qi, 2005). **Figure 13**Figure 13 shows a snapshot of the network developed using VISSIM software.

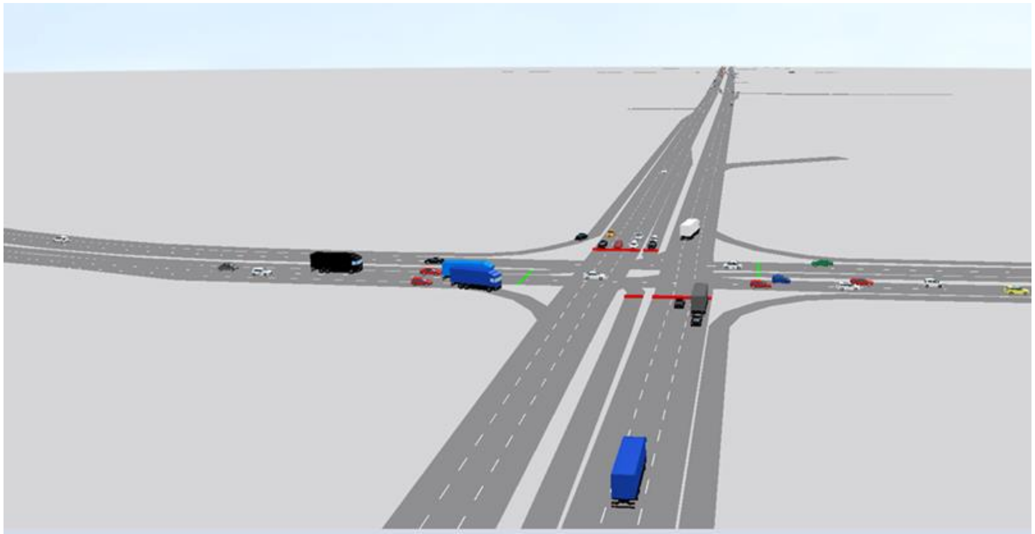


Figure 13: Snapshot from VISSIM Software (Network built for this study)

Kim (2019) conducted a study to evaluate the potential impact of truck-only lanes on fuel consumption and emissions on Interstate 75 between Atlanta and Macon, GA. The study's results suggest that truck-only lanes could significantly improve traffic flow and reduce energy and emissions. Zhang et al. (2009) used VISSIM to evaluate specific toll pricing schemes. Michalaka (2012) used an enhanced version of CORSIM to estimate the impact of HOT. The study developed three major modeling components (pricing strategies, a lane choice module, and toll structures for multisegmented facilities) to simulate HOT lanes. Michalaka concluded that the CORSIM enhancements successfully captured the primary characteristics of HOT lane operations and management and that the study's method could be used to analyze another HOT lane project.

Various studies have used traffic volume as a performance measure to explain the distribution of vehicles especially in uncongested traffic conditions where the distribution of the vehicles is based mainly on total traffic flow (Amin and Banks, 2005; Hurdle et. al., 1997; Yang et. al. 2008; Hong and Oguchi, 2008; Smith and Conklin, 2002). The studies generally found that lane usage is closely related to capacity and safety. Lane usage is also an informative factor for understanding lane-by-lane variations for microscopic traffic simulation models (Banks 2006).

Garber and Liu (2007) investigated the impact of truck lane restrictions. They used average speed and density as their performance measures. The study showed a tendency for unrestricted lanes to have a lower average speed and a higher density. The study also found that an increase in traffic or an increase in truck percentage leads to a decrease in average speed. The results were statistically significant at the 90% confidence level using an ANOVA test (Garber and Liu 2007). El-Tantawy et al. (2009) used the same approach to access truck lane restriction and a truck only lane in downtown Toronto.

Macro and microsimulation models have been developed for bus lane priority studies (Waterson et al., 2003; Liu et al., 2006). The studies used a combination of macro and micro approaches to model issues such as travel behaviour, modal shift, trip suppression, bus rerouting, and bus retiming. The results suggest that the effects of bus priority measures depend as much on the characteristics of the local travellers as on characteristics of the bus priority measures. The macrosimulation models were used to provide accurate estimates of the effects of the priority bus lanes on traffic flow, and the microscopic models were used to study vehicle interactions and the individual characteristics of each traveller.

Ghariani et al. (2015) used EMME to forecast traffic volumes and determine the level of traffic infiltration in the City of Pickering and the Town of Ajax for five scenarios. The five scenarios were 1) curbside bus-only lanes, 2) High-Occupancy Vehicle (HOV) lanes, 3) mixed traffic lanes, 4) median transit ways, and 5) do-nothing. EMME was used to forecast traffic volumes at different horizon years along major corridors in the study area, and VISSIM was used to assess the effects of the different scenarios in the areas in the vicinity of the major corridors.

Ghariani et al. concluded that a hybrid approach using macroscopic and microscopic simulation was feasible on a large-scale network is feasible if the model is well calibrated. The researchers also noted that such a study should undertake numerous simulations runs.

The study conducted for this thesis uses both macrosimulation and microsimulation. The macrosimulation model is used to obtain changes in traffic volume on implementation of ILU tactics, and the microsimulation model is used to analyse which ILU tactic is most beneficial when travel volume is unchanged and when travel volume changes due to implementation of the ILU tactic.

2.5. Chapter Summary

This chapter discussed various literatures studied on topics relating to this study. Freight transportation has been extensively studied within past years. There have been many complications and issues pertaining to management of truck volumes on Canadian roads, hence many studies have been performed to provide a solution for these issues. The simultaneous use of lanes by trucks and general traffic gives rise to various safety & efficiency concerns owing to the large size and slow speeds of trucks. From various literatures, one approach to tackle this problem is to provide separate lane(s) for trucks to reduce truck and general traffic interaction. Separating trucks from general traffic could be done by physical or operational implementations. Literature showed that physical separation is expensive and requires various resources whereas operational separation has been found to be easy to implement, hence this thesis mainly focuses on operational separation of truck lanes. This thesis thus focuses on two special provisions, truck only lanes and truck lane restrictions.

Various literatures were reviewed to study the methods to implement the above-mentioned provisions. Studies based on macro & microsimulations have been extensively studied and discussed in the respective sections of this chapter. Microsimulation is used for a detailed analysis and can only be effectively applied over a short span. It is mainly used to study the vehicular interaction and other parameters such as Level of Service (LOS) and queue length. Alternatively, macrosimulation is mainly used for a larger study area. Macrosimulation gives general results in terms of traffic volume and travel time for a region/city. This thesis focuses on both of these approaches to observe overall effects of operationally separated truck lanes on an intersection level as well as the whole corridor.

CHAPTER 3. STUDY AREA AND DATA

This chapter discusses the study area and data resources used in this thesis. The macrosimulation analysis, for instance, requires the origin and destination (OD) matrix which is used to establish vehicle demand and the travel time matrix between zones in the study area. Actual travel times, signal timing, and traffic volumes are required to perform the microsimulation on the selected corridors.

3.1. Study Area

According to 2016 census data, Ontario's Greater Toronto and Hamilton Area (GTHA) is approximately 8,244 square kilometers with a population of approximately 7.0 million and approximately 3.4 million jobs (City of Toronto, 2017). An efficient roadway network that minimizes traffic congestion and delay is clearly vital.

The GTHA is subdivided into six municipalities: The City of Toronto, the City of Hamilton, and the Regional Municipalities of Halton, Peel, York and Durham. There are 2,272 traffic zones within the study area, 405 of which are in Peel Region (City of Toronto, 2017). The study area covers the Peel Region in Ontario, Canada. Peel Region is located west of the City of Toronto and consists of three municipalities: the City of Mississauga, the City of Brampton, and the Town of Caledon. In 2014, approximately CAD 1.8 billion worth of freight was transported through the Peel Region daily. This has contributed CAD 49 billion to the Region's economy and accounted for 43% of all employment in the Region (Peel Region, 2015).

Peel Region plays an important role in the Greater Golden Horseshoe area. Metrolinx (2011) conducted a commercial vehicle survey to gather information from 106 sites on Ontario highways and border crossings. They collected information about the trips, commodities, vehicles, companies and drivers of vehicles with a gross minimum vehicle weight of 4.5 tons. The results showed that 58% of commercial vehicle trips on Ontario highways in 2006 had an origin or destination in the Greater Golden Horseshoe area and 42% of commercial vehicle trips had both their origin and destination in the area. **Figure 14** shows the Peel Region as well as the two corridors that passes across Brampton and Mississauga. The red box indicates approximately 5 km vicinity to the study corridors. These two study corridors are analysed for both the approaches.

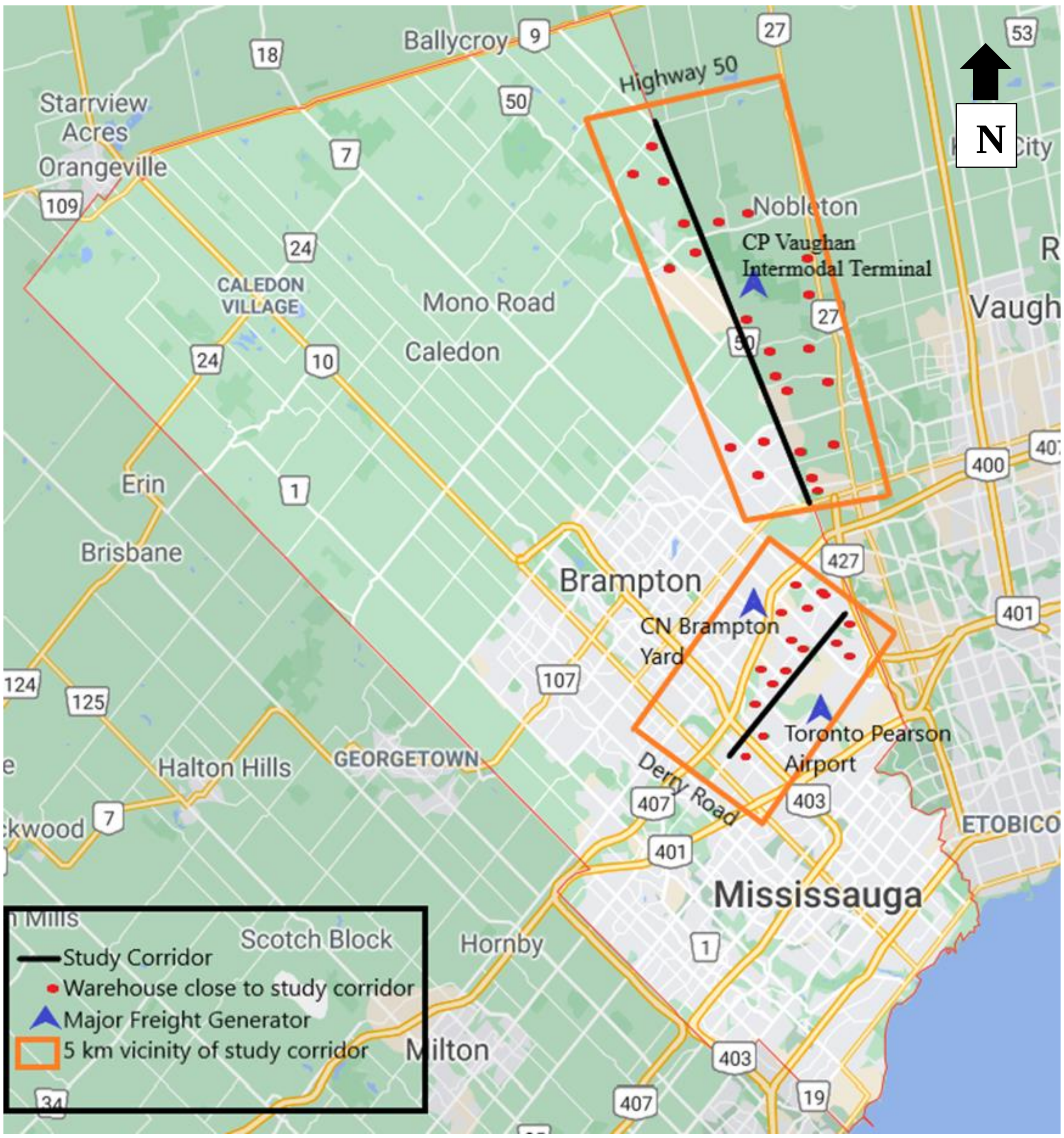


Figure 14: Study Corridors

Derry Road is a major south west - north east arterial in Mississauga. It passes Toronto Pearson International Airport and crosses Highway 410 near the 410/407 interchange. Derry Road passes many City of Mississauga's major distribution centres including Metro Supply Chain Logistics group, Purolator, Matrix logistics Service, and Wayfair Warehouse all located within 1 km of Derry Road.

Highway 50 is a major south east - north west arterial in Brampton. The highway passes Canadian Pacific (hereafter CP) Vaughan Intermodal Terminal, an Amazon Fulfilment Centre, FedEx Ground Terminal, DHL Supply Chain, and other logistics company warehouses in Brampton.

Derry Road and Highway 50 were selected as the target study corridors because they carry substantial (more than 15%) daily truck volumes (AADT,2011) and provide connections to the nearby freeway network (especially Highways 410, 403, 407, and 401) and to other major arterials (e.g., Airport Road, Dixie Road, Castlemore Road and Nashville Road). This study will use these two corridors as the target study corridors.

3.1.1. Derry Road

Figure 15 shows the section of Derry Road selected as the study corridor. The corridor runs for 9.22 km from Kenderry Gate in the south west to Rexwood Road in the north east. **Figure 15** also shows the 16 signalized intersections and three unsignalized intersections along the study corridor.

Figure 15: Derry Road

The road has three lanes in each direction and the average distance between two signalized intersection is 0.79 km. According to Google Earth, all intersections have dedicated left turn lanes except the intersection at Hull Street. Dixie Road, Bramalea Road, Torbram Road, and Airport Road have direct exits to Toronto Pearson airport. The entrance and exit ramps for Highway 410 between Kennedy Road and Tomken Road allow major truck traffic from Highway 410 to use Derry Road to reach the airport, the CN Brampton yard and other major distribution centres.

3.1.2. Highway 50

Figure 16 shows the section of Highway 50 selected as the study corridor. The corridor runs for 11.0 km from Parr Boulevard in the north west to Huntington Road in the south east. Figure 16 also shows the 11 signalized intersections and three unsignalized intersections along the study corridor. The average distance between two adjacent signalised intersections from Queen Street to Castlemore Road is 0.73 km, and 1.25 km from Castlemore Road to Mayfield Road.

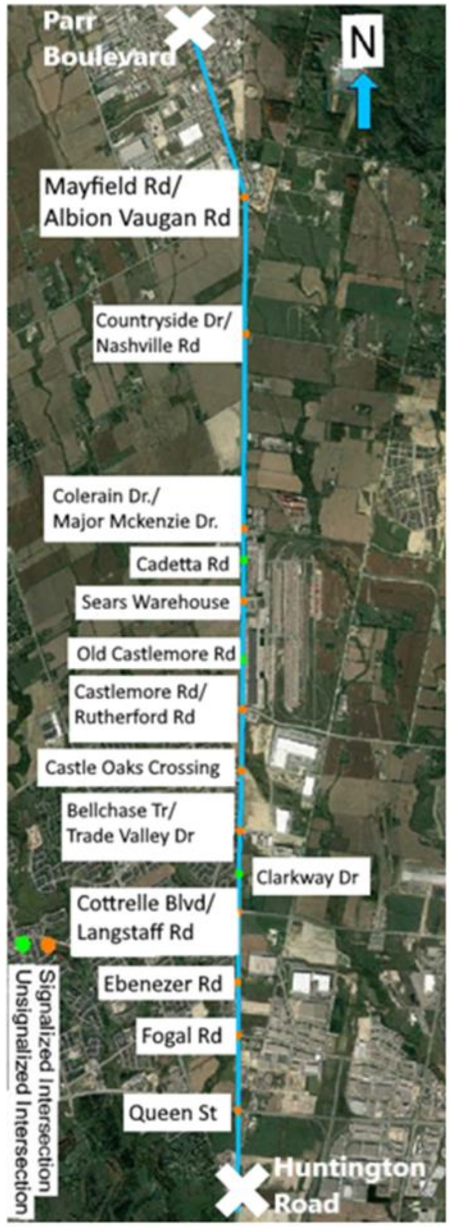


Figure 16: Highway 50

From Mayfield Road south to Sears Warehouse, there are two lanes per direction. There are then three lanes each direction from Sears Warehouse south to Queen Street. According to Google Earth, all intersections have dedicated turning lanes. From Castlemore Road to Queen Street the corridor is very busy with major warehouses close to the roadway. Further north at

Nashville Road, the CP Vaughan Intermodal Terminal plays a prominent role in freight movement in GTHA and has attracted many logistics companies to the area.

3.2. Input Data for Macrosimulation

The major input data required for EMME modelling include: 1) Route ID, 2) Nodes, 3) Segment Length, 4) Speed, 5) Volume-delay Function (vdf), and 6) Lane Capacity. The outputs are Travel Time and Traffic Volume.

Peel Region supplied the 2011 PMPKHR CV models (in EMME) for the GTHA. The 2011 EMME data consist of three scenarios: 1) PM peak hours commercial vehicle model, 2) 14-hour commercial vehicle model (to calibrate and validate the model), and 3) passenger + commercial vehicle model for AM (6:30 am to 9:30 am) and PM peak hours. The trips for the PM model were recorded between 3:00 pm and 6:00 pm (3 hours).

The model was structured according to the methodology discussed in US Federal Highway Administration (FHWA) Quick Response (QR) freight manual. QR methodology uses the parameter and general structure from other jurisdiction and is generally employed when there is limited data for estimation of a model. It consists of three stage: trip generation, distribution, assignment. Turn penalty was not considered in this model. For this study impedance parameter was calibrated against Cordon Count Data from region of peel ATR and Cordon count data obtained from the data management group of the University of Toronto. Also, the QR method was used to synthesise internal trips, long distance trips were drawn from Commercial Vehicle Survey (CVS). For trip generation purpose local truck trips based on Population/Employment data was taken and was assumed to be same for both the origin and destination. The adjustment factor was developed by applying the combination of factors including regional/municipality specific factor, a land use classification factor and screen lines count calibration factor Region of Peel have higher trip rates for heavy truck and overall second highest rate which also shows the adjacent regions of Toronto and York having higher truck traffic adding up their traffic here.

Gravity model was used for trip distribution purpose and model parameter was from QRFM. The estimated parameters varied by truck class hence showing sensitivity to travel time. The results were favourable though; it overestimated trips ranging between 5-10kms and underestimated the trips above 50kms. The 14-hour trip assignment used a standard multiclass assignment in EMME, this assignment was approximate. Results showed majority of the screen lines close to unity, hence good result. For this assignment they scaled the 14-hour model and then adjusted to account the directionality pattern. The results were like the 14-hour assignment model. The use of a 14-hour time period is necessitated to calibrate and validate the model. Prior to integration with the passenger vehicle model, 14-hour truck trip matrices were converted to a.m. and p.m. peak period matrices. The p.m. peak period matrices were used for this study.

The models provide data for 2011 and for two forecasted years (2031 and 2041). The 2031 and 2041 EMME models consist of all the 2011 scenarios and the 14-hour passenger + commercial vehicle model for each scenario.

Each EMME model has 20,365 nodes, 384 defined node attributes, 62,000 links, and 22 defined travel modes. The models use 2,272 zones, 405 of which are in Peel Region. Trips to and from municipalities outside of the GTHA areas were assigned as external zones, there are 31 in total. in traffic volume unlike microsimulation which was performed to collect travel time as a result.

The turn functions were not included in the model to reduce times when vehicles approach intersections. **Eq. 1** is Volume-Delay Function (VDF) which is the fundamental component of equilibrium trip assignment models.

$$fd_i = \left(\frac{length \times 60}{ul2_i}\right) \times \left(\left(\frac{1 + (volau_i + volad_i)}{lanes \times ul3_i}\right)^4\right)$$

Eq. 1

Where,

ul2 is speed,

ul3 is capacity per lanes,

volau is auto volume,

volad is additional volume.

The EMME model defines 22 modes of transportation including long rail transit (LRT), HOV 2+, HOV3+, walk, transit, light truck, medium truck, and heavy trucks. The Commercial Vehicle (CV) model runs after the passenger model, i.e., the different vehicle classes are not assigned simultaneously. The model assigns all vehicle classes under the general auto mode “c” for passenger cars. When the CV model’s run is finished, the CV model is integrated with the passenger model. The models provide an OD matrix for light, medium and heavy trucks for 2011, 2031 and 2041. As our study’s base year is 2016 (following discussion with Peel Region), we developed a 2016 dataset for the road network and OD matrices. This dataset was based largely on the 2011 and 2031 EMME datasets. To develop the OD matrix for 2016, we used linear interpolation. We considered four modes: passenger car, light truck, medium truck and heavy truck.

Attributes such as length of the link, speed, capacity and vdf etc. available for the original roadway network were used as reference for the new lanes added to the network. To calculate travel times between origins and destinations, we used a function representing the relationship between link delays and link flows. OpenStreetMap, which is embedded in EMME, was used to find the exact location of our two study corridors.

3.3. Input Data for Microsimulation

A microsimulation exercise requires data for 1) Route ID, 2) Segment Length, 3) Speed, 4) Traffic Signal data, 5) Detectors, 6) and Vehicle turning movements. The outputs from microsimulation include Travel time, Level of Service and Emissions. This thesis focuses on travel time. Average speed data were obtained for the PM peak hours (3 pm - 6 pm). The study performed analysis for an hour traffic volume between 4 pm and 5 pm.

The Peel Region supplied Synchro Network files containing 2016 PM peak hour traffic volume and traffic turning movement data for all intersections in the two study corridors. The Synchro data also contained the truck percentages and signal phase information for each signalized intersection along the two study corridors. These datasets were used as main inputs for the development of VISSIM microsimulation model.

Table 1 shows total hourly traffic volume (each direction), the number of trucks and the truck percentage passing through the six major intersections on the Derry Road study corridor. Truck traffic accounts for 38.9% of total traffic at the six intersections. The intersections at Dixie Road (4,054 trucks in 7,767total traffic) and Tomken Road (4,724 trucks in 8,586 total traffic) have the most truck traffic due to the Highway 410 ramps on Derry Road just south of the Tomken Road intersection.

Table 1: Total Traffic, Number of Trucks and Truck Percentage for Major Intersections on Derry Road

Intersection	Total Hourly Traffic Volume	Number and Percentage of Trucks			
		SB	WB	NB	EB
Goreway Road	4,971	375 (7.55%)	312 (6.27%)	162 (3.25%)	363 (7.30%)
Airport Road	6,723	556 (8.27%)	715 (10.63%)	325 (4.84%)	643 (9.57%)
Bramalea Road	4,723	460 (9.74%)	345 (7.30%)	75 (1.58%)	368 (7.80%)
Dixie Road	7,767	1065 (13.71%)	855 (11.01%)	906 (11.66%)	1228 (15.81)
Tomken Road	8,586	1472 (17.14%)	671 (7.81%)	1084 (12.63%)	1497 (17.44%)
Kennedy Road	7,012	577 (8.23%)	503 (7.18%)	463 (6.60%)	458 (6.53%)

Table 2 shows total hourly traffic volume (each direction), the number of trucks and the truck percentage passing through the six major intersections on the Highway 50 study corridor. Total traffic at the Highway 50 intersections is lower than at the Derry Road intersections. The truck traffic on Queen Street, Fogal Road and Langstaff Road is significantly higher than rest of the intersections. For example, Fogal Road intersection has very much more truck traffic (2,158) than do the other intersections (which average 1,077).

Table 2: Total Traffic, Number of Trucks and Truck Percentage for Major Intersections on Highway 50

Intersection	Total Hourly Traffic Volume	Number and Percentage of Trucks			
		SB	WB	NB	EB
Queen Street	3,736	519 (13.89%)	279 (7.46%)	170 (4.54%)	294 (7.86%)
Fogal Road	4,577	665 (14.54%)	359 (7.85%)	710 (15.51%)	424 (9.27%)
Langstaff Road	3,300	452 (13.69%)	58 (1.77%)	469 (14.20%)	41 (1.24%)
Bell-Chase Road	4,059	390 (9.61%)	213 (5.24%)	499 (12.30%)	266 (6.56%)
Rutherford Road	4,994	389 (7.78%)	291 (5.83%)	489 (9.79%)	100 (2.00%)
Mayfield Road	3,345	104 (3.10%)	119 (3.55%)	137 (4.10%)	106 (3.08%)

This study used the Bing Map embedded in VISSIM to develop the VISSIM network. The Bing map was used, for example, to establish the starting point of a tapered lane and to estimate the turning radius at an intersection.

According to the traffic signal parameters provided in the Synchro database, the two study corridors use the Ring Barrier Signal Control (RBC) system. The Synchro database included phase numbers, direction of movement, minimum pedestrian walking time, green time, amber time, all red time, and total time (i.e., green + amber + red). The database also included split information, cycle length information, signal offset information, and whether an intersection was controlled locally or by semi-actuated mode. Additional data included which direction signal was coordinated with the lead/lag phase.

The study considered signal timing plan to obtain maximum traffic flow. All this information was used in the VISSIM microsimulation to replicate the existing signal timing plan and develop the Ring Barrier Controller (RBC)file for each intersection. A ring barrier signal control organizes phases by grouping them in a continuous loop (or ring) and separating the conflicting traffic streams with time between when they are allowed to operate. This is done by either making the movements sequential or adding a barrier between the movements. The ring identifies phases that may operate one after another and are typically conflicting phases organized in a particular order. For instance, it may be desirable to separate the traffic traveling through the intersection in the northbound direction from the southbound left turn movement. A change interval and clearance time is used to separate that movement in time (FHWA, 2017).

3.4. Chapter Summary

This chapter discusses the targeted study area and study corridors. Region of Peel has been identified as a region with high truck volume and a major hub for goods transportation and hence, this study focuses this region as the study area. Two corridors, Derry Road and Highway 50 are selected as study corridors which are 9.22 km and 11.02 km in length, respectively.

Macrosimulation data was also provided by the Region of Peel for pm peak hours. The data provided was for base year 2011 and forecasted year 2031. The data for the year 2016 needs to be extracted based on the data provide for these two years. Full Origin Destination (OD) matrix for the light, medium and heavy trucks passing through the zones covered in the model along with their Directionality factors were provide.

Microsimulation data for PM peak hours was obtained for the year 2016. The RBC file for each intersection was developed based on the data collected to replicate the existing signal timing plan. The synchro file was used for turning movement at each intersection.

The Approach I of this study uses fixed traffic demand which considers that there will be no change in traffic volume upon implementation of ILU tactic, thus uses the microsimulation software for performing the analysis to identify the ILU tactic that generates greatest travel time saving. Whereas Approach II uses changed traffic demand, which considers that traffic volume will change on the study corridor (and surrounding roadways) upon implementation of ILU tactic. For this approach a macrosimulation analysis was performed to obtain the changes in traffic volume on the study corridor (and surrounding roadway). This changed traffic volume was used as input to perform microsimulation analysis to identify the ILU tactic that generates greatest travel time saving. Approach II is more rigorous as compared to Approach I, this is because in real world when any changes are imposed on a roadway corridor a change in traffic demand observed for that corridor.

CHAPTER 4. MACROSIMULATION MODEL DEVELOPMENT

This chapter discusses the development of the macrosimulation models. Macrosimulation models are widely used to estimate changes in traffic volume due to surface infrastructure improvements (e.g., widening existing roadways by adding additional lanes) and to predict future traffic volume on new roadway networks. Approach II uses EMME model to obtain changed traffic volume due to implementation of ILU tactic.

Our study focuses on estimating changes in traffic volume for passenger cars and trucks due to the implementation of selected ILU tactics on sections of two arterials in Peel Region, Derry Road and Highway 50. Passenger cars may experience increased travel time where ILU tactics favour heavy vehicles. As a result, some passenger cars may decide to use a different route. Reduced truck travel times brought about by ILU tactics may result in attracting additional truck volumes to the study corridors and reducing truck volumes on nearby arterials (e.g., Old Castlemore Road and Huntington Road near Highway 50). We expect that a macrosimulation model can show the possible network-wide impact of the ILU tactics evaluated in this study.

4.1. EMME Model Development

The EMME macrosimulation model presents a multimodal roadway network using nodes which represent intersections and links that constitute streets between nodes. The modellers can assign specified modes to the nodes and links.

This study's base year is 2016, but the EMME model obtained from Peel Region has EMME models for 2011, 2031, and 2041. This study needed to estimate 2016 OD matrices for 1) passenger cars, 2) light trucks (4-tire commercial vehicles, including delivery and service vehicles), 3) medium trucks (single unit trucks with 6 or more tires), and 4) heavy trucks (combination trucks consisting of power unit and one or more trailing units). Each matrix in the Peel Region models contains 2,303 × 2,303 OD pairs. This study also needed to develop a base year roadway network that reflects changes in surface infrastructure (e.g., changed number of lanes) introduced from 2011 to 2016.

4.1.1. Base Year Origin-Destination (OD) Matrix Development

This study considered two candidate methods to estimate the 2016 OD matrices. They were 1) the fratar growth factor method (NPTEL, 2007), and 2) the linear interpolation method. As the two methods produced very similar outputs in our case, we decided to use linear interpolation largely because it is the simpler method.

Using the 2011 and 2031 matrices and a linear interpolation method, this study was able to generate four different 2016 OD matrices (i.e., one OD for each transportation mode):

- mf60 2016 OD matrix for passenger vehicles
- mf61 2016 OD matrix for light trucks
- mf62 2016 OD matrix for medium trucks (PCE)
- mf63 2016 OD matrix for heavy trucks (PCE)

Where PCE means passenger car equivalent. For medium trucks it is 1.5 time the volume and for heavy trucks it is 1.75 time the volume. The estimated 2016 OD matrices were stored in a CSV format that can easily be input into the EMME model for further analyses.

4.1.2. Roadway Network Development

We used the 2011 EMME model network as our base network and investigated changes in key link characteristics (e.g., number of lanes) that occurred between 2011 and 2016. We used historical street views in Google Earth Pro to investigate changes in the number of lanes on major roadways in the study area.

Figure 17 shows the roads checked for a change in the number of lanes in the area of Derry Road. Derry Road is shown in blue. The roads in black had no change in the number of lanes. The roads in red had a change. The total length of roads checked was 203.5 kilometres. All the roads checked pass through Mississauga, but some started or ended in Brampton or Caledon.

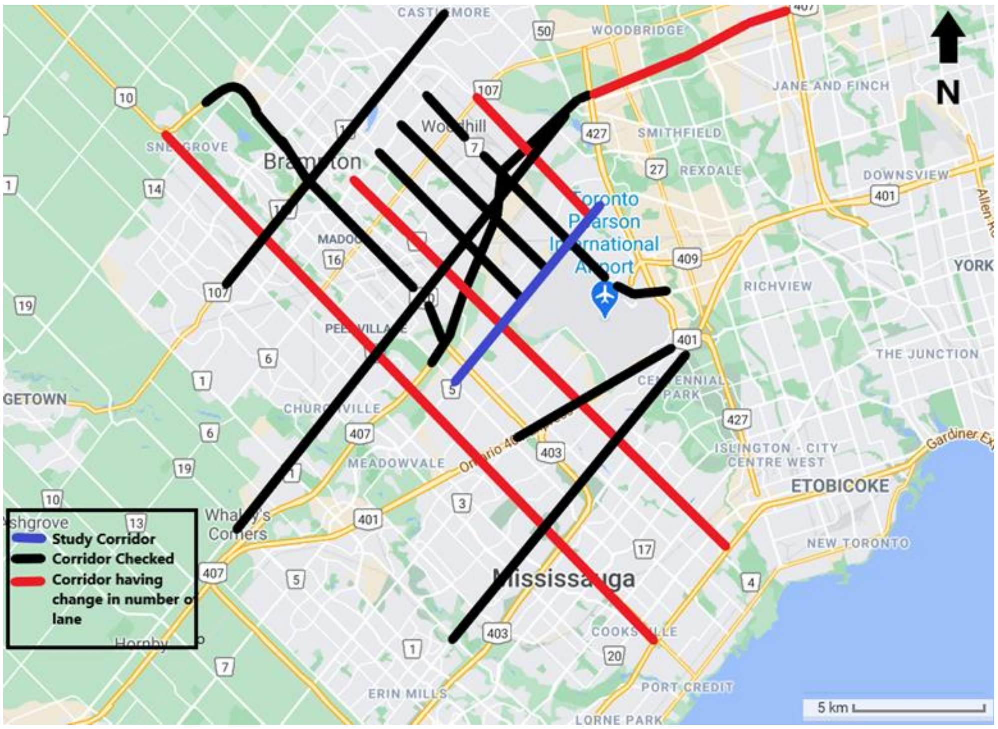


Figure 17: Roadways near Derry Road investigated for a change in the number of lanes

The roads checked were:

- Airport Road from Williams Parkway to American Drive (10.05 km)
- Bramalea Road from Williams Parkway to Derry Road East (7.66 km)
- Derry Road East from Hurontario Street to Highway 401 (10.69 km)
- Dixie Road from Williams Parkway to Eglinton Avenue East (13.96 km)
- Eglinton Avenue East from Hurontario Street to Martin Grove Road (10.71 km)

- Goreway Drive from Highway 107 to Carlingview Drive (9.24 km)
- Highway 107 from Winston Churchill Boulevard to Goreway Drive (18.56 km)
- Highway 401 from Kennedy Road to Renforth Drive (7.21 km)
- Highway 407 from Kennedy Road to Pine Valley Drive (17.62 km)
- Highway 410 from Old School Road to Steeles Avenue East (13.63 km)
- Hurontario street from Old School Road to Highway 403 (23.82 km)
- Queen Street East from Kennedy Road to Highway 400 (20.79 km)
- Queen Street West from Main Street to Kennedy Road (1.4 km)
- Steeles Avenue East from Hurontario Street to Islington Avenue (17.43 km)
- Steeles Avenue West from Trafalgar Road to Hurontario Street (13.04 km)
- Torbram Road from Williams Parkway to Derry Road East (7.73 km)

Figure 18 shows the roads checked for a change in the number of lanes in the area of Highway 50. Highway 50 is shown in blue. The roads in black had no change in the number of lanes. The roads in red had a change. The total length of roads checked was 113.0 kilometres. All the roads checked pass through Brampton, but some started or ended in Mississauga or Caledon. It is to be noted over here that Highway 50 has a red line, which indicates that a few intersections on Highway 50 had change in number of lanes.

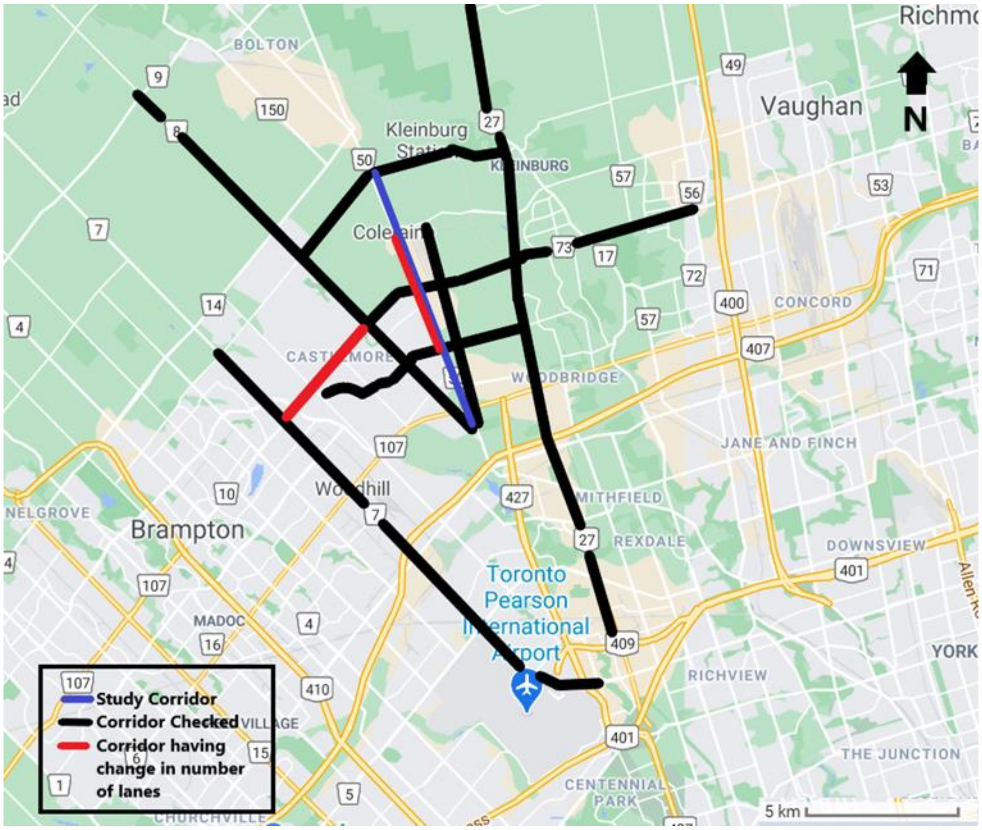


Figure 18: Roadways near Highway 50 investigated for a change in the number of lanes

The roads checked were:

- Airport Road from Highway 401 to King Street (23.67km)
- Castlemore Road from Goreway Drive to Highway 50 (5.00 km)
- Highway 8 from Highway 9 to Highway 50 (14.45 km)
- Highway 27 from Regional Road 9 to Highway 407 (28.59km)
- Highway 50 from Queen Street East to George Bolton Parkway (12 km)
- Huntington Road from Kirby Road to Highway 7 (6.00 km)
- Langstaff Road from McVean Drive to Highway 27 (5.58 km)

- Nashville Road from Highway 27 to Gore Road (8.25 km)

- Rutherford Road from Highway 56 to Highway 50 (9.50 km)

Table 3 provides a summary of network changes in terms of the number of lanes from 2011 to 2016.

Table 3: Network changes (changes in number of lanes) on Derry Road and Highway 50

Corridor	Segment	From intersecting Roadway	To intersecting Roadway	Number of Lanes	
				2011	2016
Derry Road	Road 107 (Queen Street)	Main Street	Kennedy Road	4	6
	Highway 407	Highway 427	Pine Valley Drive	8	10
	Dixie Road	Clark Boulevard	Steeles Avenue East	4	6
	Hurontario Street	Theatre Lane	Elgin Drive	4	6
	Goreway Drive	Highway 107	Derry Road East	4	6
Highway 50	Castlemore Road	Goreway Drive	Highway 50	0	4
	Highway 50	Ebenezer Road	Nashville Road	4	6

4.2. Simulation Scenario Development

We developed three scenarios: 1) base scenario, 2) truck only lane scenario for Derry Road, and 3) truck only lane scenario for Highway 50.

- Scenario 4 presents the base scenario developed for the year 2016. This scenario is also known as the Do-Nothing scenario. The 2016 OD matrix was estimated using linear interpolation. No ILU tactic was implemented on this scenario. This scenario was used as a base for two other scenarios.
- Scenario 5 presents the truck only lane scenario for Derry Road. Derry Road has three lanes in each direction. In Scenario 2, the third lane (outermost lane) is designated to be used by medium and heavy trucks only.

- Scenario 6 presents the truck only lane scenario for Highway 50. There are three lanes in each direction from Queen Street to Sears Warehouse (it is a connecting roadway between Old Castlemore Road and Cadetta Road). The third lane (outermost lane) is designated for medium and heavy trucks only along this section of the study corridor. The remaining section of the corridor from Sears Warehouse to Mayfield Road has two lanes in each direction. Here, the outermost lane is converted to a truck only lane.

We introduced the truck only lanes by using EMME's network editor function to code links parallel to the study corridors. We made sure that the newly added lanes had all the properties of the original link. This means that:

1. the link attributes for the added lane shared the same attributes as the original links in terms of volume-delay function, capacity per lane, speed, and length, etc.

2. the added links were connected to all the nodes that the original links were connected to. For example, if a node distributed vehicle through centroid connectors, the links added also connected to the centroid connectors; and

3. general auto mode (c) was assigned to all the links and other modes allowed to use the newly added links were selected for all the new links.

Figure 19 provides an example of changes made to the existing EMME network in order to implement scenario 5 at the intersection of Bramalea Road at Derry Road. The grey line (adjacent to blue line) represents two of the original three lanes on Derry Road. These two lanes allow all modes except medium and heavy trucks. The blue line represents the truck only lane. This lane only allows medium truck and heavy trucks. The model was developed for PM peak hour between 4:00 pm to 5:00 pm.

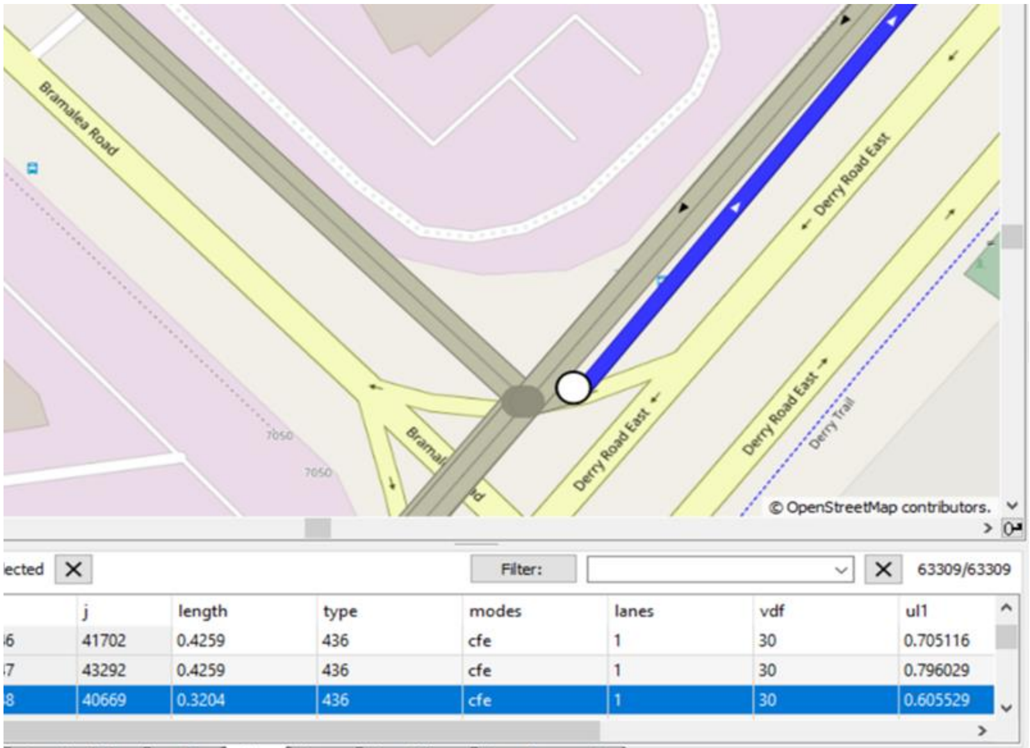


Figure 19: Implementing truck only lane in EMME

4.3. Macrosimulation Process

The base commercial vehicle model uses a multi-class all-or-nothing assignment for the light trucks, medium trucks and heavy trucks, this happens after the passenger model is finished running using User Equilibrium. The truck assignment takes into consideration travel times from passenger model which are fixed values and causes the all-or-nothing assignment. User equilibrium traffic assignment was run after implementing changes in the network to develop a base scenario.

After developing each truck only scenario, a multiclass traffic assignment was run for passenger cars, light trucks, medium trucks, and heavy trucks using the user equilibrium traffic assignment from EMME modeller. A macrosimulation analysis was performed to obtain percentage changes in traffic volume.

The percentage changes in traffic volume obtained from macrosimulation analysis were used as an input for Approach II of microsimulation.

4.4. Chapter Summary

This chapter discusses the macrosimulation model development. Macrosimulation study data was also provided by the Region of Peel for pm peak hours. The data provided was for base year 2011 and forecasted year 2031. The study is also using the Microsimulation approach, the data for which is provided for PM Peak hour for the year 2016.

Hence, data for the year 2016 was extracted based on the data provide for these two years. Full Origin Destination (OD) matrix for the Light, Medium and Heavy trucks passing through the zones covered in the model along with their Directionality factors were developed. These OD-matrices were then imported to the EMME software and necessary network changes were made in order to develop the base model.

Once the base model was developed, two new scenarios were developed in order to implement Truck Only Lane. As EMME is a macrosimulation model developing just one scenario for each study corridor is enough to obtain the results. A multiclass traffic assignment was run to obtain the results.

CHAPTER 5. MICROSIMULATION MODEL DEVELOPMENT

Microsimulation model, such as VISSIM, used in this study, can replicate realistic conditions such as road capacity, speed changes, simple and complex intersections, and traffic volumes. These models can also generate measures such as travel time, speed, traffic queues, delays, and levels of service to evaluate the performance of a study network. Unlike a macrosimulation model, that can generate only aggregated results (e.g., average speed, total volume), microsimulation models can produce much more detailed results regarding individual vehicles' travel times, travelled lanes, etc. for each and every segment.

This chapter discusses how our study used a microsimulation (VISSIM) model to evaluate the performance of selected ILU tactic (i.e., truck only lane) in terms of possible improvements in truck mobility (e.g., reduced travel time). As shown in **Figure 3**Error! Reference source not found. in Chapter 1, we applied two distinct microsimulation approaches.

- Approach I (using fixed traffic demand): We assumed no change in traffic demand on the study network with/without the implementation of an ILU tactic, i.e., the link traffic volumes for passenger vehicles and trucks remained identical for the same condition with/without ILU tactics. We used traffic volumes recorded in Peel Region's Synchro network.
- Approach II (using changed traffic demand): We assumed that traffic demand on the study network changed due to the implementation of an ILU tactic. We consider this approach to be more realistic than the fixed traffic demand of Approach I. We used traffic volumes estimated by the EMME model (see Chapter 4) as an input for the VISSIM simulation

model to investigate the effect of changed traffic volumes on the two study corridors (Derry Road and Highway 50) after the implementation of ILU tactics.

5.1. Development of VISSIM Model

PTV VISSIM ver. 2020.00-02 was used to simulate our two study corridors. In VISSIM simulation, car following and lane changing logics play a key role in mimicking real-world traffic environment. For our VISSIM model, we collected roadway environment data (e.g., presence of left and/or right exclusive turn lane), traffic data (e.g., type of vehicle, traffic volumes, etc.), and each intersection's traffic control system information (e.g., signalized/un-signalized and signal phase information such as green time, cycle length, yellow and red-amber time).

Vehicle composition was limited to passenger cars and trucks (medium and heavy trucks). We obtained the truck percentage values for each direction from the Synchro data. As the data showed inconsistencies between the number of vehicles entering a certain link and the number of vehicles exiting from the same link (as we were obtained the traffic volumes at intersections only), we added a few imaginary links between intersections to balance out the in-and-out traffic volumes. These imaginary links, for instance, can present driveways to nearby plazas/malls along the corridors that were not embedded in the Synchro database.

Each intersection's signal phase information (green, red and yellow time, cycle length, etc.) was obtained from the Synchro data. All the signalised intersection of both the study corridors uses Ring Barrier Signal Controller (RBC). The **Figure 21** shows how signal controller was developed in VISSIM software. National Electrical Manufacturers Association Phasing (NEMA) was used for phasing purpose (see **Figure 20**). Detectors were defined according to the phases to obtain traffic volumes and travel times at each intersection.

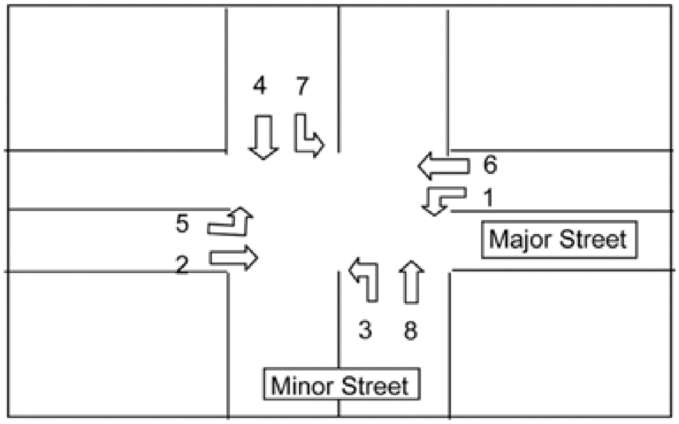


Figure 20: National Electrical Manufacturers Association (NEMA) Phasing System

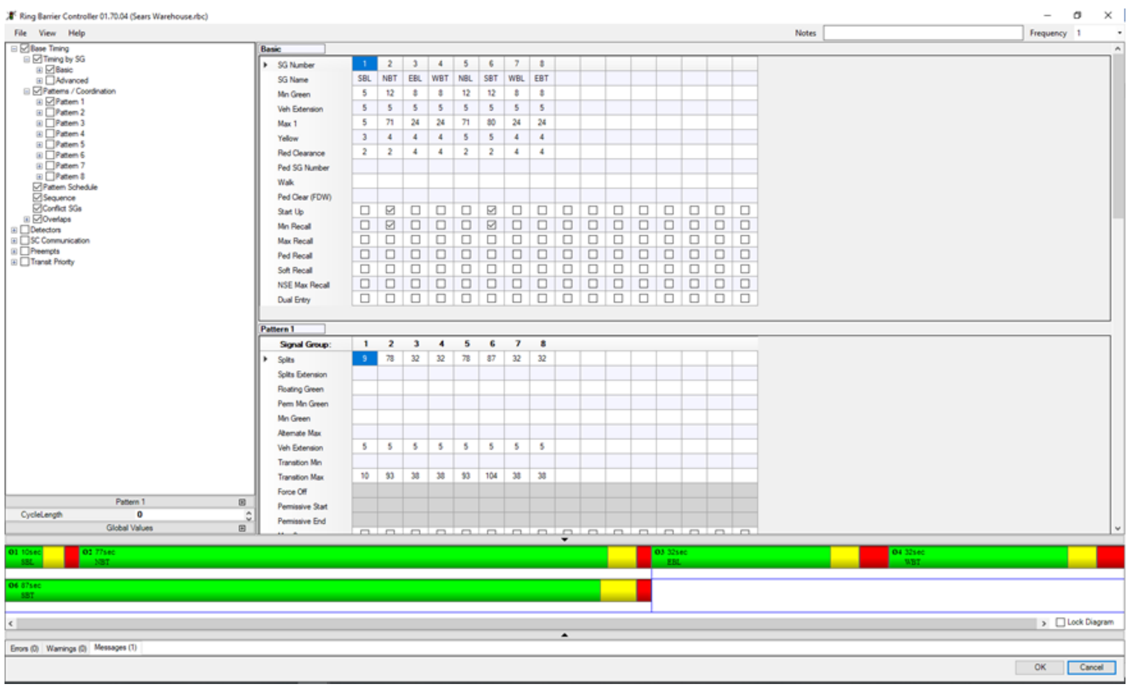


Figure 21: Signal controller modelled in VISSIM

Figure 22 shows how we used this information to place signal heads and detectors at each intersection. We adjusted the travel speed for turning movements at each intersection using the posted advisory speed limits (the yellow rectangular boxes at each intersection) and we placed vehicle travel time measurement stations at each intersection. Non-signalized intersections were treated as stop sign controlled intersections. Where green and red lines intersect in **Figure 22**, the green line is given priority and the red has to yield.

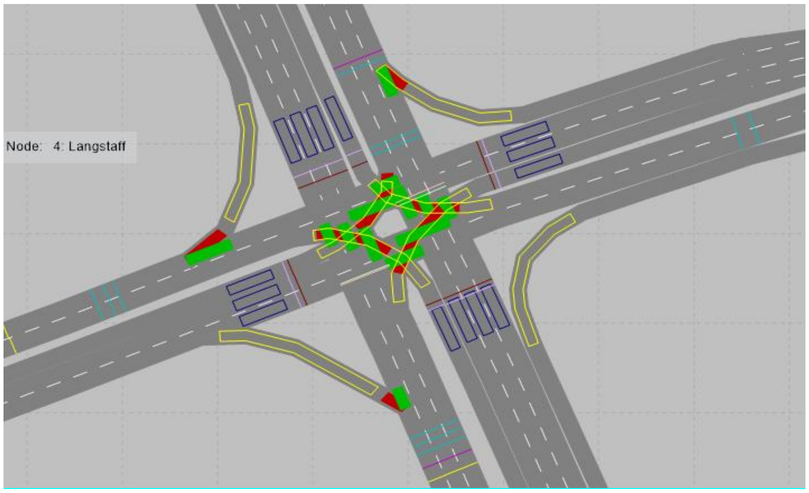


Figure 22: Intersection Modelled in VISSIM

To produce simulation outcomes that represent real-world traffic conditions as closely as possible, many microsimulation parameters (e.g., lane change behaviour, node adjustment, acceleration, and deceleration rates) needed to be updated. This process is known as model calibration. We assumed static routing decision and used directional traffic volume information obtained from Synchro data (discussed in Chapter 3). Detectors were placed along links that approached intersections with fully actuated or semi-actuated signal operation. Each detector length was 10 meters.

Once all the parameters were defined, the simulation was performed. We used a simulation period of 6,000 seconds as suggested by the Virginia Department of Transportation's VISSIM guide (2020). The first 900 seconds were a warm-up period. Results for defined nodes and vehicle travel time were collected every 900 seconds from 900 seconds to 4,500 seconds. The last 900 seconds were a cool down period. Number of simulation runs were calculated using standard deviation of modelled data, mean, t-test and acceptable error (Qi, et al., 2017). A total of 5 simulation runs were performed for each of the study corridor.

5.2. Model Calibration

Calibration is the process of achieving adequate reliability or validity for a microsimulation model by searching and selecting for appropriate input parameters (in our case, Synchro traffic data) that replicate real-world traffic conditions as closely as possible. Data quality is critical in the calibration process as good quality data combined with well calibrated simulation model parameters can increase confidence in the simulation results. In our case, the input parameters were specific to the study corridors' roadway and traffic conditions. As the calibration process requires comparing outputs from simulation to real-world traffic data, the process could be conducted only for the base scenario (i.e., the do-nothing scenario). It is to be noted that traffic volume data was obtained from Region of Peel and travel time data was obtained from MTO, hence these two sets of information were collected on a different day. This travel time data does not reflect exact travel time corresponding to traffic volume**.** A typical calibration process for a microsimulation model such as ours relies on two different measures: 1) travel time, and 2) traffic volume.

We compared average travel time estimated from our VISSIM model to MTO's probe-vehicle based observed travel time data (received from Peel Region). **Figure 23** compares the observed travel time (blue line) with the calibrated travel time i.e., Scenario 1 which is the base scenario (orange line) for eastbound Derry Road. The calibration was done for 9.2 km of Derry Road from Kenderry Gate to Rexwood Road and included 16 signalised intersections. **Figure 23** shows nine links (between the ten major intersections) for which observed travel time was available to compare with simulated travel time. The intersections included were Kenderry Gate, Kennedy Road, Tomken Road, Dixie Road, Dixie Road, Bramalea Road, Torbram Road, Cattrick Street, Airport Road and Goreway Drive

As the travel time difference between the observed and calibrated time between each intersection was less than 20 seconds, and the difference over the whole 9.2 km was only 0.23 minutes, we could conclude that the VISSIM model was well calibrated. The analysis was performed for traffic volume between 4 pm and 5 pm.

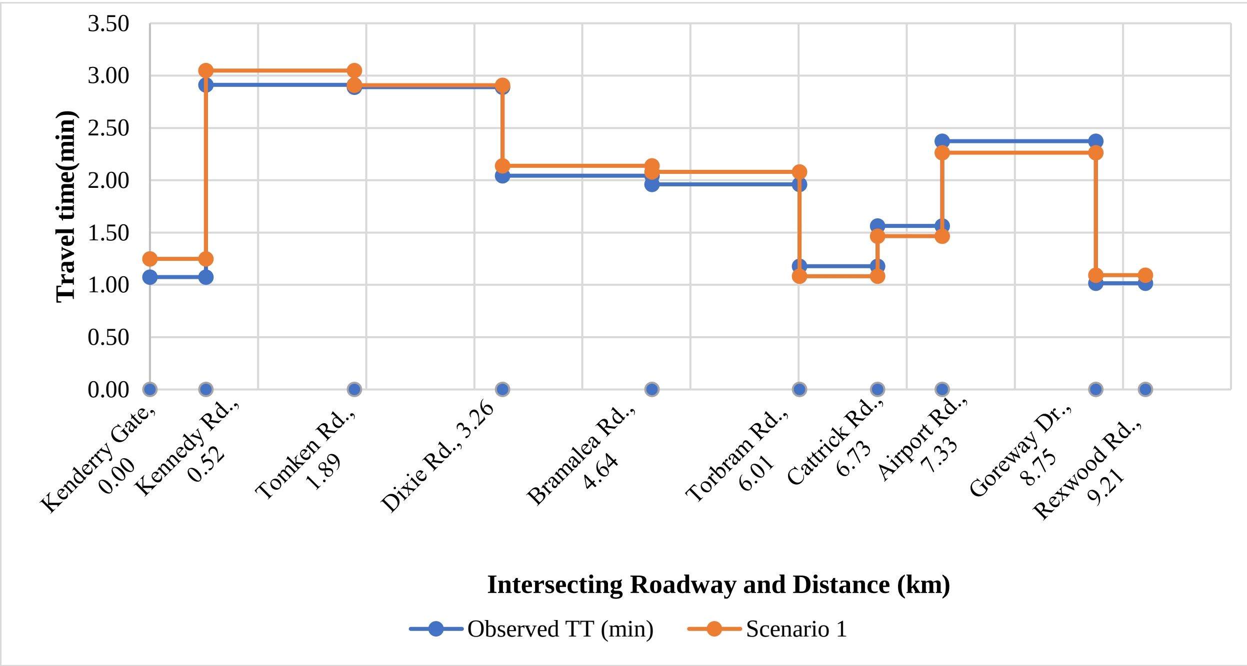


Figure 23: Eastbound Derry Road Travel Time Calibration

Figure 24 shows the statistical association between the observed and Scenario 1 travel time data (i.e., observed vs. estimated data) for the same nine links along eastbound Derry Road. The figure compares the observed travel time with the simulated travel time. The blue dots show the travel time for each link. The VISSIM model's calibrated travel time data show a statistically significant association with the observed travel time data as evidenced by the high R^2 value (0.98). The orange dot in **Figure 24** shows the travel time of the link between Bramalea Road and Torbram Road which is 118 seconds (1.58 minutes) observed travel time and 124 second simulated travel time (2.04 minutes) which can also be seen in **Figure 23** (between Bramalea Road and Torbram Road).

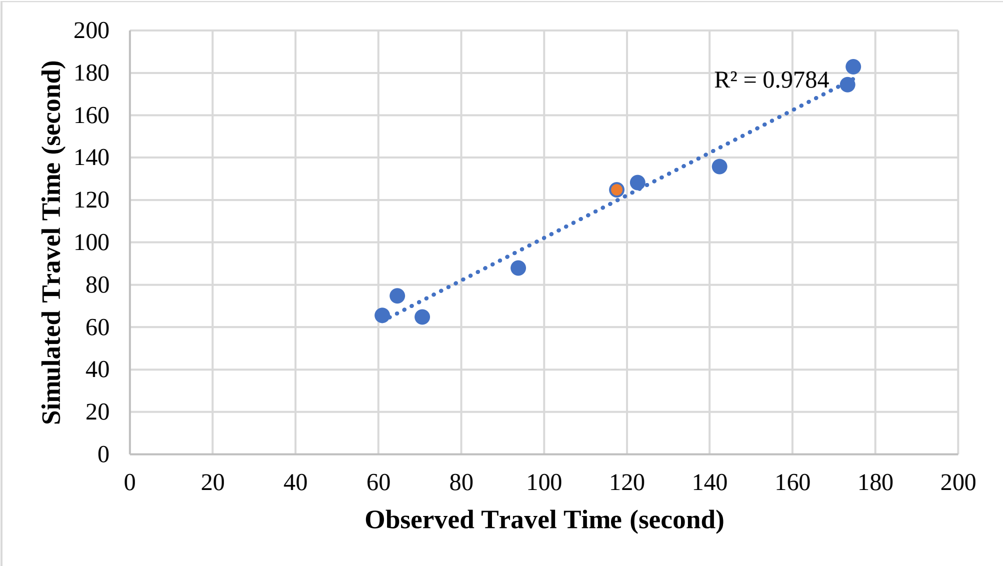


Figure 24: Eastbound Derry Road Calibration

Figure 25 shows the travel time calibration for southbound Highway 50. This calibration was done for the seven links between eight signalised intersections along 11.02 km of Highway 50. The difference over the whole 11.02 km was 2.46 minutes (total observed travel time of 15.10 minutes and total simulated travel time of 12.64 minutes). But difference between the observed and calibrated time was less than 0.5 minutes for all links except the link between Langstaff Road and Queen Street which had a 1-minute travel time difference. This 1-minute difference might have led to an overall 2.46-minute difference.

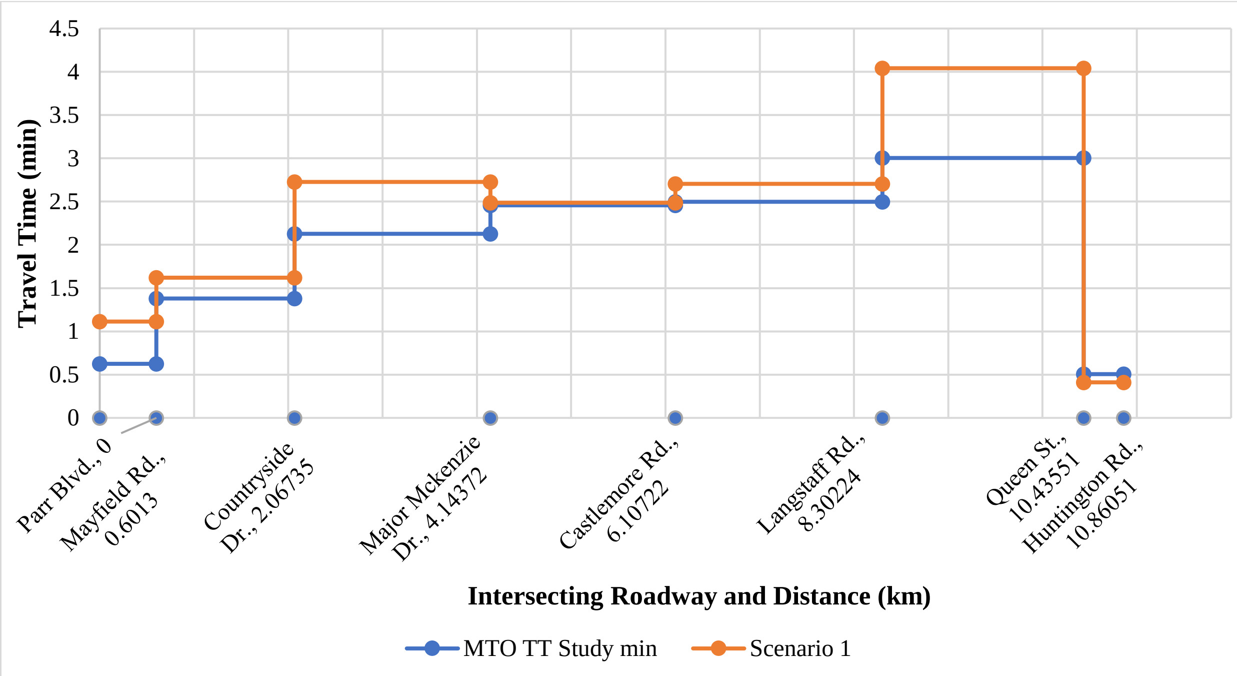


Figure 25: Southbound Highway 50 Travel Time Calibration

Appendix D provides the results of travel time calibrations for westbound Derry Road and northbound Highway 50. As the results were comparable with those for eastbound Derry Road and southbound Highway 50, we concluded that our models were well calibrated and suitable for further analyses.

Eq. 2 shows T-test result. This statistic estimates the true difference of mean using the ratio of the difference between mean and theoretical value over the pooled standard deviation and root of number of simulations runs. A minimum number of samples required to perform T-test is 10 i.e., the number of travel time simulation should be at least 10. This is irrespective of the vehicle categories and locations as long as flow and proportion of vehicles were relatively high. In order to assume that the travel time is normally distributed during analysis, the minimum number of samples should be greater than thirty (Varsha et.at., 2014). The value of t within ± 2 is acceptable.

$$T = \frac{m-\mu}{s/\sqrt{n}}$$

Eq. 2

Where,

m is average travel time

μ is mean of simulated travel time

s is standard deviation of the simulated travel time

n is the number of simulation runs

Table 4 shows the result of T-test on east bound Derry Road. The value for links between each intersecting roadway is within the range of ± 2, hence it is considered that the model is calibrated well.

Table 4: T-test Eastbound Derry Road

Intersection		Observed Average Travel Time	Simulated Travel Time	Simulated Standard Deviation	T-test
Kennedy Gate	Kennedy Rd	64.52	74.86	17.75	1.43
Kennedy Rd	Tomken	174.70	182.88	10.75	1.86
Tomken	Dixie	173.31	174.46	8.75	0.32
Dixie	Bramalea	122.58	128.33	18.50	0.76
Bramalea	Torbram	117.57	124.79	17.50	1.01
Torbram	Cattrick	70.61	64.94	22.50	-0.62
Cattrick	Airport	93.76	87.98	17.00	-0.83
Airport	Goreway	142.39	135.82	13.00	-1.24
Goreway	Rexwood	60.92	65.61	17.50	0.66
Kennedy Gate	**Rexwood**	**1020.37**	**1039.66**	**143.25**	**0.33**

Table 5 shows t-value for Highway 50. The values are not within the acceptable range of ± 2; this may be due to the reason that this study only performed 5 simulation runs which is less than 10. Appendix T-test result for westbound Derry Road and Southbound Highway 50

Table 5: T-test Northbound Highway 50

Intersection		Observed Average Travel Time	Simulated Travel Time	Simulated Standard Deviation	T-test
Huntington Rd	Queen	40.36	70.17	8.25	8.85
Queen	Langstaff	154.97	244.82	8.75	25.16
Langstaff	Castlemore Road	177.85	196.00	13.00	3.42
Castlemore Road	Train yard Entrance (Major Mckenzie)	161.73	198.29	10.75	8.33
Train yard Entrance (Major Mckenzie)	Countryside Dr/Nashville	121.01	179.49	14.00	10.23
Countryside Dr	Mayfield Rd	88.48	100.84	11.50	2.63
Mayfield Rd	Parr Blvd	42.76	39.16	16.00	-0.55
Huntington Rd	**Parr Blvd**	**787.15**	**1028.76**	**82.25**	**7.20**

Eq. 3 shows the GEH Statistic. This statistic compares two sets of traffic volumes (i.e., observed and Scenario 1 traffic volumes) to understand how similar the two traffic volumes are. If the GEH is less than 5, the simulated traffic volume is usually considered similar to the observed traffic volume. If the value is higher than 10, the simulation is not considered representative of the observed traffic and the model cannot be used. If the GEH is between 5 and 10, the model outcome can be used, but the results must be interpreted with extra caution. This study, therefore, considered a GEH value of less than 5 to be good, between 5 and 10 to be moderate, and greater than 10 to be poor (Doustmohammadi, 2017).

$$GEH = \sqrt{\frac{2(S-O)^2}{S+O}}$$

Eq. 3

where:

GEH = test statistic

S = simulated truck volume per hour

O = observed truck volume per hour

Table 6 shows the GEH values for Derry Road. The table shows all the roads that intersect Derry Road. The GEH value for each link is less than 5 except between the Highway 410 NB Ramp and Tomken Road which is 8.01, a value considered to be moderate. **Table 6** shows that the model was well calibrated.

Table 6: GEH value for EB Derry Road

Intersecting Roadway		Observed	Simulated	GEH
Kenderry Gate	Kennedy Rd.	7,012	7,010	0.02
Kennedy Rd.	HWY 410 SB Ramp	4,272	4,321	0.75
HWY 410 SB Ramp	HWY 410 NB Ramp	3,222	3,093	2.30
HWY 410 NB Ramp	Tomken Rd.	8,586	7,860	8.01
Tomken Rd.	Maxwell Rd.	4,542	4,312	3.46
Maxwell Rd.	Cardiff Blvd.	4,353	4,152	3.08
Cardiff Blvd.	Dixie Rd.	7,767	7,504	3.01
Dixie Rd.	Telford Rd.	4,441	4,485	0.66
Telford Rd.	Bramalea Rd.	4,723	4,760	0.54
Bramalea Rd.	Vanguard Dr.	4,021	4,053	0.50
Vanguard Dr.	Torbram Rd.	4,849	4,902	0.76
Torbram Rd.	Cattrick St.	5,105	5,122	0.24
Cattrick St.	Harrow Rd.	3,202	3,195	0.12
Harrow Rd.	Burlington Rd.	4,345	4,343	0.03
Burlington Rd.	Airport Rd.	6,723	6,710	0.16
Airport Rd.	Hull St.	2,362	2,374	0.25
Hull St.	Go Station	5,086	5,115	0.41
Go Station	Professional Rd.	2,567	2,686	2.32
Professional Rd.	Goreway Rd.	4971	5059	1.24

Appendix C provides a summary of the GEH analysis for Highway 50.

5.3. Development of Simulation Scenarios

In this study, we developed three scenarios. They are 1) base scenario, 2) truck only lane scenario, and 3) truck restriction lane scenario for both study corridors.

1) Scenario 1 is the base scenario (i.e., do-nothing scenario). This scenario was developed to calibrate and validate the VISSIM model with respect to the real-world situation and for comparison with the other scenarios.

2) Scenarios 2 and 7 are the truck only lane (TOL) scenario. In this ILU scenario, one lane is dedicated just for truck travel and no passenger cars can use the lane. This scenario is divided into two scenarios:

   i. Scenario 2.1 and Scenario 7.1 are the innermost TOL scenario: the innermost lane of the study corridors was dedicated as a truck lane. Note that a TOL lane can be travelled by passenger cars for 150 m before an intersection so that passenger cars can make a left turn. Scenario 2.1 was developed for Approach I microsimulation and Scenario 7.1 was developed for Approach II microsimulation.

   ii. Scenario 2.2 and Scenario 7.2 are the outermost TOL scenario: the outermost lane of the study corridors was dedicated as a truck lane. Note that a TOL lane can still be travelled by passenger cars for 150 m before an intersection so that passenger cars can make a right turn. Scenario 2.2 was developed for Approach I microsimulation and Scenario 7.2 was developed for Approach II microsimulation.

3) Scenario 3 is the truck restriction lane scenario. The innermost lane of the study corridors was prohibited for truck travel and the lane can be used by passenger cars only. Note that the lane can be travelled by trucks 150 m before an intersection so that trucks can make a left turn.

Scenario 3 was developed for Approach I microsimulation. This scenario was not developed for Approach II analysis.

Notice that all three scenarios were analysed in Approach I (fixed traffic demand), but only scenarios 1 and 2 were analyzed in Approach II (changed traffic demand). The study conducted a total of 12 different analyses (6 analyses for each corridor).

5.3.1. Base Scenario

The base scenario (Scenario 1) is the do-nothing scenario for both corridors with no ILU tactic applied. Google map street view was used to collect the roadway characteristics (e.g., number of lanes and presence/absence of exclusive turning lanes) required to develop the base scenario for each corridor. The signalised intersections were defined using RBC signal controller, and the unsignalised intersections were treated as intersections with stop signs where a vehicle having right-of-way will travel first. The base scenario models were applied for both Approach I and Approach II.

5.3.2. Innermost Truck Only Lane Scenario

The innermost truck only lane scenario (Scenario 2.1 and Scenario 7.1) means that trucks can travel the innermost lane only (see green line in **Figure 26**) and cannot use the centre or shoulder lanes. As stated, this study allowed trucks to travel outside this lane from 150 m before each intersection (see the yellow line in **Figure 26**). Zhou et. Al. (2006) called this 150 m the relaxation zone meaning a short distance of roadway which can be accessed by all types of vehicle. **Figure 26** shows a 150 m relaxation zone for NB trucks wishing to turn right from Derry Road onto Goreway Drive. Passenger cars could also use this relaxation zone to turn left.

At a few locations, no ILU tactic was implemented because the intersections were too close (<150 m) to each other. For example, on the 115 m link between the Airport Road and Hull Street intersections), trucks were not blocked from using the other two lanes as the distance was too short to provide a relaxation zone. In such situations, all three lanes were accessible by all the vehicles classes defined.

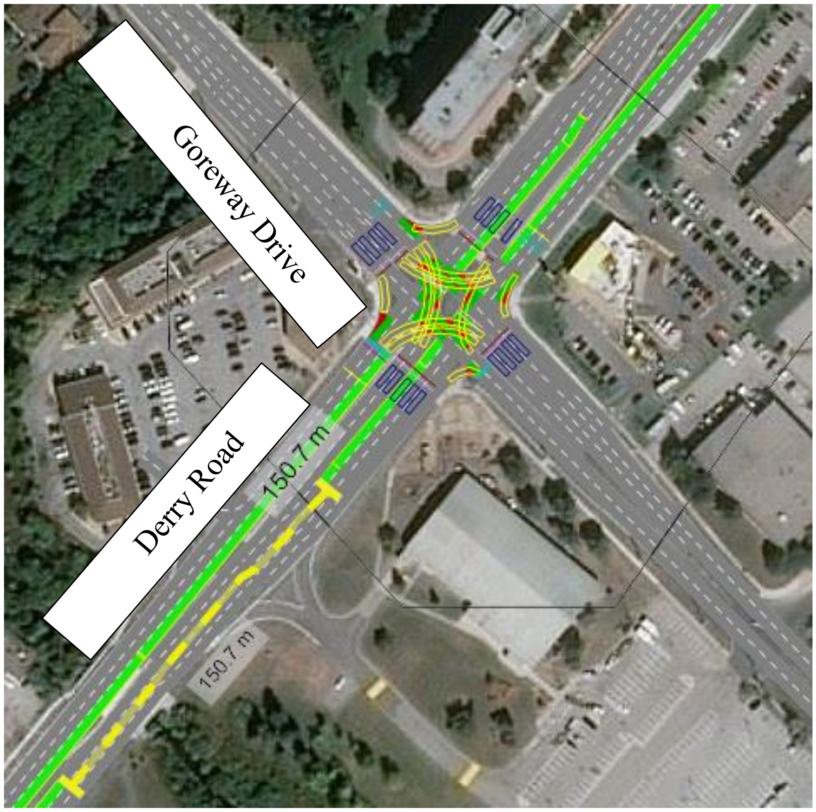


Figure 26: 150 m Relaxation zone near intersection

5.3.3. Outermost Truck Only Lane Scenario

The outermost truck only lane scenario (Scenario 2.2 and Scenario 7.2) means that the outermost lane was dedicated for truck travel (green line). A 150 m relaxation zone (yellow line) was provided so trucks can turn left at the intersection and passenger cars can turn right. **Figure 27** shows an outermost truck only lane implemented in VISSIM.

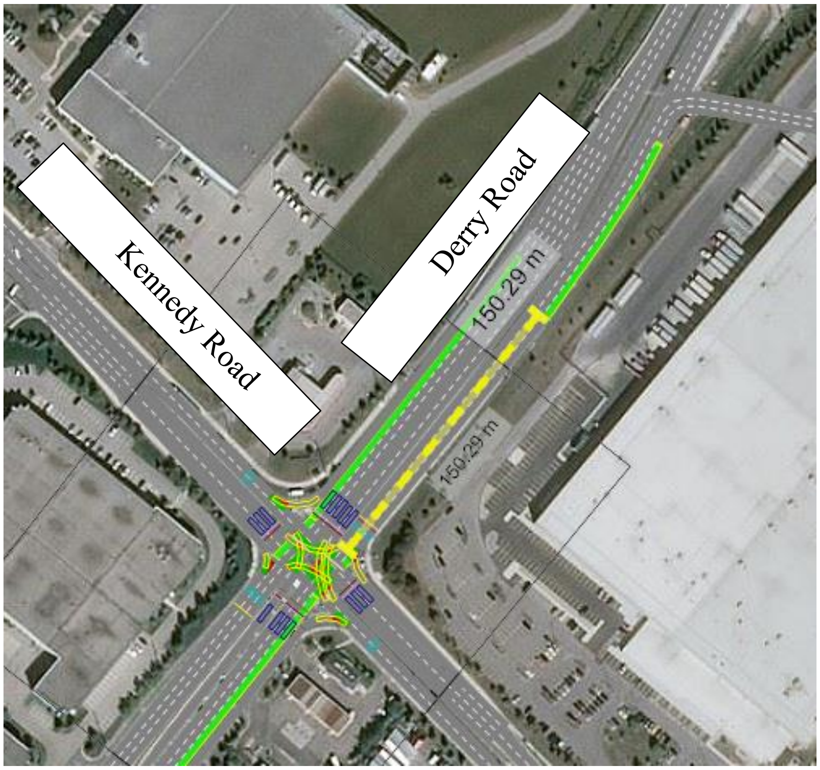


Figure 27: 150 m Relaxation Zone near intersection

5.3.4. Truck Restriction Lane Scenario

The truck restriction lane scenario (Scenario 3) means that trucks are prohibited from the innermost lane except those when making a left turn at an intersection. A 150 m of relaxation zone was provided to allow left turns. No relaxation zone was provided when intersections were close to each other. (This situation occurred on Derry Road, but not on Highway 50.) All the vehicles were allowed to use all the lanes without any restriction i.e., no ILU tactic was implemented for links between these intersections.

5.4. Chapter Summary

This chapter has discussed the development of the microsimulation models. Two approaches were used to perform the microsimulation analysis. Approach I considered fixed traffic demand. This involved collecting traffic volume data to analyze the three scenarios. Approach II considered changed traffic demand. This involved a macrosimulation analysis to obtain the input traffic volumes required in order to perform the microsimulation analysis. As Approach II was performed only for scenarios 1, 2 and 7 the microsimulation analyses for Approach II were performed only for scenarios 1, 2 and 7.

As the development of the base scenario may find that the simulation does not match the real-world volumes, imaginary links were developed to add or remove excess traffic. The model was developed in the software using this balancing file. Ring Barrier Controller was used for the signals at all the signalised intersection. The calibration and GEH Statistics showed that the base models reflected the real-world scenario well. A 6,000 second simulation run was conducted with results were collected every 900 seconds from 900 seconds to 4,500 seconds.

The study performed a total of 12 analyses (6 analyses for each study corridor). Each scenario had five simulation runs based on calculations using the mean and standard deviation. The results from Approach II were accurate, as it considered change in traffic demand. This is what generally happens in real world.

CHAPTER 6. RESULT OF SIMULATION ANALYSIS

This chapter discusses the results of the simulation analysis. We used travel time as the primary measure of performance when evaluating the three ILU tactics (i.e., innermost truck only lane, outermost truck only lane and truck restriction lane). Section 6.1 discusses the results of the analysis in Approach I (the microsimulation results for the ILU tactics implemented under fixed traffic demand condition). Section 6.2 discusses result of Approach II macrosimulation analysis and Section 6.3 discusses the results of the microsimulation analysis in Approach II (the results for the ILU tactics implemented under changed traffic demand condition).

As stated in Chapter 4 and Chapter 5, the ILU scenarios tested are discussed in **Table 7**

Table 7: Scenario List

<table>
<tr><th>Approach</th><th>Simulation analysis</th><th>Scenario number</th><th>Description</th></tr>
<tr><td rowspan="4">Approach I</td><td rowspan="4">Microsimulation</td><td>Scenario 1</td><td>Base/Do-Nothing Scenario</td></tr>
<tr><td>Scenario 2.1</td><td>Innermost Truck Only Lane</td></tr>
<tr><td>Scenario 2.2</td><td>Outermost Truck Only Lane</td></tr>
<tr><td>Scenario 3</td><td>Truck Restriction Lane</td></tr>
<tr><td rowspan="5">Approach II</td><td rowspan="3">Macrosimulation</td><td>Scenario 4</td><td>Base/ Do-Nothing Scenario</td></tr>
<tr><td>Scenario 5</td><td>Derry Road Truck Only lane</td></tr>
<tr><td>Scenario 6</td><td>Highway 50 Truck Only lane</td></tr>
<tr><td rowspan="2">Microsimulation</td><td>Scenario 7.1</td><td>Innermost Truck Only Lane</td></tr>
<tr><td>Scenario 7.2</td><td>Outermost Truck Only Lane</td></tr>
</table>

6.1. Results of Approach I Analysis (Microsimulation)

6.1.1. Travel Time Analysis for Derry Road

1) Travel Time for All Vehicles

Figure 28 compares the eastbound Derry Road base scenario travel time with the travel times of the other scenarios.

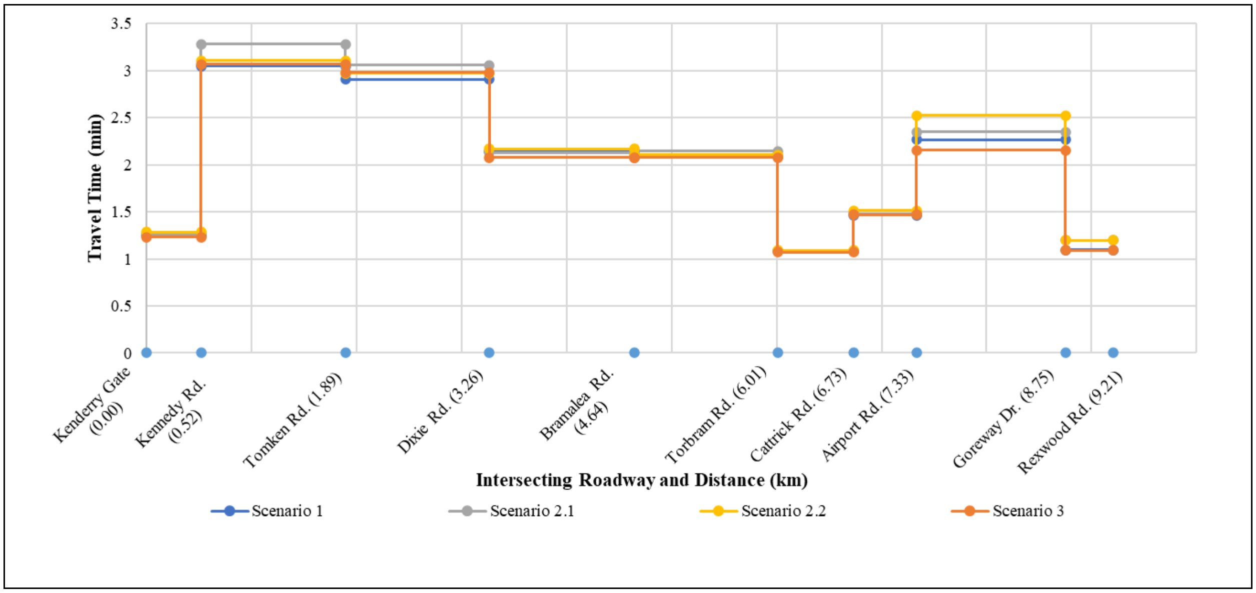


Figure 28: Eastbound Derry Road All vehicle travel time

The results for each ILU tactic are very similar for most of the links, but there are some differences. For instance, compared with the base scenario, for the link between Tomken Road and Dixie Road (1.4 km), the two TOL scenarios (Scenarios 2.1 and 2.2) show a reduced travel time: 0.15 minutes per vehicle for Scenario 2.1, and 0.07 minutes per vehicle for scenario 2.2. The link between Airport Road and Goreway Drive (1.42 km) shows the biggest difference: Scenario 2.2 shows an increase in travel time of 0.26 minutes per vehicle.

In terms of total travel time along the 9.22 km of the entire section of eastbound Derry Road, **Figure 28** shows that Scenario 3 provides a small saving in travel time for all vehicles. Compared with the base scenario, Scenario 3 shows a 0.11 minutes (0.63%) travel time saving per vehicle, from 17.33 minutes to 17.22 minutes. Compared with the base scenario, Scenario 2.1 shows a total travel time of 18.00, and Scenario 2.2 shows a total travel time of 17.96 minutes. These travel times are 0.67 (3.86%) and 0.63 minutes (3.63%) longer respectively than the base scenario. The very small time saving of Scenario 3 and the longer times of Scenarios 2.1 and 2.2 suggest that the ILU tactics tested are not suitable for eastbound Derry Road.

Figure 29 compares the westbound Derry Road Scenario 1 travel time with the travel times of the other scenarios.

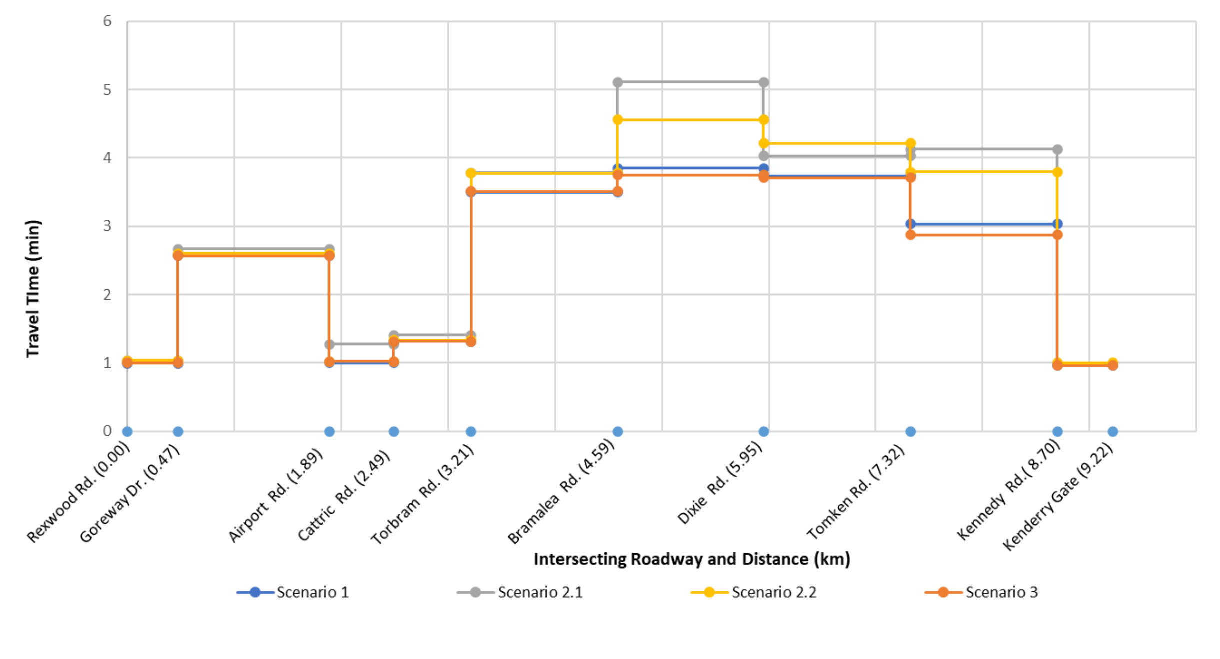


Figure 29: Westbound Derry Road All vehicle travel time

Figure 29 shows that Scenario 2.1 has the largest travel time increases on the links. For example, travel time on the three links from Bramalea Road to Kennedy Road (4.12 km) increases on an average of 0.88 minutes per vehicle. An increased travel time is also observed for Scenario 2.2 for the four links from Torbram Road to Kennedy Road (5.49 km) where travel time increases by an average of 0.58 minutes per vehicle. The remaining links show similar results for all the scenarios.

A detailed comparison shows that Scenarios 2.1 and 2.2 result in a considerable increase in travel time for all vehicles. Scenario 2.1 shows 3.46 minutes (16.5%) increase in total travel time per vehicle (to 24.41 minutes) and Scenario 2.2 shows 2.39 minutes (11.4%) increase in travel time per vehicle (to 23.34 minutes) compared to the base scenario 1's travel time per vehicle of

20.95 minutes. Scenario 3 (20.71 minutes) shows a 0.24 minutes (1%) travel time saving per vehicle compared to the base scenario.

The results indicate that Scenarios 2.1 and 2.2 are not suitable for westbound Derry Road and that Scenario 3 makes very little difference.

2) Travel Time for Trucks

Truck travel time was analyzed separately. **Figure 30** shows the results for eastbound Derry Road.

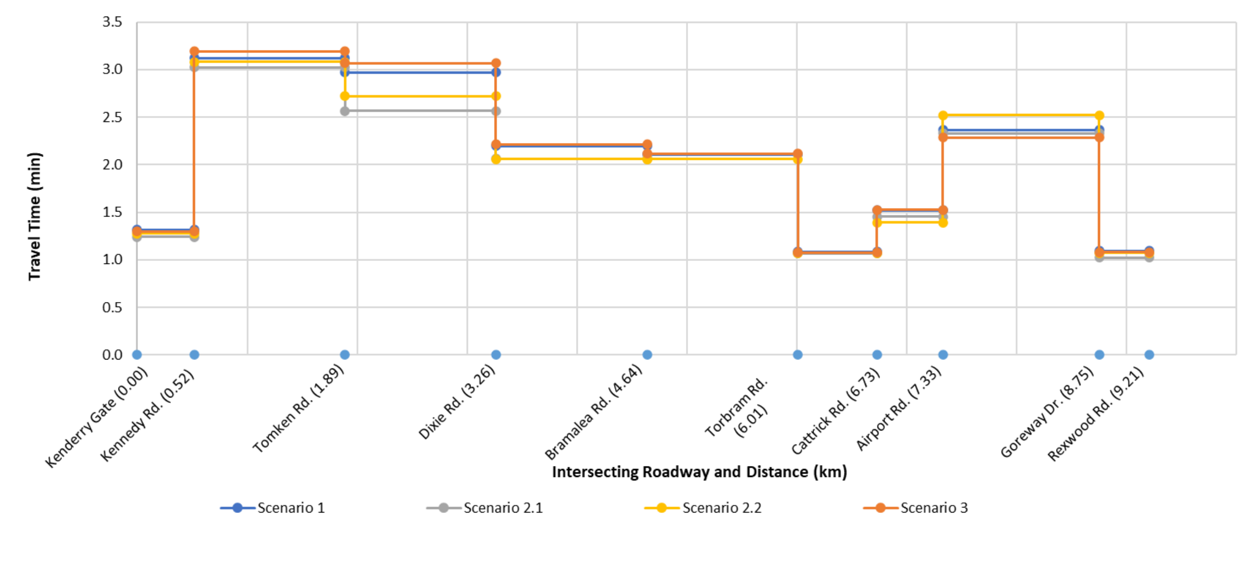


Figure 30: Eastbound Derry Road truck travel time

For Scenarios 2.1 and 2.2, **Figure 30** shows a visible reduction in truck travel time for trucks on the link between Tomken Road and Dixie Road (1.37 km). The reduced travel time is estimated as 0.41 minutes per truck (Scenario 2.1) and 0.25 minutes per truck (Scenario 2.2). However, the 1.42 km link between Airport Road and Goreway Road shows an increased travel time of 0.15 minutes per truck for Scenario 2.2.

Compared to the base scenario of 17.78 minutes for trucks travelling eastbound on Derry road, Scenario 2.1 is considered the best option as it gives the lowest truck travel times (16.88

minutes), a savings of 0.9 minutes for each truck. Scenario 2.2 has a slightly longer truck travel time (17.24 minutes). The estimated truck travel time for Scenario 3 is 17.85 minutes, an increase of 0.07 minutes over the base scenario.

Although Scenario 2.1 (innermost truck only lane) shows an improvement in truck travel time, the improvement (0.9 minutes) is too small to suggest that a truck lane should be implemented on the Eastbound Derry Road corridor.

Figure 31 shows the analysis for trucks travelling westbound on the Derry Road. Compared to the base scenario, Scenarios 2.1, 2.2 and 3 appear to show similar or reduced travel times on most of the links. The links from Airport Road to Cattrick (0.60 km) are an exception.

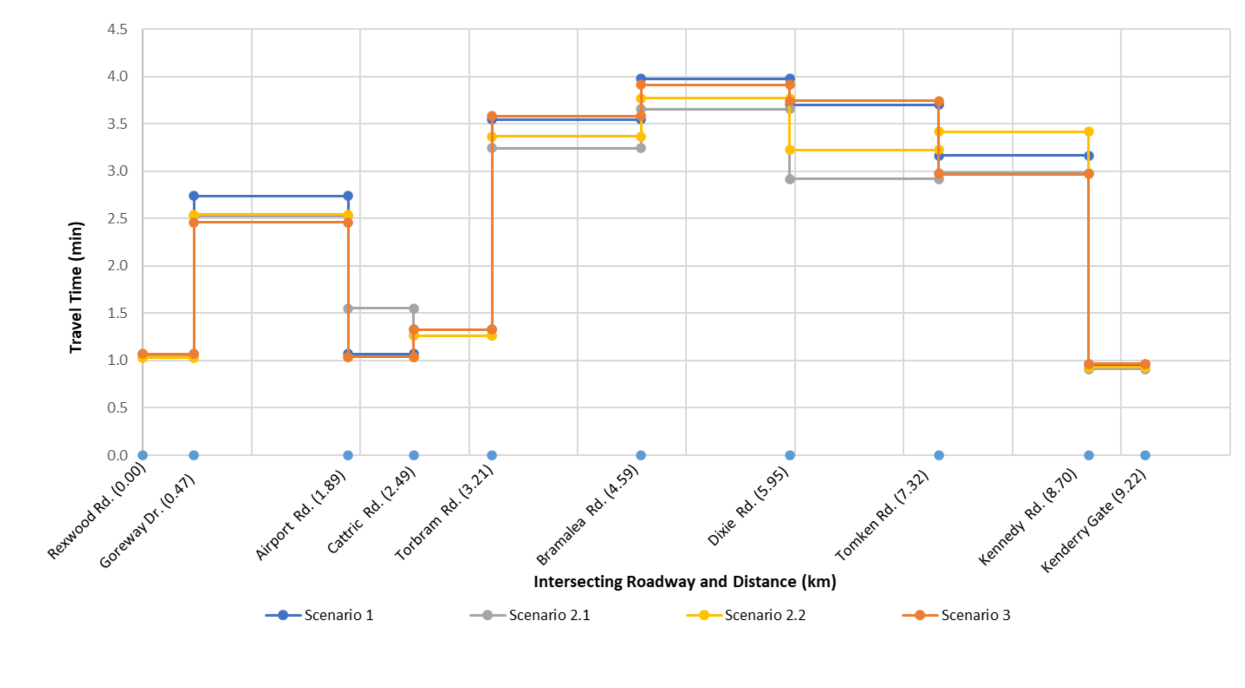


Figure 31: Westbound Derry Road truck travel time

Scenario 2.1 produces the shortest truck travel times on the westbound Derry road section. The scenario reduces the base scenario of 21.55 minutes to 20.10 minutes, a saving of 1.45 minutes per truck (6.7%). Scenario 2.2 increases truck travel time to 20.58 minutes (a saving of 0.3 minutes or 4.5%), and Scenario 3 decreases truck travel time to 21.07 minutes (an increase of 0.48 minutes or 2.23%). The results suggest that Scenario 2.1 may help to decrease truck travel times for westbound trucks on Derry Road.

Although Scenario 2.1 reduces travel times both east and westbound trucks on Derry Road, we cannot recommend any of the three ILU tactics considered as Scenario 2.1_{AI} and Scenario 2.2_{AI} increase the corridor's total travel time for all vehicles and travel time saving for Scenario 3 is negligible.

6.1.2. Travel Time Analysis for Highway 50

As mentioned in Chapter 3, Highway 50 is 11.02 km long. From Queen Street north to Sears Warehouse, there are three lanes in each direction. There are then two lanes in each direction north towards Mayfield.

1) Travel Time for All Vehicles

Figure 32 shows the results of the travel time analysis for all vehicles on northbound Highway 50.

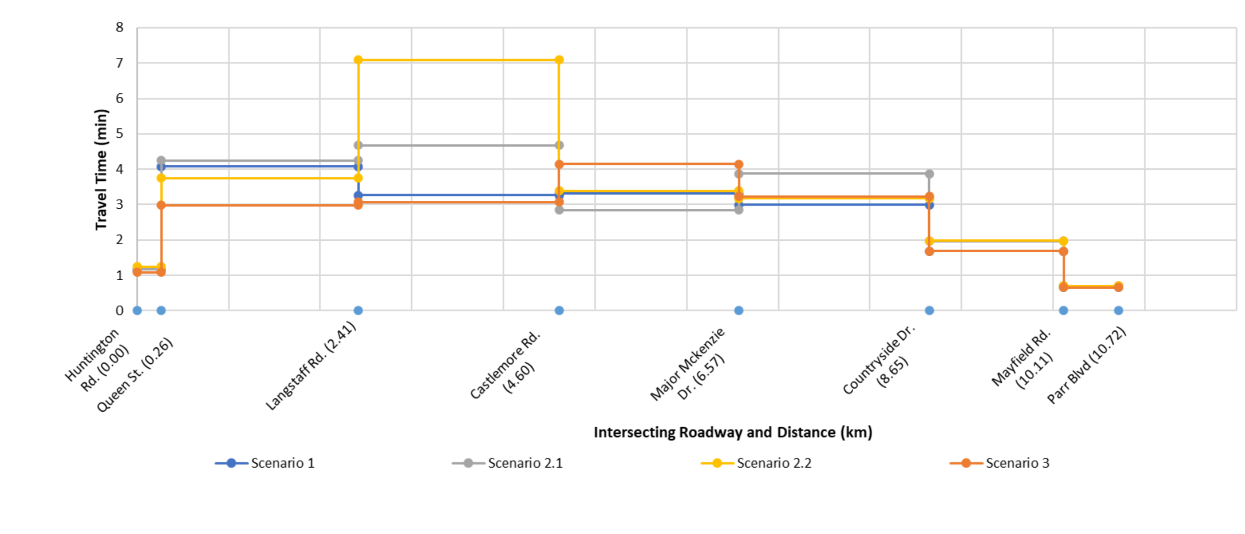


Figure 32: Northbound Highway 50 All vehicle travel time

The base scenario travel time for all northbound vehicles for the whole corridor (11.02 km) was 17.15 minutes. Compared to the base scenario, no tactic is consistently associated with a noticeable increase or decrease in travel time. In the case of the two truck only lane scenarios, Scenario 2.1 increases travel time for all vehicles by 2.32 minutes (13.5%) and Scenario 2.2 by 4.18 minutes (24 %). The increase is especially noticeable on the 2.19 km link between Langstaff Road and Castlemore Road. Scenario 3 saves travel time for every link on the corridor except the link between Castlemore Road and Major McKenzie Drive (1.97 km), but the total saving is only 0.3 minutes (1.7%).

The results suggest that there is slight improvement in Scenario 3 all vehicle travel times on northbound Highway 50.

Figure 33 shows the results of the travel time analysis for all vehicles on southbound Highway 50.

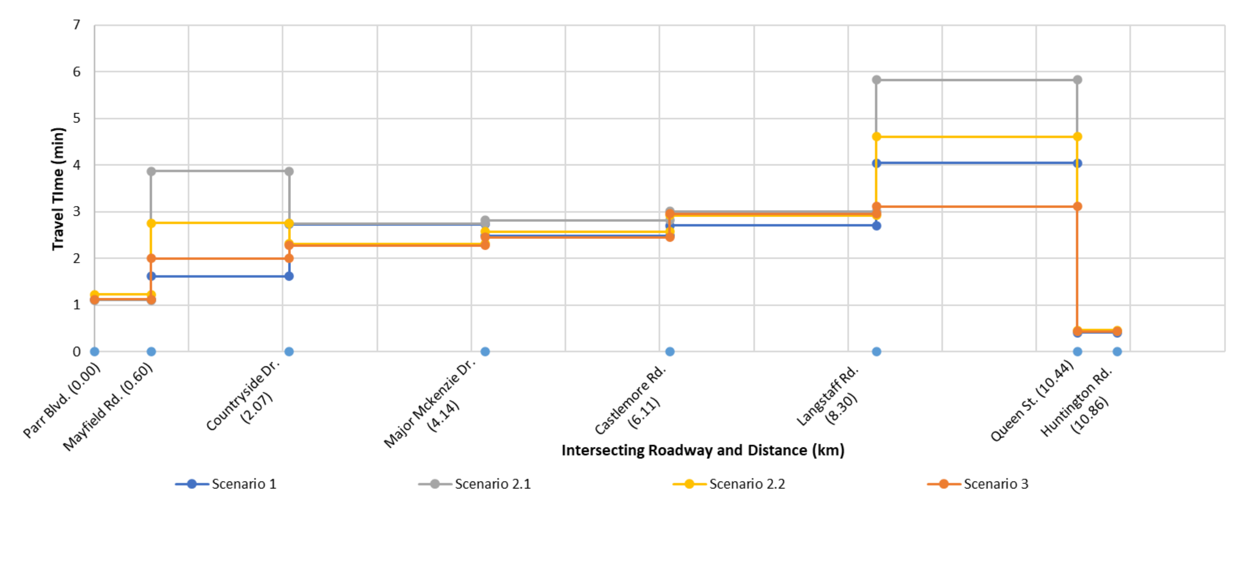


Figure 33: Southbound Highway 50 All vehicle travel time

The base scenario travel time for all southbound vehicles for the whole corridor (11.02 km) was 14.35 minutes. Compared to the base scenario, no tactic is consistently associated with a noticeable increase or decrease in travel time. In the case of the two truck only lane scenarios, Scenario 2.1 increases travel time for all vehicles by 5.46 minutes (38%) and Scenario 2.2 by 2.52 minutes (17.6%). The two truck only lane scenarios are particularly ineffective on the 2.19 km link between Langstaff Road and Castlemore Road. Scenario 3 saves 0.3 minutes (1.7%) compared with the base scenario.

The results suggest that Scenario 3 make a slight reduction in all vehicle travel times on southbound Highway 50.

1) Travel Time for Trucks

Figure 34 shows the results of the travel time analysis results for trucks on northbound Highway 50.

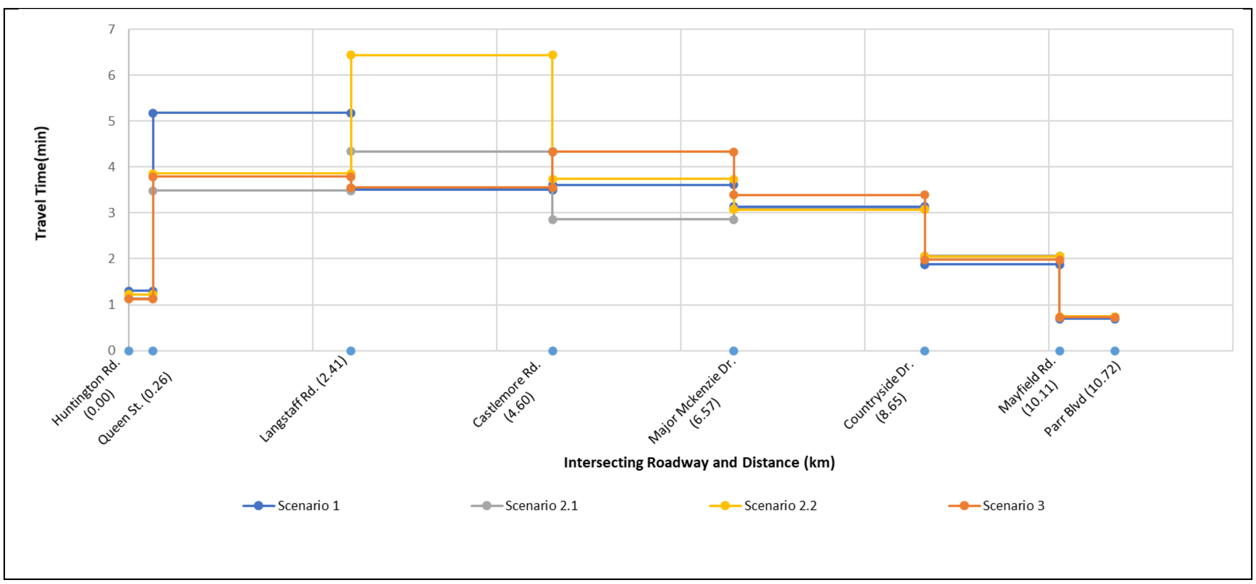


Figure 34: Northbound Highway 50 truck travel time

The base scenario travel time for northbound trucks on the whole corridor (11.02 km) was 19.31 minutes. Compared to the base scenario, **Figure 34** shows that no tactic is consistently associated with a noticeable increase or decrease in travel time. Scenario 2.1 is the best ILU tactic saving 1.62 minutes (8%) of travel time for trucks. Scenario 2.2 increases truck travel time by 1.81

minute (9.37%). Scenario 3 saves 0.43 minutes (2.23%). The Queen Street to Langstaff Road link (2.15 km) shows the largest decrease in truck travel time (led by Scenario 2.1) and the Langstaff Road to Castlemore Road link (2.19 km) shows the largest increase (led by Scenario 2.2).

The results suggest that the best ILU option for trucks on northbound Highway 50 is Scenario 2.1. but Scenario 3 also shows improvement in travel time.

Figure 35 shows the results of the travel time analysis results for trucks on southbound Highway 50.

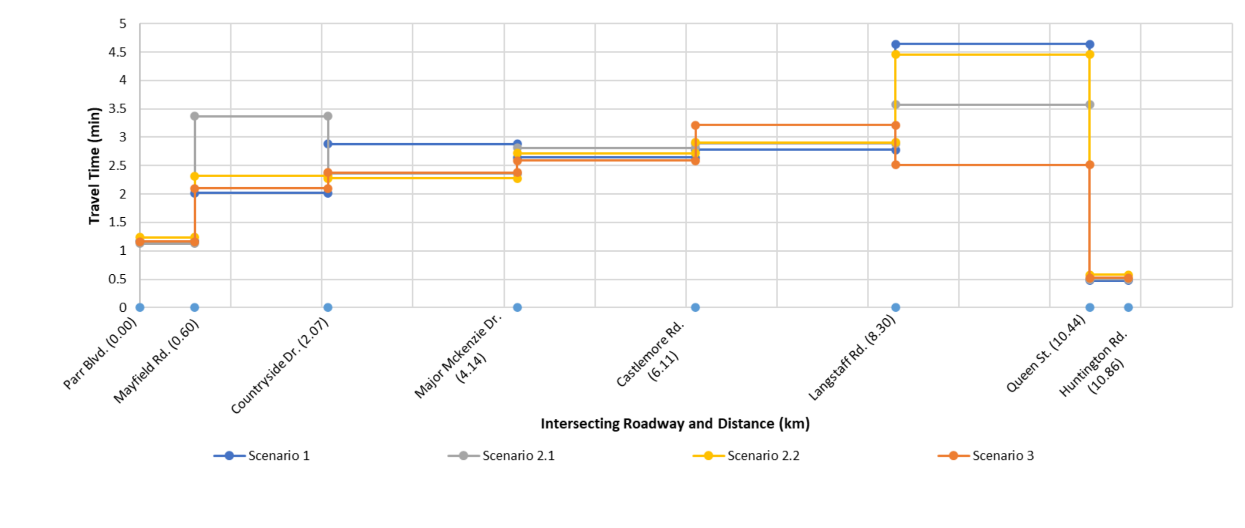


Figure 35: Southbound Highway 50 truck travel time

The base scenario travel time for southbound trucks on the whole corridor (11.02 km) was 16.61 minutes. Scenario 2.1 slightly increases truck travel time (by 0.1%), and Scenario 2.1 slightly decreases truck travel time (by 0.8%). Scenario 3, however, saves 2.13 minutes (14.7%). **Figure 35** shows that the Queen Street to Langstaff Road link (2.15 km) has the largest decrease in truck travel time (led by Scenario 3) and the Mayfield Road to Countryside Drive link (1.47 km) has the largest increase (led by Scenario 2.1).

The results suggest that the best ILU option for trucks on southbound Highway 50 is Scenario 3. **Table 8** summarises result for Approach I.

Table 8: Approach I Result Summary

Corridor	Vehicle Type	Direction	Scenario 1	Scenario 2.1	Scenario 2.2	Scenario 3
Derry Road	All Vehicle	EB	20.95	18.70	17.42	18.10
		WB	17.33	17.30	17.18	16.62
	Trucks	EB	21.55	17.47	16.80	18.30
		WB	17.78	16.79	16.92	17.29
Highway 50	All Vehicle	NB	17.15	18.58	19.37	14.31
		SB	15.10	15.62	14.87	14.22
	Trucks	NB	19.31	18.07	19.52	15.79
		SB	16.61	14.81	15.60	15.62

6.2. Results of Analysis of Approach II (Macrosimulation)

To reflect changes in traffic demand due to the implementation of ILU tactics, we conducted a multiclass traffic assignment using EMME for four vehicle classes. The results were aggregated into two classes (passenger vehicles and trucks only) and used as inputs in the VISSIM microsimulation. (See Chapter 3 for details.) The Approach II analysis compared the base scenario with the truck only lane scenarios, i.e., the truck restriction lane scenario was not considered in Approach II. Also, truck only lane was implemented only on the outer lane, as EMME is a macroscopic model implementing truck only lane in innermost lane or outermost lane will produce same results.

6.2.1. Estimated Traffic Volume on Derry Road

Table 9 shows passenger traffic on Derry Road. The table shows that the implementation of ILU tactics on Derry Road reduces east and westbound passenger car traffic by an average of 22% (eastbound) or 23% (westbound). The displaced passenger car traffic travels on adjacent roadways perhaps to avoid increased congestion on Derry Road due to the implementation of a truck only lane.

Table 9: Hourly Passenger car Traffic Volumes on Derry Road

Intersection		Scenario 4		Scenario 5		Difference	
From	To	EB	WB	EB	WB	EB	WB
Kenderry Gate	Kennedy Road	814	881	631	666	-23%	-24%
Tomken Road	Maxwell Road	696	717	550	543	-21%	-24%
Maxwell Road	Cardiff Boulevard	665	686	523	532	-21%	-22%
Cardiff Boulevard	Dixie Road	925	777	772	625	-17%	-20%
Torbram Road	Cattrick Road	971	1034	756	805	-22%	-22%
Harrow Street	Burlington Street	973	1032	758	802	-22%	-22%
Burlington Street	Airport Road	973	1032	758	802	-22%	-22%
Airport Road	Hull Street	633	479	466	329	-26%	-31%
Hull Street	Professional Court	761	613	577	463	-24%	-24%
Professional Court	Goreway Drive	773	718	581	560	-25%	-22%
Goreway Drive	Rexwood Road	975	816	765	627	-22%	-23%
Average		833	799	649	614	**-22%**	**-23%**

Table 10 shows truck traffic on Derry Road. After implementing a truck only lane scenario on Derry Road, eastbound truck traffic increases by an average of 63%, and westbound truck traffic increases by an average of 41%. The 6% reduction in truck traffic on westbound Derry Road from Kenderry Gate to Kennedy Road is associated with the southbound ramp to Highway 410. Due to the implementation of a truck only lane, it appears that truck volume is decreased because eastbound trucks coming from this ramp tend to go towards Tomken rather that going west on Derry Road where the ILU tactic is implemented only to Kenderry Gate.

Table 10: Hourly Truck Traffic Volumes on Derry Road

Intersection		Scenario 4		Scenario 5		Difference	
From	To	EB	WB	EB	WB	EB	WB
Kenderry Gate	Kennedy Road	78	91	118	85	51%	-6%
Tomken Road	Maxwell Road	84	82	124	117	47%	43%
Maxwell Road	Cardiff Boulevard	81	80	122	111	51%	39%
Cardiff Boulevard	Dixie Road	101	110	145	142	43%	29%
Torbram Road	Cattrick Road	102	121	172	178	69%	46%
Harrow Street	Burlington Street	103	124	174	180	68%	45%
Burlington Street	Airport Road	103	124	174	180	68%	45%
Airport Road	Hull Street	74	81	138	129	86%	60%
Hull Street	Professional Court	88	90	149	136	68%	52%
Professional Court	Goreway Drive	89	94	151	140	69%	49%
Goreway Drive	Rexwood Road	85	90	147	134	72%	49%
Average		90	99	147	139	**63%**	**41%**

6.2.2. Estimated Traffic Volume on Highway 50

Table 11 shows passenger traffic on Highway 50. Passenger traffic decreases by an average of 16% northbound and 8% southbound. This traffic uses adjacent roadways to avoid using Highway 50.

Table 11: Hourly Passenger Traffic Volumes on Highway 50

Intersection		Scenario 4		Scenario 6		Difference	
From	To	NB	SB	NB TOL	SB TOL	NB	SB
Albion Road	Queen Street	537	256	343	199	-36%	-22%
Queen Street	Fogal Road	586	346	447	297	-24%	-14%
Fogal Road	Ebenezer Road	908	531	747	489	-18%	-8%
Ebenezer Road	Langstaff Road	939	611	762	529	-19%	-13%
Langstaff Road	Clarkway Drive	911	583	766	526	-16%	-10%
Clarkway Drive	Rutherford Road	644	458	735	483	14%	6%
Rutherford Road	Old Castlemore Road	867	630	493	373	-43%	-41%
Old Castlemore Road	Cadetta Road	659	521	708	568	7%	9%
Cadetta Road	Major Mackenzie Drive	645	491	454	404	-30%	-18%
Major Mackenzie Drive	Nashville Road	345	226	419	338	22%	50%
Nashville Road	Mayfield Road	360	271	283	197	-21%	-27%
Mayfield Road	Parr Boulevard	363	263	350	250	-4%	-5%
Average		591	397	491	357	**-16%**	**-8%**

Table 12 shows truck traffic on Highway 50. The table shows that implementing a truck only lane increases truck traffic on Highway 50 by an average of 311% increase northbound and 91% southbound.

Table 12: Hourly Truck Traffic Volumes on Derry Road

Intersection		Scenario 4		Scenario 6		Difference	
From	To	NB	SB	NB TOL	SB TOL	NB	SB
Albion Road	Queen Street	75	50	233	84	212%	70%
Queen Street	Fogal Road	75	70	236	111	214%	59%
Fogal Road	Ebenzer Road	107	104	288	131	170%	27%
Ebenzer Road	Langstaff Road	137	148	309	183	125%	24%
Langstaff Road	Clarkway Drive	142	132	292	184	106%	40%
Clarkway Drive	Rutherford Road	117	98	265	159	126%	63%
Rutherford Road	Old Castlemore Road	108	111	256	158	137%	42%
Old Castlemore Road	Cadetta Road	84	78	267	156	217%	100%
Cadetta Road	Major Mackenzie Drive	95	77	283	145	197%	87%
Major Mackenzie Drive	Nashville Road	32	34	204	84	543%	147%
Nashville Road	Mayfield Road	34	39	217	92	531%	137%
Mayfield Road	Parr Boulevard	29	29	137	77	372%	164%
Average		75	72	241	122	**311%**	**91%**

6.2.3. Estimated Traffic Volume near Highway 50

As there was a decrease in passenger car traffic and a very large increase in truck traffic on Highway 50 corridor following implementation of a truck only lane, truck volumes on roadways near Highway 50 were estimated. We considered two adjacent parallel roadways: 6.24 km of

Huntington Road from Highway 7 to Kirby Road, and 13.5 km of Highway 27 from Finch Avenue West to Forest Height Boulevard.

Table 13 shows that on the Huntington Road section investigated, the number of trucks decreased by an average of 76% northbound and 28% southbound.

Table 13: Hourly Truck Traffic Volumes on Huntington Road

Intersection		Scenario 4		Scenario 6	
From	To	NB	SB	NB	SB
Highway 7	Fogal Road	12	2	0.01	0
Fogal Road	New Huntington Road	32	23	6	16
New Huntington Road	Langstaff Road	32	23	6	16
Langstaff Road	Trade Valley Drive	23	20	5	13
Trade Valley Drive	Rutherford Road	23	20	5	13
Rutherford Road	No name 1	18	12	1	6
No name 1	McGillivray Road	18	12	1	6
McGillivray Road	No name 2	13	18	11	16
No name 2	Nashville Road	10	6	5	14
Nashville Road	Kirby Road	10	6	1	2
Average		**19**	**14**	**4**	**10**

Table 14 shows truck volumes on the Highway 27 section investigated. The number of trucks decreased by an average of 24% northbound and 8% southbound.

Table 14: Hourly Truck Traffic Volumes on Highway 27

Intersection		Scenario 4		Scenario 6	
From	To	NB	SB	NB	SB
Finch Avenue West	Carrier Drive	22	26	21	25
Carrier Drive	Albion Road	38	35	37	35
Albion Road	Royal Crest Road	53	50	52	50
Royal Crest Road	Steeles Avenue West	48	37	43	37
Steeles Ave West	407 ramp 1	97	113	72	104
407 ramp 1	407 ramp 2	63	113	40	104
407 ramp 2	407 ramp 3	77	111	52	101
407 ramp 3	407 ramp 4	77	115	52	105
407 ramp 4	407 ramp 5	77	115	51	105
407 ramp 5	Royal Gate Boulevard	88	102	61	91
Royal Gate Boulevard	Highway 7	72	90	51	82
Highway 7	Zenway Boulevard	38	58	28	55
Zenway Boulevard	Medallion Boulevard	61	113	49	109
Medallion Boulevard	Nickle Gate	55	110	41	105
Nickle Gate	Langstaff Road	55	110	41	105
Langstaff Road	Sanreme Court	43	121	29	95
Sanreme Court	Martin Grove Road	41	109	26	83
Martin Grove Road	Royal Parkway	43	111	28	85
Royal Parkway	Rutherford Road	48	115	33	89
Rutherford Road	Humber River	58	111	37	92
Humber River	Major McKenzie Drive	50	104	29	85
Major McKenzie Drive	Humber Bridge Trail	65	72	40	69
Humber Bridge Trail	Nashville Road	43	69	42	80
Nashville Road	Islington Avenue	47	58	43	60
Islington Avenue	Forest Height Boulevard	47	59	44	61
Average		56	89	42	80

6.3. Results of Analysis of Approach II (Microsimulation)

6.3.1. Travel Time Analysis for Derry Road

The Approach II microsimulation analysis considered changed traffic demand. The results of the Approach II macrosimulation were used as input for the analysis. As a macrosimulation analysis was not conducted for the truck restriction lane, the Approach II microsimulation analysis did not analyze the truck lane restriction scenario.

1) All Vehicle Travel Time Analysis for Derry Road

Figure 36 compares the base scenario for all vehicle travel time on eastbound Derry Road with the all-vehicle travel time of Scenarios 7.1 and 7.2.

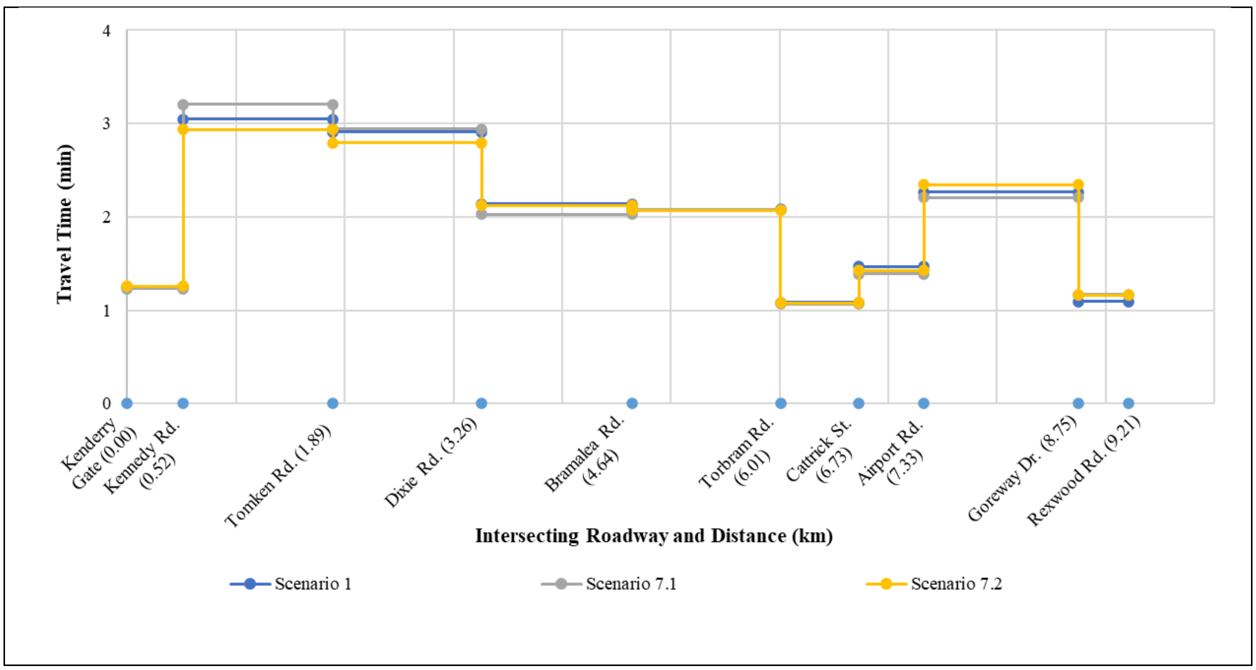


Figure 36: Eastbound Derry Road All vehicle travel time

The all-vehicle travel time for the base scenario is 17.33 minutes. The **Figure 36** shows that the ILU tactics make very little difference in all vehicle travel time on the study corridor. Scenario 7.1 improves all vehicle travel time by 0.03 minutes (0.17%) and Scenario 7.2 by 0.15

minutes (0.87%). Within the corridor, some segments show a slight increase in all vehicle travel time and none shows a clear decrease.

The results suggest that Scenario 7.2 makes slight reduction in all vehicle travel times on eastbound Derry Road.

Figure 37 compares the base scenario for all vehicle travel time on westbound Derry Road with the all-vehicle travel time of Scenarios 7.1 and 7.2.

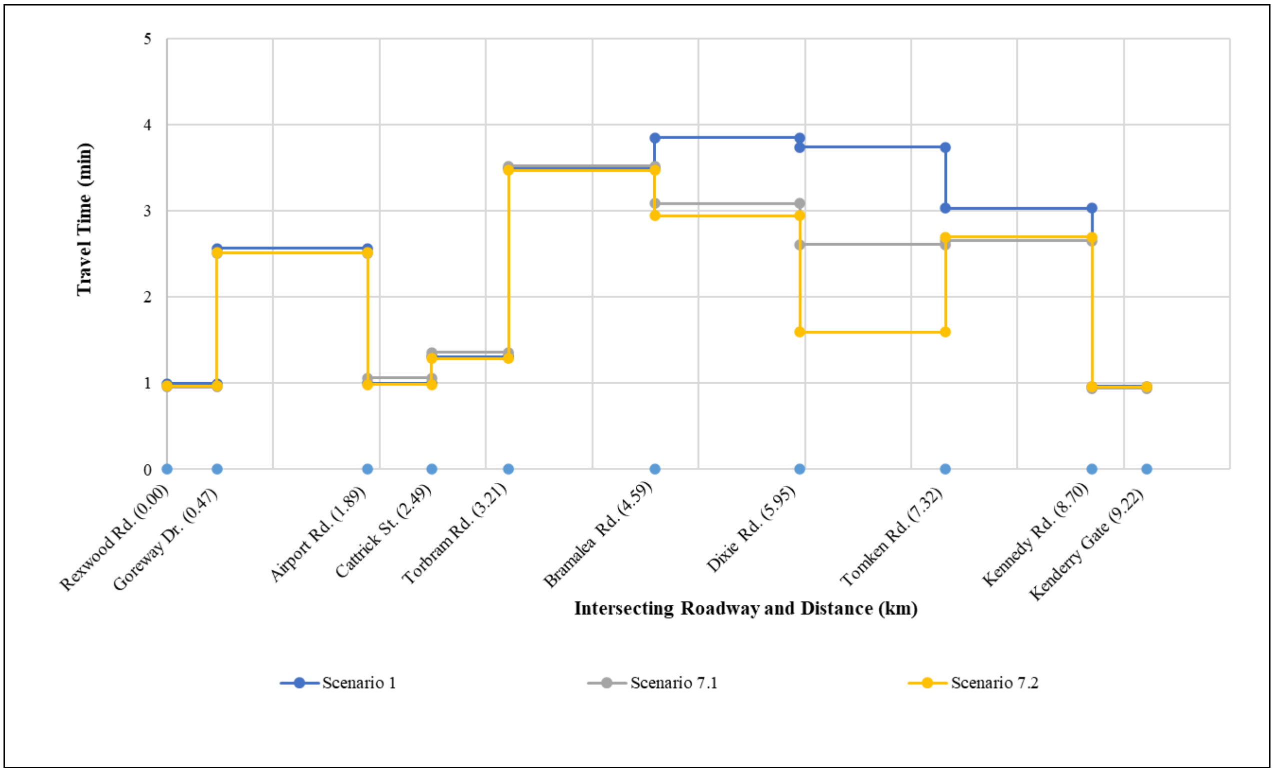


Figure 37: Westbound Derry Road All vehicle travel time

It is to be noted over here that all the three-scenario used for this study showed an overall improvement in travel time. Between Bramalea Road and Kennedy Road (4.12 km), both Scenarios 7.1 and 7.2 have significant reduction in travel time, with 2.27 minute per vehicle travel time saving for scenario 7.1 and 3.38 minute per vehicle travel time saving for scenario 7.2. The all-vehicle travel time for the base scenario is 20.95 minutes. Scenario 7.1 improves all vehicle travel time by 2.25 minutes (10.7%) and Scenario 7.2 by 3.53 minutes (16.8%). Within the corridor, it is clear that the main time savings are on the three links between Bramalea Road and Kennedy Road. Scenario 7.2 is particularly successful on the Dixie Road to Tomken Road link.

The results suggest that both scenarios may make a noticeable reduction in all vehicle travel times on westbound Derry Road. Scenario 7.2 appears to offer the better option.

2) Truck Travel Time Analysis for Derry Road

Figure 38 compares the base scenario for truck travel time on eastbound Derry Road with the all-vehicle travel time of Scenarios 7.1 and 7.2.

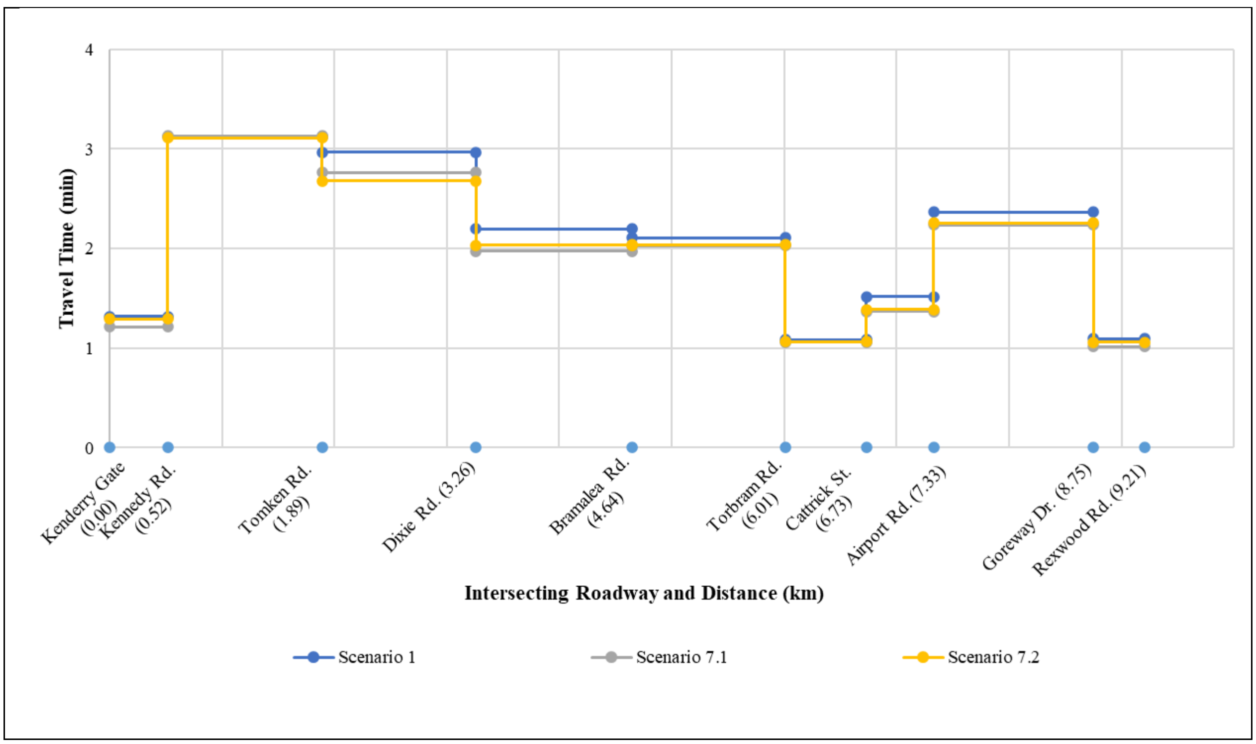


Figure 38: Eastbound Derry Road truck travel time

The truck travel time for the base scenario is 17.78 minutes. The **Figure 38** shows that the ILU tactics make a small improvement in truck travel time on the study corridor. Scenario 7.1 decreases travel time by 0.99 minutes (5.56%) and Scenario 7.2 by 0.86 minutes (4.83%). Within the corridor, the travel time decreases vary with the best decrease being Scenario 7.2 on the link from Tomken Road to Torbram Road of 0.51 minute per truck.

The results suggest that both scenarios may make a small reduction in truck travel times on eastbound Derry Road. Scenario 7.1 appears to offer a slightly better option.

Figure 39 compares the base scenario for truck travel time on westbound Derry Road with the truck travel time of Scenarios 7.1 and 7.2.

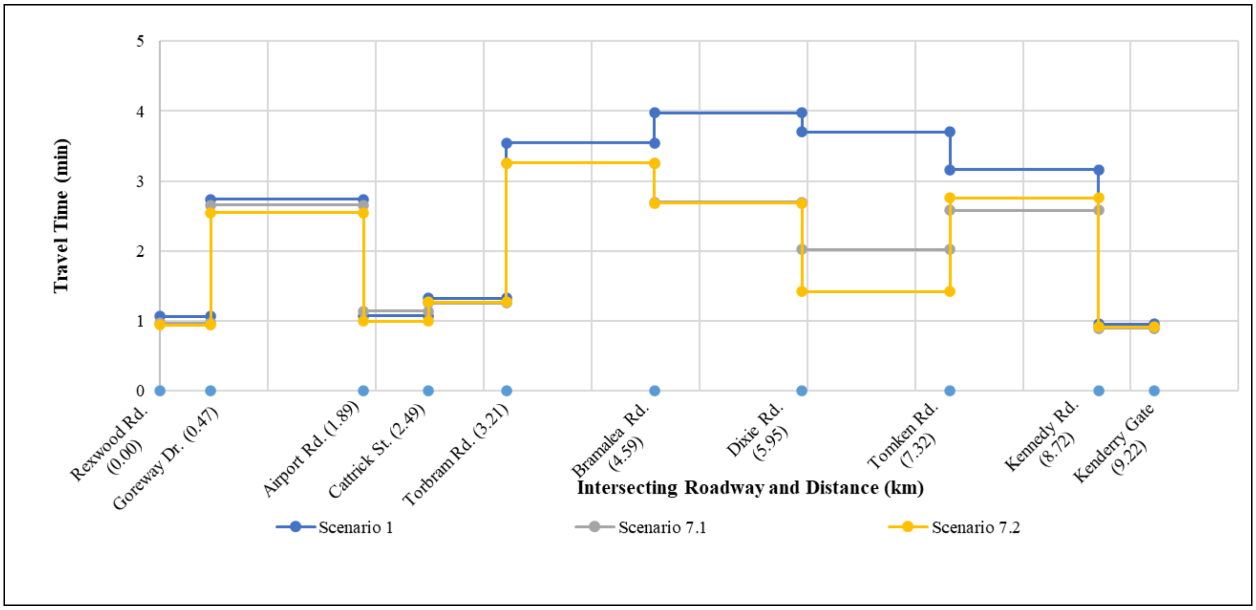


Figure 39: Westbound Derry Road truck travel time

The truck travel time for the base scenario is 21.55 minutes. The **Figure 39** shows that both Scenario 7.1 and Scenario 7.2 reduce truck travel time on the study corridor. Scenario 7.1 decreases travel time by 4.08 minutes (18.9%) and Scenario 7.2 by 4.75 minutes (22.0%). Within the corridor, the travel time decreases vary with the best decrease being Scenario 7.2 on the link from Dixie Road to Tomken Road of 2.28 minute per truck.

The results suggest that both scenarios may make a noticeable reduction in truck travel times on westbound Derry Road. Scenario 7.2 appears to offer a particularly promising option.

6.3.2. Travel Time Analysis for Highway 50

1) All Vehicle Travel-time Analysis for Highway 50

Figure 40 compares the base scenario for all vehicle travel time on northbound Highway 50 with the all-vehicle travel time of Scenarios 7.1 and 7.2.

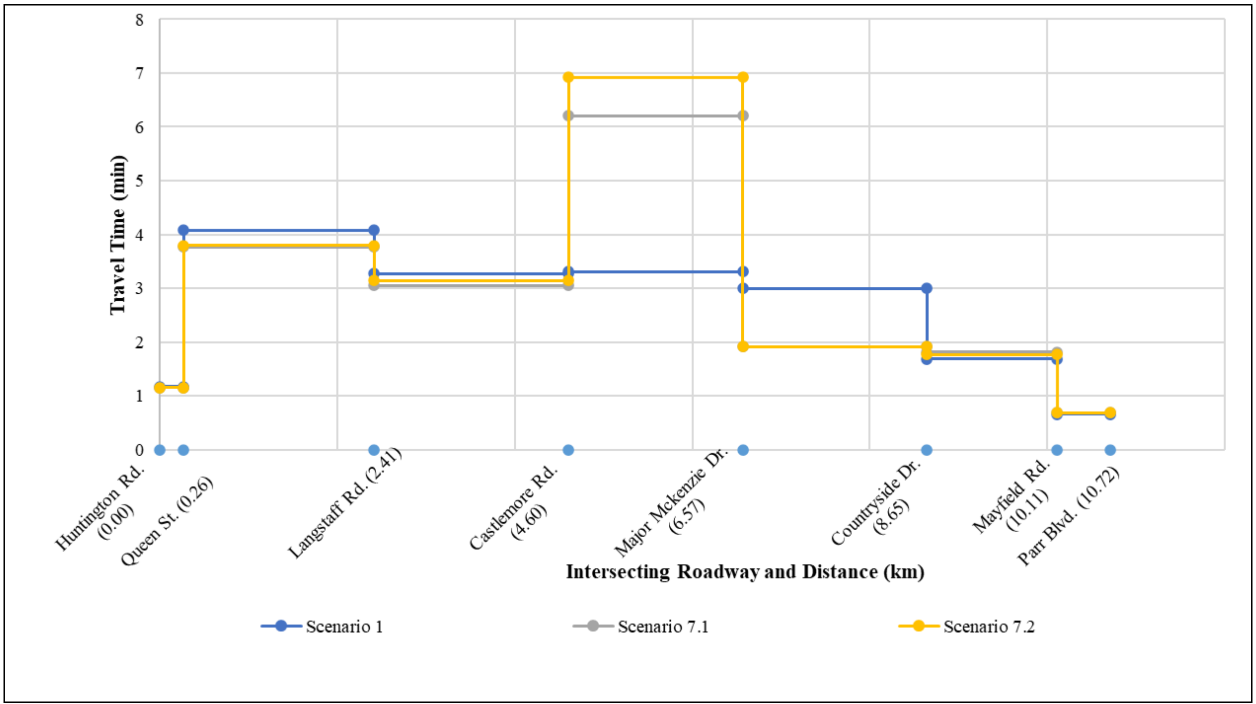


Figure 40: Northbound Highway 50 all vehicle travel time

The all-vehicle travel time for the base scenario is 17.15 minutes. The **Figure 40** shows that the ILU tactics considerably increase the all-vehicle travel time on the study corridor, especially on certain links. Scenario 7.1 increases all vehicle travel time by 1.43 minutes (8.0%) and Scenario 7.2 by 2.22 minutes (13%). Within the corridor, some segments show a very marked increase in all vehicle travel time especially the link between Castlemore Road and Major Mackenzie Drive 2.91 minute per vehicle increase for Scenario 7.1 and 3.62 minute per vehicle increase for Scenario 7.2. However, the links i.e., between Major McKenzie Drive and Countryside Drive (2.08 km) a reduction in travel time is observed for both Scenario 7.1 (1.03 minute) and 7.2 (1.08 minute).

The results suggest that neither scenario tested is suitable for implementation on Northbound Highway 50. **Figure 41** compares the base scenario for all vehicle travel time on southbound Highway 50 with the all-vehicle travel time of Scenarios 7.1 and 7.2.

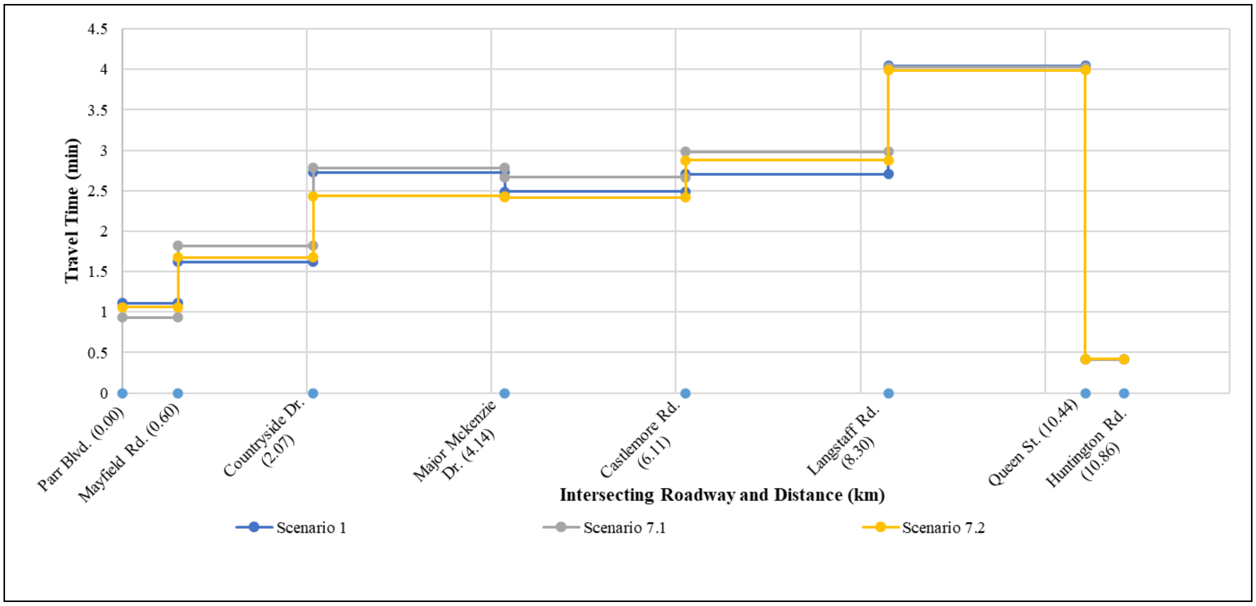


Figure 41: Southbound Highway 50 All vehicle travel time

The all-vehicle travel time for the base scenario is 15.10 minutes. The **Figure 41** shows that the ILU tactics have small and mixed results across the corridor's links. Scenario 7.1 decreases all vehicle travel time by 0.23minutes (1.5%) and Scenario 7.2 by 0.52 minutes (3.44%). Links between Countryside Drive and Castlemore Road (1.96 km) 0.37 minute per vehicle travel time saving is observed for Scenario 7.2.

The results suggest that neither scenario tested is likely to make a noticeable reduction in all vehicle travel times on southbound Highway 50.

2) Truck Travel Time Analysis for Highway 50

Figure 42 compares the base scenario for truck travel time on northbound Highway 50 with the truck travel time of Scenarios 7.1 and 7.2.

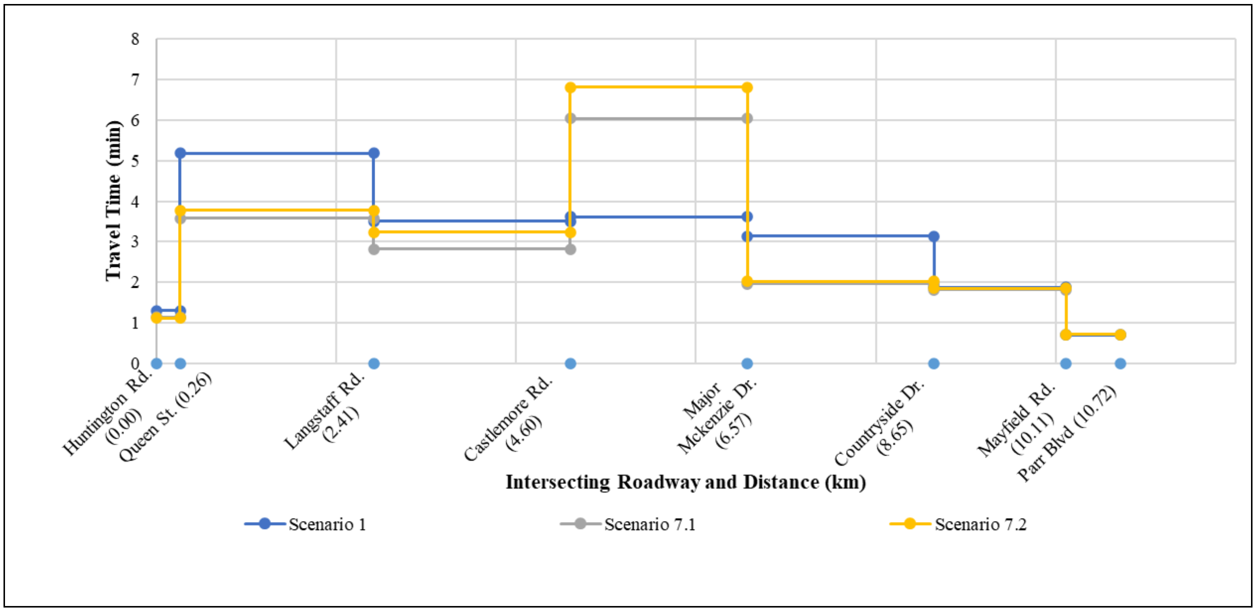


Figure 42: Northbound Highway 50 truck travel time

The truck travel time for the base scenario is 19.31 minutes. The **Figure 42** shows that the ILU tactics have mixed results on the various links in the study corridor. Overall, Scenario 7.1 improves truck travel time by 1.24 minutes (6.42 %), but Scenario 7.2 increases truck travel time by 0.61 minutes (0.87%). For links between Castlemore Road and Major McKenzie Drive (1.97 km) travel time increases by 2.43 minute per truck for Scenario 7.1 and 3.21 minute per truck for Scenario 7.2.

The results suggest that Scenario 7.1 may improve truck travel time on northbound Highway 50, but Scenario 7.2 should not be considered as it increases trucks travel time. **Figure**

43 compares the base scenario for truck travel time on southbound Highway 50 with the truck travel time of Scenarios 7.1 and 7.2.

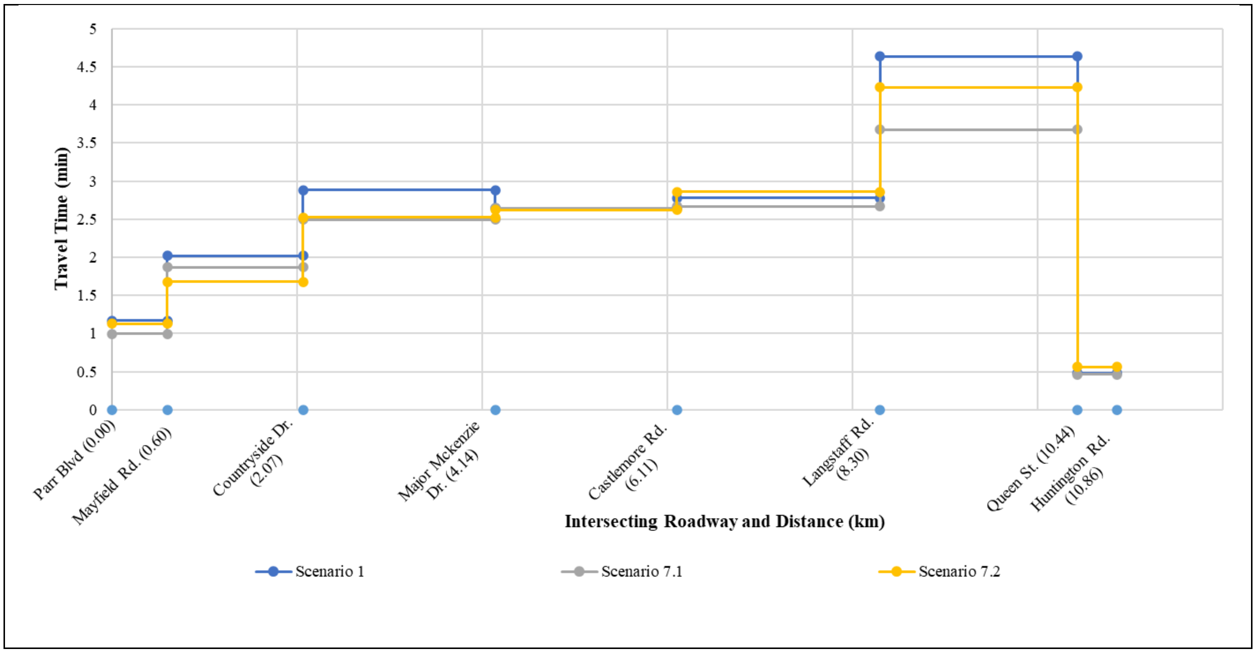


Figure 43: Southbound Highway 50 truck travel time

The truck travel time for the base scenario is 16.61 minutes. Scenario 7.1 improves travel time by 1.8 minutes (10.83%) and Scenario 7.2 by 1.01 minutes (6.08%). Within the corridor, the Langstaff Road to Queen Street link shows the biggest improvement in truck travel times especially in the case of Scenario 7.1. Links between Parr Boulevard and Major McKenzie Drive (4.13 km) both Scenarios 7.1 and 7.2 show a considerable reduction in travel time of about 1.11 minute and 0.74 minute respectively. For links between Langstaff Road and Queen Street (2.13 km) about 0.97 minute per truck reduction in travel time is observed for Scenario 7.1. For links between Mayfeild Road and Major Mckenzie(3.53 km) 0.54 minute per truck travel time saving is observed for Scenario 7.1 and for Scenario 7.2, 0.7 minute per truck travel time saving is observed.

The results suggest that Scenario 7.1 may be worth considering for southbound highway 50. **Table 15** summarise result of Approach II analysis.

Table 15: Approach II Result Summary

Corridor	Vehicle Type	Direction	Scenario 1	Scenario 7.1	Scenario 7.2
Derry Road	All Vehicle	WB	20.95	18.70	17.42
		EB	17.33	17.30	17.18
	Trucks	WB	21.55	17.47	16.80
		EB	17.78	16.79	16.92
Highway 50	All Vehicle	NB	17.15	18.58	19.37
		SB	15.10	15.62	14.82
	Trucks	NB	19.31	18.07	19.52
		SB	16.61	14.81	15.60

6.4. Chapter Summary

This study applied two approaches to the analysis of the effect of ILU tactics. Approach I considered fixed traffic demand and conducted a microsimulation analysis. Approach II considered changed traffic demand and conducted a macrosimulation analysis to obtain estimates of the change in traffic demand due to the implementation of ILU tactics.

The Approach II macrosimulation analysis was conducted only for the truck only lane scenarios (Scenarios 7.1 and 7.2) and not for the truck restriction lane scenario (Scenario 3). In Approach II, travel times between signalized intersections were recorded along the Derry Road and Highway 50 corridors for all the vehicles and for trucks to identify the impact of the ILU tactics. These times were compared with the base scenario.

The following observations were made regarding the travel time analysis results:

- In the base scenario, the total travel time on Derry Road was 17.33 minutes eastbound and 20.95 minutes westbound. The total travel time on Highway 50 was 17.70 minutes northbound and 15.10 minutes southbound.
- The Approach I microsimulation showed that the ILU tactics did not improve travel times on Derry Road/ On Highway 50, the truck restriction lane (Scenario 3) was considered suitable ILU tactic as it reduced truck travel time by 0.43 minutes (2.23%) northbound and by 2.13 minutes (14.7%) southbound). Scenario 3 reduced all vehicle travel time on Highway 50 by 0.3 minutes (1.7%) northbound and by 0.75 minutes (4.96%) southbound.
- The results of the Approach II macrosimulation analysis showed the percentage increase/decrease in passenger car and truck volumes on the two truck only lanes. Derry Road showed a slight decrease in the volume of passenger cars and a moderate increase in the volume of trucks. Highway 50 showed slight decrease in the volume of passenger cars and a large increase in the volume of trucks. Further investigation found that truck traffic from nearby roadways like Huntington Road and Highway 27 was diverted to Highway 50. The results of the Approach II macrosimulation analysis were used as input in the Approach II microsimulation analysis.
- The Approach II microsimulation analysis showed that the two truck only lane scenarios generally showed improvement in travel time for trucks and all vehicles on both two study corridors, but the improvement was very small for Highway 50 and some links on this corridor showed large increase in travel time. On Derry Road, Scenario 7.2 reduced eastbound all vehicle travel time by 0.15 minutes (0.87%) and westbound all vehicle travel time by 3.53 minutes (16.8%). Truck travel time on Derry Road was reduced by 0.86 minutes (4.83%)

eastbound and by 4.75 min (22%) westbound. Hence, the ILU tactic can be applied to the 6.86 km corridor between Torbram Road and Kennedy Road for both bound traffic. On Highway 50 none of the ILU tactics improved travel times. Although Scenario 7.1 delivered the best results for eastbound Derry Road, Scenario 7.2 was considered the better option for Derry Road because Scenario 7.2 improved the travel time of all the vehicle classes.

CHAPTER 7. CONCLUSION AND RECOMMENDATION

The objective of this study was to evaluate the impact of ILU tactics on two roadways in the GTHA. The analysis required a microsimulation and a macrosimulation. The study used two approaches; Approach I considered fixed traffic demand and Approach II considered changed traffic demand. Study evaluated travel time for trucks and all vehicles (passenger car and trucks).

7.1. Research Summary and Major Findings

7.1.1. Research Summary

Freight transportation plays a vital role in the economy and efficient truck transportation is essential for moving products and goods. As reducing truck travel time can enhance economic growth and development, this study evaluated potential savings in truck travel time with the implementation of different ILU tactics. Two GTA roadways (Derry Road and Highway 50) were selected as the study corridors.

The study evaluated operationally separated truck lanes rather than physically separated truck lanes. This is because the two study corridors pass through established areas where it is unlikely that adding additional lanes and/or physical barriers is feasible. Two types of operationally separated truck lane tactics were selected for evaluation: truck only lane and truck lane restriction. The evaluation used two simulation tools (EMME and VISSIM).

This study used two approaches. Approach I considered fixed traffic demand and conducted a microsimulation analysis using the observed traffic volumes recorded in Synchro Data. In this approach, it was assumed that there would be no change in traffic volume along the study corridors with/without ILU tactic implementation. Approach II considered changed traffic demand, i.e., it was assumed that traffic volume would change with the implementation of an ILU tactic.

Approach II required a macrosimulation analysis (which used EMME) to estimate traffic volume changes due to ILU tactics. The traffic volume estimated in EMME was used as an input in the microsimulation analysis.

The study conducted analysis for PM peak hour, hence the volume of truck on links between each intersection was high. In this study we used only single lane as truck only lane, if the volume of truck is higher than the capacity of one lane then it may lead to congestion. Also, the thesis does not discuss the impact of ILU when the truck traffic on the roadway is low.

7.1.2. Major Findings

1) Findings of the Approach I Analysis

The major research findings of the Approach I analysis can be summarized as follows.

- For Derry Road, none of the ILU tactics was considered to improve travel time. This is because mixed results were obtained. For trucks Scenario 2.1 saves travel time by 1 minute (5.62%) eastbound and 1.45 minutes (6.7%) westbound. For all vehicles Scenario 3 showed a very small reduction in travel time on Derry Road, but the truck only lane scenarios increased travel time for all vehicles.
- For Highway 50, none of the ILU tactics was considered to improve travel time. But truck restriction lane (Scenario 3) saved 0.43 minutes (2.23%) northbound and 2.13 minutes (14.7%) southbound for trucks and saved 0.3 minutes (1.7%) northbound and 0.75 minute (4.96%) southbound for all vehicles. Scenario 2.1 made the largest travel time savings for trucks in northbound Highway 50. The Queen Street to Langstaff Road link had a particularly large reduction in travel time. The reason for this may be that the corridor has three lanes in each direction from Queen Street to Sears Warehouse and then only two lanes

in each direction from Sears Warehouse to Mayfield Road. A similar pattern was observed in the study conducted by Hanscom (1990) which is discussed in Chapter 2.3.

2) Findings of the Approach II Analysis

The Approach II analysis applied the increased truck traffic and decreased passenger vehicle traffic after implementing the truck only lane tactics. The changed traffic volumes were obtained from the EMME model. (See Chapter 4 for details.) The Approach II microsimulation analysis did not investigate the truck restriction lane option (Scenario 3) as the truck restriction lane option was not included in the macrosimulation analysis.

The major research findings can be summarized as follows:

- For Derry Road, the outermost truck only lane (Scenario 7.2) achieved the largest reduction in travel time for eastbound trucks (0.86 minutes or 4.83%), westbound trucks (4.75 minutes or 22%), eastbound all vehicles (0.11 minute or 0.6%), and westbound all vehicles (3.53 minute or 16.8%). In the case of eastbound Derry Road, the innermost truck only lane (Scenario 7.1) also showed a considerable travel time improvement. Details of the location may explain these results:
    1. For eastbound, the inner lane is the best tactic as many trucks turn left to the numerous warehouses and inter-modal yard facilities located in the north direction. The truck has to be on inner lane to turn left.
    2. For westbound, the outermost lane makes it easier to turn north and to take highways and exit. Travelling west, vehicles do not make many left turns which would benefit from the inner lane option.
- For Highway 50, none of the ILU tactics improved travel time. The two truck only lane scenarios, especially Scenario 7.1 improved travel time by 1.24 minutes (6.42%) for

northbound trucks and by 1.8 minutes (10.83%) for southbound trucks, but when all vehicles are considered, northbound travel time increased by 1.43 minutes (8%). None of the ILU tactics appeared to be suitable ways to reduce travel time on Highway 50.

3) Major Findings

The analysis revealed some interesting points:

- On roadways with only two through lanes in each direction, ILU tactics should be avoided. This recommendation is based on the simulation results where it was observed that areas with a low number of lanes and closely spaced intersections experienced excessive vehicle queues that lowered travel speeds.
- The Derry Road corridor simulation revealed operational advantages associated with trucks being restricted to use the right lane. These results apply to urban roadways with sparsely spaced driveways and to frontage roads where driveway entrances or exits are not directly from the right lane to which trucks are restricted.
- As the ILU tactics discussed here are location and traffic specific, the results of this analysis can not be used for other corridors, but the methods and processes used in this study could be used future projects.
- Many studies analyze fixed traffic demand and conduct only a microsimulation. Our study found that the fixed traffic demand results were very different from the changed traffic demand results. As we consider that the Approach II analysis, i.e., including changed traffic demand, is a very rigorous approach, we suggest that changed traffic demand should be considered by researchers undertaking similar studies.
- The spacing of signalized intersections is crucial and must be carefully evaluated in the field. If signalized intersections spaced closer than 150m, ILU tactics may not be feasible

as trucks will not have the length of roadway required to execute safe lane changes. Care should also be taken when considering the relaxation distances close to major signalized and unsignalized intersections to enable trucks and other vehicles to move safely in between the lanes to turn left or right at the intersection.

The implementation of ILU tactics on arterial streets also requires careful consideration of the design and placement of signs related to the ILU. Highly urbanized roadways already have numerous signs on the shoulder and medians. Adding more signage may be problematic. The success of enforcement of ILU technique on arterial streets will depend on careful design and placement of signs warning drivers of the rules applied. The signs may also need to inform truck drivers of the relaxation distances in the vicinity of the intersections.

7.2. Future Work and Recommendations

There is a need for more research into the benefits of ILU implementation. This research should include operational improvements such as higher speed limits on passenger vehicle only lanes and allowing Long Combination Vehicles (LCV) to use truck only lane facilities. It may be possible to use thinner pavements on lanes used only by cars, and these lanes may reduce maintenance which would help to save roadway repair costs. The anticipated benefit of this research was to provide a baseline that could help transportation agencies to determine potential ILU techniques in terms of improved travel times for trucks and all vehicles, but it is clearly only a starting point when we are considering major roadway changes and possible supporting technologies that would affect millions of users.

This thesis did not take into consideration the safety impact of ILU tactics. ILU tactics may be associated with a potential increase or decrease in the number of conflicts between passenger cars and trucks. On truck only lanes, there may be problems with trucks being restricted from overtaking trucks ahead of them.

Emissions are another issue needing research. Emissions are a function of travel speed and fuel consumption. An emissions analysis might consider travel speed as a variable and estimate emission reduction when an ILU tactic is implemented. If the separation of passenger cars and trucks reduces congestion, emissions may be reduced. Traffic simulation modelling can provide information about the travel speed changes resulting from implementing ILU tactics, and this information may be helpful in reducing the emissions.

Truck platooning refers to the linking of two or more trucks in a group by using automated and connected vehicle technology. The platoon forms a set of trucks that can travel close to each other. The truck at the head of the platoon acts as the leader. The other vehicles in the platoon react and adapt to changes in the leader's movement with little to no action required from drivers. At the simplest level of platooning, drivers remain in control at all times and can decide whether to leave the platoon and drive independently (ACEA, 2017). Gains in fuel efficiency are a potential benefit of truck platooning. This fuel saving depends on the size of the gap between vehicles, the speed, the number of vehicles, and the location of a vehicle within a platoon. These variables offer interesting directions for simulation analysis designed to understand the effects of truck platooning in truck only lanes.

Traffic Signal Priority (TSP) and queue jump could be implemented along with an ILU tactic. At signalized intersections, TSP is a special treatment designed to improve the mobility of transit vehicles, emergency vehicles, and/or trucks. A priority signal strategy involves detecting the presence of a particular type of approaching vehicle and, depending on the traffic situation, providing a priority signal phase for the approaching vehicle. Typical priority signal phases include an early green signal or holding a green signal that is already displaying as green. TSP may reduce travel time delay due to traffic congestion at an intersection and can improve the time reliability of vehicles given the priority signal phase. TSP for transit is particularly useful for maintaining transit's time-competitiveness compared with other transportation modes. TSP is also regarded as a good strategy for reducing vehicle miles travelled and improving the quality of the environment by reducing greenhouse gas emissions. TSP can be implemented with both operationally and physically separated truck lanes. However, a physically separated truck lanes must be operated with TSP. In this case, higher saving in truck travel time is expected.

To enhance the positive impact of TSP, a queue jump technique can be considered. A queue jump is known to reduce the number of collisions associated with lane change behaviour at sections where weaving occurs. A queue jump lane is a travel lane (usually the right most lane) on the approach to signalized intersections and allows a particular type of vehicle to jump to the front of a queue and gain additional benefit from the traffic signal priority.

The approach and findings of this thesis can be used to guide future research and investment of resources to examine and evaluate mobility issue related to trucks. The modelling tools used for transportation analysis are not integrated well enough to provide a complete and accurate assessment of the transportation systems. The selection and combination of modelling tools to investigate congested conditions and advanced strategies like ILUs are challenging tasks for transportation modellers. There is also a need for model integration to consider incorporating supporting tool and decision-making tools. Agencies need to evaluate strategies by using tools that are sensitive to supply and demand calibration and this requires the use and integration of analysis tools across multiple resolutions, e.g., macrosimulation and microsimulation tools (FHWA, 2013a).

References

1. Abdelgawad, H., et. al. Simulation of Exclusive Truck Facilities on Urban Freeways, Journal of Transportation Engineering, Vol. 137 (8), 2011, pp. 547-562.
2. Active Traffic Management Feasibility Study. Report to Washington State Department of Transportation, Urban Corridors Office. Seattle, WA: PB Americas, Carter + Burgess, EarthTech, Inc., and Telvent Farradyne, 2007
3. Alecsandru, C.D. (2006). A Stochastic Mesoscopic Cell Transmission Model for Operational Analysis of Large-Scale Transportation Networks. Ph.D. Dissertation. Louisiana State University.
4. Anderson, B., The Border and the Ontario Economy, Cross-Border Transportation Centre, 2015.
5. Anis, Sidra, "Microsimulating Cross-Border Truck Movements between Ontario and the United States: An Application using Connected Vehicle Technology" (2019). Electronic Theses and Dissertations. 8159. https://scholar.uwindsor.ca/etd/8159Shabanian, Sh. (2014). Advanced Methodologies in Dynamic Traffic Assignment Modeling of Managed Lanes. (Ph.D. Dissertation). Florida International University, Florida, United States.
6. Arsham, H., Systems Simulation: The Shortest Route to Applications, National Science foundation, 9th Edition, 2015, Retrieved from: http://home.ubalt.edu/ntsbarsh/simulation/sim.htm
7. Bachmann, C., Improved Time-to-Collision Definition for Simulating Traffic Conflicts on Truck-Only Infrastructure. Transportation Research Record: Journal of the Transportation Research Board, 2011, pp. 31-40.
8. Bain, R., Moveable barrier technology – the key to the dynamic highway? 2001

9. Banks, J.H. (2006). "Effect of Time Gaps and Lane use Distributions on Freeway Bottleneck Capacity." J. Transportation Research Board, No. 1965, 3-11

10. Beacher, A., Fontaine, M., & Garber, N., Field Evaluation of Late Merge Traffic Control in Work Zones, Transportation Research Record: Journal of the Transportation Research Board, Vol. 1911, 2005, pp. 33-41

11. Bhattacharyya, K., Maitr, B., and Boltze, M., Implementation of Bus Priority with Queue Jump Lane and Pre-Signal at Urban Intersections with Mixed Traffic Operations: Lessons Learned?, Transportation Research Record: Journal of the Transportation Research Board, Vol. 2673(3), 2019, pp. 246-657

12. Bloomberg, L., Dale, J., 2000, Comparison of VISSIM and CORSIM traffic simulation models on a congested network. Transportation Research Record 1727, 52-60.

13. Brinckerhoff, P., HOV Managed Lanes and Ramp Metering Policy Manual. 2006.

14. Bureau of Transportation Statistics, December 2019 North American Transborder Freight Numbers, 2020, Retrieved from: https://www.bts.gov/newsroom/december-2019-north-american-transborder-freight-numbers

15. Cate, M., Another View of Truck Lane Restrictions, Transportation Research Record: Journal of the Transportation Research Board, TRB, National Research Council, Washington, D.C., 2004, pp. 19-24

16. CH2M Hill, Analysis of Freeway Operational Strategies Related to the Use of Managed Lanes by Trucks, Report submitted to San Diego Association of Governments, 2012

17. Chien, S. and X. Liu, The Development of Dynamic Travel Time Prediction Models for South Jersey Real-Time Motorist Information System. 2002, New Jersey Institute of Technology: New Jersey

18. Chrysikopoulos, G., Freeway Travel Time Estimated as a Function of Demand, Thesis submitted to The University of Florida, 2010
19. Chrysler, S., Preferential Lane use for Heavy Trucks, Texas A&M Transportation Institute, 2016
20. City of Toronto, 2016 Census: education, labour, journey to work, language of work, mobility and migration, 2017
21. Currie, G., M. Sarvi, and B. Young. A New Approach to Evaluating On-Road Public Transport Priority Projects: Balancing the Demand for Limited Road-Space. Transportation, Vol. 34, No. 4, 2007, pp. 413–428
22. Damodaran, S., Integrated Passenger & Commercial Vehicle Model for Assessing the Benefits of Dedicated Truck-only Lanes on the Freeways, Submitted at The Annual Conference of the Transportation Association of Canada, 2012
23. DeCorla-Souza, P., and Whitehead, R. E. (2003). The value of pricing the use of roads. Journal of Public Works Management & Policy, 7(4), pp.267-276.
24. Douglas, J., Handbook for planning truck facilities on urban highways, 1st Edition, 2004
25. Doustmohammadi, M., et. al., Examining Model Accuracy: How well did we do in the 1990's Predicting 2015, International Journal of Traffic and Transportation Engineering, Vol. 6 (1), 2017, pp. 15-21
26. Dumores Collision, 2020, Retrieved from: http://www.dumorescollision.com/benefits-of-using-route-planning-software/
27. Emerging Issues: Barrier Vs. Buffer separated managed lanes, Georgia Department of Transportation, 2010.

28. El-Tantawy, S., S. Djavadian, M. J. Roorda, and B. Abdulhai. Safety Evaluation of Truck Lane Restriction Strategies Using Microsimulation Modeling. In Transportation Research Record: Journal of the Transportation Research Board, No. 2099, Transportation Research Board of the National Academies, Washington D.C., 2009, pp. 123–131
29. FDOT, myTBI. (2013, March). *I-4 / selmon expressway connector (new road)*.
30. FDOT, Managed lanes subject brief, 2020, Retreived form: dotwww.blob.core.windows.net
31. Fisher, M., Ahanotu, D., and Waliszewski , J., Planning Truck-Only Lanes: Emerging Lessons from the Southern California Experience, Transportation Research Record: Journal of the Transportation Research Board, 1833(1), 2003, pp. 73-78.
32. Gao, W., Comparisons between MATSim and EMME/2 on the Greater Toronto and Hamilton Area Network, University of Toronto, 2009.
33. Garber, N., Liu, Q., Identifying the Impact of Truck -Lane Restriction Strategies on Traffic Flow and Safety Using Simulation, 2007
34. Garber, N., and Gadiraju, R., Effects of Truck Strategies on Traffic Flow and Safety on Multilane Highways, Transportation Research Record: Journal of the Transportation Research Board, No. 1256, 1990, pp. 49-54.
35. Ghariani, N., Jagannathan, R., Garland, J., Durham Highway 2 Transit Priority measures: Class Environmental Assessment and Design (Macroscopic and Microscopic Modelling)
36. Gingerich, K., Maoh, H. & Anderson, W., 2016. Characterization of internation origindestination truck movements across two-major US-Canadian Border Crossings. Transportation Research Board, pp. 1-10.

37. Goodin, G., Design and Operational Challenges Associated with Managed Lanes, "Active Management 101: Techniques for Making Managed Lanes Work," given at the IBTTA Annual Meeting & Exhibition in Dallas, Texas, in September 2006.
38. Harwood, D.W., Potts, I.B., Torbic, D.J., Glauz, W.D. Commercial Truck and Bus Safety Synthesis 3 on Highway/ Heavy Vehicle Interaction. Federal Motor Carrier Safety Administration, Washington, DC, 2003
39. Hanscom, F., Operational Effectiveness of Truck Lane Restrictions, Transportation Research Record 1281, TRB, National Research Council, Washington, D.C., 1990, pp. 119–126.
40. He, R.R., Ran, B., and Choi, K. (2000). Decision Support System for Value Pricing Strategies on I-394 Corridor Network. 79th Annual Meeting of the Transportation Research Board, National Research Council, Washington D.C., USA.
41. Heynsi, W., Jaarsveld, S., Transportation modelling in practive : connecting basic theory to practice, 2017
42. Highway 407, Ontario's Provincially owned Toll highway, 2020 retrieved from: https://www.on407.ca/en/index.html.
43. Highway Statistics, U.S. Department of Transportation; Federal Highway Administration, 2006
44. Highway 7 West Woodbridge / Vaughan, Viva Next, Retrieved from: http://www.vivanext.com/project_Hwy7West, 2020
45. High Occupancy Vehicle Lanes (HOV lanes) - diamond lanes, City of Toronto, 2020.
46. High Occupancy Vehicle (HOV) Lanes, Ministry of Transportation, Retrieved from: http://www.mto.gov.on.ca/english/ontario-511/hov-lanes.shtml, 2020

47. HNTB Corporation. (2010). Barrier versus Buffer Managed Lanes. Atlanta, GA: Georgia Department of Transportation

48. Holguín-Veras, J. (2007), "Necessary conditions for off-hour deliveries and the effectiveness of urban freight road pricing and alternative financial policies in competitive markets", Transportation Research Part A, doi:10.1016/j.tra.2007.10.008.

49. Holguin-Veras, J. Sackey, D. Hussain, S. & Ochieng, V. (2003). Economic and financial feasibility of truck toll lanes. Transportation Research Record, 1833, 66-72.

50. IBI Group, Travel Demand Forecasting Model Update: 2011 AM and PM Peak Period Models, Report prepared for Peel Region, 2018

51. IBI Group, Travel Demand Forecasting Model Update: 2011 Commercial Vehicle Model, Report prepared for Peel Region, 2018

52. Interstate 80 Planning Study (PEL), The Iowa Department of Transportation, 2017

53. Jasek, D., Shafer, M., Picha, D., and Urbanik, T., Guidelines for Truck Lane Restrictions in Texas Research Report 1726-S. Texas Transportation Institute, College Station, Aug. 1997

54. Janson, M., and David L., "HOT or not," Research in Transportation Economics, 2014, 44, 21–32.

55. Janson, B.N., and A. Rathi, Feasibility of Exclusive Facilities for Cars and Trucks, Final Report, Contract No. DTFH61-89-Y-00018, Center for Transportation Analysis, Oak Ridge National Laboratory, Oak Ridge, TN, April 1990.

56. Jayakrishnan, R., H.S. Mahmassani, and T.Y. Hu, An Evaluation Tool for Advanced Traffic Information and Management Systems in Urban Networks. 1994, Transportation Research C 2C. p. 129-147

57. Jayakrishnan, R., et al., Simulation of Urban Transportation Networks with Multiple Vehicle Classes and Services: Classifications, Functional Requirements and General-purpose Modeling Schemes, in Transportation Research Board. 2003, TRB: Washington DC.

58. Jepson, D., and L. Ferreira. Assessing Travel Time Impacts of Measures to Enhance Bus Operations. Part II: Assessment Criteria and Main Findings. Road and Transport Research, Vol. 9, No. 1, 2000, pp. 3–18

59. Jo, S., Gan, A., and Bonyani, G., Impacts of Truck-Lane Restrictions on Freeway Traffic Operations, presented at the 82nd Annual Meeting of The Transportation Research Board, Washington, D.C., 2003

60. Karim, I., Sayed, T., Lim, C., A Study of the Commercial Vehicle Value of Time for Operation at Border Crossings, Transportation Association of Canada, 2009

61. Kaufmann, S., Kerner, B.S., Rehborn, H., Koller, M., Klenov, S.L., Aerial observation of inner-city traffic and analysis of microscopic data at traffic signals. In: Transportation Research Board 2017 Annual Meeting, 2017

62. Kuhn, B. Efficient Use of Highway Capacity Summary. Report No. FHWA-HOP-10-023. College Station, TX: Texas Transportation Institute, The Texas A&M University System. 2010.

63. Kiattikomol, V., An Evaluation of the Impact of Lane Use Restrictions for Large Trucks Along I-40 near Knoxville. Master’s thesis submitted to University of Tennessee, Knoxville, Aug. 2002

64. Kim, D., et. al., Energy and Environmental Impact of Truck-Only Lanes: A Case Study of Interstate 75 between Macon and Mcdonough, Georgia, Submitted at Transportation Research Board 98th Annual Meeting, 2019.

65. Kriger, D., Regional Transportation Plan Legislative Review Backgrounder: Urban Goods Movement, Full Report, CPCS Ref: 14453 / DKCI Ref: 1145, Prepared for Metrolinx, July 2016

66. Kunhe, R., Rodiger, M., Macroscopic simulation model for freeway traffic with jams and stop-start waves, 1991 Winter Simulation Conference Proceedings, 1991, pp. 762-770

67. LEPC, Peel Halton workforce development group, e Peel Halton Workforce Development Group, November 2016

68. Lieberman, E. and A.K. Rathi, Traffic Simulation. 2006. p. 23.

69. Lindsey, R., “Reforming road user charges: A research challenge for regional science,” Journal of Regional Science, 2010, 50 (1), 471–492.

70. Lindsey, R., and Verhoe, E., Traffic congestion and congestion pricing, Tinbergen Institute Discussion Paper, 2000

71. Lipnicky, K., Burris, M., Influence of HOV lane access on HOV lane utilization. Journal of Transportation Engineering, 136(11), 1030 – 1038. 2010

72. Liu, R., Van Vliet D., and Watling D., Microsimulation models incorporating both demand and supply 26 dynamics. Transportation Research Part A: Policy and Practice, Vol. 40, No. 2, 2006, pp. 125-150.

73. Liu, Xiaoyue, Zhang G., Wu Y., and Wang Y., “Measuring the Quality of Service for High Occupancy Toll Lanes Operations,” Procedia - Social and Behavioral Sciences, 2011, 16, 15–25.

74. Lord, D., Middleton, D., Whitacre, J., Does Separating Trucks from Other Traffic Improve Overall Safety? Submitted at 84th Annual Meeting of the Transportation Research Board, 2005

75. MANAGED LANES A Cross-Cutting Study, U.S. Department of Transportation; Federal Highway Administration, 2004.
76. Managed Lanes: A Primer, U.S. Department of Transportation; Federal Highway Administration, 2008
77. Managed Lanes: A Primer, U.S. Department of Transportation; Federal Highway Administration, 2017
78. Managed Lanes - What They Are and Why We Need Them, Texas Department of Transportation, Retrieved from: “https://www.txdot.gov/driver/managed-lanes/managed-lanes.html, 2020.
79. Maryland Transportation Authority, New Lower E-ZPass Maryland Toll Rates Effective July 1, 2015
80. MapArt.com, MapArt Ontario Back Road Atlas, 2019
81. MBA Skool, Movement of Goods, Retrieved from: https://www.mbaskool.com/business-concepts/operations-logistics-supply-chain-terms/16288-movement-of-goods.html, 2016
82. Mekky, A., The Cost of Congestion in The Greater Toronto Area, Presented at Annual Conference of the Transportation Association of Canada, Saskatoon, Saskatchewan, 2007
83. Metrolinx, GTHA Urban Freight Study, Final Draft, Toronto, Ontario, February 2011
84. Michilika, D., Enhancement and evaluation of dynamic pricing strategies of managed toll lanes, University of Florida, 2012
85. Middleton, D. & Lord, D. (2005). Safety and operational aspects of exclusive truck facilities. TAMU
86. Middleton, D., Venglar, S., Quiroga, V., Lord, D., and Jasek, D., Strategies for separating trucks from passenger vehicles: Final report, 2006.

87. Mily Parveen, Calibration of the aggregate transit assignment model of EMME/2 using genetic algorithm, 2003

88. Mohamed, A., Laman, H., Oloufa, A., and Abou-Senna, H., A framework for Assessing the Impacts of State Level Platooning Truck only Lane Strategies in Florida, Submitted at Transportation Research Board 97th Annual Meeting, 2018.

89. Mwakalonge, J., Evaluation of Truck Lane Restriction on Non-Limited Access Urban Arterials, International Journal of Transportation Science and Technology, Vol. 1 (2), 2012, pp. 191-204.

90. NCHRP (National Cooperative Highway Research Program), Project 03-73 Separation of Vehicles – CMV Only Lanes Task 7 – Interim Report

91. Park, B., & Qi, H., Development and evaluation of a procedure for the calibration of simulation models. Transportation Research Record: Journal of the Transportation Research Board, 1934(1), 2005, pp. 208-217.

92. Neil, S and Jones, J., HOT Lanes, Cool Facts, 2020, United States Department of Transportation - Federal Highway Administration

93. "Northwest U.S. 290 QuickRide" – U.S. 290, Houston, TX, HOV to HOT Conversion Project, FHWA, 2010. Retrieved from: "https://ops.fhwa.dot.gov/freewaymgmt/publications/documents/nrpc0610/workshop_materials/case_studies/houston.pdf"

94. Oregon Department of Transportation, (2009). White paper #7: Truck-only toll (tot) lanes. http://www.oregon.gov/ODOT/TD/TP/docs/tolling/whitepaper7.pdf

95. Pennsylvania Department of Transportation (PDOT), (2011). Overview of potential transportation systems management & operations strategies: I-95 design management and review project.

96. Planning for Special Treatment of Trucks in Traffic, FDOT, 2015

97. Platooning Roadmap, ACEA, 2017, Retrieved from:" https://www.acea.be/uploads/publications/Platooning_roadmap.pdf".

98. PTV Group, 2016b. Introduction to Component Object Model (COM) Interface in VISSIM 8.0 User Manual. PTV Group, Karlsruhe.

99. Qi, Y., and Ryan, F., How Many Times Should I run the Model? Performance Measure Specific Findings from Vissim Models in Missouri, 2017.

100. Rakha, H., Flintsch, A, M., K, Ahn, I, El-Shawarby, and M, Arafeh (2005). Evaluating Alternative Truck Management Strategies along Interstate 81. In Transportation Research Record: Journal of the Transportation Research Board, No. 1925, pp. 76-86.

101. Report, CPCS Ref: 14453 / DKCI Ref: 1145, Prepared for Metrolinx, July 2016

102. Region of Peel, Goods Movement – Strategic Plan 2017-2021, February 2017

103. Regional Plan Association, Why Good Movement Matters, (2016), Retrieved from: https://rpa.org/work/reports/why-goods-movement-matters

104. Review of transportation improvement concept, Central Phoenix Transportation Framework Study, 2011.

105. Reversible Lanes, City of Toronto, Retrieved from: https://www.toronto.ca/services-payments/streets-parking-transportation/traffic-management/traffic-signals-street-signs/traffic-signal-operations/reversible-lanes/, 2020.

106. Road Safety & Traffic Data Management Transportation and Community Planning, Annual Average Daily Traffic, 2011. Retrieved from: "http://archives.york.ca/councilcommitteearchives/pdf/part%203.pdf"

107. Road Pricing: Congestion Pricing, Toll Roads and HOT Lanes, TDM Encyclopedia; Victoria Transport Policy Institute, 2019

108. Roles of Transportation Management Centers in Incident Management on Managed Lanes, FHWA-HOP-14-022, 2014

109. Rodrigue, J., The Geography of Transport Systems FIFTH EDITION, ISBN 978-0-367-36463-2, 2020

110. Roorda, M., et. al., Exclusive Truck Facilities in Toronto, Ontario, Canada, Transportation Research Record: Journal of the Transportation Research Board, Vol. 2168 (1), 2010, pp. 114-128.

111. Rudra, M., Roorda M., Truck-only Lanes on Urban Arterials: A Value of Time Approach, Procedia - Social and Behavioral Sciences, Vol. 125, 2014, pp. 75-83.

112. Rudra, M and Mattherw Roorda, Truck-Only Lanes on Urban Arterials: A Value of Time Approach. 2014. p. 75-83

113. Safirova, Elena, Kenneth Gillingham, Ian Parry, Peter Nelson, Winston Harrington, and David Mason, “Welfare and Distributional Effects of Road Pricing Schemes for Metropolitan Washington, DC,” Research in Transportation Economics, 2004, 9, 179–206

114. Safety Performance of Truck Lane Restrictions in Dallas-Fort Worth, Texas A&M Transportation Institute, 2016

115. Schrank, D., & Lomax, T., The 2005 Urban Mobility Report. Texas Transportation Institute, The Texas A&M University System, 2005.

116. Shalaby, A. Simulating Performance Impacts of Bus Lanes and Supporting Measures. Journal of Transportation Engineering, Vol. 125, No. 5, 1999, pp. 390–397

117. Stockton, W., et. al. Investigating the General Feasibility of High Occupancy/Toll Lanes in Texas, Report submitted to Texas Transportation Institute, 2000

118. Tao, H., Evaluation of Traffic Operations and Safety of Reserved-Lanes, Thesis Submitted to Concordia University, Montreal, Quebec, 2015

119. The Canadian Encyclopedia, Trucking Industry, 2014, retrieved from https://www.thecanadianencyclopedia.ca/en/article/trucking-industry

120. The Highway Capacity Manual. 2012; California Department of Transportation. Available from: http://www.dot.ca.gov/hq/tsip/otfa/microsim/whatis_modeling.html. Last seen in 8 of August of 2014.

121. The Effective Integration of Analysis, Modeling, and Simulation Tools, Federal Highway Administration, 2013.

122. Thomson Reuters' Business, FindLaw, 2020, retrieved from https://www.findlaw.com/company/contact-us/contacts.html

123. Transportation Association of Canada, Primer on Truck Lanes in Canadian Urban Areas, February 2014

124. Transport Canada, 2012. Transportation in Canada 2011: Comprehensive Review, s.l.: s.n.

125. Transport Canada, 2016. Transportation in Canada 2015, s.l.: s.n.

126. Transport Canada, 2018. Transportation in Canada: Overview Report, s.l.: s.n.

127. Transportation Research Board, Separation of Vehicles – CMV-only Lanes, Joint Report between National Cooperative Highway Research Program Report 649 and National Freight Research Program Report 3, Washington D. C., 2010

128. Transportation Research Board, Statewide Travel Demand Modeling, Longboat Key, Florida, 2005.

129. Traffic Signal Timing Manual, US DOT, FHWA, 2017, retrieved from: https://ops.fhwa.dot.gov/publications/fhwahop08024/chapter4.htm

130. Traffic Volumes, Ministry of Transportation Ontario, 2016.

131. Triangle strategic tolling study, managed lane and tolling best practice, WSP, 2017.

132. Trip Distribution, Chapter 8, NPTEL, 2007 Retrieved from: https://nptel.ac.in/content/storage2/courses/105101087/downloads/Lec-8.pdf.

133. TTI Evaluates Lane Restrictions for Houston Demonstration Project, Texas Transportation Researcher, Volume 38, Number 1 (2002)

134. Toledo, T., Omar, M., Haddad J., Optimal Dynamic Tolls for Managed Lanes, Transportation Research Record: Journal of the Transportation Research Board, 2017

135. Tuffin, B., Hirel, C., Choudhary, P., Trivedi, K., Simulation versus Analytic-Numeric Methods: Illustrative Examples, 2007.

136. Ullah, M., et. al., Travel Demand Modeling for the Small and Medium Sized MPOs in Illinois, Report prepared for Illinois Center for Transportation, 2011

137. . Urban Transportation Monitor. Consideration of Exclusive Truck Lanes Moves Forward in U.S. December 2004 Issue

138. Use of Freeway Shoulders for Travel — Guide for Planning, Evaluating, and Designing Part-Time Shoulder Use as a Traffic Management Strategy, Retrieved from: https://ops.fhwa.dot.gov/publications/fhwahop15023/ch1.htm, FHWA, 2020.

139. Varsha, V., Gaurav, H. Pandey, K. Ramachandra Rao, Bindhu B.K., Determination of Sample Size for Speed Measurement on Urban Arterials, 11th Transportation Planning and Implementation Methodologies for Developing Countries, December 2014, Mumbai, India.

140. Vickrey, W.S. Pricing in urban and suburban transport. American Economic Review, 53, 452- 465, 1963

141. Vilain, P. and P. Wolfrom (2001), “Value pricing and freight traffic: Issues and industry constraints in shifting from peak to off-peak movements”, Transportation Research Record 1707, 64-72.

142. VISSIM 4.1 User Manual. March 2005.

143. VISSIM guide user, VDOT Traffic Engineering Division, 2020.

144. Waters, W.G. Variations in the Value of Travel Time Savings: Empirical Studies and the Values for Road Project Evaluation. Institute of Transport Studies, The University of Sydney, Sydney. 1993: 9

145. Waterson, B., Raj Bhandari, B., and Hounsell, N., Simulating the Impacts of Strong Bus Priority Measures. 24 Journal of Transportation Engineering, Vol. 129, No. 6, 2003, pp. 642-647.

146. WSP Global Inc, Transportation Master Plan, Prepared for The City of Barrie, Thornhill, Ontario, 2019.

147. Wolshon, B., and Lambert, L., NCHRP Synthesis 340: Convertible Roadways and Lanes. A Synthesis of Highway Practice. Transportation Research Board, National Research Council, Washington, D.C., 2004.

148. Xu L., Potential single-occupancy vehicle demand for the Katy Freeway and Northwest Freeway high-occupancy vehicle lanes. Ph.D. dissertation, Texas A&M Univ., College Station, TX, 2005.

149. Yan, X. Y. and Crookes R. J., 2010. ‘Energy demand and emission from road transportation vehicles in China’, Journal of progress in Energy and Combustion Science, 36, 657-676.

150. Yang, C., Managed lane weaving and access guidelines, 2009

151. Yang, C., Regan, A C., Impacts of Left Lane Truck Restriction on Urban Freeways, University of California Transportation center, 2007.

152. York Region, Bus Only Lane, Markham, 2014 retrieved from: https://www.yorkregion.com/news-story/4866741-section-of-bus-only-lane-opens-in-markham/

153. Zamparini, L & Reggiani, A. (2007). Freight transport and the value of travel time savings: A meta-analysis of empirical studies. *Transp. Reviews, 27(5)*, 621-636.

154. Zhao, Y., and Kockelman, K., Anticipating the Regional Impacts of Connected and Automated Vehicle Travel in Austin, Texas, Journal of Urban Planning and Development, Vol. 144, (4)

155. Zhou, L., An Anisotropic Mesoscopic Traffic Simulation Model for Dynamic Transportation Network Modeling, in Civil Engineering 2005, University of Texas at El Paso: El Paso. p. 109.

156. Zhou, G., and Gan, A., Performance of Transit Signal Priority with Queue Jumper Lanes, Transportation Research Record: Journal of the Transportation Research Board, Vol. 1925, 2005, pp. 265-271

157. Zhou, G., Gan., A and Zhu, X., Determination of Optimal Detector Location for Transit Signal Priority with Queue Jumper Lanes, Transportation Research Record: Journal of the Transportation Research Board, Vol. 1978, 2006, pp. 123-12

158. Zhang, G., Yan, S., Wang, Y., 2009. Simulation-based investigation on high-occupancy toll lane operations for Washington State Route 167. Journal of Transportation Engineering 135(10), 677-686.

Appendices

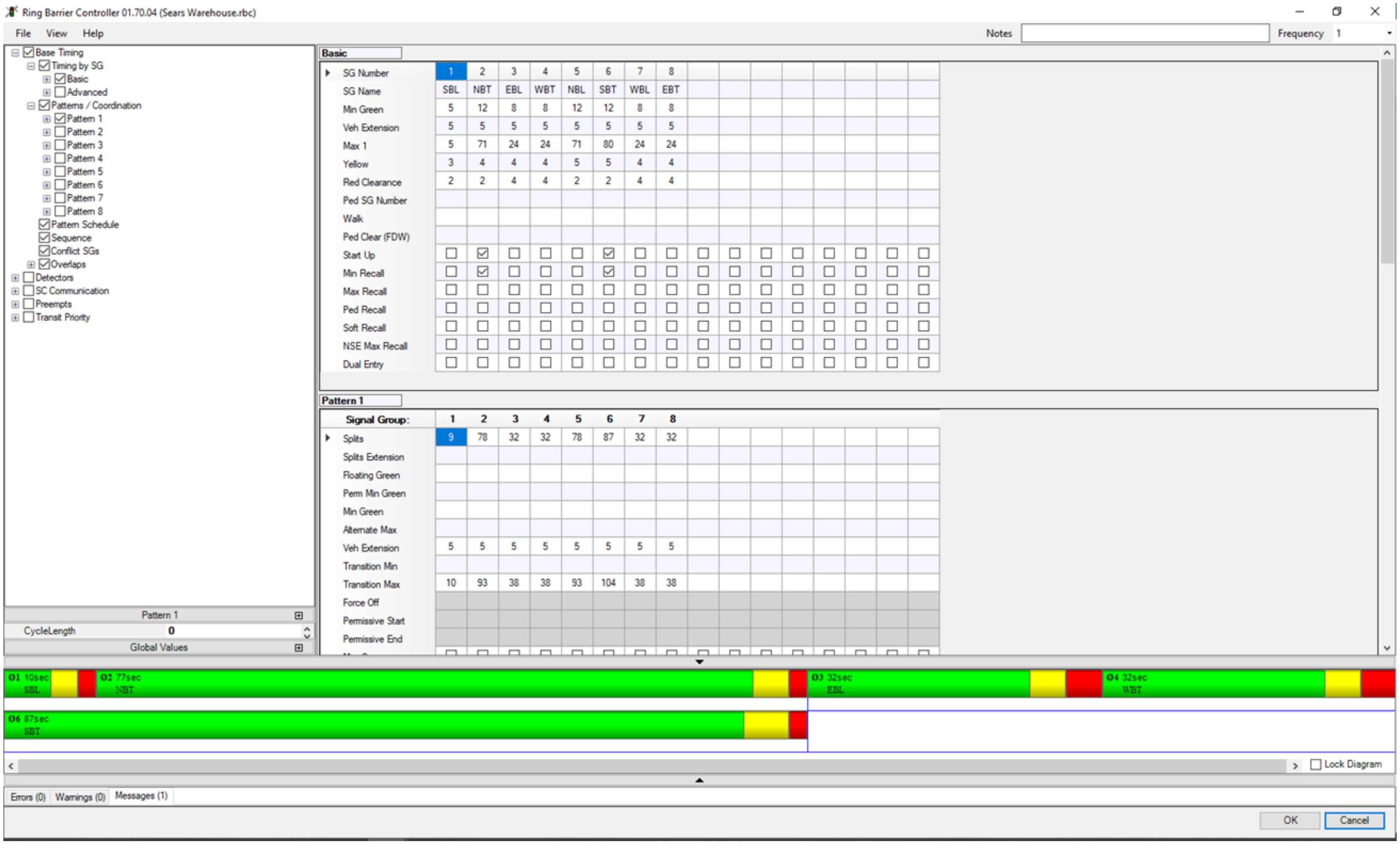
Appendix A: Derry Road Turning Movement Count PM Peak

Appendix B: Traffic Signal Data

Appendix B-1: Derry Road PM Signal Timing

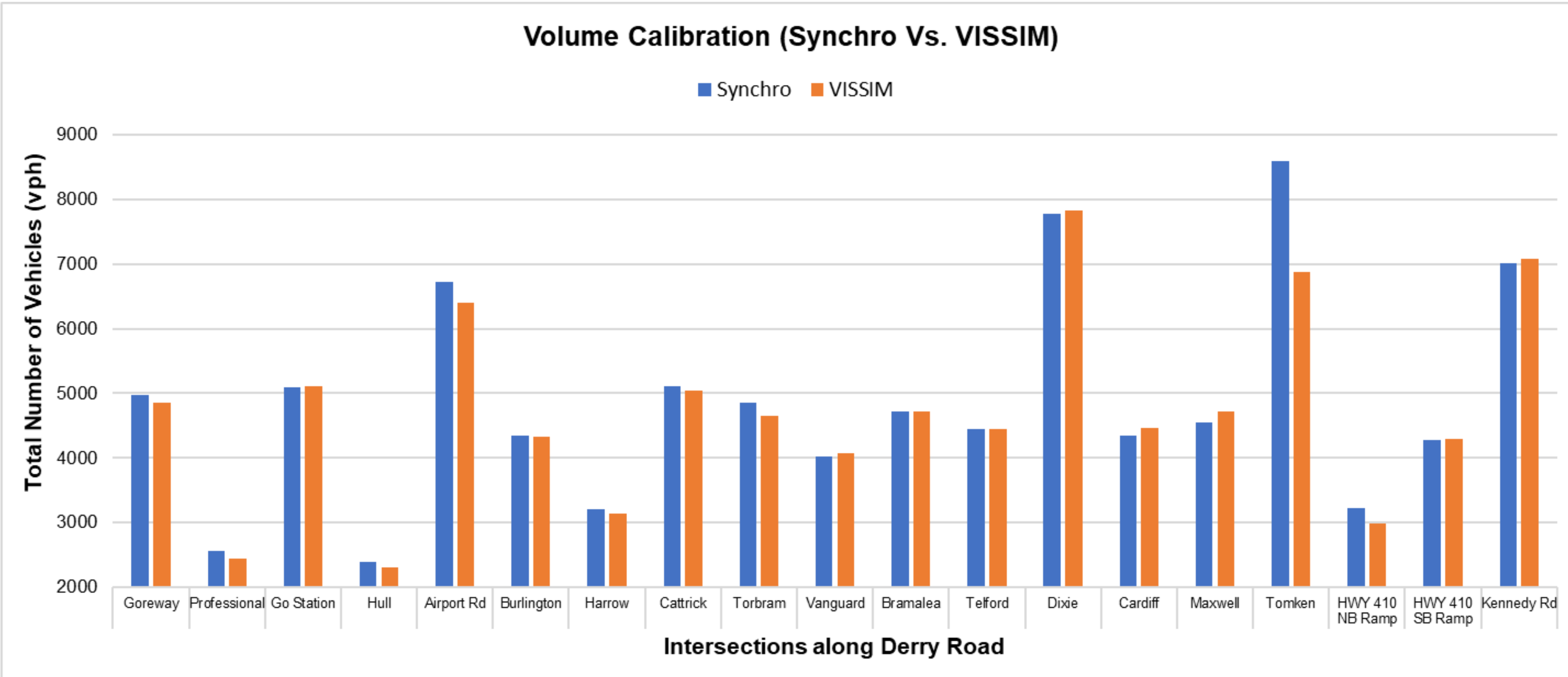
TIMING SETTINGS	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR	PED	HOLD
Lanes and Sharing (#RL)	↰↰	↑↑↑	↱	↰↰	↑↑↑	↱	↰↰	↑↑↑	↱	↰↰	↑↑↑	↱	—	—
Traffic Volume (vph)	317	1206	129	672	1652	219	214	1182	535	182	987	472	—	—
Future Volume (vph)	317	1206	129	672	1652	219	214	1182	535	182	987	472	—	—
Turn Type	Prot	—	Free	Prot	—	Free	Prot	—	Free	Prot	—	Free	—	—
Protected Phases	5	2		1	6		7	4		3	8			
Permitted Phases			Free			Free			Free			Free	—	—
Permitted Flashing Yellow	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Detector Phases	5	2	None	1	6	None	7	4	None	3	8	None	—	—
Switch Phase	0	0	0	0	0	0	0	0	0	0	0	0	—	—
Leading Detector (m)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	—	—
Trailing Detector (m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—
Minimum Initial (s)	8.0	8.0	—	8.0	8.0	—	8.0	12.0	—	8.0	12.0	—	—	—
Minimum Split (s)	13.0	38.0	—	13.0	38.0	—	13.0	38.0	—	13.0	38.0	—	—	—
Total Split (s)	22.0	46.0	—	37.0	61.0	—	16.0	43.0	—	14.0	41.0	—	—	—
Yellow Time (s)	3.0	5.0	—	3.0	5.0	—	3.0	5.0	—	3.0	5.0	—	—	—
All-Red Time (s)	2.0	3.0	—	2.0	3.0	—	2.0	3.0	—	2.0	3.0	—	—	—
Lost Time Adjust (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—
Lagging Phase?	☐	☑	—	☐	☑	—	☐	☑	—	☐	☑	—	—	—
Allow Lead/Lag Optimize?	☑	☑	—	☑	☑	—	☑	☑	—	☑	☑	—	—	—
Recall Mode	None	C-Max	—	None	C-Max	—	None	None	—	None	None	—	—	—
Speed limit (km/h)	—	70	—	—	70	—	—	70	—	—	70	—	—	—
Actuated Effct. Green (s)	17.0	38.0	140.0	32.0	53.0	140.0	11.0	35.0	140.0	9.0	33.0	140.0	—	—
Actuated g/C Ratio	0.12	0.27	1.00	0.23	0.38	1.00	0.08	0.25	1.00	0.06	0.24	1.00	—	—
Volume to Capacity Ratio	0.96	1.02	0.10	1.03	0.95	0.17	0.91	1.04	0.42	0.98	0.96	0.36	—	—
Control Delay (s)	93.2	98.4	0.1	93.9	55.2	0.3	100.3	95.2	0.9	125.0	71.7	0.7	—	—
Queue Delay (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—
Total Delay (s)	93.2	98.4	0.1	93.9	55.2	0.3	100.3	95.2	0.9	125.0	71.7	0.7	—	—
Level of Service	F	F	A	F	E	A	F	F	A	F	E	A	—	—
Approach Delay (s)	—	89.7	—	—	60.7	—	—	69.6	—	—	57.2	—	—	—
Approach LOS	—	F	—	—	E	—	—	E	—	—	E	—	—	—
Queue Length 50th (m)	49.6	~139.7	0.0	~107.4	170.5	0.0	33.2	~137.2	0.0	27.8	104.9	0.0	—	—
Queue Length 95th (m)	#79.2	#169.8	0.0	#145.6	#203.5	0.0	#57.3	#167.2	0.0	#53.0	#133.5	0.0	—	—
Stops (vph)	290	1101	0	598	1508	0	196	1077	0	157	909	0	—	—
Fuel Used (l/hr)	48	189	5	113	230	12	28	151	8	31	129	17	—	—

Appendix B-2: Ring Barrier Signal Controller



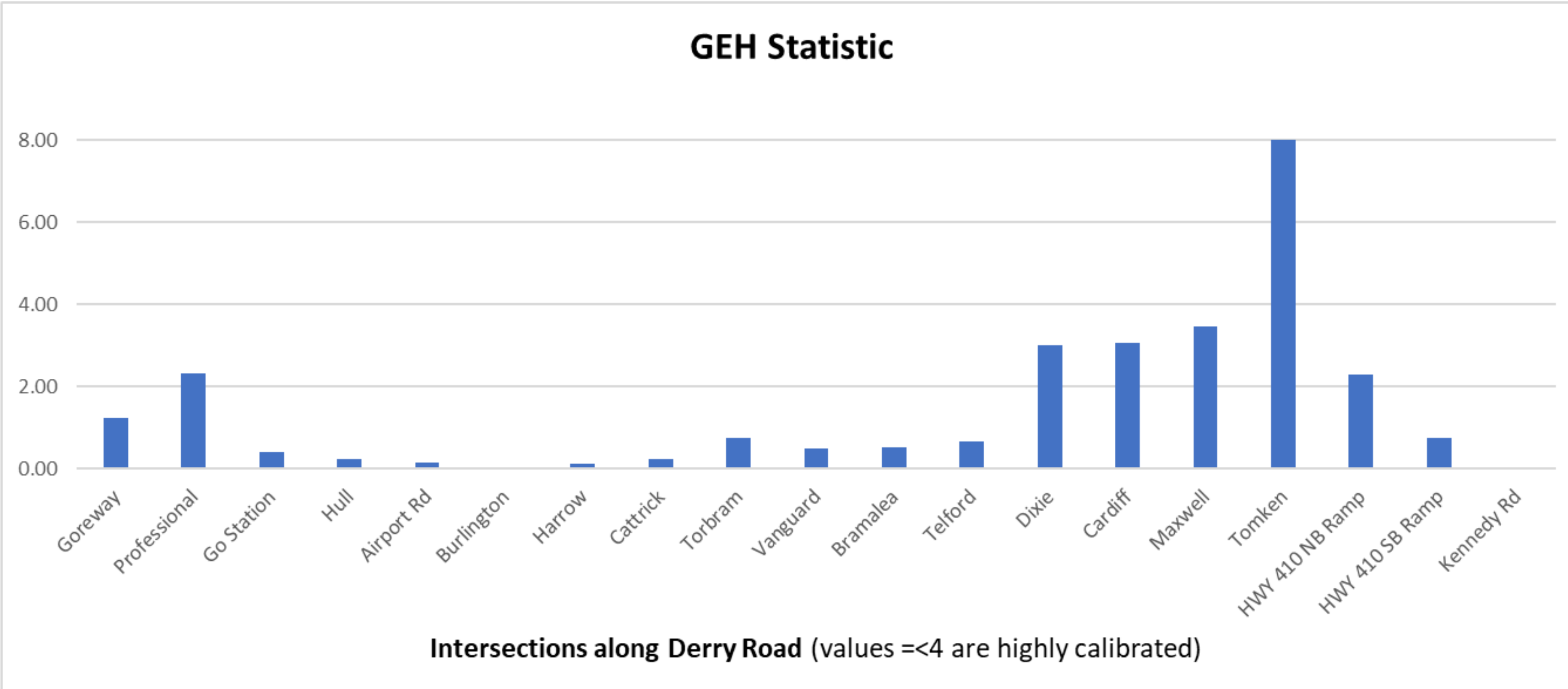
Appendix C: Calibration and Validation- Traffic Volume

Appendix C-1: Calibration and Validation-Traffic Volume - Derry Road

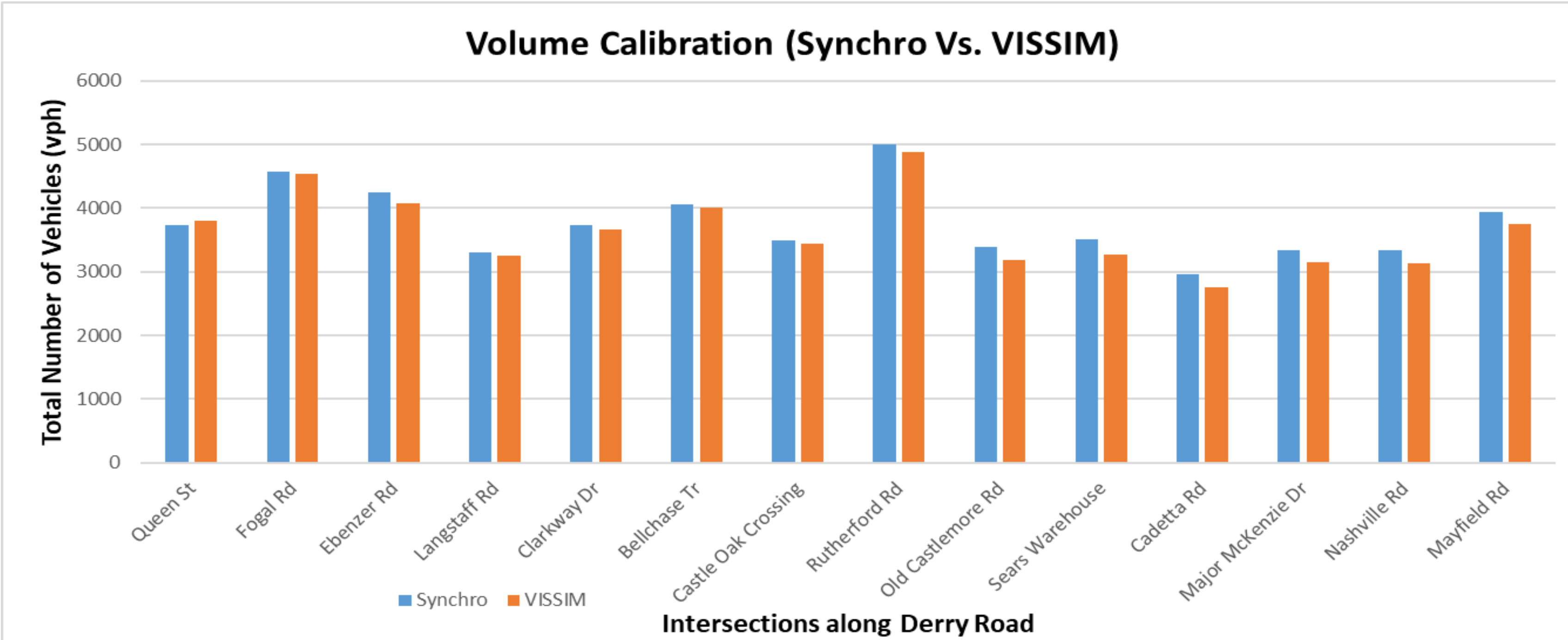


	Goreway	Professional	Go Station	Hull	Airport Rd	Burlington	Harrow	Cattrick	Torbram	Vanguard	Bramalea	Telford	Dixie	Cardiff	Maxwell	Tomken	HWY 410 NB Ramp	HWY 410 SB Ramp	Kennedy Rd
Synchro	4971	2567	5086	2362	6723	4345	3202	5105	4849	4021	4723	4441	7767	4353	4542	8586	3222	4272	7012
VISSIM	5059	2686	5115	2374	6710	4343	3195	5122	4902	4053	4760	4485	7504	4152	4312	7860	3093	4321	7010
GEH	1.24	2.32	0.41	0.25	0.16	0.03	0.12	0.24	0.76	0.50	0.54	0.66	3.01	3.08	3.46	8.01	2.30	0.75	0.02
Difference	2%	5%	1%	1%	0%	0%	0%	0%	1%	1%	1%	1%	3%	5%	5%	8%	4%	1%	0%

Appendix C-2: Calibration and Validation- GEH Result Derry Road PM Peak

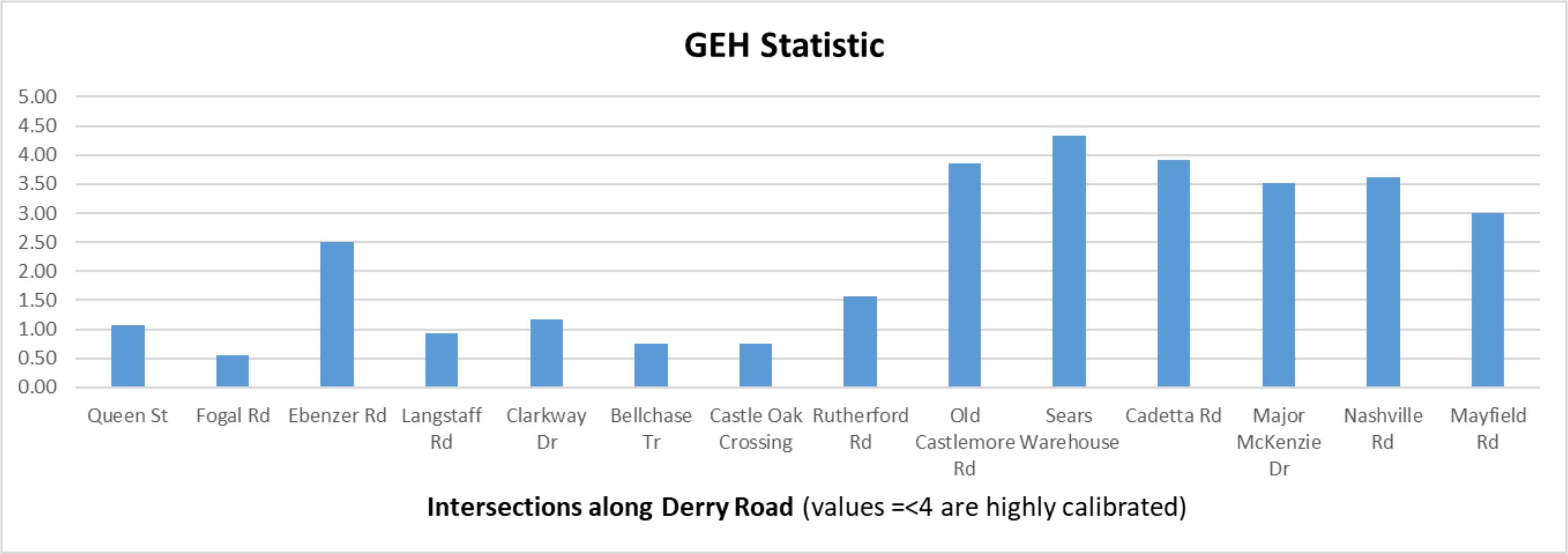


Appendix C-3: Calibration and Validation-Traffic Volume – Highway 50 (PM)



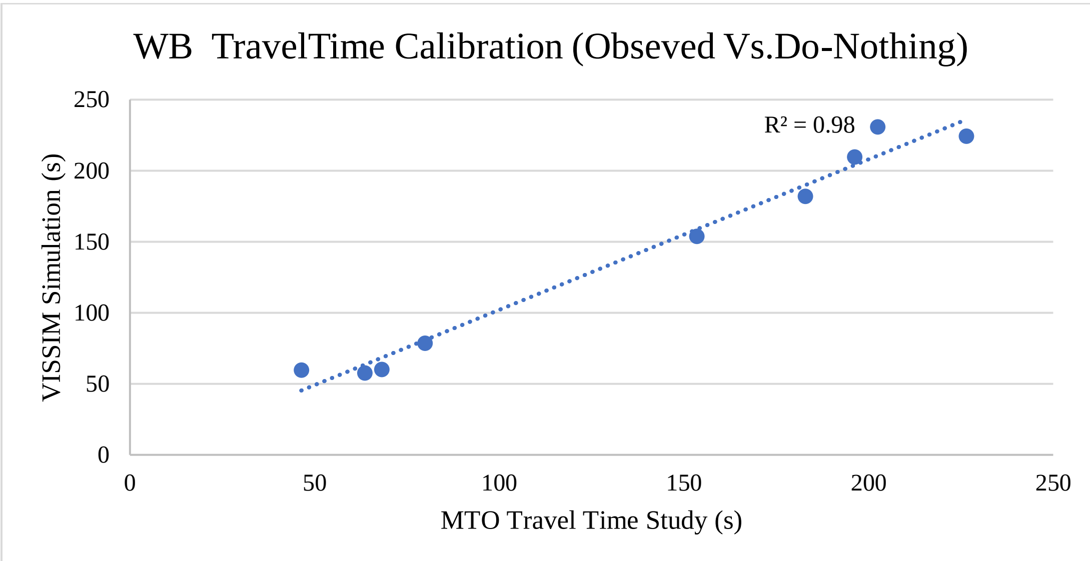
	Queen St	Fogal Rd	Ebenzer Rd	Langstaff Rd	Clarkway Dr	Bellchase Tr	Castle Oak Crossing	Rutherford Rd	Old Castlemore Rd	Sears Warehouse	Cadetta Rd	Major McKenzie Dr	Nashville Rd	Mayfield Rd
Synchro	3736	4577	4245	3300	3736	4059	3487	4994	3397	3515	2969	3345	3336	3932
VISSIM	3802	4540	4083	3247	3665	4011	3443	4884	3176	3263	2760	3145	3130	3746
GEH	1.08	0.55	2.51	0.93	1.17	0.76	0.75	1.57	3.86	4.33	3.91	3.51	3.62	3.00
Difference	2%	1%	4%	2%	2%	1%	1%	2%	7%	7%	7%	6%	6%	5%

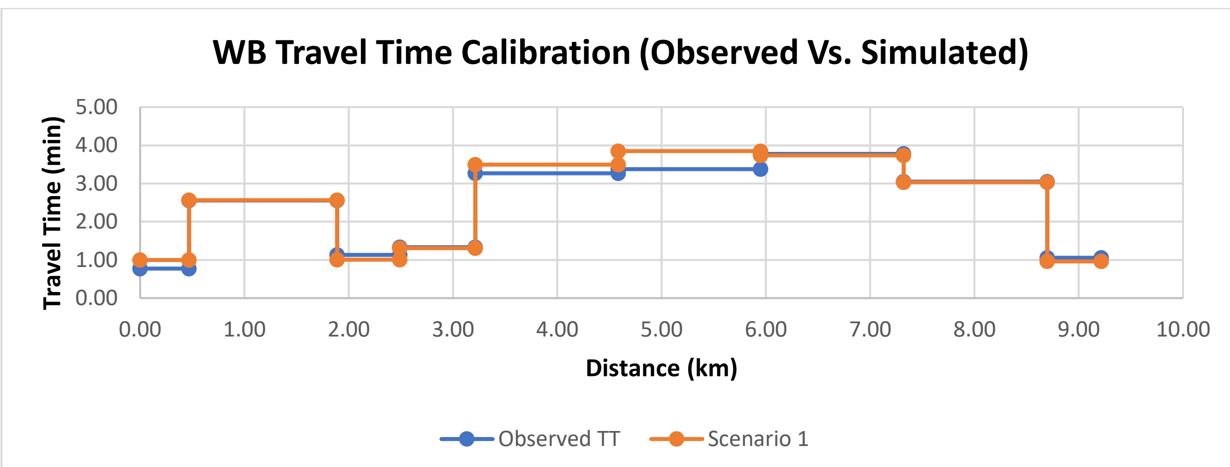
Appendix C-4: Calibration and Validation- GEH Result Highway 50



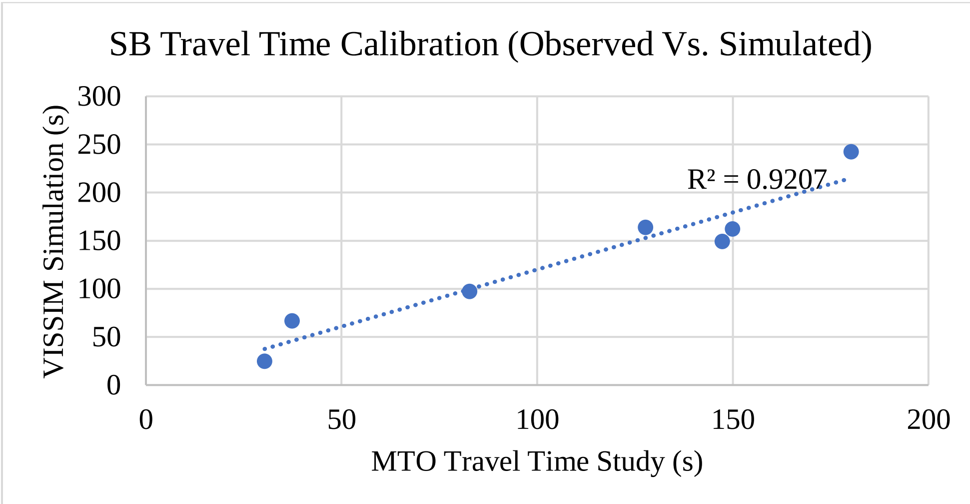
Appendix D: Calibration and Validation- Travel Time

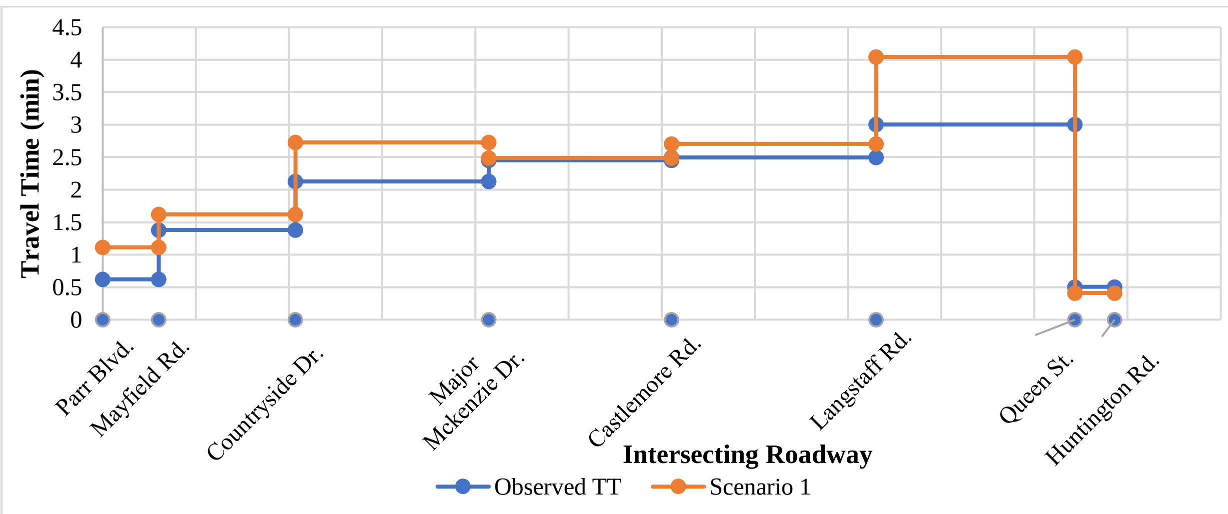
Appendix D-1: Calibration and Validation - Travel Time (TT) - Derry Road West-East Bound



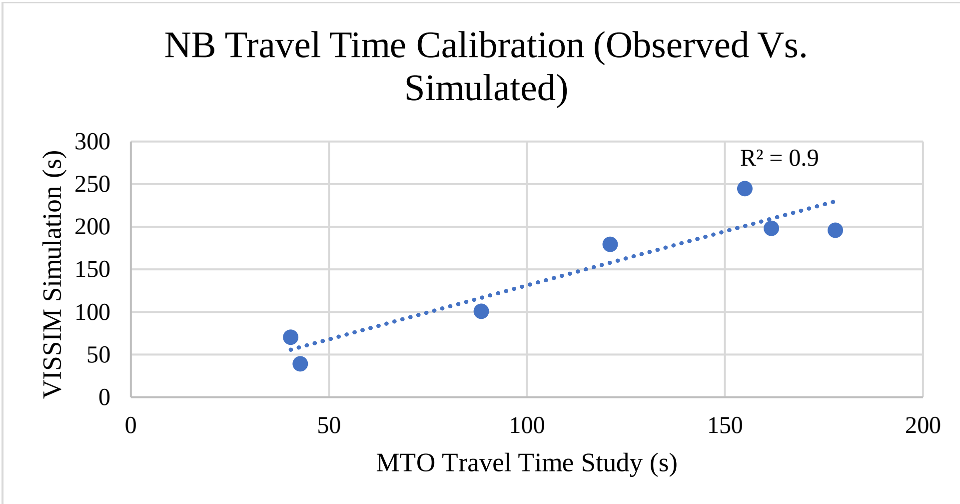


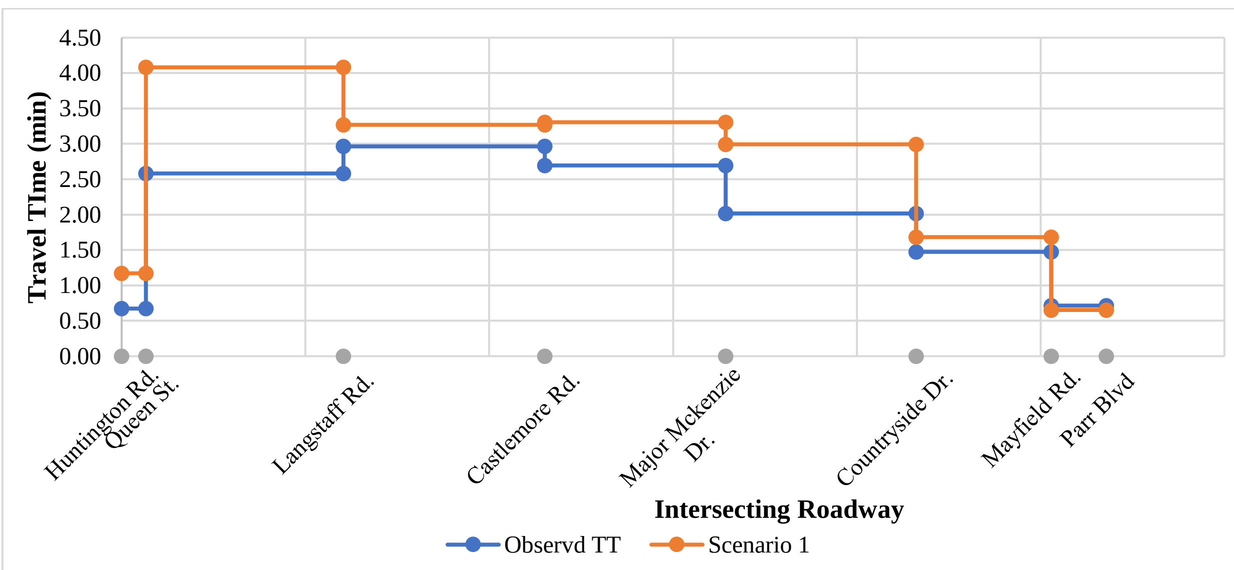
Appendix D-2: Calibration and Validation- Travel Time (TT) - Highway 50 South - North Bound (PM)





Appendix D-3: Calibration and Validation- Travel Time (TT) - Highway 50 North-South Bound (PM)





Appendix E : T-Test Results

Appendix E1: T-test for Westbound Derry Road

Intersection		Observed Average Travel Time	Simulated Travel Time	Simulated Standard Deviation	T-test
Rexwood	Goreway	46.40	59.68	16.75	1.94
Goreway	Airport	153.52	153.91	6.75	0.14
Airport	Cattrick	68.14	60.16	14.25	-1.37
Cattrick	Torbram	79.86	78.59	20	-0.16
Torbram	Bramalea	196.27	209.77	21	1.58
Bramalea	Dixie	202.49	230.94	19.5	3.57
Dixie	Tomken	226.50	224.40	22.5	-0.23
Tomken	Kennedy	182.83	181.97	10	-0.21
Kennedy Rd	Kennedy Gate	63.57	57.64	30.75	-0.47
Rexwood	**Kennedy Gate**	**1220**	**1257.06**	**161.50**	**0.57**

Appendix E2: T-test for Southbound Highway 50

Intersection		Observed Average Travel Time	Simulated Travel Time	Observed Standard Deviation	T-test
Parr Blvd	Mayfield Rd	37.40	66.79	14.00	5.14
Mayfield Rd	Countryside Dr	82.72	97.14	20.00	1.77
Countryside Dr	Train yard Entrance (Major Mckenzie)	127.72	163.73	25.25	3.49
Train yard Entrance (Major Mckenzie)	Castlemore Road	147.31	149.22	10.00	0.47
Castlemore Road	Langstaff	149.96	162.26	5.50	5.48
Langstaff	Queen	180.23	242.48	6.50	23.46
Queen	Huntington Rd	30.35	24.66	15.50	-0.90
Parr Blvd	**Huntington Rd**	**755.69**	**906.29**	**96.75**	**3.81**

Appendix F: VISSIM Model Parameters

Appendix F1: The maximum acceleration and deceleration functions used to develop VISSIM model

Category	Cars	Trucks
Maximum acceleration	3.5 m/s^2	7.3 m/s^2
Desired acceleration	3.5 m/s^2	2.5 m/s^2
Maximum deceleration	-7.5 m/s^2	-5.5 m/s^2
Desired deceleration	-2.8 m/s^2	-1.3 m/s^2

Appendix F2: Desired speed limit

Turning Direction	Vehicle Class	Desired Speed limit
Right Turns	Cars	15 km/h
	Trucks	12km/h
Left Turns	Cars	25 km/h
	Trucks	20 km/h

Appendix G: EMME Model Parameters

Appendix G-1: Auto Occupancy rate

Auto vehicle trips are converted to auto person trips that can be assigned to the network; this is known as auto occupancy rates. The Table below shows the Auto Occupancy Rates by trip purpose used in the EMME model. The table only shows the PM occupancy rate and not the AM occupancy rate as the study focuses only on the PM peak hour traffic.

Purpose Type	PM occupancy rate
Work- Manufacturing	1.14
Work- Office	1.08
Work- Retail/Sales	1.12
All other (including Schools)	1.42
Go Rail Access/ Egress	1.36

Appendix G-2: Volume Delay function

The link performance functions used for modelling Derry road and Highway 50 in both the direction are mentioned below:

VDF for East-bound Derry Road

East Bound		VDF	Speed(ul2)	Capacity (ul3)
Kenderry Gate	Kennedy Road	40	70	800
Tomken Road	Dixie Road	30	70	900
Dixie Road	Bramalea Road	30	70	900
Bramalea Road	Torbram Road	30	70	900
Torbram Road	Cattrick Road	30	70	900
Cattrick Road	Airport Road	30	50	900
Airport Road	Goreway Drive	40	60	800
Goreway Drive	Rexwood Road	30	60	900

VDF for West-bound Derry Road

West Bound		VDF	Speed(ul2)	Capacity (ul3)
Rexwood Road	Goreway Drive	30	60	900
Goreway Drive	Airport Road	40	60	800
Airport Road	Cattrick Road	30	50	900
Cattrick Road	Torbram Road	30	50	900
Torbram Road	Bramalea Road	30	70	900
Bramalea Road	Dixie Road	30	70	900
Dixie Road	Tomken Road	30	70	900
Kennedy Road	Kenderry Gate	40	70	800

VDF for North-bound Highway 50

North Bound		VDF	Speed (ul2)	Capacity (ul3)
Huntington Road	Queen Street	25	80	900
Queen Street	Langstaff Road	25	80	900
Langstaff Road	Castlemore Road	25	80	900
Castlemore Road	Train yard Entrance (Major Mckenzie)	25	80	900
Train yard Entrance (Major Mckenzie)	Countryside Drive/Nashville Road	25	80	900
Countryside Drive	Mayfield Road	20	80	900
Mayfield Road	Parr Boulevard	20	80	1000

VDF for South-bound Highway 50

South Bound		VDF	Speed (ul2)	Capacity (ul3)
Parr Boulevard	Mayfield Road	20	80	1000
Mayfield Road	Countryside Drive	20	80	1000
Countryside Drive	Train yard Entrance (Major Mckenzie)	25	80	900

South Bound		VDF	Speed (ul2)	Capacity (ul3)
Train yard Entrance (Major Mckenzie)	Castlemore Road	25	80	900
Castlemore Road	Langstaff Road	25	80	900
Langstaff Road	Queen Street	25	80	900
Queen Street	Huntington Road	25	80	900

Where; VDF's are

$$fd_i = \left(\frac{length \times 60}{ul2_i}\right) \times \left(\left(\frac{1 + (volau_i + volad_i)}{lanes \times ul3_i}\right)^4\right)$$

Here,

ul2 is speed, ul3 is capacity per lanes, volau is auto volume, volad is additional volume. For volume delay functions, if a link's volume-to-capacity ratio is smaller than or equal to 1, the standard Bureau of Public Roads (BPR) formulation is used; and for volume-to-capacity ratio above 1 the increase in travel time is assumed to increase linearly along the tangent of the BPR curve at capacity. These conditions are represented using formulations below:

For volume/capacity less than 1,

$$time = Length/Speed \times [1 + \left(\frac{volume}{capacity}\right)^n]$$

For volume/capacity greater than 1

$$time = Length/Speed \times [1 + n\left(\frac{volume}{capacity}\right) - (n-2)]$$

Appendix H: Growth Factor method

This method was used for developing 2016 Data for EMME software Origin-Destination (OD) Matrix.

Total Trip Production: $\sum_{j=1}^{N} T_{ij} = TP_i = O_i\,;\; i = 1, 2, \dots, N$

Total Trip Attraction: $\sum_{i=1}^{N} T_{ij} = TA_j = D_j\,;\; j = 1, 2, \dots, N$

Total Number of Trips: $\sum_{i=1}^{N} O_i \; \sum_{j=1}^{N} D_j \; \sum_{i=1}^{N} \sum_{j=1}^{N} T_{ij} = T$

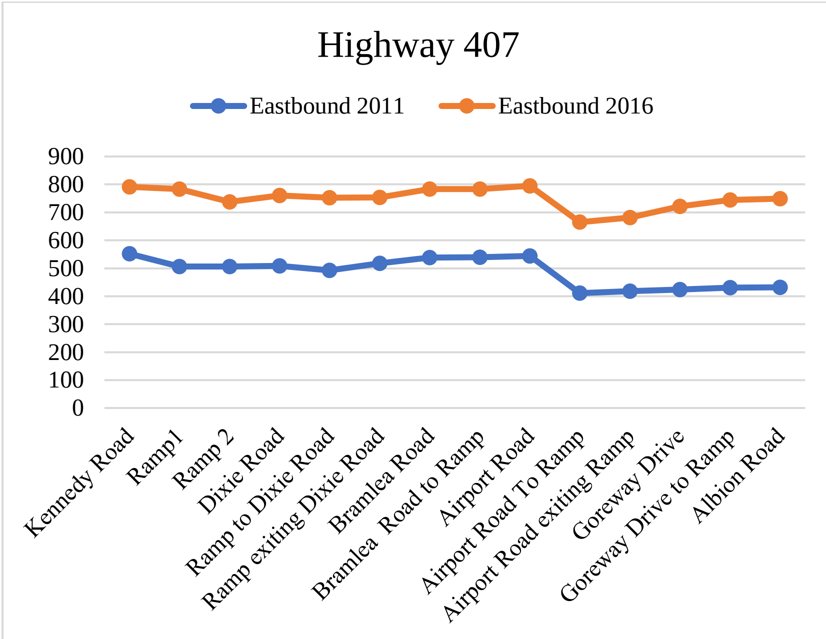
Growth factor method is also known as Fratar method.

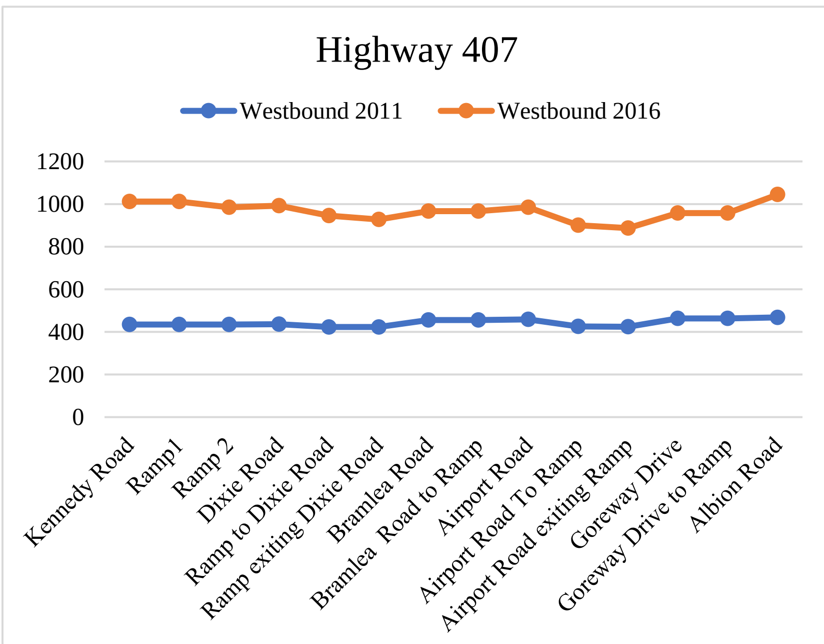
$T_{ij}^{(t+1)} = T_{ij}^{\,t} \times A_i \times B_j$ Where, $A_i = f_i \times O_i$ *and* $B_j = f_j \times D_j$

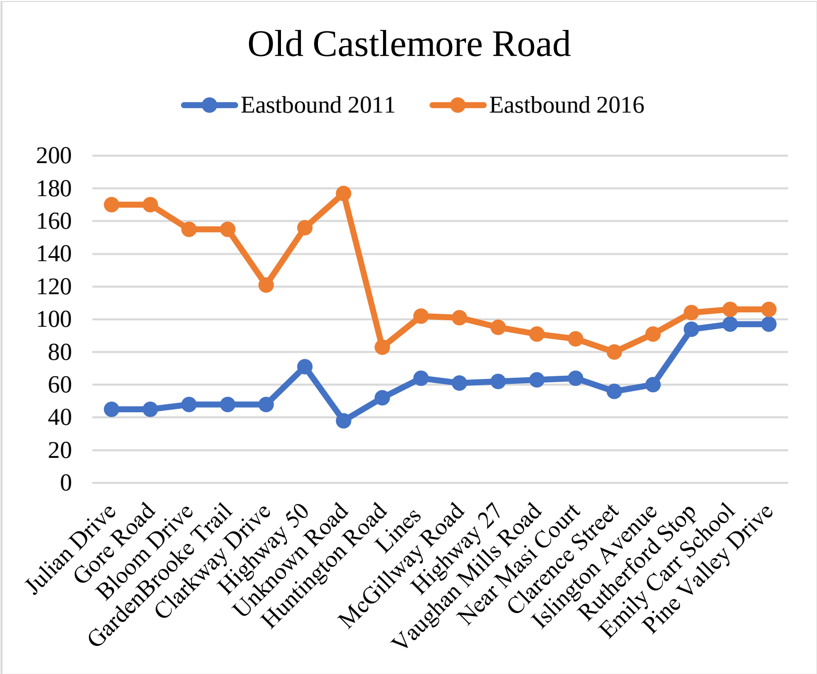
Appendix I: Network Comparison for Vehicle Volume between 2011 and 2016

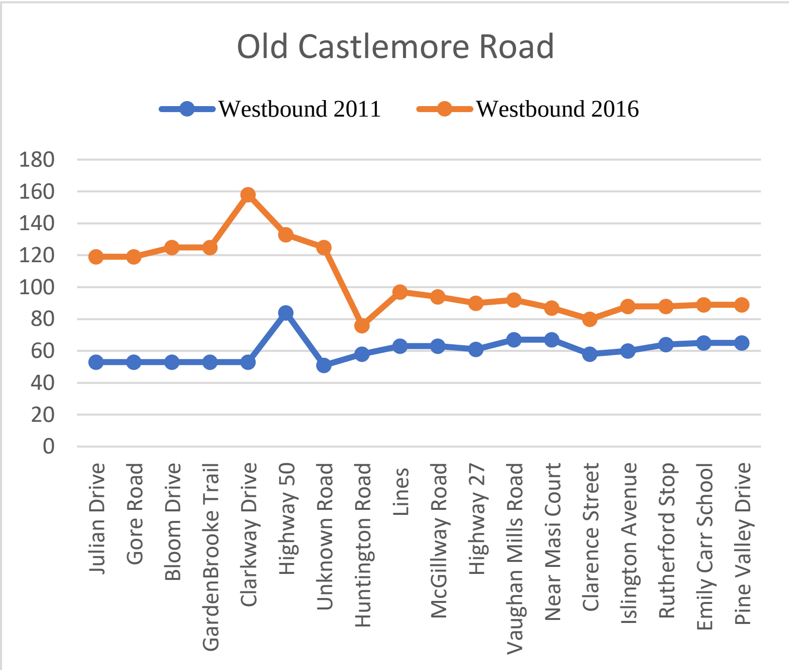
Appendix I1: Network comparison of Vehicle Volume 2011 and 2016

Heavy Truck Volume



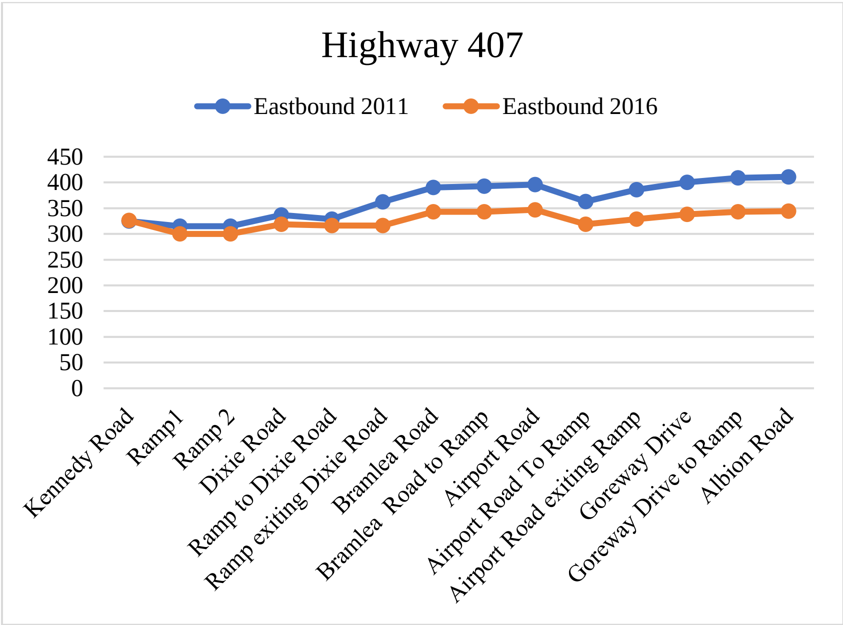


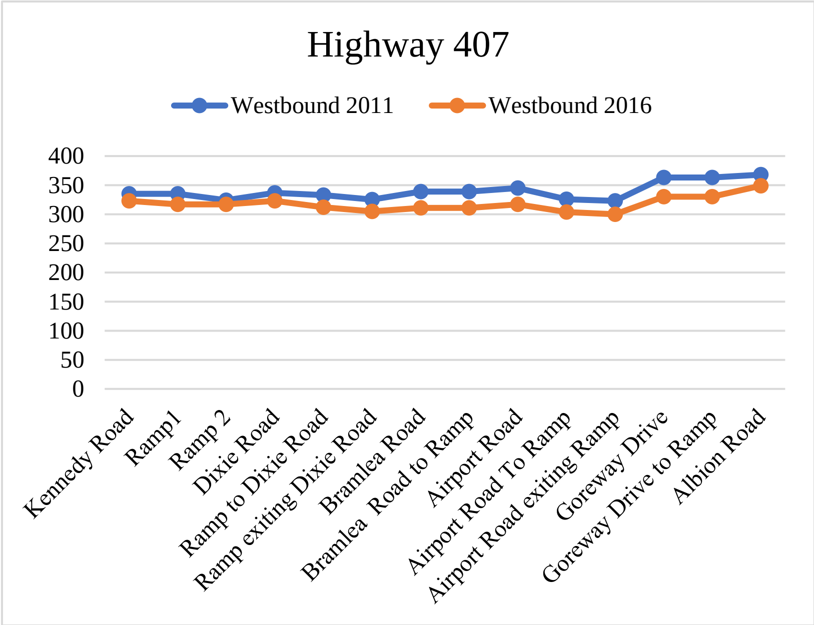

Old Castlemore Road
Eastbound 2011
Eastbound 2016
200
180
160
140
120
100
80
60
40
20
0
Julian Drive
Gore Road
Bloom Drive
GardenBrooke Trail
Clarkway Drive
Highway 50
Unknown Road
Huntington Road
Lines
McGillway Road
Highway 27
Vaughan Mills Road
Near Masi Court
Clarence Street
Islington Avenue
Rutherford Stop
Emily Carr School
Pine Valley Drive

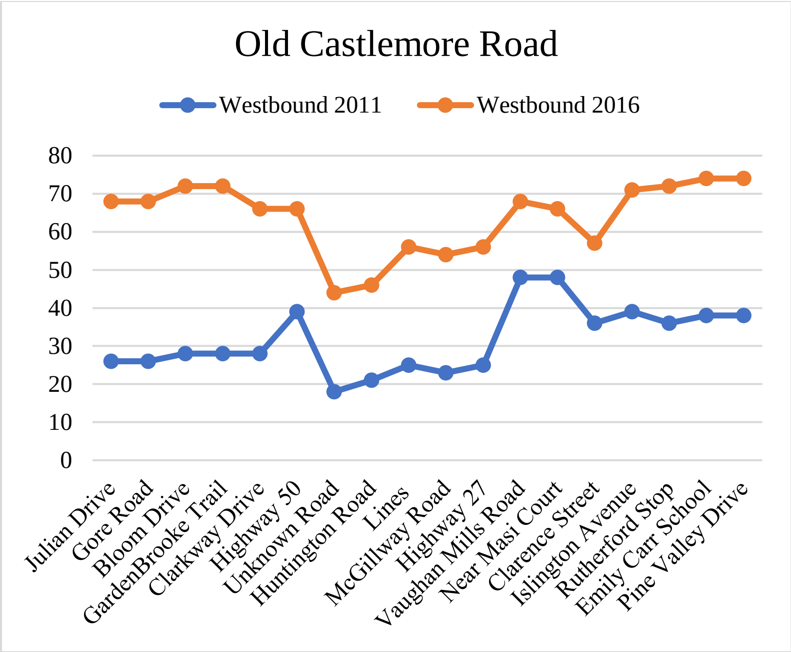

Old Castlemore Road
Westbound 2011
Westbound 2016
180
160
140
120
100
80
60
40
20
0
Julian Drive
Gore Road
Bloom Drive
GardenBrooke Trail
Clarkway Drive
Highway 50
Unknown Road
Huntington Road
Lines
McGillway Road
Highway 27
Vaughan Mills Road
Near Masi Court
Clarence Street
Islington Avenue
Rutherford Stop
Emily Carr School
Pine Valley Drive

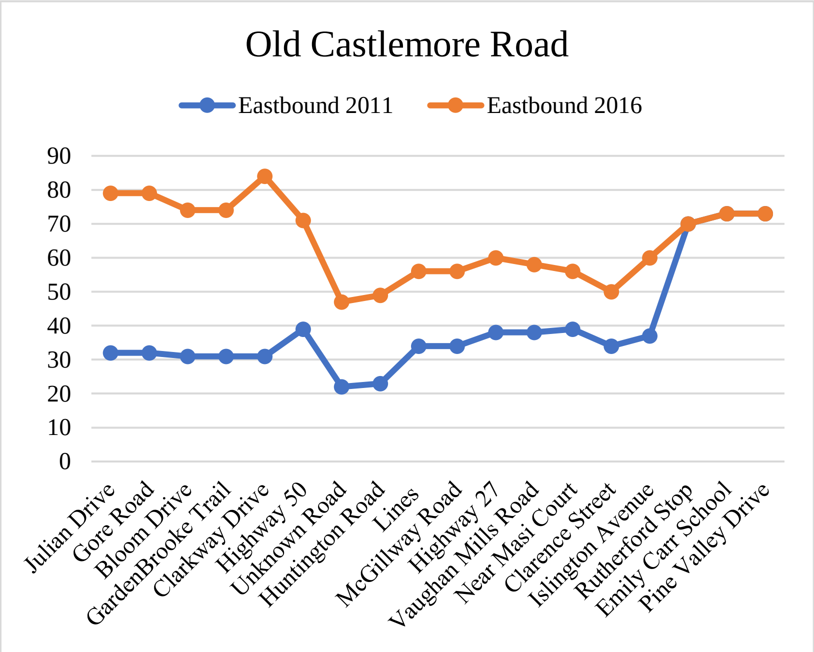
Appendix I2: Network comparison of Vehicle Volume 2011 and 2016

Medium Truck Volume



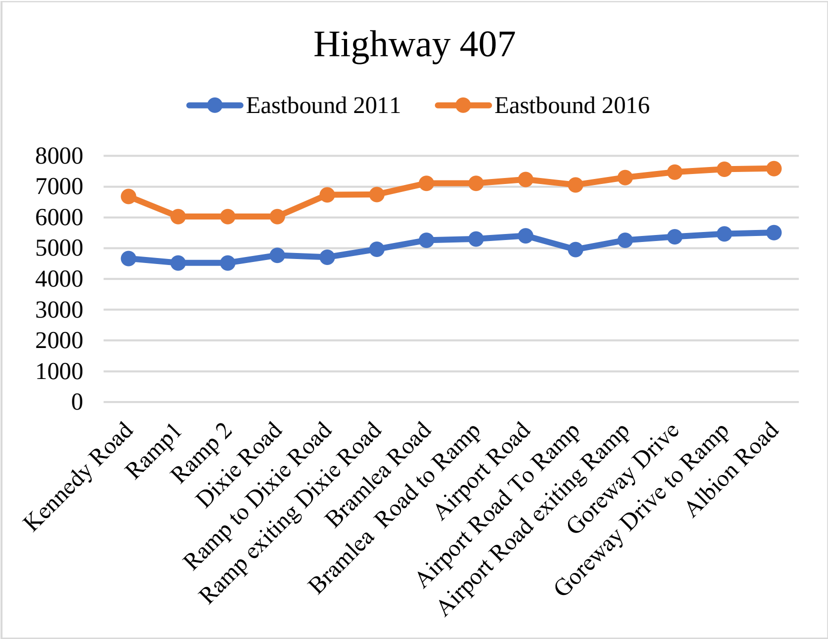


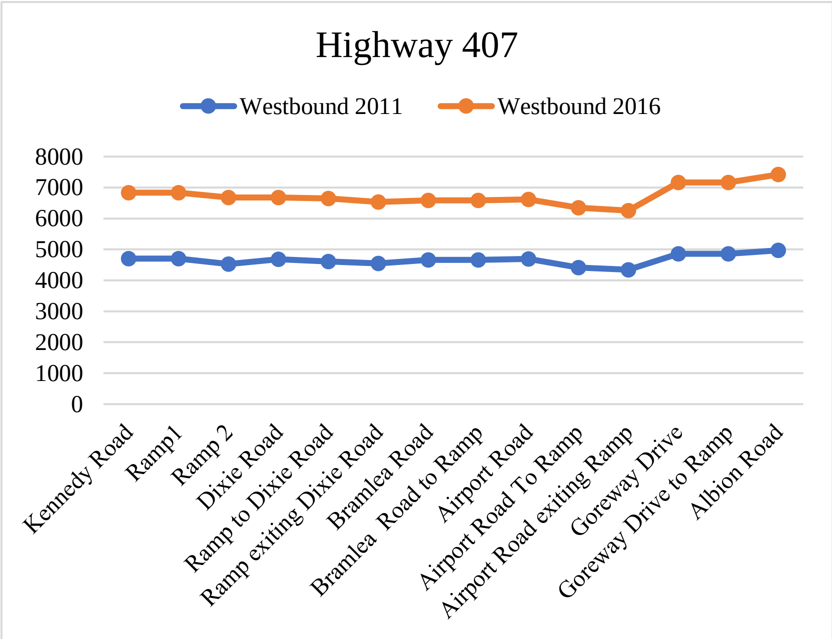

Old Castlemore Road
Westbound 2011
Westbound 2016
80
70
60
50
40
30
20
10
0
Julian Drive
Gore Road
Bloom Drive
GardenBrooke Trail
Clarkway Drive
Highway 50
Unknown Road
Huntington Road
Lines
McGillway Road
Highway 27
Vaughan Mills Road
Near Masi Court
Clarence Street
Islington Avenue
Rutherford Stop
Emily Carr School
Pine Valley Drive

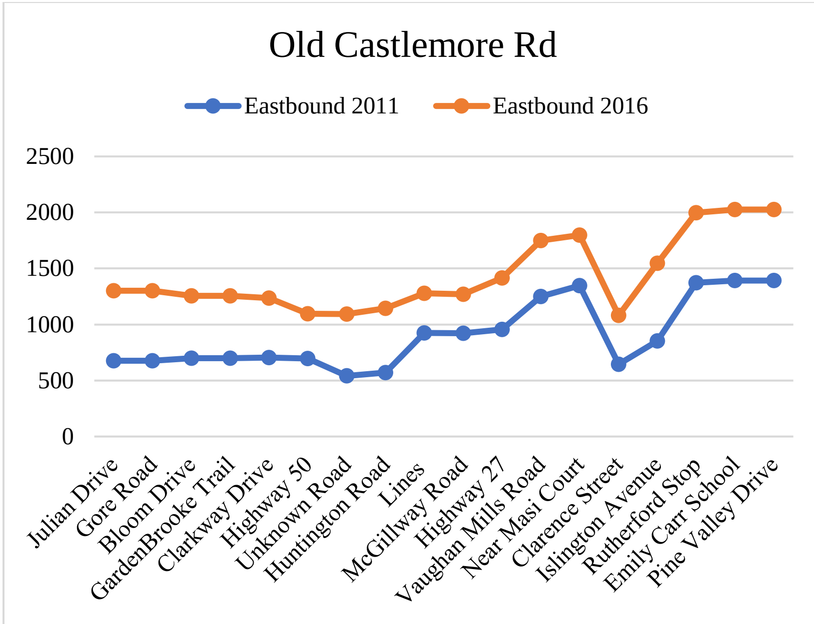

Old Castlemore Road
Eastbound 2011
Eastbound 2016
90
80
70
60
50
40
30
20
10
0
Julian Drive
Gore Road
Bloom Drive
GardenBrooke Trail
Clarkway Drive
Highway 50
Unknown Road
Huntington Road
Lines
McGillway Road
Highway 27
Vaughan Mills Road
Near Masi Court
Clarence Street
Islington Avenue
Rutherford Stop
Emily Carr School
Pine Valley Drive

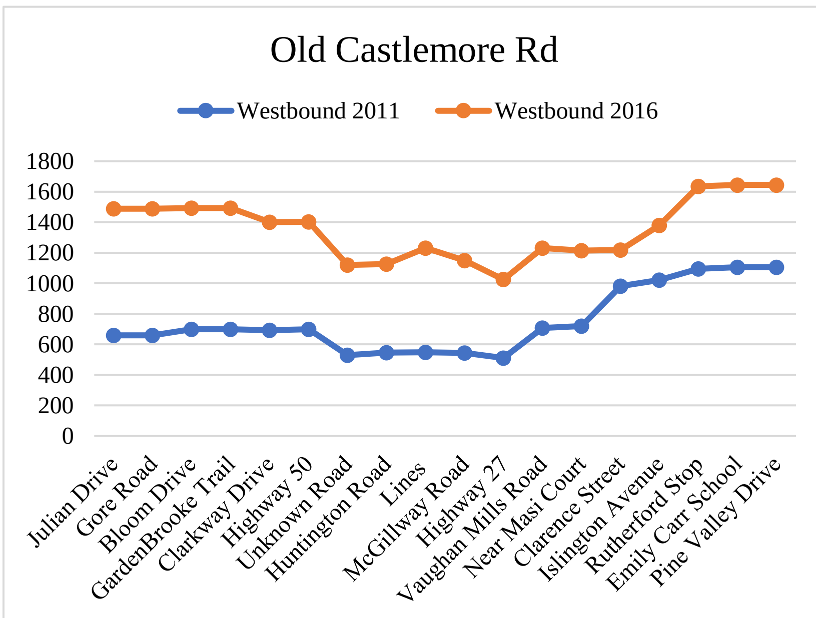
Appendix I3: Network comparison of Vehicle Volume 2011 and 2016

Passenger Car Truck Volume





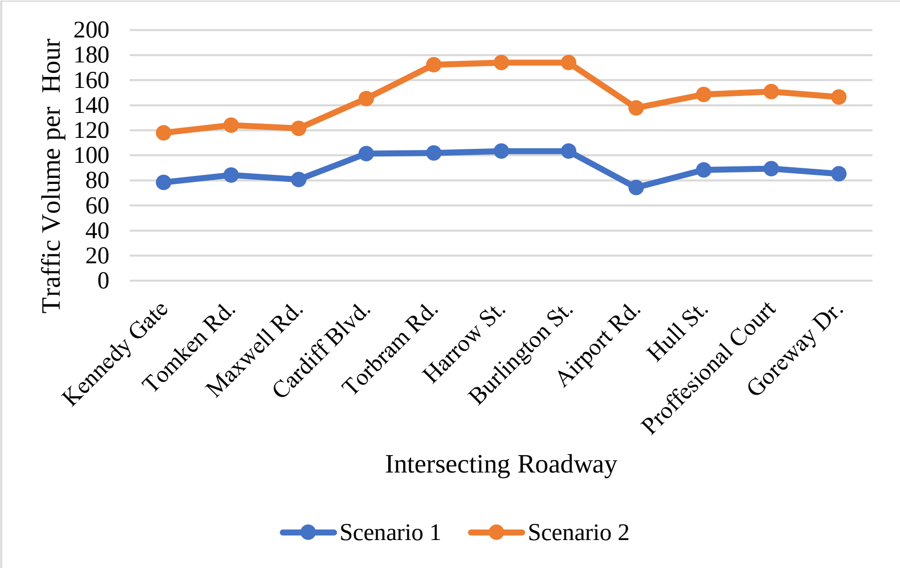

Old Castlemore Rd
Eastbound 2011
Eastbound 2016
2500
2000
1500
1000
500
0
Julian Drive
Gore Road
Bloom Drive
GardenBrooke Trail
Clarkway Drive
Highway 50
Unknown Road
Huntington Road
Lines
McGillway Road
Highway 27
Vaughan Mills Road
Near Masi Court
Clarence Street
Islington Avenue
Rutherford Stop
Emily Carr School
Pine Valley Drive


Old Castlemore Rd
Westbound 2011
Westbound 2016
1800
1600
1400
1200
1000
800
600
400
200
0
Julian Drive
Gore Road
Bloom Drive
GardenBrooke Trail
Clarkway Drive
Highway 50
Unknown Road
Huntington Road
Lines
McGillway Road
Highway 27
Vaughan Mills Road
Near Masi Court
Clarence Street
Islington Avenue
Rutherford Stop
Emily Carr School
Pine Valley Drive

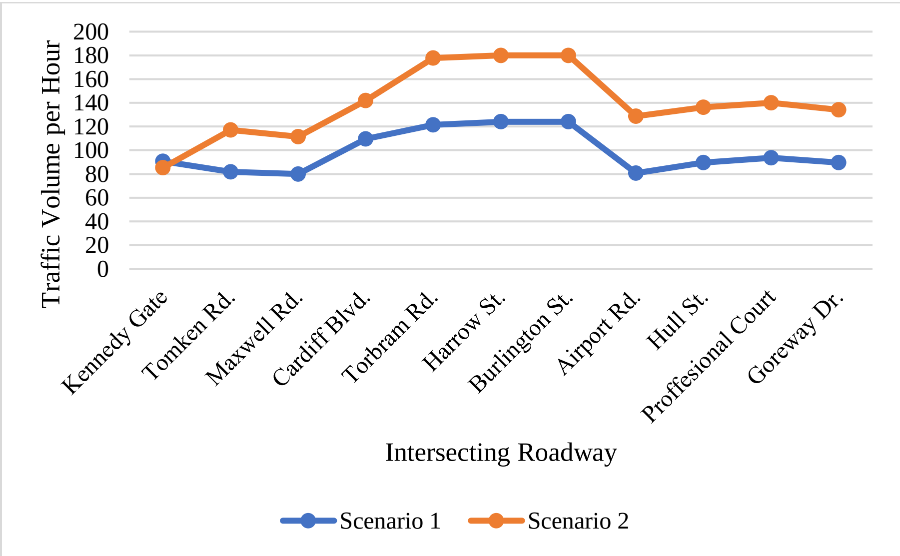
Appendix J: Macrosimulation Analysis Results

Appendix J1: Macrosimulation analysis result for Derry Road (Volume difference between Base scenario and Truck Only Lane scenario)

Eastbound Derry Road

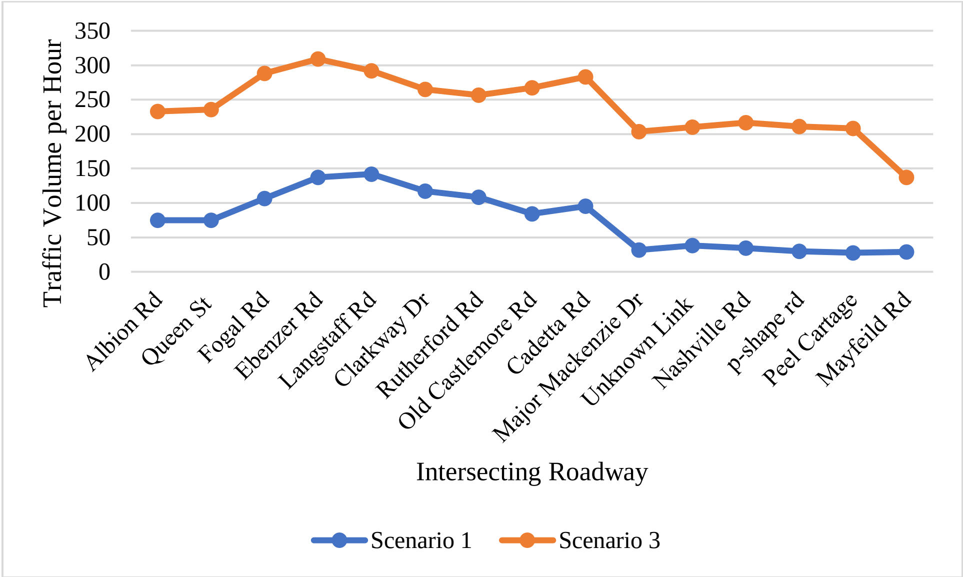


Westbound Derry Road



Appendix J2: Macrosimulation analysis result For Highway 50 (Volume difference between Base scenario and Truck Only Lane scenario)

Northbound Highway 50



Southbound Highway 50