# EVALUATING THE OPERATIONAL IMPACT OF MULTI-MODAL SIGNAL PRIORITY IN AN URBAN ARTERIAL CORRIDOR

MCKEEN YOUSIF

A THESIS SUBMITTED TO

THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

GRADUATE PROGRAM IN CIVIL ENGINEERING

YORK UNIVERSITY

TORONTO, ONTARIO

August 2025

# Abstract

Urban growth in the Greater Toronto and Hamilton Area (GTHA) has intensified congestion and reduced the reliability of passenger and freight travel. This study evaluates the operational and environmental impacts of transit signal priority (TSP), freight signal priority (FSP), and a dedicated bus lane (DBL), applied individually and in combination, along a 9.9 km segment of Queen Street in Brampton, Ontario with 17 signalized intersections. A calibrated PTV VISSIM microsimulation model was used to assess changes in average travel time, total person-delay, and emissions relative to a base case. Results show that TSP and FSP increased automobile and freight average travel times by less than 3%, while reducing transit travel times by up to 9%. DBL increased automobile and freight travel times by approximately 5-13% and increased total person-delay by up to 9%, despite reducing transit delay by more than 10%. Emissions and fuel consumption increased by up to 8% under DBL, whereas TSP and FSP resulted in negligible changes (approximately 3%). Combined strategies mitigated some DBL impacts but did not fully offset them, highlighting trade-offs in multimodal corridor prioritization.

# Acknowledgement

To my supervisors, my mentors, my colleagues, the staff at Lassonde School of Engineering and the Faculty of Graduate Studies, my family and friends, and everyone who participated and contributed to getting me to where I am right now; thank you.

I would like to also extend my gratitude to the Smart Freight Centre and the Region of Peel for their support.

# Table of Contents

# List of Tables

# List of Figures

# List of Acronyms

APC - Automatic Passenger Counter

BRT - Bus Rapid Transit

CO - Carbon Monoxide

DBL - Dedicated Bus Lane

EB - Eastbound

ELD - Electronic Logging Device

FSP - Freight Signal Priority

GHG - Greenhouse Gases

GTHA - Greater Toronto and Hamilton Area

LPI - Leading Pedestrian Interval

MOE - Measure of Effectiveness

MTO - Ministry of Transportation of Ontario

NOx - Nitrogen Oxides

TSP - Transit Signal Priority

VOC - Volatile Organic Compounds

WB - Westbound

# Chapter 1. Introduction

This study discusses the potential impact of applying signal priority for transit (buses) (TSP) and freight (FSP) along with a dedicated bus lane (DBL) for bus services on an urban arterial in Ontario, Canada. Using PTV VISSIM, multiple microsimulation models have been developed to quantify the impact of tiered signal priority conditions combined with DBL condition. Indeed, while including a DBL will benefit the transit vehicles (buses) the most in comparison to other modes such as personal/passenger vehicles (autos) and freight (trucks), it is crucial to introduce some balance in mobility for other modes, especially for freight.

## 1.1. Problem Statement

Urban roads today face growing pressure to support both reliable public transit and the smooth flow of freight traffic. While strategies like Transit Signal Priority (TSP), Freight Signal Priority (FSP), and dedicated bus lanes (DBL) have each been studied on their own and shown to improve performance, there is little research exploring what happens when these strategies are used together. The impact of combining these measures remains largely unexamined. This study aims to fill that gap by evaluating the combined impact of TSP, FSP, and dedicated lanes on a busy urban corridor, with a focus on reducing transit travel times and delays while maintaining efficient freight movement.

The bigger picture of this study is to enhance the public transit experience and offer potential solutions and strategies to make it more reliable and attractive for commuters, which may potentially influence a modal paradigm shift in commuting within the Greater Toronto Area Region from using personal/passenger vehicles to public transit. This study is conducted with the emphasis on reducing public transit average travel time and total person's delay, while, at the same time, keeping freight movement and mobility into consideration.

According to a 2022 report published by Inrix, Toronto is ranked the third most congested city in North America, and the seventh worldwide. It was estimated that a total of 118 hours was lost due to congestion, with on-peak speed of around 30 kmph and off-peak speed of around 60 kmph (Inrix, 2022). These relatively high numbers may have resulted due to multiple factors, including the return to in-person activities especially for students and employees, as well as an increase in travel demand in a more convenient mode of transportation such as personal/passenger vehicles.

Additionally, the travel demand in Ontario is at a continuous increase. StatCan reported in 2022 that the total number of registered vehicles on roadways in Canada has increased in 2021 by 1.9% compared to that of 2020. The statistics also show that the passenger vehicles (or passenger cars) are the most common type on Canadian roadways (StatCan, 2020). In Ontario alone, the number of registered vehicles in 2021 increased by 1.3% compared to 2020, with an increase in the number of passenger vehicles of 0.94%. Surprisingly, though, the number of buses decreased by 14.7% in 2021 compared to 2020, potentially due to the COVID-19 pandemic. Even though the number of buses is reported as an aggregated number of buses without specifying the type of buses, it can be assumed that the decrease in number of buses in 2021 was due to the fact that a large number of bus services was not needed as students and employees worked from home instead of in-person. Additionally, the number of medium-duty (GVWR Class 4, 5, and 6) and heavy-duty (GVWR Class 7 and 8) vehicles (i.e., trucks and freight) increased in 2021 by 9.1% and 5.4%, respectively, compared to 2020. All these statistics are summarized in Table 1, including the annual data of number of registered vehicles and the vehicle type from 2017 to 2021 (StatCan, 2022).

| **Vehicle Type** | **2017** | **2018** | **2019** | **2020** | **2021** |
|---|---|---|---|---|---|
| **Total Number Road Registered Vehicles** | 8,711,241 | 8,875,296 | 9,036,981 | 9,335,112 | 9,456,317 |
| **Total Number of Light-duty (Passenger Vehicles)** | 8,197,858 | 8,355,954 | 8,513,466 | 8,788,860 | 8,872,498 |
| **Total Number of Medium-duty Vehicles** | 122,688 | 125,442 | 127,943 | 137,469 | 151,211 |

| Vehicle Type | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| **Total Number of Heavy-duty Vehicles** | 146,470 | 150,267 | 153,417 | 159,209 | 168,355 |
| **Total Number Buses** | 21,290 | 21,494 | 21,580 | 23,751 | 20,257 |

*Table 1 - Number of Road Registered Vehicles in Ontario [Source: StatCan 2022]*

Although StatCan's statistics are aggregated for the entire province of Ontario, it is important to note that the Greater Toronto and Hamilton Area (GTHA) region is the most populated and the most active region in Ontario. Therefore, it is safe to assume that the region/area with the most impact on StatCan's statistics comes from the GTHA.

The demand for reliable transit in the GTHA region is proportionally increasing with the increase in the region's population. In 2015, the population of the GTHA region was projected to have an increase of 2.9 million people by the year 2041 (Metrolinx, 2016). According to a study conducted by Metrolinx, the current rapid transit network in the GTHA is planned to serve destinations in Toronto's downtown, majorly since those destinations are for office-based employment. However, as the population density rapidly grows in the region, more employment is being created in the suburbs surrounding downtown Toronto, hence the need to accommodate more suburb-to-suburb trips, especially in the locations that have large employment such as Highway 7 and its surroundings (Metrolinx, 2018).

Moreover, the current real-estate bubble that is occurring in the region also plays a role in the increase of travel demand to and from the suburbs, where cheaper and more affordable dwellings are present (Hertel, Sean, et al., 2022). In the Metrolinx 2020-2021 annual report, it is stated that there had been an increase in transit ridership in the period of 2017 to 2020 including transit services such as GO trains, GO buses, and UP trains. For context, GO trains are commuter rail services operated by Metrolinx, which is the agency responsible for providing Ontario's regional public transit network in the GTA. Furthermore, UP Express (or UP trains) is a rail link between Union Station in downtown Toronto and Toronto Pearson International Airport, and it is operated by Metrolinx. However, due to COVID-19 restrictions, the total ridership saw a 91.1% drop in 2020-21 (Metrolinx 2021). Despite this drastic drop in total transit ridership in the region, a 2022 Metrolinx board meeting report indicated that there is a 49% recovery in total ridership of GO and UP transit services, this recovery is compared to the 2019-2020 levels of transit ridership, and it is believed that the recovery will continue increasing (Byrne-Nearing, et al., 2022). This shows that there is an increased demand for public transit systems within the GTHA region.

The Ministry of Transportation in Ontario (MTO, 2025) indicates that the municipal transit ridership in largely populated metropolitan centres may havenot met the targeted number of ridership, especially in the years prior to the pandemic. Figure 1 shows the targeted (or projected) travel demand, and the achieved (or actual) travel demand via transit in large municipal metropolitan (or urban) centres (MTO, 2025). illustrates a steady upward trend in both targeted and achieved municipal transit ridership from 2006 through 2014. During this period, achieved ridership closely followed the targeted projections, with only minor shortfalls. From 2015 to 2019, achieved ridership began to plateau around 860 million rides annually, while targets continued to grow modestly, peaking near 900 million by 2019. Notably, in these later years, achieved ridership consistently fell short of the targets, indicating a growing gap between expected and actual performance even before the onset of the COVID-19 pandemic. The impact of the COVID-19 pandemic is clearly visible in 2020, where both targeted and achieved ridership figures dropped sharply. Achieved ridership fell more drastically, bottoming out around 300 million in 2021, significantly below the revised target for that year. The data available for 2022 suggests that the achieved ridership exceeded the targeted ridership, but this year generally is not indicative as the pandemic restrictions were loosening at the time. (MTO, 2025). The data for 2023-2025 do not seem to be available at the time of writing this thesis.

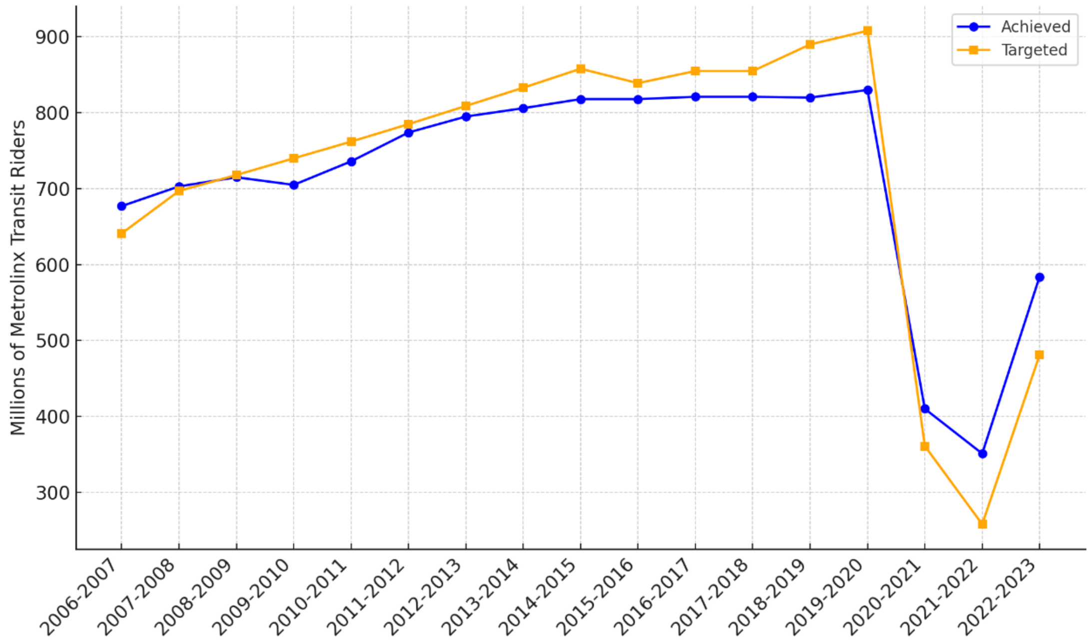



*Figure 1 - Municipal Ridership in Large Metropolitan Centres (in Millions) [Source: MTO]*

Furthermore, Figure 2 shows that the achieved Metrolinx transit ridership of GO trains, GO Buses, and UP (Union-Pearson) Express also has not met the targeted (or projected) ridership in the years of 2019 to 2022. Between 2012 and 2019, Metrolinx transit ridership showed a consistent upward trend. Achieved ridership steadily increased from just under 65 million to about 76 million annual riders, closely mirroring the targeted values. During this period, the achieved and targeted ridership lines tracked closely, with only slight differences, indicating successful alignment between planning targets and actual performance. However, by 2019, although both continued to rise, achieved ridership slightly lagged behind targets, suggesting early signs of a performance gap. The effects of the COVID-19 pandemic became evident in 2020, with a steep decline in achieved ridership falling to under 10 million riders by 2021. While targets were also adjusted downward, they remained significantly higher than what was achieved, highlighting the severity of the disruption. Despite a modest recovery in 2022, achieved ridership still falls short of the targeted ridership suggesting that Metrolinx continues to face challenges in regaining pre-pandemic ridership levels and achieving its projected recovery pace. The data for 2023-2025 do not seem to be available at the time of writing this thesis. (MTO, 2025).

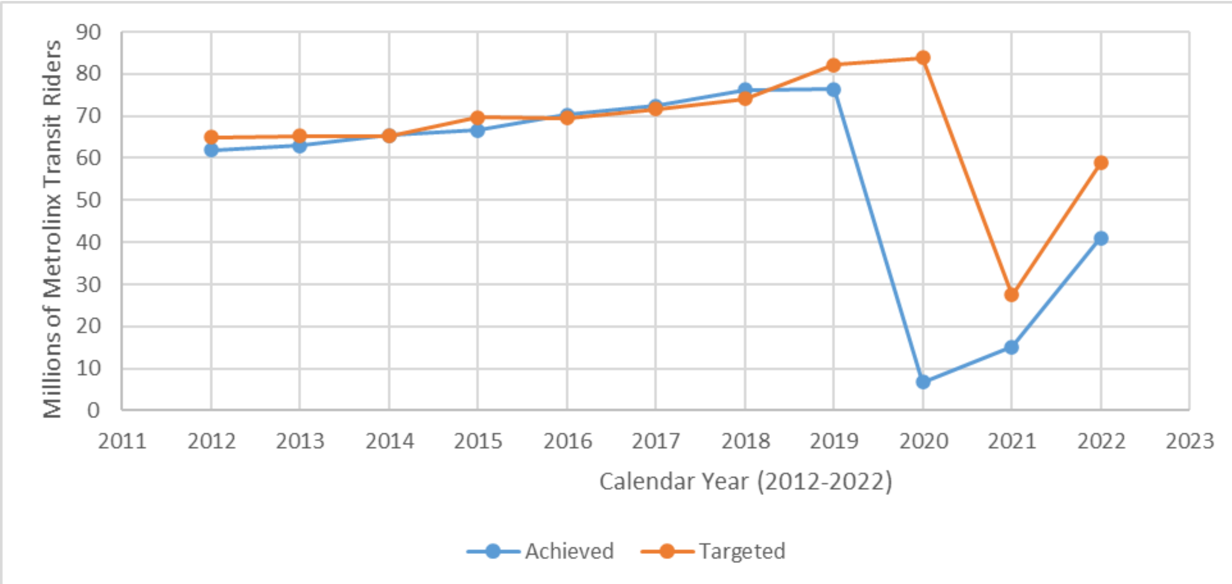



*Figure 2 - Metrolinx Transit Ridership (in Millions) [Source: MTO]*

The conclusion that can be drawn from Figure 1 and Figure 2 is that despite the available transit services within municipalities and or the GTHA region, traveling via transit does not seem attractive, especially in the years prior to the pandemic when the achieved ridership figures did not meet the targeted ridership figures. The reason for its unattractiveness may be due to its unreliability, especially when considering travel time as the major factor. Therefore, strategies that increase transit-use desirability and service reliability are crucial.

The Region of Peel plays a key role in supporting freight mobility not only within the Greater Toronto and Hamilton Area (GTHA), but nationally as well. Peel consists of Brampton, Mississauga, and Caledon, and its strategic location adjacent to major 400-series highways, regional logistics hubs, and Toronto Pearson International Airport. Peel's industrial and employment zones are home to major warehousing, distribution, logistics, and cold-chain storage facilities that supply both local and national markets. This makes the Region of Peel an operationally attractive freight gateway in Ontario. According to the Peel Goods Movement report, Peel processes approximately 25% of all goods moving through southern Ontario (Peel Region, 2024). In 2019, nearly $1.8 billion worth of freight moved daily through Peel by truck, making it one of the most critical freight distribution regions in Canada (Peel Freight Study, 2024). The reliance on trucks for goods movement is further amplified by the fact that approximately

90% of urban freight in the GTHA is moved by road, making arterial corridors within Peel essential for regional economic activity (Transport Canada, 2020). Peel's economic dependence on trucking services is also reflected in employment. More than 28% of Peel's workforce is tied to freight-dependent sectors such as retail, logistics, wholesale trade, and manufacturing (City of Brampton, 2022). Therefore, inefficiencies in goods movement translate directly into economic losses for businesses, higher shipping costs, and reduced service reliability (Metrolinx, 2018). These realities motivate the need for a balanced evaluation of transit and freight performance, as proposed in this thesis, under various traffic signal control treatments.

Specifically, Highway 50, which connects with Highway 7, east of Queen Street, is a major arterial in Brampton that extends northwest-southeast (NW-SE). The majority of the goods movement generate by multiple logistics companies and warehouses including the Amazon Fulfilment Centre, FedEx, and DHL.

The study focuses on the Queen Street corridor in Brampton, Ontario, a key urban arterial recognized as the city's highest-growth corridor. Over the next 25 years, it is projected to accommodate approximately 50% of Brampton's total population growth, positioning it as a critical area for future urban intensification and transit-oriented development. In the decade leading up to the COVID-19 pandemic, the corridor experienced a 168% increase in transit ridership, reflecting a sharp rise in demand for efficient, high-capacity public transit. This substantial and sustained growth demonstrates the urgent need for enhanced transit infrastructure, including reliability improvements, capacity upgrades, and rapid transit interventions, to support current and future mobility needs, while also accommodating freight mobility. (City of Brampton, 2025).

## 1.2. Study Goals and Objectives

This study will analyze and examine the impact of applying bus dedicated lanes, TSP and FSP technologies on a corridor in Ontario, Canada. The intention of the analysis favors improving the public transit measures-of-effectiveness as the primary priority, while placing the freight as the secondary priority. This study will also outline the potential reliability benefits of combining signal priority strategies (TSP and/or FSP) with a corridor that utilizes directional Bus dedicated lane. This study will utilize unconditional TSP and FSP, accompanied by the green extension method at signalized intersections.

The goal of this study is to investigate the impact of utilizing a bus dedicated lane, accompanied by either TSP, FSP, or both, along an urban corridor (arterial) that contains traffic with signalized intersections. This research has two major objectives:

1. Evaluate the impact of implementing TSP, FSP, and a combination of the two strategies, using various measures of effectiveness (MOE), such as average travel time, total person's delay, and the change in the emissions (CO, NOx, VOC) and fuel consumption
2. Evaluate the impact of implementing bus dedicated lanes, and a combination of bus dedicated lanes and TSP, FSP, and both, using MOEs of average travel time, total person's delay, and emissions.

The evaluation of the above MOEs will show which implementation scenario performs the best with respect to reducing average travel time and total person's delay for buses and trucks simultaneously.

## 1.3. Study Scope

This research utilizes microsimulation models using PTV VISSIM 2021 as the main analysis tool, and Excel spreadsheets to process the results. This study focuses on the eastbound of Queen Street in Brampton, Ontario, which is 9.9 km in length in the eastbound and westbound, including all signalized intersections from West Drive to Goreway Drive. This study follows the assumption that there is no construction accompanied in the corridor (e.g., no new lane construction is required). While queue-jumping lanes (QJL) for transit exist at the time of writing this thesis on the map along the study corridor, this study only considers them geographically (i.e., detector and stop locations), and it assumes normal traffic signals for them since the QJL data is not provided. For the bus dedicated lane models, only the curb-side right-hand lane is considered on both sides of the corridor. For TSP and FSP, only the green extension strategy (10 seconds) is considered. The VISSIM microsimulation models use the PM peak hours data of 2017 of 17 intersections in Queen Street E. The data contains unbalanced directional traffic volume (vph). To mitigate the effect of the unbalanced traffic volumes, in-between intersections are created to act as windows for the unbalanced volumes to go in to and out of. For the results, the MOEs used in conducting the analysis are the average travel time, the total person's delay, and the environmental emissions. Additionally, electrical vehicles (EVs) are not considered in this study as the topic of EVs is still relatively new and such vehicles are currently not as popular as the gasoline vehicles.

## 1.4. Thesis Structure

The thesis for this study includes six chapters in total. Chapter 2 contains the outcome of a literature review that identifies the research gap that is present in the previous studies. Chapter 3 includes the study area of which this study builds its case upon, as well as the input data that contributes to the building of this study. Chapter 4 covers the process that is followed in developing the microsimulation models in VISSIM, starting with developing the base model, calibrating it, then developing the various alternative scenarios. Chapter 5 outlines the results from microsimulation as well as the discussion of the evaluation of the measures of effectiveness (MOEs). Though, in Chapter 5, this essay will discuss the analyzed eastbound (EB) approach in the main body of the report, as well as the concluded results for both the eastbound (EB) and the westbound (WB). However, the discussion and analysis regarding the westbound (WB) results is placed in "Appendix C - Westbound Analysis Results" for the sake of brevity. Lastly, Chapter 6 summarizes the results and findings, along with recommendations for future work.

# Chapter 2. Literature Review

This research aims to fill this gap by conducting a multimodal corridor analysis using VISSIM microsimulations to evaluate the combined effects of TSP, FSP and DBL on improving transit and truck movement efficiency including TSP, FSP and DBL individually. The literature further reveals a shift away from traditional capacity-based metrics such as Level-of-Service (LOS) toward performance measures that better capture multimodal efficiency, including average travel time, total delay, person delay, and environmental impacts. This shift reflects growing recognition that urban arterials increasingly serve competing mobility objectives, including transit reliability, freight movement, and sustainability outcomes, which are not adequately represented by LOS alone (TRB, 2016).

## 2.1. Signal Priority Strategies, and Measures-of-Effectiveness (MOEs)

Signal priority has gained considerable attention in the transportation industry, with numerous studies evaluating and implementing strategies to improve transit vehicle travel times and reduce traffic delays. To accommodate for the increase demand of public transit in the GTHA region while keeping the service reliable, one way of making public transit more attractive and reliable for users is through utilizing technologies such as transit signal priority (TSP). Previous study in North American cities indicate that applying TSP in intersections that experience frequent delay had reduced travel time by up to 10% (Toronto Region Board of Trade, 2021). Not only does the population growth affect the movement of people, but also it directly impacts the movement of goods within the region. According to a Big Move report published by Metrolinx, 89% of the freight movement done in the region is by trucks along local roadways. Any delay that occurs in the network due to traffic congestion is costly to both the businesses and the people, and it impacts the overall flow of economy within the region (Metrolinx, 2008). To accommodate and enhance the reliability of goods movement, technologies such as freight signal priority (FSP) can be considered an engineering measure to reduce congestion.

Active traffic signal priority technologies such as transit signal priority (TSP) and freight signal priority (FSP) fall within the category of intelligent transportation systems (ITS), and they are strategies utilized to reduce congestion along roadways that contain intersections with signalized traffic (Smith, Hemily, Ivanovic, 2005). Generally, implementing TSP and FSP technologies is considered simple as it only requires loop detectors on an intersection to detect the respective vehicle class (transit or freight) (Ink, 2016). There are two widely used methods of providing transit or freight signal priority, including unconditional priority and conditional priority. Besides, there are multiple signal priority treatments and strategies that can be implemented, including early green or red truncation, green extension, green reallocation, phase insertion, and signal pre-emption (Ink, 2016. TSMO, 2022). The mechanism of the signal priority technology is rather simple to implement in already-existing infrastructure, provided that the intersection is signalized. When a prioritized vehicle approaches a detector (check-in) just before the intersection, the detector sends in a signal to the signal controller to instruct the traffic signal to grant the prioritized vehicle green time, if possible. Once the prioritized vehicle clears the intersection and checks out at a check-out detector, whether it is in the intersection or just beyond the intersection, the check-out detector instructs the traffic signals that the prioritized vehicle has passed through the intersection, and the signal controller will restore the normal traffic signal schedule (TSMO, 2022). This is illustrated in Figure 3, as it demonstrates the TSP mechanism for the two main methods: the red truncation method, and the green extension method.

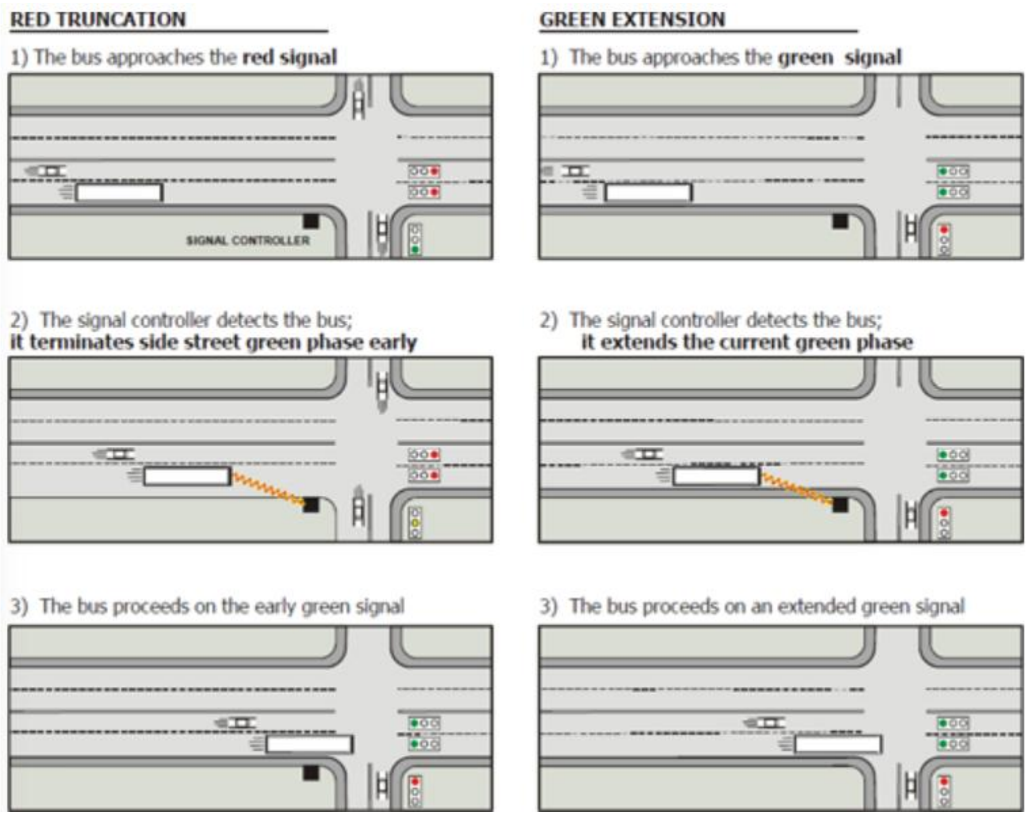



*Figure 3 - Mechanism of signal priority (FHWA, 2021)*

The red truncation method shortens the red signal phase for the general traffic when a transit vehicle is approaching an intersection. This enables the traffic signal to switch to green earlier than usual to give the transit vehicle less stoppage (red) time at the intersection (FHWA, 2021). The green extension method is one of the most prevalent signal priority strategies in North America, and it is utilized in this thesis (TSMO, 2022). Figure 4, which is adopted from the TSP Handbook, shows the general schematic of the time configuration at a signalized intersection. The movement direction with priority is allowed an extended amount of green time at the expense of the movement direction without priority, provided that the prioritized vehicle requires additional time to pass through the intersection.

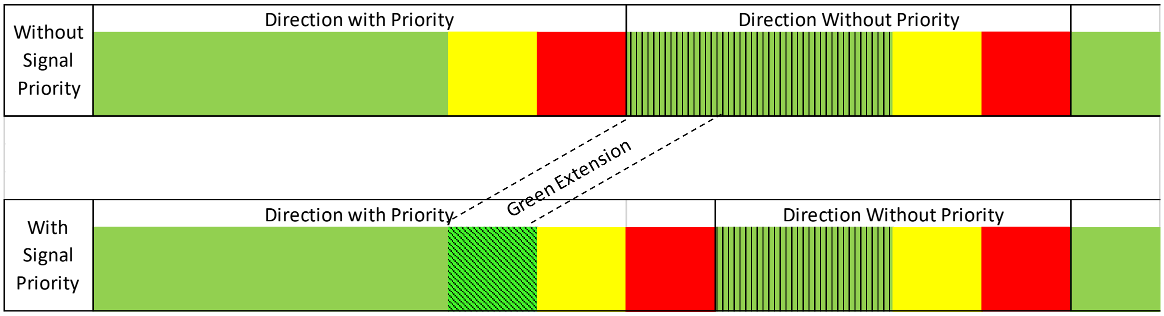



*Figure 4 - Green extension general time configuration*

Additionally, other signal priority strategies include pre-emption, phase insertion, phase skipping, and green reallocation, have seen some use in practice. First, pre-emption is the most disruptive, as it immediately overrides normal signal operation and terminates active phases to serve a priority request. Hence, it is typically reserved for emergency vehicles and rail movements, where minimizing delay is critical and temporary disruption to general traffic can be justified. Second, Phase insertion and phase skipping, while less severe than full pre-emption, still require modifications to the signal timing plan and may interrupt progression along coordinated arterials. These strategies can introduce variability in cycle lengths, degrade offset optimization, and increase delay for non-priority movements, particularly under moderate to high traffic demand conditions. Green reallocation, which involves redistributing green time among phases to favour priority movements, can improve performance for selected users but often necessitates re-timing of the intersection and may result in sustained disbenefits for competing movements. Third, red truncation provides directional benefits by shortening red intervals for priority approaches; however, it may reduce clearance times, and compromise safety margins if not carefully constrained. Both green reallocation and red truncation can also disrupt the progression quality assumed in coordinated arterial timing plans. Green extension operates by prolonging the active green phase when a priority vehicle is detected, without altering the predefined signal sequence or cycle structure. This approach minimizes disruption to cross-street traffic, preserves arterial coordination, and maintains predictable signal operations for all users. Since green extensions can be constrained within predefined maximum limits, they offer a balanced and operationally robust means of improving transit or freight performance while limiting adverse impacts on general traffic, pedestrians, and cyclists. Therefore, green extension has emerged as the most suitable and widely adopted signal priority strategy for urban arterials carrying multimodal traffic (FHWA, 2021; TSMO, 2022).

Given the corridor of Queen Street characteristics, traffic volumes, and coordination requirements, this study adopts unconditional green extension as the signal priority strategy for both transit and freight vehicles. This approach balances operational effectiveness with system stability, ensuring that priority benefits are realized without introducing excessive disruption to general traffic. This study will analyze and examine the impact of applying DBL, TSP and FSP technologies on a corridor in Ontario, Canada. The intention of the analysis favors improving the public transit measures-of-effectiveness as the primary priority, while placing the freight as the secondary priority. This study will also outline the potential reliability benefits of combining signal priority strategies (TSP and/or FSP) with a corridor that utilizes directional bus dedicated lane. This study will utilize unconditional TSP and FSP, accompanied with green extension strategy at signalized intersections.

Furthermore, Queen Street functions as both a major east-west commuter corridor and a freight-supporting arterial that provides access to industrial, commercial, and logistics destinations. As growth in Peel continues to outpace much of the GTHA, pressure on arterial infrastructure has increased not only from population-driven passenger travel demand but also from time-sensitive freight operations. Delays experienced by freight vehicles on signalized arterials translate directly into increased operating costs, reduced supply chain reliability, and higher emissions, reinforcing the need to consider freight mobility alongside transit improvements. Traditionally, roadway performance pertaining to roadway capacity has often been evaluated using Level-of-Service (LOS) as the primary metric. While LOS provides a generalized qualitative assessment of operating conditions, it is limited in its ability to capture multimodal performance, reliability, and equity considerations. LOS is particularly problematic in corridors with high transit and freight activity, as it is primarily auto-centric and delay-based at the intersection level, without accounting for vehicle occupancy, person throughput, or network-wide impacts. As a result, LOS may indicate poor performance even when person movement efficiency improves due to increased transit use (TRB, 2016). On the other hand, average travel time and total delay provide more direct and interpretable measures of system performance, especially for multimodal corridors. Travel time directly reflects user experience and reliability, which are consistently identified as primary determinants of transit attractiveness (Litman, 2021). Additionally, total person's delay allows for equitable comparison across modes by capturing the number of users affected rather than simply the number of vehicles. Given the objectives of this study, travel time and total person delay are therefore more appropriate and defensible measures of effectiveness than LOS.

In addition to operational performance, environmental sustainability is a critical consideration for transportation planning in Ontario and the GTHA. Transportation is the second-largest source of greenhouse gas (GHG) emissions in Canada, accounting for approximately 25% of national emissions, with road transportation responsible for over 85% of that share (Environment and Climate Change Canada, 2023). In Ontario specifically, on-road vehicles contribute approximately 31% of provincial GHG emissions, with passenger vehicles and medium- and heavy-duty trucks being the dominant contributors (Ontario Ministry of the Environment, Conservation and Parks, 2022). Congestion exacerbates emissions by increasing idling time, stop-and-go driving, and inefficient engine operation, particularly for heavy-duty vehicles. Given the current environmental situation, the inclusion of GHG emissions as a measure of effectiveness in this study is both timely and necessary. Evaluating emissions alongside average travel time and total person's delay allows for a more comprehensive understanding of trade-offs associated with transit and freight priority strategies. Previous studies have demonstrated that while signal priority can reduce emissions for prioritized vehicles, poorly designed implementations may increase emissions at the network level (Wijayaratna et al., 2013). As such, emissions must be evaluated explicitly rather than assumed as a secondary benefit of mobility improvements.

In evaluating priority strategies, recent literature emphasizes measures of effectiveness (MOEs) that reflect user experience and system-wide performance. Average travel time and total delay are consistently identified as more informative metrics than LOS, particularly for transit- and freight-intensive corridors. Additionally, person-based metrics and environmental indicators are increasingly incorporated to account for occupancy differences and sustainability considerations (Litman, 2021; Environment and

Climate Change Canada, 2023). By focusing on a high-growth, freight-intensive corridor in Region of Peel, and by evaluating mobility and environmental outcomes using robust performance metrics, this study contributes to the development of balanced, multimodal arterial management strategies that align with both regional economic objectives and sustainability goals.

## 2.2. Application of Single Measure

A substantial number of studies have examined operational strategies aimed at improving mobility for transit vehicles, freight traffic, and general-purpose vehicles on urban arterials. Transit Signal Priority (TSP), Freight Signal Priority (FSP), and Dedicated Bus Lanes (DBL) have each been studied extensively as individual interventions, with consistent evidence demonstrating their potential to reduce delay, improve travel time reliability, and enhance overall corridor efficiency. However, the majority of existing research evaluates these strategies in isolation or in limited paired combinations, with comparatively little emphasis on their simultaneous application within a single multimodal corridor.

A study focused on enhancing bus transit efficiency through signal priority for transit vehicles along arterial roads shared by buses and cars. Various transit preferential treatments, such as queue jump lanes and TSP have been explored, focusing on understanding of the reduced bus delays through VISSIM microsimulation models. The results revealed that relocating a nearside stop to a far-side stop could cut delays by up to 30 seconds per intersection and implementing TSP with a 15-second green extension and red truncation could reduce bus delays by up to 19 seconds. Although a detailed cost-benefit analysis was not provided, the significant delay reductions suggest that these treatments are beneficial for improving transit efficiency and justify the investment (Burak Cesme et al., 2015). In another study, GPS-based TSP ,which is an innovative TSP method that utilizes wireless communication and GPS technology to track buses in real-time and decide to dynamically provide them with signal priority at signalized intersections based on certain factors such as the bus's capacity and its schedule, along the a corridor in Salt Lake County, Utah, showed that GPS-based TSP reduced bus travel times (in seconds per vehicle) by 8% to 12% and delays (in seconds per vehicle) by 18%. Conditional TSP provided similar benefits while minimizing impacts on side-street traffic, indicating that the operational improvements justify the investment in GPS-based TSP systems (Yu Song et al., 2016). In a United Arab of Emirates corridor, applying TSP resulted in a 7% reduction in bus travel time (in seconds per vehicle) and a 14% decrease in bus delays (in seconds per vehicle). However, car travel time increased by 39% and car delays by 57%. The implementation costs were approximately $5,000 per intersection, $20,000 for software installation, and $30,000 for controller equipment. Despite increased delays for passenger vehicles (autos), the operational benefits for buses suggest that the investment in TSP is justified (Hadeel Al Khateeb et al., 2017). In another study, TSP was found to reduce bus delays by 69 seconds per vehicle kilometer and arterial car delays by 19 seconds per vehicle kilometer. While the study acknowledged potential increases in cross-street traffic delays, the overall operational benefits implied that TSP implementation is a valuable investment for improving transit efficiency (Kan Wu et al., 2020).

Another study assessed the impact of integrating TSP with dedicated short-range communication (DSRC) technology on DBL and BRT systems in Tehran, Iran. During morning peak hours, TSP reduced DBL delays (in seconds per vehicle) by 19%, stop times (in seconds per vehicle) by 42%, increased speeds by 4%, and improved travel times (in seconds per vehicle) by 4%. In the evening peak hours, delays were reduced by 22%, stop times by 48%, with speed and travel time improvements of 4%. Despite increased delays for private vehicles, the operational improvements suggest that the investment in TSP and dedicated short range communication DSRC technology, which is a wireless technology that allows for quick communication in real-time between the traffic infrastructure and the transit vehicles, is justified (Abolfathi, 2022). Further research investigated a novel strategy for enhancing Automated Guideway Transit Vehicles (AGTVs) which are fully automated transit vehicles guided by magnetic markers that are often used in applications similar to bus-rapid transit (BRT) in mixed traffic without dedicated lanes. This study utilizes a Moving-Block Operation Mode (MBOM), which stands for the activation of a dynamic dedicated median lane that activates through detection and signal control, and Dynamic Multi-request Signal Priority (DMSP) model, which is an adaptive real-time system based on traffic conditions and transit operational needs. The study demonstrated a 7% reduction in per person travel time (in seconds) and a 2% decrease in fuel consumption, indicating improved operational efficiency and sustainability. This MBOM strategy was found to outperform traditional dedicated lane setups, particularly under specific traffic conditions (Ning Huan et al., 2022). A comprehensive study on integrating TSP into a coordinated traffic signal system examined the improvements in travel time (in seconds per vehicle) and delay (in seconds per person) for both transit and general vehicles. With the utilization of the integrated TSP, two-way on the main street traffic operation had been optimized, which accounted for bus-bay capacity and stochastic dwell times. The findings of this study showed a 17.4% reduction in bus travel time delays and a 10.9% improvement in person delay compared to existing methods, suggesting that the operational benefits justify the investment in TSP infrastructure (Minji Kim et al., 2022).

A study quantified the operational impact of TSP strategies by developing multiplicative factors known as Mobility Enhancement Factors (MEF). These factors were based on metrics such as travel time (in seconds) and average vehicle delay time (in seconds), where an MEF less than 1 indicated improved mobility, while an MEF greater than 1 indicated deteriorated mobility. Specifically, the study examined the SR-7 (US-441) route in Miami, Florida, finding that TSP reduced bus travel time by approximately 7% and average vehicle delay by around 11%. Conversely, cross-street traffic experienced a 6% increase in average vehicle delay, highlighting the need to balance benefits across the network. This study examined TSP as a cost-effective method for enhancing the efficiency of transit services along the corridor (MD Sultan Ali et al., 2023a). Another study evaluated TSP's effectiveness using VISSIM simulation models, focusing on the transferability of calibrated parameters between two Florida transit corridors. The findings indicated substantial improvements in bus travel time (in seconds) and delay (in seconds), with a 9% and 18% transferability observed for two of the parameters. The operational improvements suggest that the benefits of implementing TSP justify the investment (MD Sultan Ali et al., 2023b).

A study was conducted to explore the effectiveness of traffic signal priority for trucks. The specific measure of effectiveness includes reductions in travel time (in seconds), vehicle stops, fuel consumption, and emissions, assessed using a hybrid co-simulation optimization (COSMO) approach that integrates both simulation-based and model-based methods. COSMO is a system used for the communication and support of vehicle-to-infrastructure interactions, and it allows freight vehicles to send and receive priority requests to signal controls in real-time. The application of this approach is significant for urban areas with high truck volumes, aiming to improve traffic flow and reduce delays caused by slow-moving trucks. The study's results showed that implementing truck priority reduces truck travel times (in seconds) by 5% to 10% without negatively impacting passenger vehicle travel times, while also reducing overall vehicle stops and emissions. Although a detailed cost-benefit analysis is not provided, the study implies that the operational improvements, including reduced fuel consumption and emissions, justify the investment in such systems (Yanbo Zhao et al., 2019). Another study was conducted to evaluate the effectiveness of implementing signal priority for heavy commercial vehicle (HCV) platooning or truck platooning. As measure of effectiveness (MOE), changes in travel time and the number of stops, assessed using PTV VISSIM micro-simulation models. The significance of FSP for HCV platooning lies in its potential to reduce fuel consumption, emissions, and alleviate the HCV driver shortage by enabling higher levels of vehicle automation. The result showed the implementation of signal priority for HCV platooning improved travel time and reduced the number of stops for all vehicles (Chowdhury et al., 2023). In the context of DBL application for transit vehicles, a study using VISSIM microsimulations showed significant reductions in delays on the DBL system in a city in China, with a congested intersection delays decreasing from 123 seconds to 29 seconds. Average vehicle travel speed (km/hr) along major roads more than doubled, indicating improved traffic flow and reduced congestion, justifying the investment in DBL systems (Wu Xiaodan et al., 2014). In the case of DBL, a study was conducted to investigate the effectiveness of DBL systems in reducing congestion on Faisal Street. The measure of effectiveness focuses on travel time (in seconds), delay (in seconds), and the level of service (LOS), which is a function of delay, for both DBL and general traffic, using the PTV VISSIM simulation platform. The study examines four DBL scenarios with different conflict resolution strategies, from traffic signals to grade separation. The results show that grade separation (scenario 4) can reduce overall travel time by up to 18%, compared to an 80% increase in scenario 1. Additionally, scenario 4 improved the LOS from F to E in one direction and from E to D in the other, highlighting its effectiveness. Although a detailed cost-benefit analysis is not included, the operational improvements suggest that the investment in DBL infrastructure, particularly grade separation, is justified by the significant reduction in delays and enhanced traffic flow (M. Mohamed et al., 2022).

The study by Wijayaratna et al. (2013) evaluates the environmental impact of Transit Signal Priority (TSP) using a microsimulation model on the El Camino Real corridor in California. The primary goal of TSP is to improve transit efficiency by reducing delays for buses at signalized intersections. However, while the study found that TSP effectively reduced bus travel time and emissions due to fewer stops and idling periods, it also led to an overall increase in emissions across the corridor. This increase was attributed to disruptions in the signal cycle, which caused longer delays and additional stop-and-go movements for other traffic. As a result, while transit vehicles benefited, the net environmental impact was not necessarily positive. The study investigates the importance of optimizing TSP implementation to balance the benefits for transit users while mitigating unintended negative effects on other vehicles. It also proposes a future direction toward an "Eco-Transit Signal Prioritization" model that integrates emissions reduction objectives into signal timing strategies (Wiiavaratna et al., 2013).

Osorio and Nanduri (2015) propose to integrate high-resolution traffic and emissions models into transportation optimization algorithms. Traditional traffic management strategies primarily focus on improving congestion metrics, such as travel time and vehicle throughput, while emissions reductions are typically evaluated as an afterthought. This study argues that by embedding emissions data directly into traffic signal control optimization, transportation agencies can systematically design networks that minimize both congestion and environmental impact. A case study using traffic signal optimization demonstrated that a metamodel-based approach could identify signal timing plans that reduce vehicle delays while also lowering CO2 and NOx emissions. The study further emphasizes that incorporating real-time emissions data into traffic control strategies can help develop more sustainable urban transportation networks, aligning environmental objectives with traffic performance goals (Osorio & Nanduri, 2015).

Shaheen and Lipman (2007) provide a comprehensive review of sustainable transportation strategies aimed at reducing greenhouse gas (GHG) emissions and fuel consumption. The study examines various technological and policy-driven approaches, including the implementation of Intelligent

Transportation Systems (ITS), road pricing policies, car-sharing programs, and transit signal priority (TSP). One key finding is that TSP and electronic toll collection systems can significantly reduce emissions by minimizing stop-and-go traffic conditions, which are known to increase fuel consumption and pollutant emissions. The authors highlight that while vehicle technology improvements, such as hybrid and electric buses, play a crucial role in reducing transportation-related GHG emissions, optimizing traffic flow through ITS and mobility management strategies can provide immediate and scalable benefits. The study also emphasizes that integrated approaches, combining technological advancements with policy interventions, are necessary to achieve long-term reductions in transportation sector emissions (Shaheen & Lipman, 2007).

Park et al. (2019) focus on the implementation of Freight Signal Priority (FSP) in a connected vehicle environment and its impact on emissions. Unlike traditional TSP, which prioritizes public transit vehicles, FSP is designed to improve the efficiency of freight transport by providing green signal extensions to trucks approaching intersections. The study used a simulation testbed incorporating VISSIM microscopic traffic simulation software and the Motor Vehicle Emission Simulator (MOVES) emissions model to evaluate the energy and environmental impacts of FSP under different traffic conditions. The results demonstrated that FSP significantly reduced fuel consumption and emissions for connected trucks, with network-wide fuel consumption decreasing by 11.8% and emissions of $CO_2$, HC, CO, and $NO_x$ dropping by 11.8%, 28.3%, 24.8%, and 25.9%, respectively. However, the study also identified potential trade-offs, as non-prioritized side-street vehicles experienced increased emissions due to reduced green time allocation. Their finding highlights the need for a balanced approach to FSP implementation that considers the environmental impact on the broader traffic network rather than focusing solely on freight efficiency.

Alam et al. (2014) examined the effects of strategies such as reserved bus lanes, express bus services, and smart card fare payment on emissions along an urban corridor in Montreal. The study found that reserved bus lanes and express services were the most effective in reducing GHG emissions, with a combined reduction of up to 40% compared to conventional bus operations. Reserved lanes minimized delays and stop-and-go movements, thereby enhancing fuel efficiency, while express services reduced overall bus travel time and unnecessary idling. Additionally, the adoption of smart card payments contributed to lower idling emissions by streamlining boarding processes, reducing dwell times, and limiting fuel wastage. These findings demonstrate the potential of targeted transit strategies in mitigating transportation-related emissions while improving service reliability and efficiency (Alam et al., 2014).

Studies evaluating TSP consistently report reductions in bus travel time and delay across a variety of urban contexts. Microsimulation-based analyses indicate that TSP can reduce bus delay by approximately 15-30 seconds per intersection and decrease corridor-level travel time by 7-19%, depending on traffic conditions, stop placement, and priority logic. Compared to TSP, the literature on FSP is less extensive but demonstrates growing relevance in freight-intensive regions. Simulation studies show that FSP can reduce truck travel time by 5-10%, decrease the number of vehicle stops, and lower fuel consumption and emissions, particularly when implemented in connected vehicle environments.

These studies collectively highlight the diverse applications and benefits of TSP, FSP and DBL systems, with emphasis on their potential to enhance transit efficiency, reduce delays, and improve overall traffic management. Despite the variations in context and implementation, the consistent outcome is the operational benefits that justify the consideration in these advanced traffic management strategies for this study.

## 2.3. Application of Multiple Measures

Despite extensive research on improving the movement of people and goods, there is a notable gap in studies examining the combined impact of Transit Signal Priority (TSP), Freight Signal Priority (FSP), and DBL on arterials. While individual strategies such as TSP, FSP, and bus-only lanes have been widely studied, literature lacks comprehensive analyses that integrate these methodologies to assess their combine impact on mobility.

For the case of multimodal signal priority, i.e., combining TSP and FSP, a study conducted by Ahn et al. that discussed a potential simulation model development utilizing a combination of TSP and FSP. The study concluded that implementing a combination of TSP and FSP caused a reduction in travel time (in seconds) by up to 29% for buses, 28% for passenger vehicles, and 35% for trucks. In addition to the travel time reduction, it was noted that implementing TSP and FSP might cause system-wide delay due to the decrease in greenlight signals on the minor roadways (Ahn, et al., 2016).

Numerous studies have shown that the application of multiple Intelligent Transportation Systems (ITS) strategies can significantly enhance the operational performance of transit vehicles, trucks, and passenger cars. For instance, a study evaluated the impact of a Multimodal Intelligent Traffic Signal System (MMITSS), which is a system that uses real-time multimodal vehicle communication technology to provide signal coordination and signal priority, on urban traffic flow, focusing on reductions in vehicle delay (in seconds) and increases in average traffic speed, using VISSIM microscopic traffic simulation software. MMITSS integrates various intelligent signal control systems, including TSP and FSP, to enhance the mobility of all transportation modes. The study found that MMITSS reduced vehicle delay by up to 35% and increased average traffic speed by 27%. Specifically, TSP reduced travel times for transit and passenger vehicles by up to 29% and 28%, respectively, while FSP significantly reduced truck delays but increased systemwide delay in scenarios with high truck volumes. Despite the lack of a detailed cost-benefit analysis, the operational improvements suggest that MMITSS deployment is justified, potentially yielding substantial benefits for urban mobility and efficiency (Kyoungho Ahn et al., 2016).

Another study examined the combined impact of TSP with DBL and Queue Jump Lanes (QJL) across multiple intersections, focusing on bus and person delay savings. Using extensive traffic microsimulation modeling, the study found that combining TSP with DBL or QJL resulted in a multiplier effect, increasing bus travel time (in seconds) savings by 5% to 8% per additional intersection. For instance, eastbound bus delay benefits from TSP intersection benefits, showing additional benefits of 40% and 25% for V/C ratios of 0.5 and 0.7, respectively. Although a detailed cost-benefit analysis was not provided, the significant delay reductions and improved bus travel times suggest that investing in such transit priority measures is justified (Long T. Truong et al., 2017).

Similarly, another study investigated the efficacy of combining DBL with Transit Signal Priority (TSP) using performance indicators such as travel time reduction (in seconds), average travel speed (in km/hr), queue length (in meters), and overall passenger delay (in seconds). This approach aimed to enhance the reliability and efficiency of a DBL system by reducing delays at intersections, making public transit more appealing. Focusing on a BRT line in Addis Ababa, Ethiopia, one of the city's highest ridership lines, the study evaluated scenarios with and without TSP using PTV VISSIM. The results showed a reduction in travel time by up to 5% in the priority direction and a decrease in passenger delay by around 15%, concluding that TSP is a cost-effective long-term solution for improving public transit services (Robel Desta et al., 2022).

Abbasi et al. (2021) analyzed the impact of TSP and actuated traffic signals on a busy corridor in Tehran's bus-rapid transit (BRT) DBL system, which operates in a dense urban environment with highly heterogeneous traffic conditions. Using microscopic traffic simulation in Aimsun, the study compared scenarios with and without TSP to evaluate their effects on travel time (in seconds), fuel consumption, and emissions. The results showed that implementing TSP and actuated traffic signals led to substantial improvements in transit performance, including reduced travel time and fewer stops for buses. More importantly, environmental indicators showed a significant reduction in emissions: CO emissions decreased by 25.9%, NOx emissions by 6.2%, and overall fuel consumption was reduced. These findings highlight the potential for advanced traffic signal control strategies to enhance both transit efficiency and environmental sustainability. However, the study also notes that TSP strategies must be carefully designed to avoid excessive delays for non-transit vehicles, which could counteract the overall emissions reduction benefits (Abbasi et al, 2021).

In addition, a study explored the effectiveness of integrating TSP and FSP using a simulation study and decision tree algorithm. The specific measure of effectiveness was the reduction in travel time (in seconds) and delay (in seconds) for transit and freight vehicles, quantified through calibrated VISSIM simulation models. The proposed model reduced transit vehicle delay by up to 19% and freight vehicle delay by 24%, with corresponding improvements in travel time. The cost-benefit analysis, based on delay reduction and occupancy values, indicated substantial operational benefits, justifying the investment in TSP and FSP systems (Shahadat Iqbal et al., 2022).

It is evident that a number of studies have investigated the impact of implementing transit-improvement strategies or treatments such as TSP and DBL, along with studies related to freight improvement and FSP. However, there is a research gap in studying the combination of these strategies.

## 2.4. Chapter Summary

It is evident that there is a plethora of research and studies in the literature that investigated the impact(s) of implementing transit-improvement strategies or treatments such as TSP and DBL, along with studies related to freight improvement and FSP. Also, the topic of GHG emissions and transit and freight implementation strategies are present in the literature. While each of the following strategies including Transit Signal Priority (TSP), Freight Signal Priority (FSP), and Dedicated Bus Lanes (DBL) has been studied individually, there is a clear gap in research evaluating the combined implementation of all three strategies. To date, no study has comprehensively assessed their joint effects or compared them using multiple performance metrics such as average travel time, total person delay, and GHG emissions. Table 2 summarizes the findings from the literature review.

| Author (Year) | Implementation Strategy | MOEs | Findings |
|---|---|---|---|
| Burak Cesme et al., 2015 | TSP & Queue Jump Lanes (QJL) | bus delay (sec/veh) | Decrease in bus delays by 19-30 seconds |
| Yu Song et al., 2016 | GPS-based TSP on arterial | Bus travel time & delay (sec/veh) | Travel time decreased by 8-12%; Delay decreased 18%; Conditional TSP minimized side-street impacts. |
| Hadeel Al Khateeb et al., 2017 | TSP corridor (UAE) | Travel time & delay | Bus travel time decreased 7%; Bus delay decreased 14%; Car delay increased 57%. |
| Kan Wu et al., 2020 | TSP effects on mixed traffic | Delay (sec/veh-km) | Bus delay decreased 69s/km; Car delay decreased 19s/km; cross-street delays slightly increased. |
| Abolfathi, 2022 | TSP + DSRC on BRT system | Delay, stop time, speed, travel time | Delay decreased 19-22%; Stop time decreased 42-48%; Speed increased 4%; Travel time increased 4%. |

| Author (Year) | Implementation Strategy | MOEs | Findings |
|---|---|---|---|
| Ning Huan et al., 2022 | Dynamic dedicated median lane + adaptive priority | Travel time, fuel consumption | Per person travel time decreased 7%; Fuel decreased 2%; Better than traditional dedicated lanes. |
| Minji Kim et al., 2022 | Integrated TSP in coordinated signal control | Travel time, delay (sec/person) | Bus delays decreased 17.4%; Person delay decreased 10.9%. |
| MD Sultan Ali et al., 2023 | Transit mobility enhancement factors (MEF) | Travel time & delay | Bus travel time decreased 7%; Delay decreased 11%; Cross-street delay increased 6%. |
| MD Sultan Ali et al., 2023 | TSP transferability simulation | Travel time & delay | Bus travel time increased; Delay increased; 9-18% transferability of parameters. |
| Yanbo Zhao et al., 2019 | COSMO truck priority | Travel time, stops, emissions | Truck travel time decreased 5-10%; Stops decreased; Emissions decreased; No negative PV impacts. |
| Chowdhury et al., 2023 | Truck platooning + signal priority | Travel time, stops | Travel time decreased; Stops decreased for all vehicles. |
| Wu Xiaodan et al., 2014 | DBL in China | Speed, delay | Intersection delay decreased 123 to 29 sec; Avg speed more than doubled. |
| M. Mohamed et al., 2022 | Multiple DBL configurations | Travel time, delay, LOS | Grade-sep decreased travel time 18%; LOS from F to E & E to D; Scenario 1 increased delays. |
| Wijayaratna et al., 2013 | Emissions impact of TSP | Travel time, emissions | Bus emissions decreased; Network emissions increased due to signal cycle disturbance. |
| Osorio & Nanduri, 2015 | Emissions-integrated signal optimization | Delay, emissions | Optimized signals decreased delays and decreased $CO_2$/NOx; Calls for environmental-aware control. |
| Shaheen & Lipman, 2007 | Review of ITS strategies on GHG | Fuel/emissions | TSP decreased emissions: ITS + EVs + policies needed for sustainability. |
| Park et al., 2019 | FSP emissions assessment (connected trucks) | Emissions ($CO_2$, HC, CO, NOx), fuel | Network fuel decreased 11.8%; $CO_2$ decreased 11.8%; NOx decreased 25.9%; Side streets increased emissions. |
| Alam et al., 2014 | DBL + express services + smart cards | GHG emissions | Up to 40% GHG decreased; Reserved lanes decreased idling; Faster boarding decreased delay. |

| Author (Year) | Implementation Strategy | MOEs | Findings |
|---|---|---|---|
| Ahn et al., 2016 | Combined TSP + FSP model | Travel time, systemic delay | Travel time decreased 29% (bus), decreased 28% (cars), decreased 35% (trucks); Minor roads delay increased. |
| Kyoungho Ahn et al., 2016 | MMITSS (multimodal priority) | Delay, avg speed | Delay decreased 35%; Speed increased 27%; TSP decreased 29% (transit), decreased 28% (cars); FSP: truck delay decreased but system delay increased when heavy. |
| Long T. Truong et al., 2017 | TSP + DBL or QJL | Travel time, delay | Multiplier gain: 5-8% per added intersection; EB-delay benefits increased 40% at V/C=0.5. |
| Robel Desta et al., 2022 | DBL + TSP (BRT) | Travel time, passenger delay | Travel time decreased 5%; Passenger delay decreased 15%; Effective long-term. |
| Abbasi et al., 2021 | TSP + actuated signals (BRT) | Travel time, stops, fuel, emissions | CO decreased 25.9%; NOx decreased 6.2%; Travel time decreased; Fewer stops; Notes possible non-transit delay impacts. |
| Shahadat Iqbal et al., 2022 | TSP + FSP + decision-tree optimization | Travel time, delay, CBA | Delay decreased by 19% (transit) & decreased 24% (freight); Positive cost-benefit. |

*Table 2 - Summary of the literature review results, including implementation strategies, MOEs and performance*

This study addresses that gap by exploring, for the first time, how the integration of these three ITS strategies can simultaneously benefit transit buses and freight traffic. Building on the insights gained from the literature review, the next chapter introduces the study area and input data used to evaluate multimodal corridor performance under various treatment strategies. Given the absence of prior research that examines TSP, FSP, and DBL as an integrated strategy, this thesis performs simulation-driven analysis using microscopic modeling to quantify operational impacts on buses, trucks, and general traffic. The methodology incorporates multiple performance metrics informed by existing studies, including average travel time, total person delay, and emissions generation, to ensure a robust assessment of multimodal mobility. The following chapter describes the study area, simulation model development in VISSIM, calibration and validation procedures, and the experimental design used to analyze individual and combined treatment scenarios.

# Chapter 3. Study Area and Data

This chapter discusses the study area as well as the input data collected and used in this study. Conventionally, after identifying the study area, the input data needed are collected. Afterwards, the input data was added to PTV VISSIM to create the necessary microsimulation models. In developing the microsimulation models for this study, Table 3 shows the various types of data that are used in this study and their sources.

| Data | Source | Purpose |
|---|---|---|
| Turning Movement Counts and Signal Timing Plans for the 2017 PM Peak (Appendix A) | Synchro Reports from Region of Peel, 2017 | Microsimul ation Modelling |
| Posted Speeds | Synchro Reports from Region of Peel, 2017<br>Google Maps, 2022 | |
| Ring Barrier Control (RBC) Signalization | Synchro Reports from Region of Peel, 2017 | |
| Transit Routes and Bus Frequency along Queen St | Transitfeed, 2022-2023 | |
| Observed/Existing Travel Time | Google API (OD Matrices), 2022 | Model Calibration |
| Vehicle Occupancy<br>Auto vehicles: 1.1 per vehicle<br>Freight vehicles: 1.0 per vehicle<br>Transit vehicles: 31.52 per vehicle | TTS 2016 for freight, Callan et al 2019 for transit vehicles | Results Calculation s |

*Table 3 - Data types, sources, and purpose used in this study*

## 3.1. Study Area

The Queen Street corridor in the Region of Peel, Ontario, Canada, is strategically planned to accommodate a proposed 24 km Bus Rapid Transit (dedicated bus lane) route, connecting Brampton to Vaughan along Queen Street-Highway 7. This initiative is crucial for enhancing regional connectivity and improving transit accessibility between these two major urban centers. Moreover, the redevelopment of the Queen Street corridor aims to transform the area into a vibrant mixed-use community. This transformation is geared towards promoting sustainability by integrating residential, commercial, and recreational spaces. Emphasis is placed also on creating walkable environments that encourage active transportation and reduce reliance on cars, thereby fostering a more environmentally friendly community. Another significant goal of the corridor's redevelopment is to enhance safety, accessibility, and livability for all users. This includes pedestrians, public transit riders, motorists, and cyclists. The redesign of streets and intersections will prioritize safety measures and ensure seamless mobility for different modes of transportation.

The urban arterial segment of Queen Street East, which serves as the focus of this study, features seventeen signalized intersections and accommodates three primary modes of transportation: passenger vehicles, freight, and transit buses. Notably, it hosts one of Brampton's busiest bus routes, the 501 Züm, which recorded a substantial weekday ridership of 20,804 in Fall 2019 (Callan, 2021).

Figure 5 and Figure 6 demonstrates the studied road segment of the Queen Street E corridor, which is 9.9 km in length. Of the 17 signalized intersections, 15 of them are 4-legged intersections, and 5 of them are major intersections, which include Dixie Road, Bramalea Road, Airport Road, the Gore Road, and Goreway Road. The remaining 12 intersections are considered minor intersections, 2 of which (Torbram Road Plaza, and the Smart Center) are plaza entrances, and the other 2 intersections are 3-legged intersections. Most of the through movement in the segment contains 3 lanes per direction (i.e., 3 lanes eastbound and 3 lanes westbound). Furthermore, on the east side of the corridor segment, Queen Street E. ends at the Highway 50 and Highway 7 intersection, and Highway 7 commences onward in the eastbound. In the west side of the corridor segment, Highway 410 connects to Queen Street E. just before the intersection of Queen Street E and West Drive. The busiest intersections with apparent traffic congestion are Central Park Dr., Airport Rd., Goreway Dr., and Gore Rd., therefore, they are exempted from including signal priority for both freight (FSP) and transit (TSP). The reason for not implementing TSP and FSP in the heavily congested intersections is due to the increase in congestion as TSP and FSP are implemented.


*Figure 5 - Map of the study corridor (Metrolinx, 2021)*

Based on the initial turning movement counts from the Region of Peel, it is observed that the busiest intersections with apparent traffic congestion are Central Park Dr., Dixie Rd., Airport Rd., Goreway Dr., and Gore Rd., therefore, they are exempted from including signal priority for both freight (FSP) and/or transit (TSP) for the microsimulation models that combine them with DBL, this is shown in Figure 6. The reason for not implementing TSP and FSP in the heavily congested intersections is due to the increase in congestion as TSP and FSP are implemented.

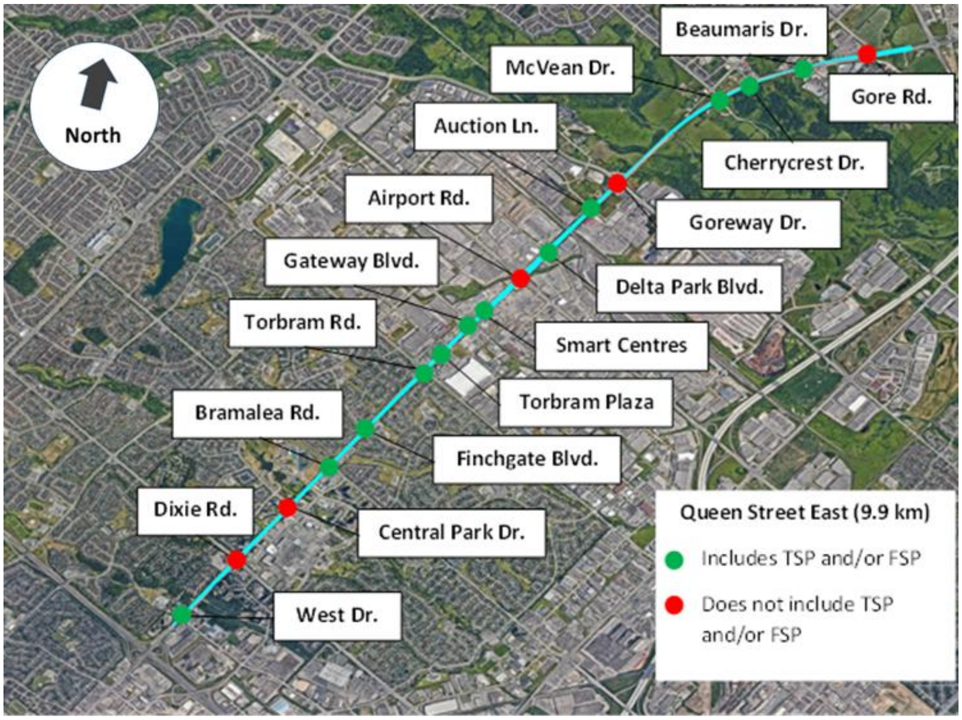



*Figure 6 - Map showing the study corridor, intersections considered for TSP and/or FSP*

Table 4 shows the posted speeds, as provided in the Synchro reports and Google Maps, in the through movement (eastbound and westbound), which varies from 60 to 80 km/hr. The total volume (vph), percentage of freight, and percentage of transit are also presented in Table 4. Additionally, the minor roads in the study intersections have relatively many vehicles in the northbound and southbound directions, with many prioritized vehicles. For example, Central Park Dr. contains a large number of buses given that is an enroute to Bramalea GO station for many bus lines, including the 501 Züm bus route.

| Intersection | Posted Speed (km/hr) | Total Volume (vph) | Freight (%) | Transit (%) |
|---|---|---|---|---|
| West Dr. | 60 | 6447 | 13 | 0.45 |
| Dixie Rd. | 60 | 7626 | 13 | 0.42 |
| Central Park Dr. | 60 | 5042 | 0 | 0.50 |
| Bramalea Rd. | 60 | 6525 | 15 | 0.14 |
| Finchgate Blvd. | 60 | 4667 | 13 | 0.17 |
| Torbram Rd. | 60 | 4967 | 26 | 0.42 |
| Torbram Plaza | 60 | 4451 | 5 | 0.18 |
| Gateway Blvd. | 60 | 4709 | 48 | 0.15 |
| Smart Centres | 60 | 4689 | 13 | 0.15 |

| Intersection | Posted Speed (km/hr) | Total Volume (vph) | Freight (%) | Transit (%) |
|---|---|---|---|---|
| Airport Rd. | 80 | 8041 | 45 | 0.30 |
| Delta Park Blvd. | 80 | 4442 | 68 | 0.16 |
| Auction Ln. | 80 | 4295 | 72 | 0.26 |
| Goreway Dr. | 80 | 9381 | 41 | 0.20 |
| McVean Dr. | 80 | 6367 | 15 | 0.14 |
| Cherrycrest Dr. | 80 | 4398 | 5 | 0.02 |
| Beaumaris Dr. | 80 | 4618 | 24 | 0.02 |
| Gore Rd. | 80 | 5154 | 20 | 0.23 |

*Table 4 - Posted speeds, total volume, percentage of freight, and percentage of transit along the study corridor.*

The study corridor consists of a set of signalized intersections exhibiting substantial variation in traffic volumes, freight composition, transit presence, and posted speeds. These differences play a role in shaping both observed operational performance and the calibration outcomes of the microsimulation model. This section of the thesis describes the operational characteristics of each intersection and discusses the extent to which traffic composition, directional travel patterns, and peak-hour demand based on the data obtained from the Region of Peel.

<u>Intersection of Queen Street & West Drive:</u>

West Drive is a major arterial intersection operating under a posted speed of 60 km/h and carries a high total volume of approximately 6,447 vehicles per hour. Freight vehicles constitute 13% of traffic, while transit accounts for nearly 45% of movements, reflecting its role as a transit-supportive node. During the PM peak period, eastbound through movements dominate, driven by commuter travel toward employment areas further east.

<u>Intersection of Queen Street & Dixie Road:</u>

Dixie Road carries one of the highest volumes in the western segment of the corridor (7,626 vph) with a balanced freight share of 13% and high transit presence (42%). The intersection functions as a significant north-south commuter route intersecting Queen Street, resulting in strong bidirectional demand during peak hours.

<u>Intersection of Queen Street & Central Park Drive:</u>

Central Park Drive exhibits moderate total volumes (5,042 vph) but a notably high transit proportion (50%) and no observed freight traffic. This intersection serves as a major transit transfer point, particularly during peak periods, with pronounced bus bunching and dwell time variability.

Intersection of Queen Street & Bramalea Road:

Also, with total volumes of 6,525 vph and a freight share of 15%, Bramalea Road represents a balanced multimodal intersection. Transit activity is comparatively low (14%), and the intersection benefits from more consistent directional flows, particularly eastbound during the PM peak.

Intersection of Queen Street & Finchgate Boulevard:

Finchgate Boulevard carries lower overall volumes (4,667 vph) with moderate freight and transit proportions. The intersection primarily serves local traffic access and experiences less severe congestion during peak hours.

Intersection of Queen Street & Torbram Road:

Torbram Road is characterized by a substantially elevated freight share (26%) and moderate transit presence (42%). This intersection plays a critical role in regional goods movement, particularly during the PM peak when eastbound truck flows increase toward industrial areas.

Intersection of Queen Street & Torbram Plaza:

Torbram Plaza exhibits relatively low total volumes (4,451 vph) and minimal freight activity (5%), reflecting its function as a commercial access intersection. Traffic demand is highly variable and driven by retail-oriented turning movements, particularly during peak shopping periods.

Intersection of Queen Street & Gateway Boulevard:

Gateway Boulevard stands out with an exceptionally high freight proportion of 48%, despite moderate total volumes (4,709 vph). The intersection supports industrial access and experiences strong directional bias during peak hours, with inbound freight movements dominating the PM peak.

Intersection of Queen Street & Airport Road:

Airport Road is one of the most critical intersections along the corridor, carrying over 8,000 vehicles per hour and a freight share of 45%. The posted speed increases to 80 km/h, reflecting its function as a high-capacity arterial. Strong eastbound commuter and freight flows dominate the PM peak, often resulting in sustained oversaturation.

Intersection of Queen Street & Delta Park Boulevard:

Delta Park Boulevard exhibits a relatively low total volume (4,442 vph) but an exceptionally high freight share of 68%. The intersection primarily serves industrial land uses and experiences pronounced directional truck surges during peak periods.

Intersection of Queen Street & Auction Lane:

Auction Lane records one of the highest freight proportions along the corridor (72%) despite modest total volumes. Traffic patterns are highly directional and time-dependent, reflecting shift-based freight operations rather than conventional commuter peaks.

Intersection of Queen Street & Goreway Drive:

Goreway Drive is the busiest intersection in the study area, with total volumes exceeding 9,300 vph and a freight share of 41%. The intersection experiences heavy bidirectional commuter and freight demand, leading to frequent queue spillback and complex signal interactions.

Intersection of Queen Street & McVean Drive:

McVean Drive carries high volumes (6,367 vph) but a relatively low freight and transit presence. Traffic is predominantly commuter-based, with strong directional flows during peak periods.

Intersection of Queen Street & Cherrycrest Drive:

Cherrycrest Drive exhibits low freight and transit activity and serves primarily local residential traffic.

Intersection of Queen Street & Beaumaris Drive:

Beaumaris Drive carries moderate volumes with a freight share of 24% and minimal transit activity. Traffic patterns reflect a mix of commuter and industrial access trips, producing moderate variability in delay.

Intersection of Queen Street & Gore Road:

Gore Road experiences a portion of freight of around 20% and transit of around 23% activity. The intersection functions as a transition point between urban and more rural travel patterns, with peak-hour congestion influenced by both commuter and goods movement demand.

Overall, the study corridor of Queen Street and the signalized intersections along Queen Street exhibit high percentages of freight with relatively significant transit presence during the PM peak. The directionality of the movement tends to be biased towards the eastbound of the corridor.

Moreover, Queen Street contains many bus routes during the PM peak (4 to 6 PM) that primarily utilize it. These bus routes are shown in Table 5, which shows the bus route as of late 2022, the frequency per direction within the peak hour, the time between each bus in a route, and the direction. From Table 5, it can be noted that there is a fair number of buses that only travel on the minor roadways, including the intersections of Central Park Dr., Dixie Rd., Airport Rd., Goreway Dr., and Gore Rd. As such, not placing signal priority in these intersections is beneficial to the buses that only travel on minor roadways.

| Bus Route | Frequency | Temporal Frequency (minute) | From | To | Mainline | Direction |
|---|---|---|---|---|---|---|
| Züm 1 | 14 | 8 | West Dr. EB | West Dr. SB | Queen St. | EB |
| Züm 1 | 12 | 12 | Bramalea Rd. NB | McVean Dr. NB | Queen St. | EB |
| Züm 501 | 12 | 10 | West Dr. EB | Central Park Dr. SB | Queen St. | EB |
| Züm 501 | 12 | 10 | Central Park Dr. NB | Queen St. EB | Queen St. | EB |
| Züm 8 | 2 | 55 | West Dr. EB | Bramalea Rd. SB | Queen St. | EB |
| Züm 31 | 2 | 65 | The Gore Rd. SB | McVean Dr. NB | Queen St. | EB |
| Züm 1 | 6 | 15 | McVean Dr. SB | Bramalea Rd. SB | Queen St. | WB |
| Züm 1 | 12 | 8 | West Dr. NB | Queen St. WB | Queen St. | WB |
| Züm 1 | 12 | 8 | Gateway Blvd NB | Central Park Dr. SB | Queen St. | WB |
| Züm 501 | 20 | 6 | Central Park Dr. NB | Queen St. WB | Queen St. | WB |
| Züm 501 | 20 | 6 | Queen St. WB | Central Park Dr. WB | Queen St. | WB |
| Züm 8 | 2 | 55 | Dixie Rd. NB | Queen St. WB | Queen St. | WB |

| Bus Route | Frequency | Temporal Frequency (minute) | From | To | Mainline | Direction |
|---|---|---|---|---|---|---|
| Züm 29 | 9 | 30 | Goreway Dr. NB | Sun Pac Blvd NB | Queen St. | WB |
| Züm 5 | 5 | 30 | Goreway Dr. NB | Humberwest Pkwy NB | Goreway Dr. | NB |
| Züm 9 | 3 | 45 | Central Park Dr. NB | Central Park Dr. NB | Central Park Dr. | NB |
| Züm 14 | 13 | 10 | Torbram Rd. NB | Torbram Rd. NB | Torbram Rd. | NB |
| Züm 17 | 3 | 40 | Central Park Dr. NB | Central Park Dr. NB | Central Park Dr. | NB |
| Züm 18 | 14 | 10 | Dixie Rd. NB | Dixie Rd. NB | Dixie Rd. | NB |
| Züm 19 | 3 | 40 | Central Park Dr. NB | Central Park Dr. NB | Central Park Dr. | NB |
| Züm 30 | 13 | 10 | Airport Rd. NB | Airport Rd. NB | Airport Rd. | NB |
| Züm 50 | 10 | 15 | The Gore Rd. NB | The Gore Rd. NB | The Gore Rd. | NB |
| Züm 5 | 3 | 30 | Airport Rd. NB | Airport Rd. NB | Airport Rd. | NB |
| Züm 505 | 8 | 20 | Airport Rd. NB | Airport Rd. NB | Airport Rd. | NB |
| Züm 29 | 8 | 15 | Humberwest Pkwy SB | Goreway Dr. SB | Goreway Dr. | SB |
| Züm 9 | 3 | 45 | Central Park Dr. SB | Central Park Dr. SB | Central Park Dr. | SB |
| Züm 14 | 12 | 10 | Torbram Rd. SB | Torbram Rd. SB | Torbram Rd. | SB |
| Züm 17 | 3 | 40 | Central Park Dr. SB | Central Park Dr. SB | Central Park Dr. | SB |
| Züm 18 | 12 | 10 | Dixie Rd. SB | Dixie Rd. SB | Dixie Rd. | SB |
| Züm 19 | 3 | 40 | Central Park Dr. SB | Central Park Dr. SB | Central Park Dr. | SB |
| Züm 30 | 12 | 10 | Airport Rd. SB | Airport Rd. SB | Airport Rd. | SB |
| Züm 50 | 10 | 12 | The Gore Rd. SB | The Gore Rd. SB | The Gore Rd. | SB |

*Table 5 - Bus routes details in each direction along Queen Street*

## 3.2. Microsimulation Input Data

The dataset used for this study was supplied by Region of Peel, and it contains traffic data for the PM-peak movement collected in 2017 for each intersection. This dataset contains necessary parameters that are crucial for developing the VISSIM models. Such parameters include turning movement traffic volumes (vph), level-of-service (LOS), percentage portion of freight vehicles (%), number of lanes, lane width (m), number of detectors, and traffic signal phases including splits, green, yellow, and red signals (s), and cycle length (s). The lane width along the major roadway (Queen Street) is 3.70 meters wide, and the lane width in minor roadways ranges from 3.3 to 3.7 meters wide. Moreover, this study used bus-specific parameters that were extrapolated from Transitfeeds and Google Maps, such as bus stop locations and bus frequency, as well as bus arrival time relative to the time in the simulation.

Additionally, ring barrier control (RBC) signal coordination system is used. The signal parameters obtained from the Region of Peel dataset include split and cycle information, and signal time schedule along each intersection (i.e., green, amber, and red timers). Figure 7 illustrates a general schematic of each intersection's RBC. The "major roadway" holds he priority over the "minor roadway." The "major roadway" is the corridor on which this study evaluates the implementation strategies. The ring functions in such a way that it follows a certain looped order.

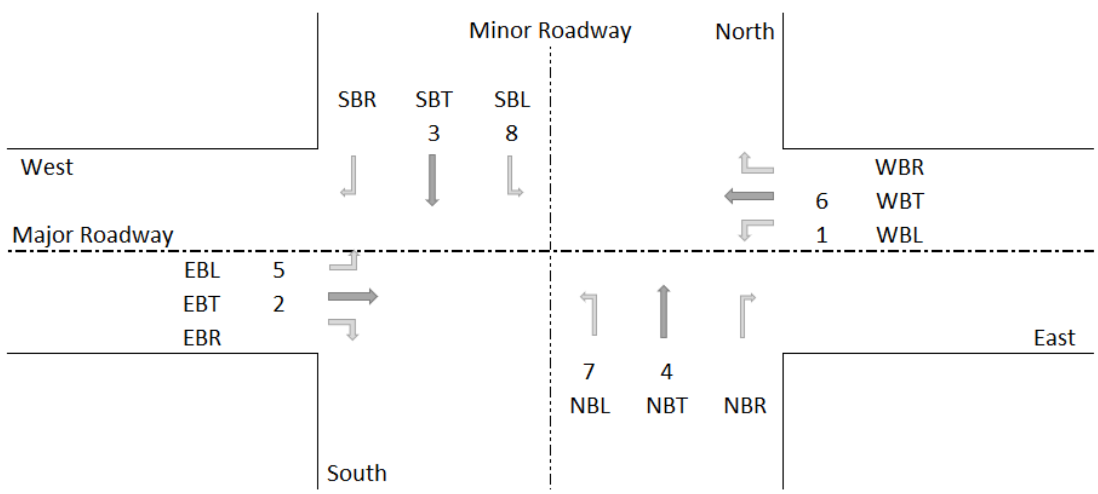



*Figure 7 - RBC signal coordination system configuration*

Each intersection holds a unique RBC file that contains the phases data. Each microsimulation model also holds a unique set of RBC files given the different implementation strategies, it is important to note that not all microsimulation models share the same RBC files, and this is mainly due to several models utilize signal priority options, while others do not contain such options. Figure 8 shows an example of some of the parameters used in the RBC. The intersection is Queen Street and West Drive, and it includes a cycle length of 140 seconds.

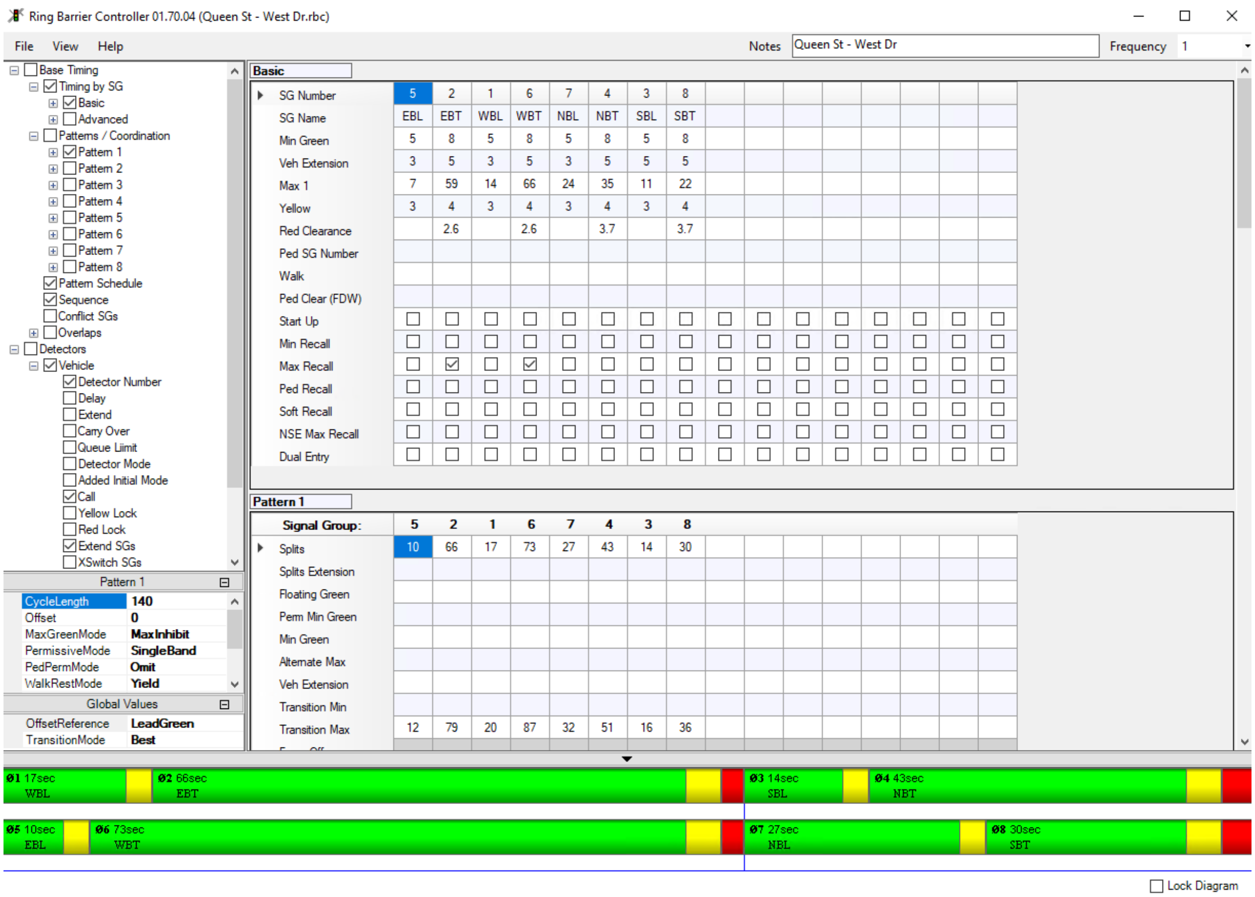


*Figure 8 - Sample of the parameters in VISSIM's RBC*

Then, the data in Table 5 is carefully inputted in every VISSIM simulation model. The table pertains to the data of bus routes, bus frequency, bus times (converted from minutes to seconds), and bus stop locations in each major and minor road. The bus-related data are taken from transitfeeds as of late 2022 to early 2023.

## 3.3. Chapter Summary

In summary, the study corridor, Queen Street, is 9.9 km in length, and it is located in Brampton, Ontario. It includes 17 signalized intersections. The input data obtained from Region of Peel contains traffic input as well as directional vehicle volumes and heavy-goods vehicle (truck) percentages in each intersection. Additionally, the data pertaining to bus frequency, schedules, and stop locations are also included. The outcome of this chapter is discussed in the following chapter, Chapter 4.

# Chapter 4. Microsimulation Model Development

This section outlines the methodology that was followed to develop the microsimulation models, including 1) input parameters, 2) model calibration, and 3) development of alternative scenarios. VISSIM software is utilized to produce models that mimic realistic roadway traffic conditions as much as possible. The outcome of these models can later be used to analyze and evaluate the MOEs. These models can also yield more results that can be analyzed; however, they are not being considered in this study, including fuel emissions, level-of-service (LOS), and lane change data.

## 4.1. VISSIM Modelling

The simulation process is done using PTV VISSIM 2021 software application. First, the driving behaviours are identified in the VISSIM models to exhibit as realistic driving behaviour in the model as possible. All models in this study use Widermann 74 car-following model to make the simulations as realistic as possible. The lane-change behaviour is set on “slow lane rule” mainly due to the short length between every two intersections. This rule is used by VISSIM to adjust the lane-change decision logic to give the preference to move back to the slower lane after overtaking and to show more realistic distribution. Additionally, the behaviour at amber signal is set on “continuous check” for the reaction of when the vehicles approach the after end of the green signal, and “stop” as the behaviour at red and amber signal for the reaction after the end of the red signal. This amber signal setting enables the drivers to continuously evaluate the stop/go decisions throughout the amber phase, meaning that there is dynamic decision-making depending on the conditions of the road during the amber phase, which in turn makes the microsimulations more realistic.

Second, Bing Maps (Aerial View) are used in the network editor interface to be used as location-based reference for creating the directional travel links, traffic signals, and bus stops. After that, the links for all 17 intersections are created, including all 4 travel directions in each intersection. Once all links are created, the traffic signals and detectors are to be placed adequately. Then, vehicle input, vehicle routes, reduced speed areas, desired speeds, public transport stops, and public transport lines are adequately placed on their respective positions and locations. For each signal head, the RBC signal controller must be adjusted to include the appropriate signal group number, signal name, and phase and split patterns and schedules. It is important to mention that all intersections contain fully actuated signal operation.

The next step is to fix conflict areas. The conflict areas indicate that there are two links that may overlap with one another, thus assigning which one gets the priority is crucial. Generally, through movement is given priority where applicable (e.g., left turning vehicles yield for the through movement and pass the intersection when it is clear). Afterwards, the regular traffic detectors are placed just before the signal heads, with a length of 10 meters for each detector. These detectors are usually for the through movement, as well as the left-turning movement vehicles. These detectors are present in all simulation models in this study. Figure 9 shows an example of a fully modelled intersection in the base scenario model.

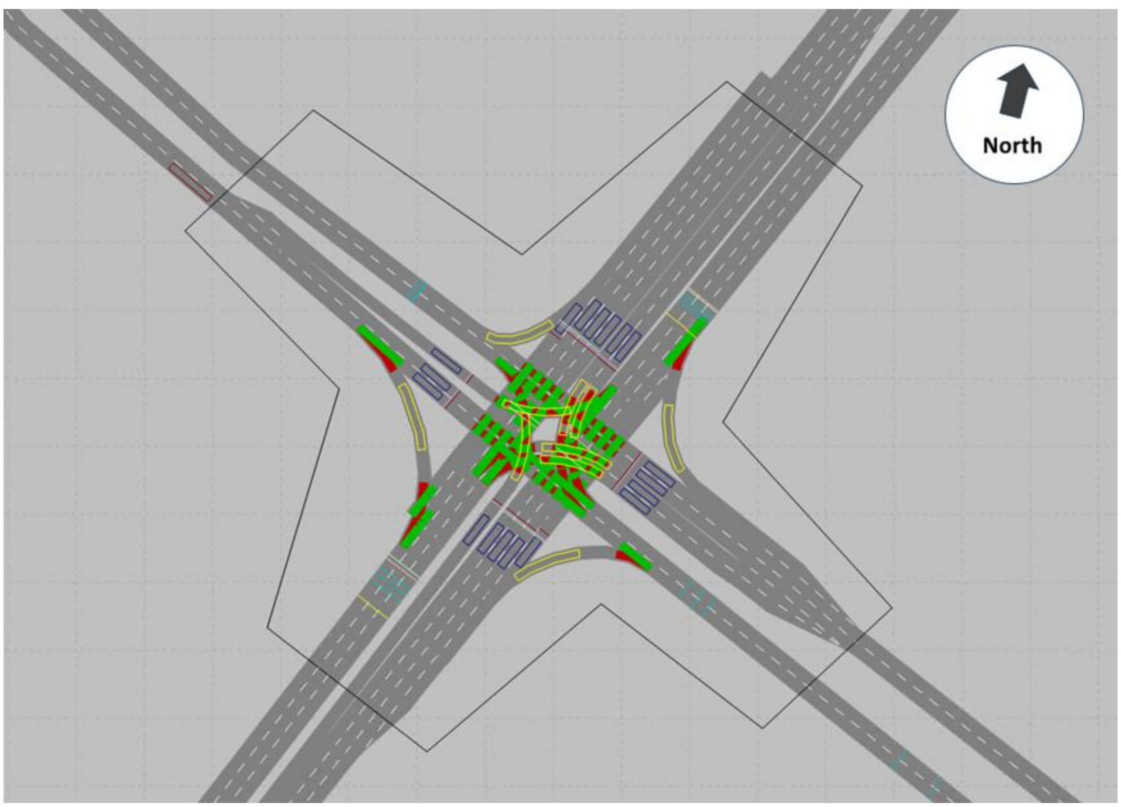



*Figure 9 - Queen St. & West Dr. intersection, modelled in VISSIM.*

The example shown in Figure 9 is the intersection of Queen Street and West Drive. The polygon with black-coloured outline represents the node in which the data is being collected. The green patches on the road indicate that the road segments have priority over the red-patched road segments. The blue rectangles present the detectors for through movement and left-turning movement. The yellow-coloured outlined patches represent the preferred speed, and these are placed on roadway segments with speeds lower than that of the mainline/through movement roadways segments. These include right-turning and left-turning movements. The maroon bars at the beginning of the intersection represent the signal heads at where the vehicles stop when the signal is turning amber or red. Moreover, it is important to note that the far-most right lane in the major roadway (Queen Street) contains QJL. As mentioned in the scope of this study, the schedule does not contain the schedules for the QJL. However, the location of where the QJL is situated in on the intersection is still modelled in accordance with the most recent BING and Google map services.

Further, vehicle travel times data collection points are created to collect the necessary travel time data (results). All microsimulation models in this study share the same locations for the data collection points for the sake of consistency. After that, the simulation parameters must be set to obtain adequate results. Figure 10 shows the VISSIM settings used for simulation parameters. The values presented in the figure will be further discussed in the Model Calibration section.

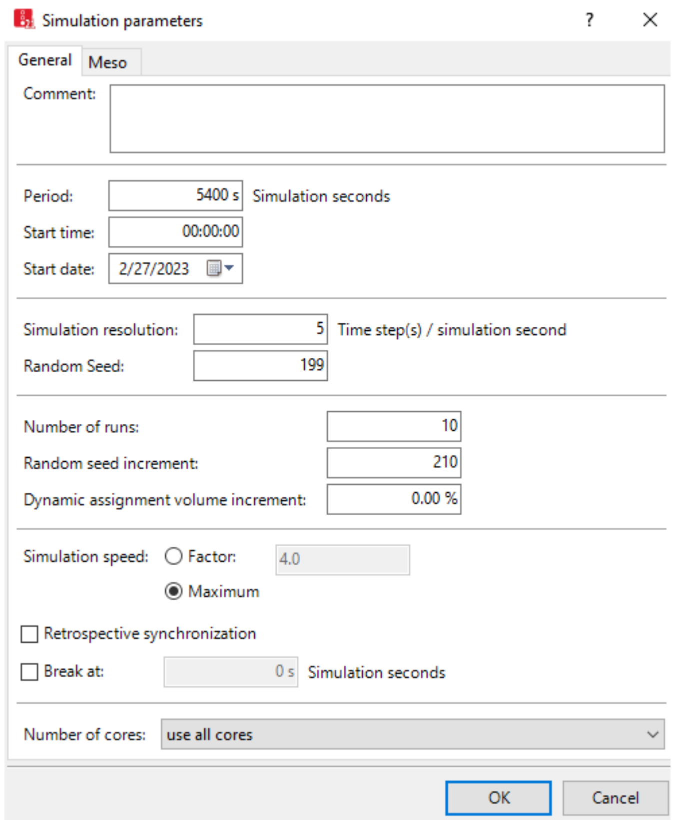
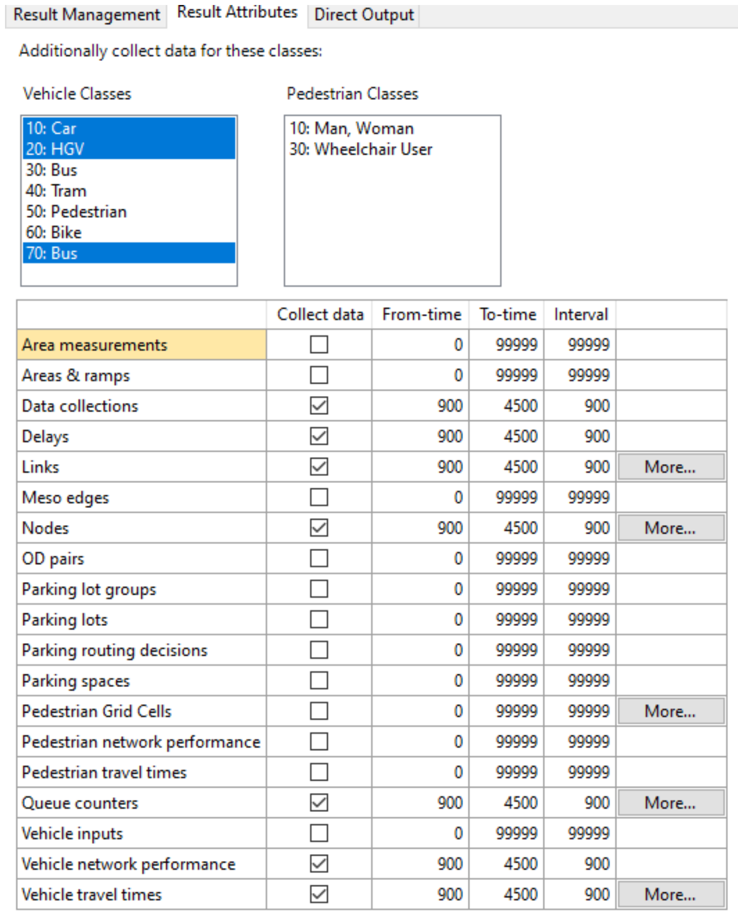



*Figure 10 - VISSIM simulation parameters*

Once the simulation parameters are set, the evaluation configuration can now be set. Figure 11 shows the settings used for evaluation configuration settings. These settings will indicate which results (output) will be recorded once the simulations have finished running. For the vehicle classes, car (passenger vehicles), HGV (freight), and bus (transit) vehicles are chosen to be recorded since evaluating the latter two are the main focus of this study.




| | Collect data | From-time | To-time | Interval | |
|---|---|---|---|---|---|
| Area measurements | ☐ | 0 | 99999 | 99999 | |
| Areas & ramps | ☐ | 0 | 99999 | 99999 | |
| Data collections | ☑ | 900 | 4500 | 900 | |
| Delays | ☑ | 900 | 4500 | 900 | |
| Links | ☑ | 900 | 4500 | 900 | More... |
| Meso edges | ☐ | 0 | 99999 | 99999 | |
| Nodes | ☑ | 900 | 4500 | 900 | More... |
| OD pairs | ☐ | 0 | 99999 | 99999 | |
| Parking lot groups | ☐ | 0 | 99999 | 99999 | |
| Parking lots | ☐ | 0 | 99999 | 99999 | |
| Parking routing decisions | ☐ | 0 | 99999 | 99999 | |
| Parking spaces | ☐ | 0 | 99999 | 99999 | |
| Pedestrian Grid Cells | ☐ | 0 | 99999 | 99999 | More... |
| Pedestrian network performance | ☐ | 0 | 99999 | 99999 | |
| Pedestrian travel times | ☐ | 0 | 99999 | 99999 | |
| Queue counters | ☑ | 900 | 4500 | 900 | More... |
| Vehicle inputs | ☐ | 0 | 99999 | 99999 | |
| Vehicle network performance | ☑ | 900 | 4500 | 900 | |
| Vehicle travel times | ☑ | 900 | 4500 | 900 | More... |

*Figure 11 - Values for evaluation configuration settings*

The total number of simulation seconds is 5400 seconds in each model. Also, VISSIM took around 100 minutes to finish modelling 10 simulation runs of each alternative scenario. The two exceptions are the scenarios (or the models) that contained a combination of TSP and FSP, and those took around 160 minutes to finish per 10 simulation runs. In Figure 11, it can be noted that the data is collected and recorded via intervals of 900 seconds. This is generally a good practice, and WisDOT recommends splitting the data collection intervals to increments of 900 seconds. The rationale for this is that the first and last 900 seconds of the simulation do not necessarily contain the actual number of vehicle volume. In other words, the first 900 seconds of the simulation act as a preparing period, or as a warm-up, and the last 900 seconds of the simulation act as a cool-off period. The collected data that will be later used as MOEs are collected from:

- Nodes: for directional volumes (vph), total delay (s), and average delay (s) in each directional movement per intersection,

- Vehicle Network Performance: this option collects the overall network-wide output, including volumes (vph) and total delay (s),
- and Vehicle Travel Times: this option produces the total travel time (s) and average travel time (s) for each mode that passes through the vehicle travel time indicators.

For the microsimulation models with TSP and FSP, the green extension strategy is used -solely- in this report. The value used in defining both TSP and FSP is 10 seconds as the green extension value. This value approximately covers 7 seconds for the stopping sight distance that allows the vehicles in the minor roadways to have enough time to stop as their traffic signal turns amber then red (i.e., the distance from the check-in location to the traffic signal location), and 3 seconds to accommodate the slack time for prioritized vehicles. Figure 12 shows the main settings used in TSP and FSP, which are applied to signal groups of 2 and 6. Signal groups 2 and 6 represent the through movement for the eastbound and westbound directions, respectively.

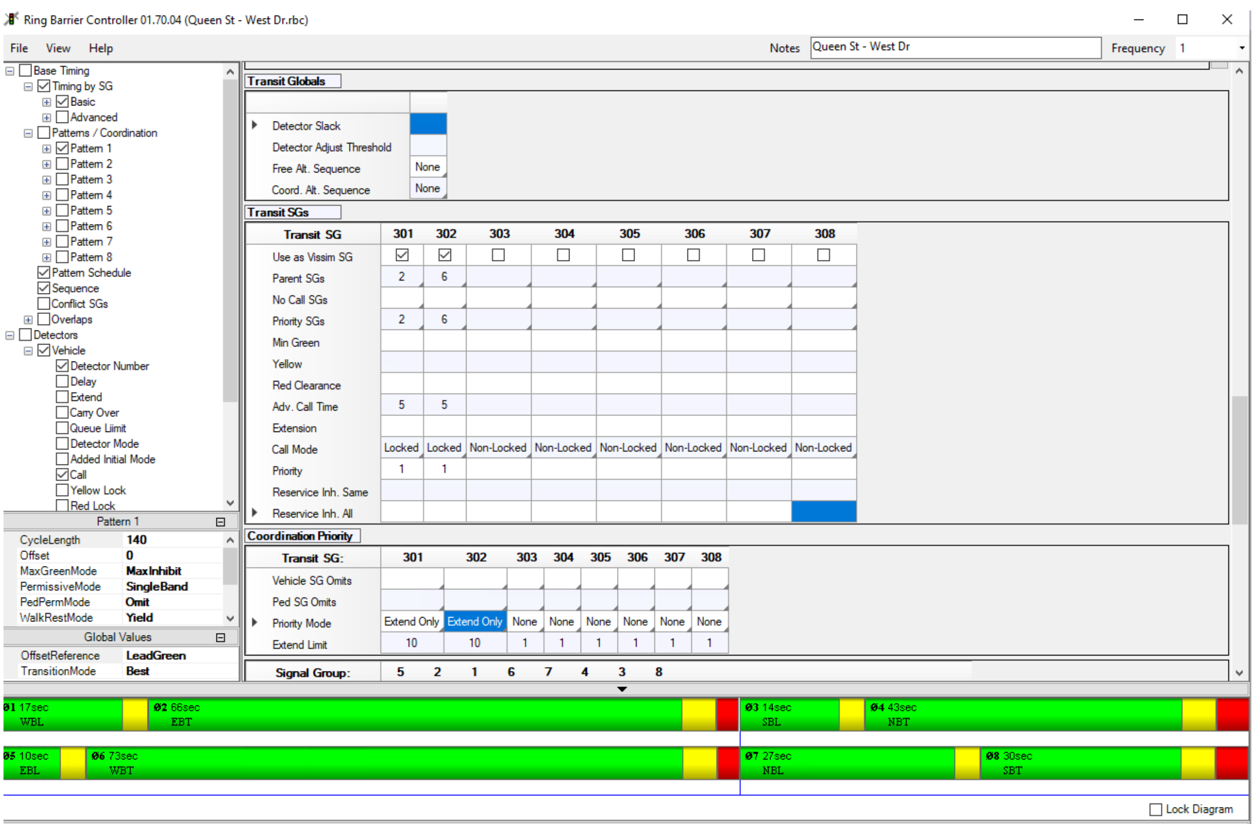



*Figure 12 - TSP and FSP settings in VISSIM's RBC*

Once all the necessary data and settings have been properly placed in VISSIM, the base model's initial number of simulation runs are 10. The next step is to determine the number of simulation runs. Even though the initial number of simulation runs was determined to be 10 simulation runs, this equation is used to verify that the initial number of simulation runs is adequate, i.e., if this equation yields a larger value for simulation runs, then this means that the initial number of simulation runs was not enough and it would need to be increased as per the equation's outcome. The main MOE used in calculating the number of simulation runs is the travel time. Equation 1 is used for calculating the number of simulations runs (WSDoT, 2014).

$$n = \left(\frac{s \cdot t_{\alpha/2}}{\bar{x} \cdot \epsilon}\right)^2 \qquad \text{(Eq. 1)}$$

Where:

n = the number of required simulation runs

s = the standard deviation of the primary MOE (in this case, the travel time)

$t_{\alpha/2}$ = the t-statistic, the value of 2.57 is used

$\mu$ = the mean of average of the primary MOE (the travel time) of the initial 10 runs

$\epsilon$ = the acceptable error, the value of 0.1 is used.

The primary MOE in this equation (i.e., the travel time) is chosen on the basis that the MOE itself is a direct and unaltered outcome of microsimulation modelling. The reason for not applying this equation on the other MOE, which is the total person's delay, is because the latter MOE includes assumed or extrapolated weights that are used for calculating it for each intersection and each travel mode to make its values more resemble to the real-world conditions. Hence, it can be said that the total person's delay MOE has been altered, and it is modified in such a way that all of its values differ greatly than those that are outputted by the microsimulation models. Additionally, the t-statistic value is from student's t-distribution for a 2-tailed test, and it is obtained as 2.57. The equation above is applied to the eastbound, westbound, and the combination of eastbound with westbound travel times, separately. The largest result is considered as the number of simulation runs for every VISSIM microsimulation model in this study hereinafter. The result of using Equation 1 is calculated to be 6.6. Therefore, the result indicates that the minimum number of simulation runs is 7 for all the microsimulation models. However, to obtain better, more refined and converged results, 10 simulation runs are considered for each microsimulation model in this study.

## 4.2. Model Calibration

The purpose of the calibration process is to calibrate the base model accordingly and adequately in order to mimic the real-life traffic conditions as much as possible. The main measures of effectiveness (MOEs) used in the calibration process are the average traffic volume, globally and locally, as well as the average travel time. Model calibration is essential due to the nature of the input data. Since the input data are collected via traffic counts of already-existing intersections in a network, some intersections in the network may contain imbalanced traffic volumes. Calibrating the base scenario model aids in balancing the traffic volumes as much as possible just so that the evaluation and analysis of the microsimulations do not drop any number of vehicles that was not included in the simulations due to the imbalanced traffic volumes. The volume balancing method followed considers the in-between intersections access points of which vehicles may enter or exit. Ideally, a more mathematical method in balancing the existing volumes (proportionally, depending on the inbound and outbound along each intersection) may have been followed. However, despite the data not being perfect, the decision was made to keep the existing conditions unaltered as much as possible.

For the purpose of performing the calibration process on the Base model, Table 6 is created to summarize the microsimulation base-model calibration process, showing the tiers, criteria and measures, descriptions, equations, calibration criteria, obtained values, and the status (pass or fail).

| Tier | Criteria and Measures | Description | Equation | Calibration Criteria | Obtained Value | Status |
|---|---|---|---|---|---|---|
| **1** | RMSPE | Root Mean Squared Percent Error; global | $RMSPE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{M_i - O_i}{O_i}\right)^2}$ | < 5.0 | 11.90 | Fail |

| Tier | Criteria and Measures | Description | Equation | Calibration Criteria | Obtained Value | Status |
|---|---|---|---|---|---|---|
| | | validation test; traffic volume in all links | (1) | | | |
| **2** | RNSE | Root Normalized Squared Error; local validation test; traffic volume in all links separately | $RNSE = \sqrt{\frac{(M-O)^2}{O}}$ (2) | < 5.0, 85% of all links | 90.9% of all links | Pass |
| | | | | 5.0 to 10.0, 10% of all links | 6.3% of all links | Pass |
| | | | | > 10.0, 5% of all links | 2.8% of all links | Pass |
| | GEH | Geoffrey E. Havers Tolerance Formula; local validation test; traffic volume all links separately | $GEH = \sqrt{2\left(\frac{(M-O)^2}{(M+O)}\right)}$ (3) | < 5.0, 85% of all links | 90.5% of all links | Pass |
| | | | | 5.0 to 10.0, 10% of all links | 6.2% of all links | Pass |
| | | | | > 10.0, 5% of all links | 3.33% of all links | Pass |
| **3** | Linear Regression | Applied as observed volume versus modelled volume | | $R^2 > 0.90$ | 0.98 | Pass |
| **4** | Link Travel Time | Travel Time (s) obtained from the Base model all Eastbound and Westbound links separately | | Within 60.0 seconds for 85% of all links | 90.9% of all links | Pass |
| **Where:**<br>$N$ **= Total number of links;**<br>$i$ **= Observation link point;**<br>$M$ **= Modelled turning movement volume (vph); and,**<br>$O$ **= Observed turning movement volume (vph).** | | | | | | |

*Table 6 - Calibration criteria and their description, value, and status (adapted from WSDoT).*

The outcome of this process is to develop the base model that represents the base (do-nothing) scenario that mimics real-world traffic flow conditions. Due to the nature of parameters that VISSIM generates, it is important to note that each simulation run (or multiple simulation runs) will yield different results than one another. Consequently, multiple simulation runs must be simulated (or modelled). For the base scenario, 10 simulations initial runs were produced in order to carry out the calibration process. The Washington State Department of Transportation (WSDOT) VISSIM microsimulation guidelines are followed in this research study. As such, a tiered calibration process is extrapolated from the WSDOT guidelines (Mai, McDanial-Wilson, Noval, 2014). The directional traffic volume and average travel times of these initial 10 runs are used in the calibration process. All of the following validation tests have been used iteratively until satisfactory results are obtained.

The first tier in model calibration is via testing (or calculating) the root mean squared percent error (RMSPE). This is considered to be the main test that may be applied to network-wide, global volume validation in a microsimulation model. Equation 2 is used to calculate the RMSPE. This statistics test, however, has a criterium that is not met in this study. The criterium is that the value of RMSPE for all links in the network, globally, must be less than 5.0%. The study's RMSPE is calculated to be 11.9%, as shown in Table 7. This means that the calibration requires more validation tests.

$$RMSPE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{M_i - O_i}{O_i}\right)^2} \qquad \text{Eq. 2}$$

Where:

$N$ = the total number of links

$i$ = the observation link point

$M$ = the modelled turning movement volume (vph)

$O$ = the observed turning movement volume (vpg)

| Sum of Modelled (vph) | Sum of Observed (vph) | Total Number of Links, N | RMSPE (%) |
|---|---|---|---|
| 177606 | 191574 | 190 | 11.9 |

*Table 7 - Aggregated input for RMSPE, with the result in percentage*

Since the calculated RMSPE does not meet the necessary criteria, further validation tests and tiers are required. The second-tier validation test is the root normalized squared error (RNSE). RNSE is applied locally on directional movement traffic volumes in all links separately. Equation 3 is used to calculate the RNSE, and the outcome is often reported as a percentage. The RNSE criteria are:

- At least 85% of all links must have GEH values of less than 5,
- At most 10% of all links must have GEH values of between 5 and 10; and,
- At most 5% of all links must have GEH values of over 10.

After applying this statistical test on all links locally and separately, the obtained results are well within the criteria since 90.9% of links have RNSE values below 5.0, 6.3% of the values are within 5.0 to 10.0, and only 2.8% of the links contain RNSE values larger than 10.0. This means that the microsimulation model for the base scenario is adequately calibrated as it passes the RNSE criteria.

Similarly, the Geoffrey E. Havers Tolerance Formula (GEH) is also used to test the validation the traffic volume of all links locally and separately. The GEH formula considers the volumes that are reported hourly, which will be of huge benefit since the volumes in this study are reported hourly. Equation 4 is used to calculate the GEH statistic. The GEH statistic has the same calibration criteria as the RNSE. The obtained results from using the GEH statistic include: 90.5% of all links have GEH value less than 5.0, 6.2% of the link values are within 5.0 and 10.0, and only 3.33% have larger than 10.0 GEH values. All the GEH values show that the model is calibrated adequately, and no further calibration is needed with respect to directional turning movement volume. It is important to note that the GEH statistic is relatively more popular in the literature than the RNSE with respect to calibrating the turning movement volumes in a microsimulation model.

Figure 13 shows the observed and modelled turning movement volumes (vph) aggregated and summed in each intersection. It can be noted that a few intersections that have a relatively large difference between the observed and modelled volumes. Intersections such as Airport Road and Goreway Drive have the highest number of vehicles and level of congestion. Therefore, these two intersections have more GEH values that are 10.0 or larger compared to other intersections.

$$RNSE = \sqrt{\frac{(M-O)^2}{O}} \qquad \text{Eq. 3}$$

$$GEH = \sqrt{2\left(\frac{(M-O)^2}{M+O}\right)} \qquad \text{Eq. 4}$$

Where:

$M$ = the modelled turning movement volume (vph)

$O$ = the observed turning movement volume (vph)

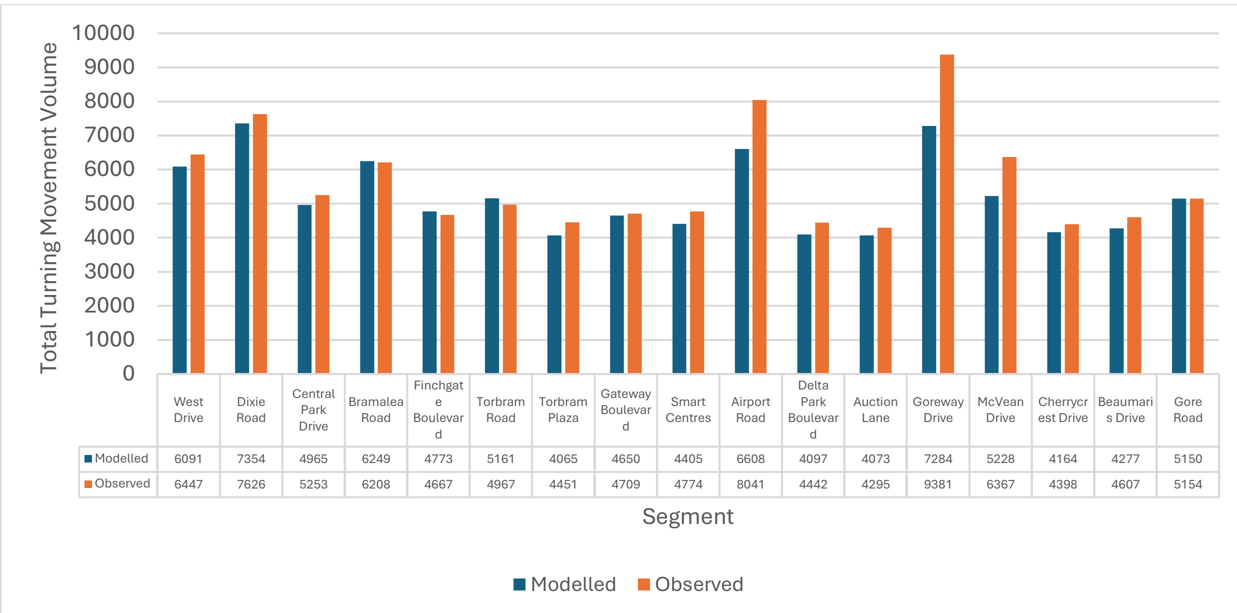



*Figure 13 - The directional turning movement volumes (vph), aggregated and summed per intersection*

The third tier of the calibration process is performed by creating a linear regression (OLS) model between the observed volumes (x-axis) and the modelled volumes (y-axis). Generally, the calibration criteria for OLS are that the value of $R^2$ and the slope must be greater than 0.90. Figure 14 shows the regression and the line of best fit for the turning movement volumes of the observed volumes versus the modelled volumes. Once the observed and modelled volumes are fitted in an OLS model, the obtained $R^2$ value is 0.99, which means that the values in the y-axis parameter are very close to the values in the x-axis parameter. Similarly, the slope of the line is approximately 0.91, which barely exceeds the limit of 0.90. Therefore, the calibrated model passes this validation test. This test indicates that no further calibration is needed for the tuning movement volumes. The OLS model includes outliers existing in the observed volumes along the intersections of Queen St & Airport Rd, Queen St & Goreway Drive, and Queen St &

McVean Drive. Potential causes to those outliers may be in the commute directionality and travel pattern that exist along Queen St during the PM peak hour. The removal of those outliers will result in less “noisy” model, however, for the sake of intersection inclusiveness along this corridor, those intersections are kept in the OLS regression model.

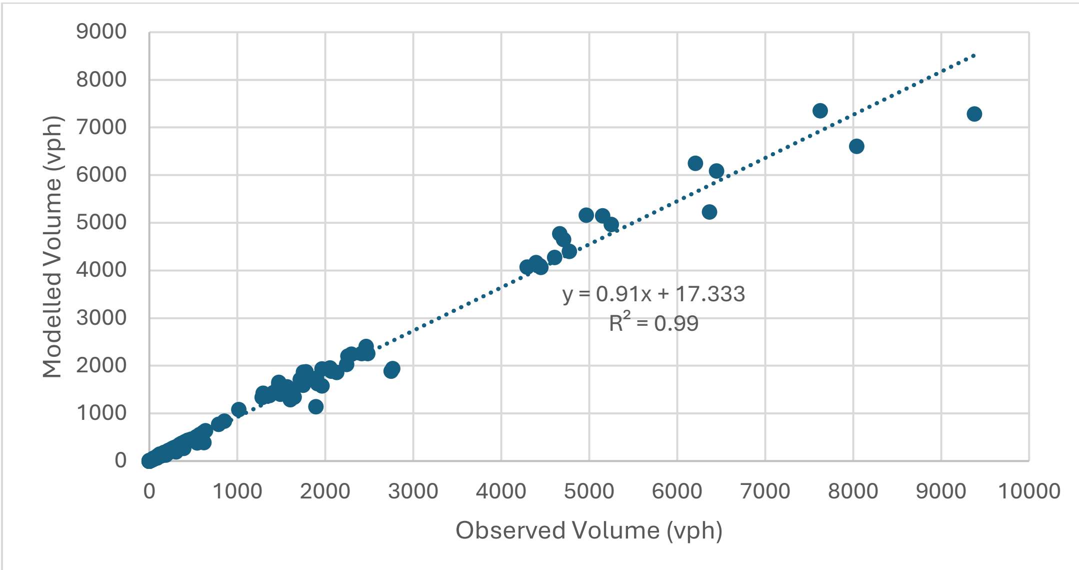



*Figure 14 - Linear regression (OLS) for the turning movement volumes*

Lastly, the fourth tier of the calibration process is related to travel time calibration. To test the validity of the model’s average travel time (measured in seconds), the modelled travel time must be compared to the observed travel time in each intersection. However, the travel time provided in the obtained Region of Peel dataset is inaccurate due to it being the travel time measured at free-flow conditions (i.e., the travel time in the dataset is simply calculated by dividing the distance over speed, which is inaccurate for the purpose of this study). Therefore, an alternative source (or method) in obtaining the “observed” travel time is approached. Google’s Distance Matrix API is utilized to obtain real-time travel times for each intersection. This API provides origin-destination (OD) matrix that produces the duration and distance values for every OD pair. Programming on Python 3 is used for the purpose of obtaining the travel times for Google’s API. The latitude and longitude coordinates for each OD pair are used as the input values to calculate the distance and travel time between each two intersections. Figure 15 illustrates an OD pair for the roadway segment between West Drive and Dixie Road intersections. The travel time and distance for each OD pair are measured from the middle of an intersection to the middle of the following intersection. This process is done for both through movement directions (eastbound and westbound) along the major roadway (Queen Street).

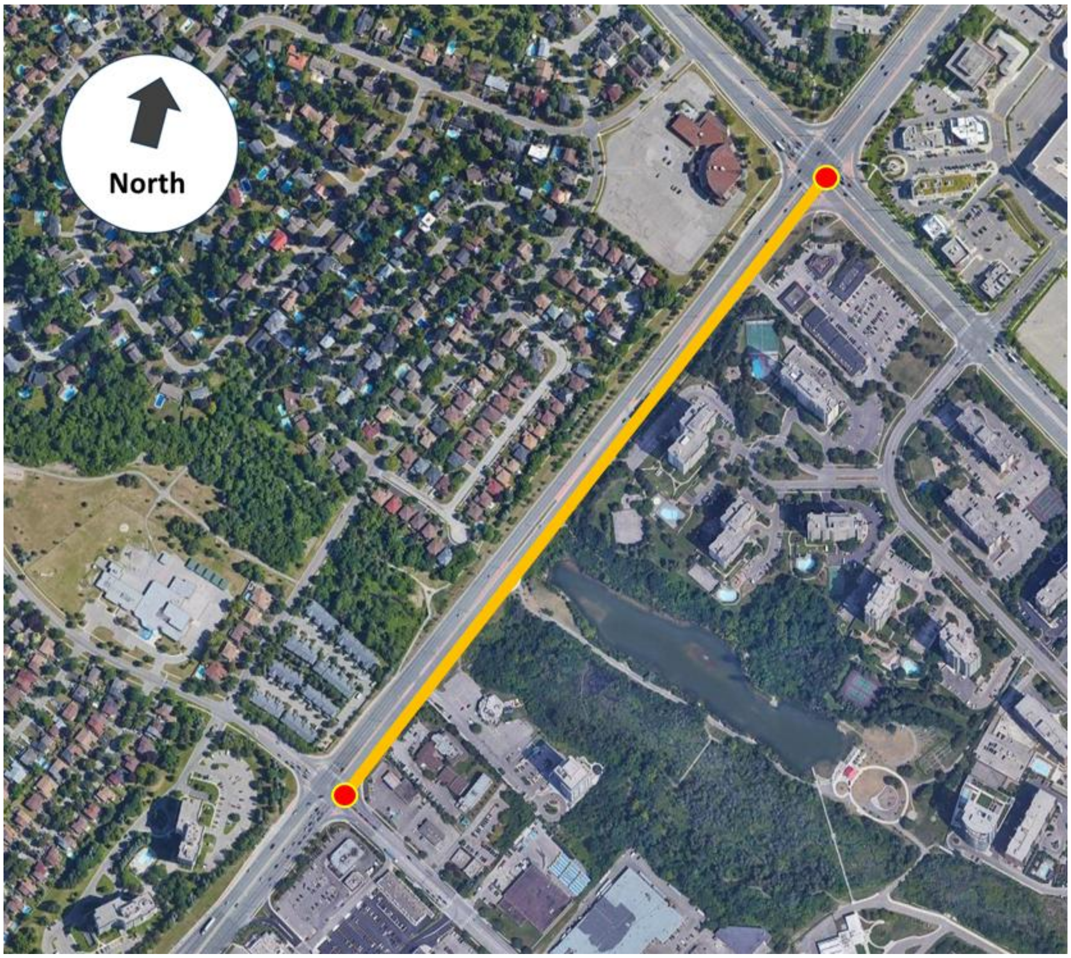



*Figure 15 - Example for an OD pair*

Table 8 shows the observed and modelled travel times (s), along with the distance (km), and the difference between the observed and modelled travel time for each intersection. Only through movement is considered, hence the travel time calibration process only covers the eastbound and westbound of the study's major roadway (Queen Street). The criterium for travel time calibration is that 85% of the links that are being calibrated must have a difference between the observed and modelled travel time of $\pm$ 60 seconds. From Table 8, it can be noted that there are 3 links that do not satisfy the travel time calibration criterium.

These links include Delta Park and Auction Lane in the eastbound with an increase of 144 seconds in the modelled travel time, Auction Lane and Goreway Drive in the eastbound with an increase of 113 seconds in the modelled travel time, as well as McVean Drive and Goreway Drive in the westbound with 132 seconds increase in the modelled travel time. Overall, the travel time calibration passes the criterium with 90.6% of the links having a travel time difference that is within the 60 seconds range. Therefore, no further calibration for the travel time is needed. It can be noted that other validation tests can be performed to calibrate the modelled travel time. However, for the nature of the obtained dataset, as well as the purpose of this study, only the mentioned travel time calibration process is considered.

| Link | Distance (km) | Observed travel time (s) | Modelled travel time (s) | Difference (s) |
|---|---|---|---|---|
| West Dr - Dixie Rd EB | 0.82 | 75 | 97 | -22 |
| Dixie Rd - Central Park EB | 0.80 | 66 | 79 | -13 |
| Central Park - Bramalea Rd EB | 0.56 | 62 | 81 | -19 |
| Bramalea - Finchage EB | 0.52 | 54 | 48 | 6 |
| Finchgate - Torbram Rd EB | 0.85 | 61 | 75 | -14 |
| Torbram Rd - Torbram Plaza EB | 0.35 | 33 | 32 | 1 |
| Torbram Plaza - Gateway EB | 0.33 | 33 | 39 | -6 |
| Gateway - Smart Centres EB | 0.31 | 33 | 43 | -10 |
| Smart Centres - Airport Rd EB | 0.38 | 49 | 76 | -27 |
| Airport Rd - Delta Park EB | 0.39 | 40 | 92 | -52 |
| Delta Park - Auction Ln EB | 0.63 | 44 | 188 | -144 |
| Auction Ln - Goreway Dr EB | 0.39 | 40 | 113 | -73 |
| Goreway Dr - McVean EB | 1.33 | 89 | 86 | 3 |
| McVean - Cherrycrest EB | 0.33 | 31 | 27 | 4 |
| Cherrycrest - Beaumaris EB | 0.71 | 39 | 39 | 0 |
| Beaumaris - Gore Rd EB | 0.44 | 38 | 41 | -3 |
| Gore Rd - Beaumaris WB | 0.43 | 45 | 29 | 16 |
| Beaumaris - Cherrycrest WB | 0.72 | 74 | 53 | 21 |
| Cherrycrest - McVean WB | 0.33 | 29 | 63 | -34 |
| McVean - Goreway WB | 1.33 | 90 | 222 | -132 |
| Goreway - Auction Ln WB | 0.38 | 37 | 50 | -13 |
| Auction Ln - Delta Park WB | 0.63 | 43 | 46 | -3 |
| Delta Park - Airport WB | 0.38 | 54 | 87 | -33 |
| Airport Rd - Smart Centres WB | 0.37 | 52 | 47 | 5 |
| Smart Centres - Gateway WB | 0.31 | 44 | 44 | 0 |
| Gateway - Torbram Plaza WB | 0.33 | 43 | 38 | 5 |
| Torbram Plaza - Torbram Rd WB | 0.35 | 48 | 55 | -7 |

| Link | Distance (km) | Observed travel time (s) | Modelled travel time (s) | Difference (s) |
|---|---|---|---|---|
| Torbram Rd - Finchgate WB | 0.85 | 70 | 68 | 2 |
| Finchgate - Bramalea Rd WB | 0.52 | 53 | 74 | -21 |
| Bramalea Rd - Central Park WB | 0.57 | 54 | 66 | -12 |
| Central Park - Dixie WB | 0.80 | 70 | 111 | -41 |
| Dixie - West Dr WB | 0.82 | 70 | 78 | -8 |

*Table 8 - Observed and modelled travel time comparison*

The study corridor includes multimodal signalized intersections with varying traffic volumes and freight and transit compositions. These differences play a role in shaping the calibration results of the VISSIM models. Using the description for each intersection available in Section 3.1, the following is a description of the calibration results for each intersection.

<u>Intersection of Queen Street & West Drive:</u>

Calibration performance at this intersection is moderately constrained by fluctuating queue spillback from upstream signals, which caused short-term saturation conditions that were difficult to replicate consistently in simulation.

<u>Intersection of Queen Street & Dixie Road:</u>

The calibration performance at Dixie Road is attributed to competing green demand between high-volume through movements and frequent bus arrivals, which generate variability in saturation flow-rates and queue clearance patterns not fully captured by static signal timing inputs.

<u>Intersection of Queen Street & Central Park Drive:</u>

The operations at this intersection, as well as this intersection's characteristics including the presence of transit vehicles, contribute to less favourable calibration results. This is due to the real-world delays being strongly influenced by stochastic bus arrivals and passenger boarding patterns that are inherently difficult to fully replicate in a microsimulation without real-time dwell data.

<u>Intersection of Queen Street & Bramalea Road:</u>

Calibration results at this location were relatively favourable, reflecting predictable platooning behavior and limited interference from transit dwell variability.

<u>Intersection of Queen Street & Finchgate Boulevard:</u>

Directional flows are evenly distributed at this intersection, which contributes to favourable calibration performance. Minor discrepancies observed in simulation outputs are attributed to short-lived queue fluctuations caused by local turning movements.

Intersection of Queen Street & Torbram Road:

There are some calibration challenges at this location that stem from the heterogeneity characteristic of this interaction. Heavy vehicles significantly affect discharge headways and lane utilization patterns, increasing variability in observed delays.

Intersection of Queen Street & Torbram Plaza:

Less favourable calibration performance is largely attributable to these short-term demand surges and irregular turning patterns, which are not easily reproduced using average peak-hour volumes.

Intersection of Queen Street & Gateway Boulevard:

Calibration discrepancies in this intersection are primarily due to variability in truck arrival patterns and acceleration behavior, which have a disproportionate influence on queue formation and dissipation.

Intersection of Queen Street & Airport Road:

Calibration at this intersection is less favourable due to queue spillback, lane blockage effects, and sensitivity to small fluctuations in arrival rates.

Intersection of Queen Street & is Park Boulevard:

Calibration performance in this intersection is impacted by the difficulty of accurately representing platooned truck arrivals and their impact on intersection capacity due to the existence of the high portion of freight (68% of al traffic).

Intersection of Queen Street & Auction Lane:

Calibration outcomes in this intersection are less robust, as standard peak-hour modeling assumptions do not fully capture these irregular demand profiles.

Intersection of Queen Street & Goreway Drive:

Calibration discrepancies in this intersection are attributed to compounded congestion effects and strong interdependence with upstream intersections.

Intersection of Queen Street & McVean Drive:

Calibration performance is generally favourable, with minor deviations caused by fluctuating demands at the turning movements.

Intersection of Queen Street & Cherrycrest Drive:

This intersection operates under stable conditions with predictable peak-hour demand, resulting in strong calibration agreement between modelled and observed performance.

Intersection of Queen Street & Beaumaris Drive:

The calibration at this intersection is majorly favourable, and the results are limited but arise from minor-road priority dynamics.

Intersection of Queen Street & Gore Road:

Calibration discrepancies in this intersection are primarily linked to fluctuating arrival patterns and downstream constraints beyond the modeled network.

It should be noted that the calibration process took the most time in the modelling process (around 2 months, 3-4 hours daily, with 10 simulation runs per calibration attempt) as numerous iterative simulation runs are performed. This is to ensure a model that is calibrated as close to reality as possible. Overall, intersections exhibiting high freight percentages, strong directional bias, and significant transit activity tend to show poorer calibration performance due to increased variability in real-world operations. Conversely, intersections dominated by stable commuter through-movements and lower modal heterogeneity demonstrate stronger alignment between simulated and observed conditions. These findings express the importance of intersection-specific context when interpreting calibration results and evaluating multimodal ITS strategies. Based on the calibrated model, simulation scenarios that pertain the different implementation strategies are developed.

## 4.3. Simulation Scenarios Development

This section outlines the development process of each alternative scenario. For TSP and FSP, the green extension strategy is solely used in this report. These scenarios are crucial and are key to this study's conclusions. All of these scenarios yield average travel time and total person's delay. The value used in defining both TSP and FSP is 10 seconds as the green extension value. This value approximately covers the stopping sight distance that allows the vehicles in the minor roadways to have enough time to stop as their traffic signal turns amber then red. There is a total of 8 models that have been created for this study:

1. Model 1 - Base Model: The base model scenario or existing conditions
2. Model 2 - TSP: The scenario implementing TSP exclusively
3. Model 3 - FSP: The scenario implementing FSP exclusively
4. Model 4 - DBL: The scenario focusing solely on DBL
5. Model 5 - TSP and DBL: The scenario combining TSP and DBL
6. Model 6 - FSP and DBL: The scenario combining FSP and DBL
7. Model 7 - TSP and FSP: The scenario combining TSP and FSP
8. Model 8 - TSP, FSP, and DBL: The scenario combining all 3 implementation strategies

These scenarios are crucial and are key to this study's conclusions. All of these scenarios yield intersection-specific travel time, total person's delay, and environmental emissions and fuel consumption.

### 4.3.1 Model 1 - The Base Scenario

The base scenario includes the do-nothing traffic conditions as per the dataset. This scenario's purpose is to function as a base which can be calibrated and later derived into multiple other scenarios that adhere to the study's goals and objectives. It includes all the necessary traffic data that can be utilized to calibrate and develop the remaining simulation models. It is essential for alternative scenarios since it contains the roadway characteristics such as the appropriate right-of-way, lane width, number of lanes, the signalized intersections and their locations, bus stop locations, and bus arrival times. The ring barrier controller (RBC) signal controllers are also set in the base model. It is important to note that the base model does not include any implementation strategy, i.e., it does not include any form of signal priority, nor does it include DBL. Once this model has been calibrated, it is copied into as many copies as there are implementation strategies in this study.

### 4.3.2 Model 2 - TSP-Only

This scenario is created specifically to implement transit signal priority (TSP) along the major roadway in the study corridor (i.e., Queen Street). This scenario has TSP allowed in all signalized intersections (total of 17 intersections) along the study corridor. The TSP in this study uses extended green as the preferred signal priority strategy.

A total of 10 seconds is considered as the extended green time, which includes 7 seconds to clear the distance from the check-in detector to the traffic signal, and 3 seconds to account for any slack time that may occur that may cause variability in the times of arrival of the transit. The check-in detectors are located 150 m to 300 m upstream, i.e., the distance between a check-in detector and the traffic signal bar is within the range of 150 m to 300 m, depending on the intersection. Additional rationale for assuming 10 seconds of extended green time is mainly since some intersections have traffic conditions that contain too much congestion potential as a consequence of reducing the green time along the northbound and southbound directional movements.

Generally, these check-in detectors send a signal to the traffic signal, informing it that there is a prioritized vehicle approaching the intersection. Hence, it is important to mention that there is no impact on the traffic condition in an intersection that contains check-in detectors but without any prioritized vehicle that triggers the detectors. In other words, it is quite accepted that an intersection in the simulation may have check-in detectors even though the intersection itself does not contain any buses that go through it, i.e., there is no impact due to the existing priority check-in detectors in such intersections.

Figure 16 demonstrates the geometry of the TSP detectors in the intersection of Queen Street and Central Park Drive. The roadway segments highlighted in blue indicate that these segments are for buses only. They are the queue-jumping lanes (QJLs) that already exist in the real-world corridor's geometry. The only caveat is that there are no data available for these QJLs (i.e., whether there are specific traffic times for them or not). Therefore, there existence in the models are only accounted for geometrically and as bus-only segments of the intersections that contain them.

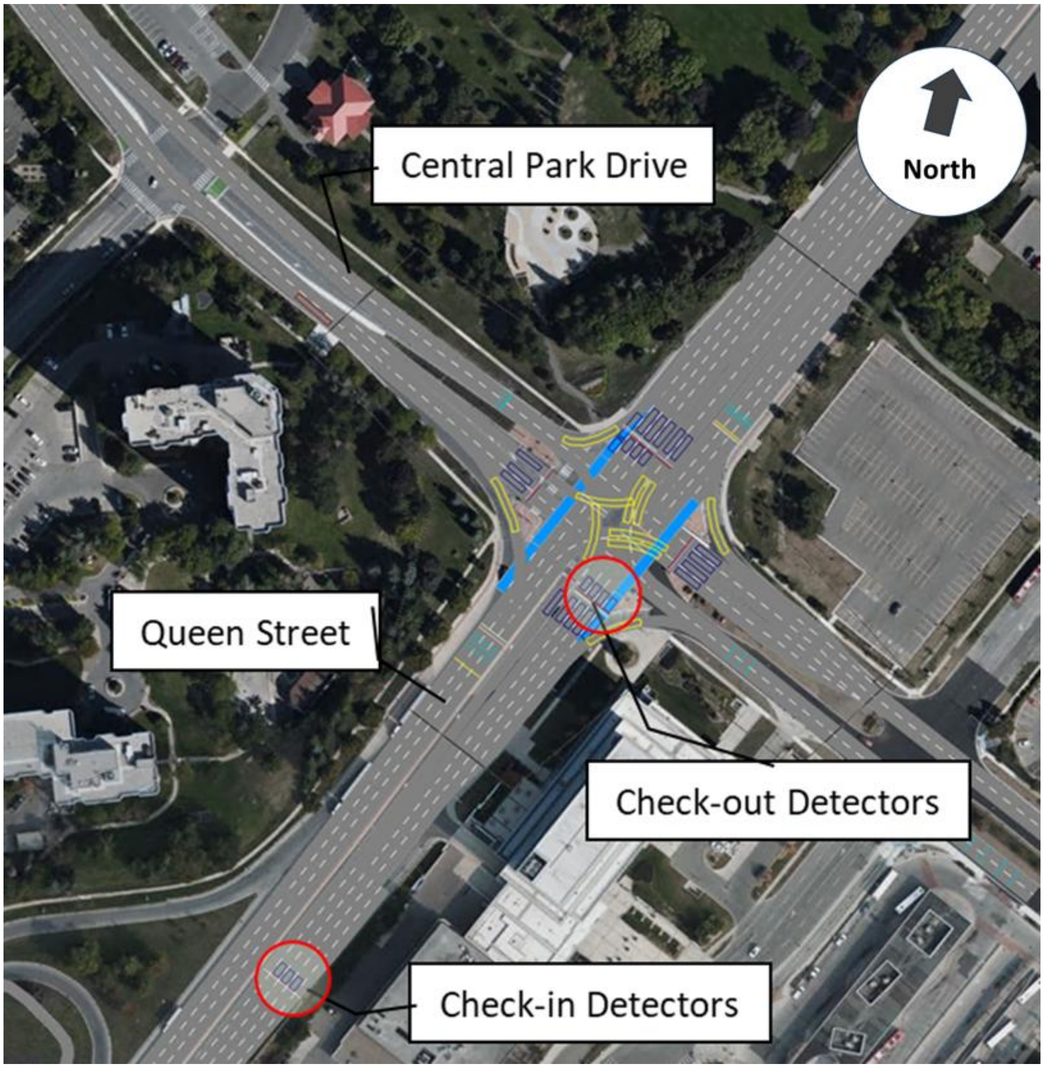



*Figure 16 - TSP configuration along Queen Street*

### 4.3.3 Model 3 - FSP-Only:

This scenario is very similar to "*Scenario 2 - TSP-Only*" in the sense that the same settings are applied, with the only difference being that the freight in this scenario is prioritized instead of transit. This scenario does not prioritize transit at all. The main purpose for this scenario is that it serves as an element for a sensitivity analysis. This sensitivity analysis will demonstrate the various implementation strategies perform compared to one another. The geometric configuration for FSP is the same as that of the TSP-only scenario, and it is shown in Figure 16 above. Similar to the scenario above, this scenario also uses 10 seconds of green extension for the prioritized vehicle class (freight).

### 4.3.4 Model 4 - DBL-only

This scenario includes a DBL in both major directions (i.e., eastbound, and westbound). The right-hand side lane is considered for the DBL in both directions. The rationale for assigning the right-hand side lane as the DBL is mainly due to the already-existing bus stops that are located on the right side of the roadway, both eastbound and westbound of Queen Street. Also, this option is the most feasible and cost efficient when it comes to implementing the DBL. Even though both the center lane and the left-hand side lane have not been tested, it can be assumed that these lanes may cause the most disruption along the corridor due to the possibility of increasing lane-change operations the other vehicle classes will have to make.

However, parts (or smaller segments) of the roadway do not include the settings for DBL. These segments, for the most part, serve as "buffer" zones, in which the traffic, or vehicles, either merge just before the intersection, or prepare to switch lanes to turn right or left. Figure 17 demonstrates the configuration of the study corridor (intersection of Queen Street and Dixie Road) with the DBL implemented in it. The "buffer" zones vary in length depending on the geometry of each intersection. These zones also allow transit to travel to and from the DBL. All other vehicle classes that are not transit are prohibited from using the DBL.

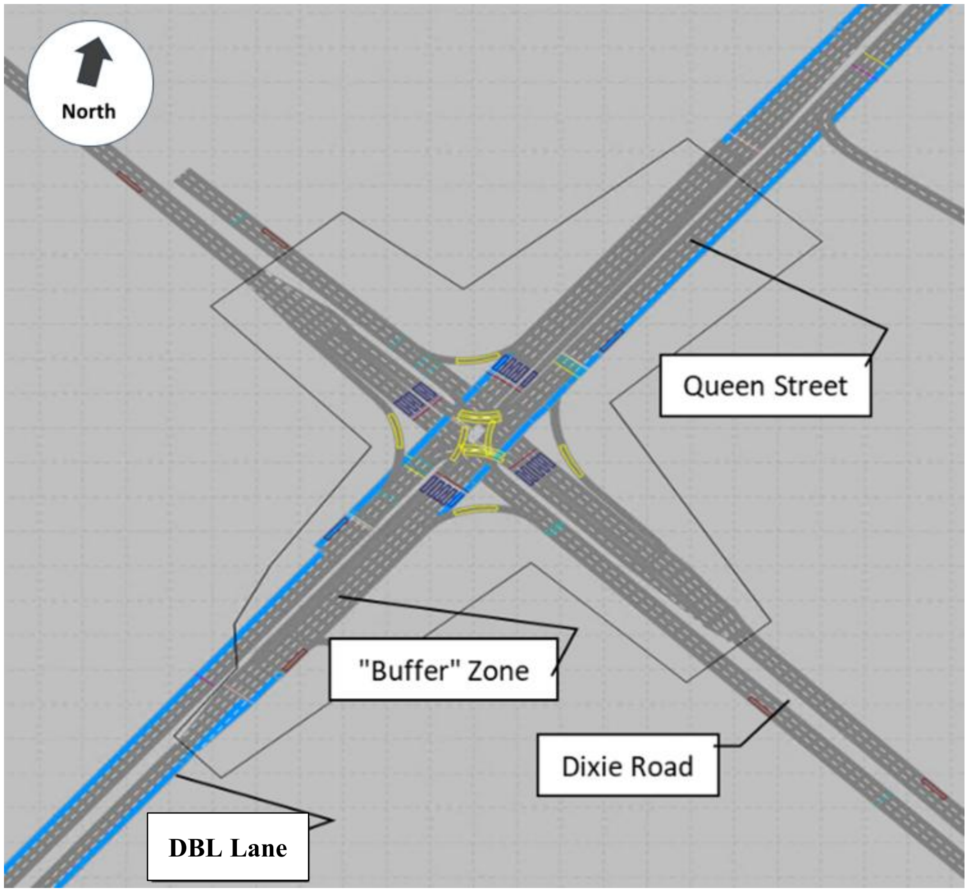



*Figure 17 - dedicated bus laneconfiguration*

## 4.3.5 Model 5 - TSP with DBL

This scenario combines the TSP strategy with DBL. This scenario heavily favours transit over other vehicle classes, making it an attractive option in the case of improving transit's travel time, at the expense of freight and passenger vehicles. This scenario also uses 10 seconds of green extension for the prioritized vehicle class (transit, in this case).

Developing this scenario is problematic in the sense that it decreases the traffic flow that originates from the congested traffic in the southbound and northbound directions that move to any of the four directions. To make the traffic less congested in the southbound and northbound directions, there are a few intersections that are exempt from having any form of TSP. These intersections are Dixie Road, Central

Park Drive, Airport Road, Goreway Drive, and Gore Road. Figure 6 in Chapter 3 is the map showing, on the map, the intersections that contain TSP (green circles) and those that do not contain TSP (red circles).

Figure 18 shows the geometric configuration of combining TSP strategy with DBL. The check-in detectors are geometrically situated using the same distance from the traffic signal bar as the check-in detectors in Scenario 2 (i.e., TSP-Only). There is only a single check-in detector in each directional movement on the major roadway, and it is placed in the DBL, with check-out detectors placed right after exiting the traffic signal bar. The reason for placing multiple check-out detectors is to provide transit the freedom to choose whichever lane that benefits them the most. However, it has been noted that buses vehicles usually stay in the lanes that are assigned for them. Therefore, there is no negative impact on the traffic conditions with the existence of check-out detectors on lanes other than those designated for transit.

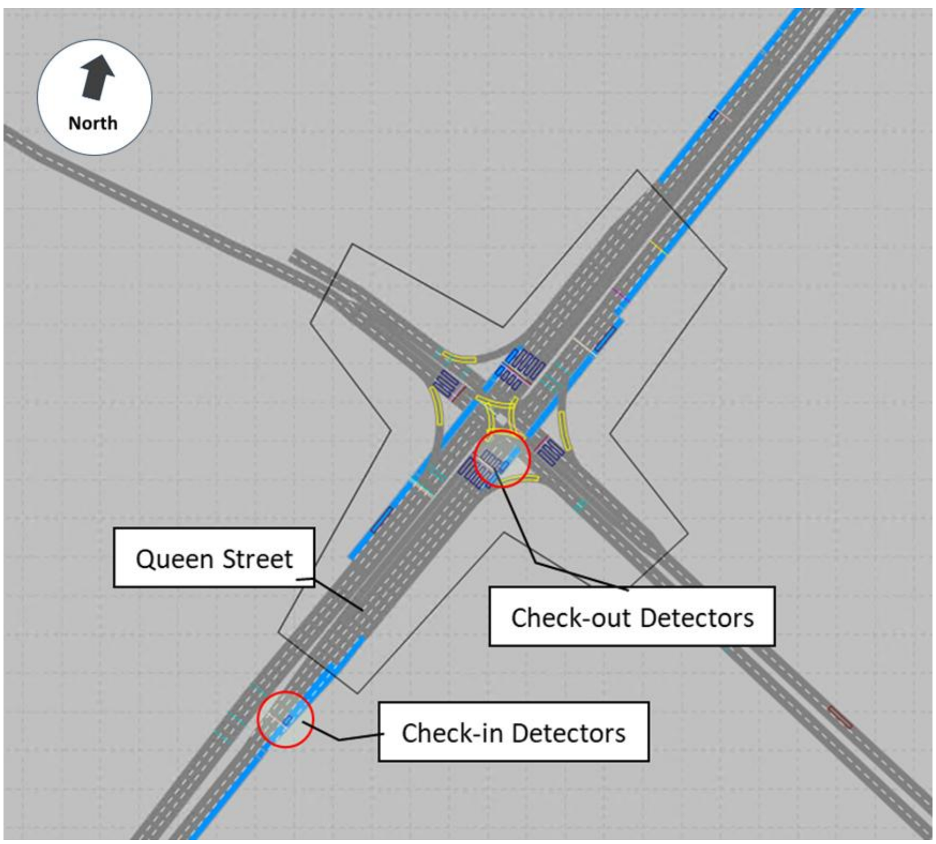



*Figure 18 - Geometric configuration of combining TSP and DBL*

### 4.3.6 Model 6 - FSP with DBL

This scenario combines FSP strategy with DBL. Similar to Scenario 6 above, this scenario is intended to investigate a method of mitigating some of the impact resulting from implementing DBL on freight along Queen Street. Additionally, this scenario gives some emphasis back to freight via implementing FSP in order to slightly improve (or decrease) travel time and total person's delay of freight, besides those for transit. The FSP in this scenario also uses 10 seconds of green extension.

Like Scenario 6, intersections of Dixie Road, Central Park Drive, Airport Road, Goreway Drive, and Gore Road are exempt from having FSP installed in them to mitigate traffic congestion in the northbound and southbound as much as possible. This is shown on the map in Figure 6 above.

Furthermore, Figure 18 shows the geometric configuration for this scenario. The check-in detectors are placed on every through-movement lane other than the lane dedicated to DBL.

### 4.3.7 Model 7 - TSP with FSP

This scenario is developed to test the validity of combining TSP and FSP strategies along Queen Street corridor. From the literature review, it is presumed that using combined check-in detectors is recommended since combining the check-in detectors is more feasible than separate check-in detectors. Additionally, the geometric configuration of this scenario is similar to that of the TSP-only and FSP-only scenarios, as shown in Figure 15 above. This scenario also uses 10 seconds of green extension for the prioritized vehicle classes.

### 4.3.8 Model 8 - TSP, FSP, with DBL

This scenario combines TSP and FSP strategies with DBL. This scenario favours transit, and it also gives freight some consideration too with respect to providing signal priority. Green extension of 10 seconds is considered for both TSP and FSP. Additionally, it is important to mention that similar to Scenario 7 and Scenario 8, the intersections of Dixie Road, Central Park Drive, Airport Road, Goreway Drive, and

Gore Road do not contain TSP nor FSP settings. This is due to the congested traffic along the southbound and northbound segments of these intersections.

Both vehicle classes have check-in detectors that are placed in the same distance with reference to the traffic signal bar. However, the TSP check-in detectors are placed on the lane dedicated for DBL. Similarly, the FSP check-in detectors are placed on every through-movement lane except for DBL. Figure 19 shows the geometric configuration for this scenario.

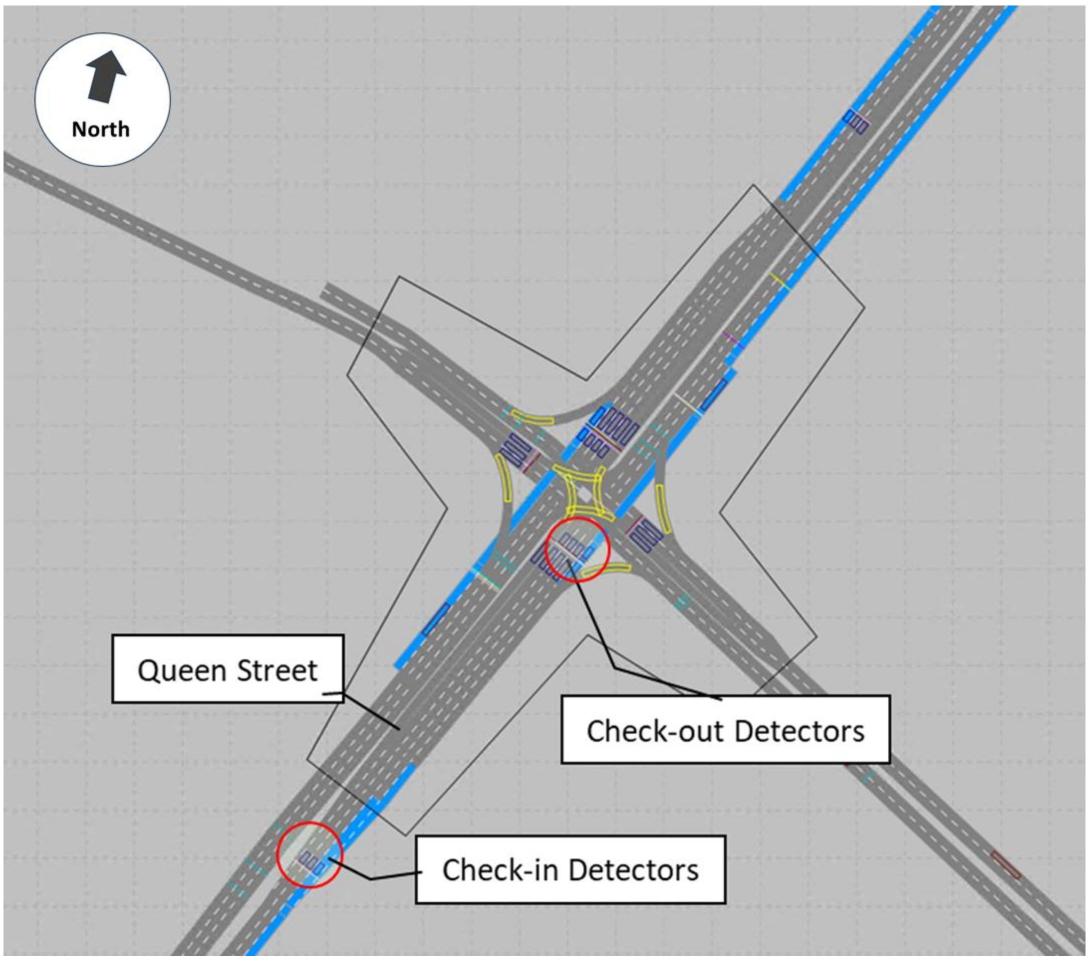



*Figure 19 - Geometric configuration for Scenario 8*

## 4.4. Chapter Summary

In summary, the development of microsimulation models along with model calibration and alternative scenario modelling has been discussed in this chapter. Firstly, the calibration process focuses on two measures-of-effectiveness (MOE), which are traffic volume and travel time. All the calibration process passed the validation tests, except for the RMSPE test for the global turning movement volume. As such, the base model is created to reflect the results from the calibration process. Additionally, 7 additional scenarios (one for each implementation strategy) are created to examine the impact of the implementation strategy on the corridor given the 3 considered MOEs.

# Chapter 5. Results and Discussion

After the completion of developing and running all the necessary simulation models, the results are collected, then analyzed. The finalized total number of simulations conducted in this study is 80, with 10 simulation runs for each of the eight scenarios. The MOEs used to conduct the analysis are 1) average travel time, 2) the total person's delay, and 3) the environmental emissions and fuel consumption. To calculate the total person's delay, the vehicular occupancy weights are obtained from the 2016 TTS report (Ashby, 2018). The passenger vehicle occupancy is obtained as 1.1, the freight occupancy 1.0, and the bus occupancy as 31.52.

## 5.1. Average Travel Time

The average travel time (seconds) results are obtained directly from the VISSIM simulation output. The average travel time results are reported as an average of averages for all vehicle classes combined, and as an average for each vehicle class on its own. The output from the VISSIM software application is programmed to produce it in seconds for this MOE. All scenarios are modelled and included for the purpose of MOE comparison among the different scenarios. Average travel time in seconds, organized by direction (EB/WB) and mode, allows for a granular understanding of how each user group, autos, freight, and transit, experiences delay or progression through the network. Collecting these times at each intersection node pinpoints specific bottlenecks or flow improvements, shedding light on where priority measures might best be refined.

### 5.1.1. Average Travel Time for Passenger Vehicles

Table 9 shows the average travel time (in seconds) for the passenger vehicle class in the eastbound (EB) of Queen Street during the PM peak hours. The results are presented for the average travel time measurement from the middle of one intersection to the middle of the intersection that follows it, per scenario. The difference in average travel time between each intersection in a scenario is also available in the table. The difference compares whether there is an increase in the average travel time (positive values, font colour red) or a decrease in the average travel time (negative values, font colour green). Figure 20 provides the graphic presentation of the values from Table 7.

| **Road Segment** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Dr - Dixie EB** | 96.49 | 97.31 (+0.82) | 95.51 (-0.99) | 113.27 (+16.78) | 108.38 (+11.89) | 109.05 (+12.56) | 95.98 (-0.52) | 115.55 (+19.06) |
| **Dixie - Central Park EB** | 77.46 | 77.18 (-0.29) | 76.5 (-0.97) | 84.87 (+7.40) | 89.53 (+12.06) | 85.82 (+8.35) | 76.34 (-1.13) | 82.67 (+5.21) |
| **Central Park - Bramalea EB** | 81.29 | 83.47 (+2.18) | 84.08 (+2.79) | 85.79 (+4.50) | 98.72 (+17.43) | 101.41 (+20.12) | 82.8 (+1.51) | 91.38 (+10.09) |
| **Bramalea - Finchgate EB** | 45.96 | 46.41 (+0.45) | 46.71 (+0.74) | 55.75 (+9.79) | 54.61 (+8.65) | 54.82 (+8.85) | 46.71 (+0.74) | 54.05 (+8.08) |
| **Finchgate - Torbram Rd EB** | 75.59 | 76.29 (+0.71) | 77.59 (+2.00) | 83.65 (+8.06) | 82.15 (+6.56) | 83.99 (+8.40) | 76.68 (+1.09) | 79.91 (+4.33) |
| **Torbram Rd - Torbram Plaza (Walmart) EB** | 29.39 | 28.79 (-0.61) | 28.4 (-1.00) | 30.97 (+1.58) | 29.88 (+0.49) | 30.74 (+1.34) | 28.22 (-1.19) | 30.53 (+1.14) |
| **Torbram Plaza (Walmart) - Gateway EB** | 38.11 | 40.42 (+2.30) | 40.18 (+2.07) | 39.77 (+1.66) | 38.89 (+0.78) | 39.07 (+0.95) | 39.14 (+1.03) | 38.86 (+0.74) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Gateway - Smart Centres (Tim Hortons) EB** | 41.34 | 39.59 (-1.76) | 42.8 (+1.46) | 43.32 (+1.97) | 40.82 (-0.53) | 38.83 (-2.52) | 38.9 (-2.46) | 43.8 (+2.45) |
| **Smart Centres - Airport Rd EB** | 78.28 | 84.77 (+6.49) | 82.08 (+3.80) | 86.41 (+8.12) | 76.66 (-1.64) | 77.73 (-0.57) | 76.14 (-2.15) | 89.23 (+10.95) |
| **Airport Rd - Delta Park EB** | 96.90 | 106.66 (+9.76) | 92.61 (-4.30) | 103.05 (+6.15) | 96.48 (-0.43) | 94.62 (-2.29) | 88.89 (-8.02) | 112.52 (+15.62) |
| **Delta Park - Auction Ln EB** | 182.01 | 179.83 (-2.19) | 171.19 (-10.82) | 165.72 (-16.29) | 157.29 (-24.72) | 164.01 (-18.01) | 169.65 (-12.37) | 170.34 (-11.67) |
| **Auction Ln - Goreway EB** | 110.58 | 106.84 (-3.74) | 108.14 (-2.44) | 107.61 (-2.98) | 103.34 (-7.25) | 104 (-6.59) | 108.47 (-2.11) | 105.53 (-5.06) |
| **Goreway - McVean EB** | 81.06 | 81.29 (+0.23) | 80.79 (-0.28) | 85.83 (+4.77) | 86.43 (+5.37) | 86.16 (+5.10) | 81.21 (+0.15) | 84.97 (+3.91) |
| **McVean - Cherrycrest EB** | 25.62 | 26.33 (+0.71) | 25.73 (+0.11) | 29.54 (+3.92) | 29.69 (+4.07) | 29.92 (+4.30) | 25.04 (-0.59) | 28.77 (+3.15) |
| **Cherrycrest - Beaumaris EB** | 37.83 | 37.58 (-0.26) | 37.98 (+0.16) | 39.04 (+1.22) | 39.11 (+1.29) | 39.48 (+1.66) | 37.67 (-0.17) | 38.54 (+0.71) |
| **Beaumaris - Gore Rd EB** | 42.64 | 43.56 (+0.92) | 44.09 (+1.45) | 43.38 (+0.74) | 43.43 (+0.79) | 43.79 (+1.16) | 44.37 (+1.73) | 42.51 (-0.14) |
| **Gore Rd EB** | 23.13 | 23.12 (-0.02) | 23.23 (+0.10) | 23.23 (+0.10) | 23.22 (+0.09) | 23.15 (+0.02) | 23.17 (+0.03) | 23.12 (-0.02) |
| **EB Cumulative** | 1163.69 | 1179.38 (+15.69) | 1157.54 (-6.16) | 1221.13 (+57.44) | 1198.54 (+34.85) | 1206.49 (+42.80) | 1139.31 (-24.39) | 1232.21 (+68.51) |

*Table 9 - Average travel time for passenger vehicles in the Eastbound direction for Queen St*

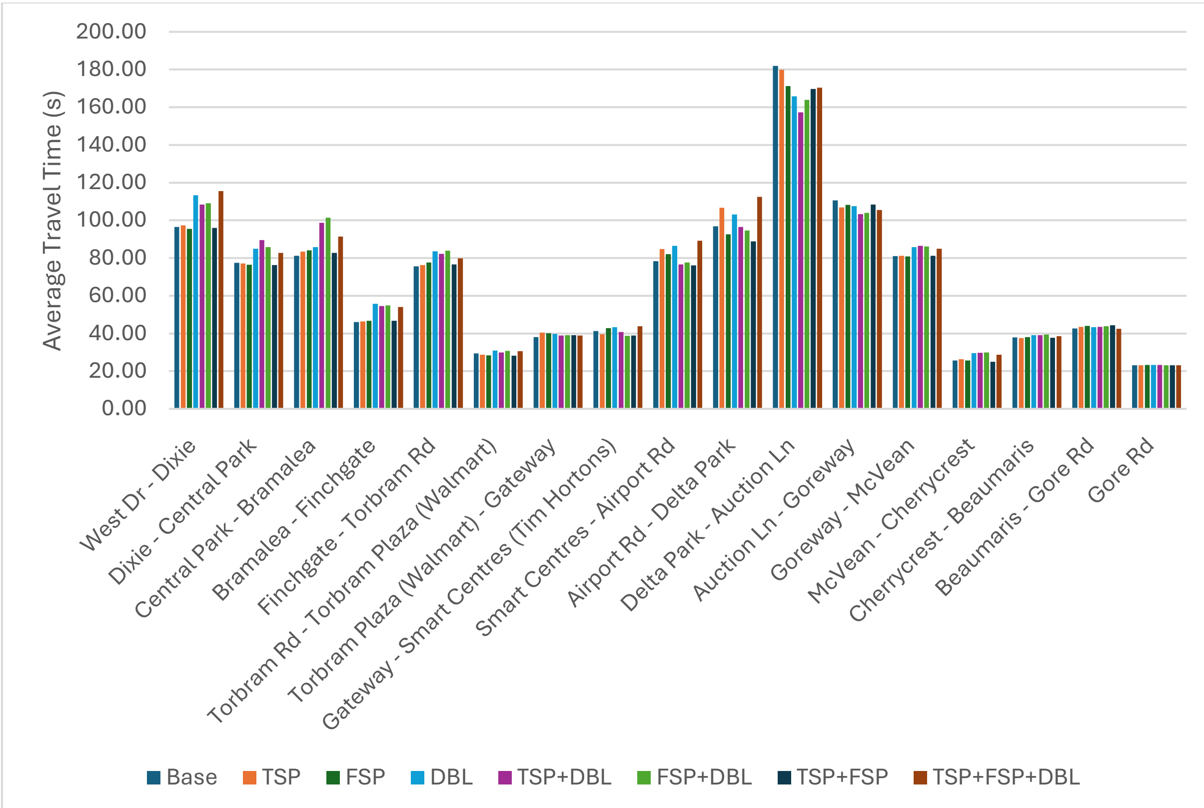



*Figure 20 - Average travel time for passenger vehicles in the Eastbound direction for Queen St*

The assessment of eastbound (EB) automobile travel times under varying traffic signal priority and DBL strategies offers valuable insights into the interplay between transit enhancements and general traffic performance. Under Base conditions, the corridor registers a cumulative EB travel time of 1163.69 seconds, serving as a reference point for evaluating the impacts of Transit Signal Priority (TSP), Freight Signal Priority (FSP), and DBL.

The introduction of TSP contributes to a moderate increase in EB travel time, rising to 1179.38s (+15.69s, +1.3%) compared to the base. Specific segments, most notably Airport Rd - Delta Park EB (+9.76s, +10.2%) and Cherrycrest - Beaumaris EB (+3.71s, +9.8%), reveal that extending green phases for transit may disrupt smooth progression for non-transit vehicles at certain intersections. Nonetheless, modest improvements, such as that observed at Dixie - Central Park EB (−0.29s, −0.4%), suggest that TSP's impact is not universally adverse and can, in certain contexts, facilitate more efficient traffic flow.

By contrast, FSP induces a slight reduction in overall travel time, with the cumulative figure declining to 1157.54s (−6.16s, −0.5%). Segments such as Torbram Rd - Torbram Plaza (Walmart) EB (−1.40s, −3.6%) and Goreway - McVean EB (−0.79s, −1.0%) demonstrate how prioritizing freight movements can lessen stop-and-go conditions for other vehicles. Nevertheless, localized increases, exemplified by Central Park - Bramalea EB (+2.79s, +3.4%), demonstrates that signal adjustments favoring freight can produce marginal delays in areas of heavy competing demand.

In contrast, the DBL scenario produces the most pronounced deterioration in travel times, with the cumulative EB value escalating to 1221.13s (+57.44s, +4.9%). This trend is driven largely by dedicating a lane to bus operations, effectively limiting capacity for general traffic. Segment-level data illustrate substantial slowdowns, most notably on West Dr - Dixie EB (+16.78s, +17.4%) and Central Park - Bramalea EB (+7.54s, +9.3%), indicating that bus-only lanes can exacerbate congestion for autos where traffic volumes are high and alternative lanes are constrained.

When TSP is integrated with DBL, the total EB travel time stands at 1198.54s (+34.84s, +3.0%), revealing that while transit signal priority can ease a portion of the lane reallocation burden, it cannot wholly counterbalance the resultant reduction in road capacity. A comparable outcome emerges in the FSP DBL scenario, recording 1206.49s (+42.80s, +3.7%), signifying that the benefits of freight-oriented signal settings are similarly overshadowed by capacity constraints. In contrast, combining TSP and FSP without DBL yields 1139.31s (−24.39s, −2.1%), suggesting that a unified approach to prioritizing both transit and freight can enhance corridor efficiency for autos. However, the addition of DBL to both TSP and FSP leads to a significant hike in EB travel time, up to 1232.21s (+68.51s, +5.9%), reflecting the compounded challenges of signal preemption and lane reduction.

In summary, these results indicate that while TSP and FSP alone produce only minor fluctuations in EB auto travel, the introduction of DBL frequently drives up delays due to decreased roadway capacity for general traffic. Nonetheless, coordinating TSP and FSP can mitigate some negative effects, helping maintain a balance between facilitating efficient transit and preserving acceptable conditions for other vehicles.

To evaluate the average travel time in each scenario for the passenger vehicles along the eastbound and westbound of Queen Street, the average travel time is summed in each direction. Figure 21 and Figure 22 show the sum of average travel time in the eastbound and westbound for passenger vehicles per scenario.

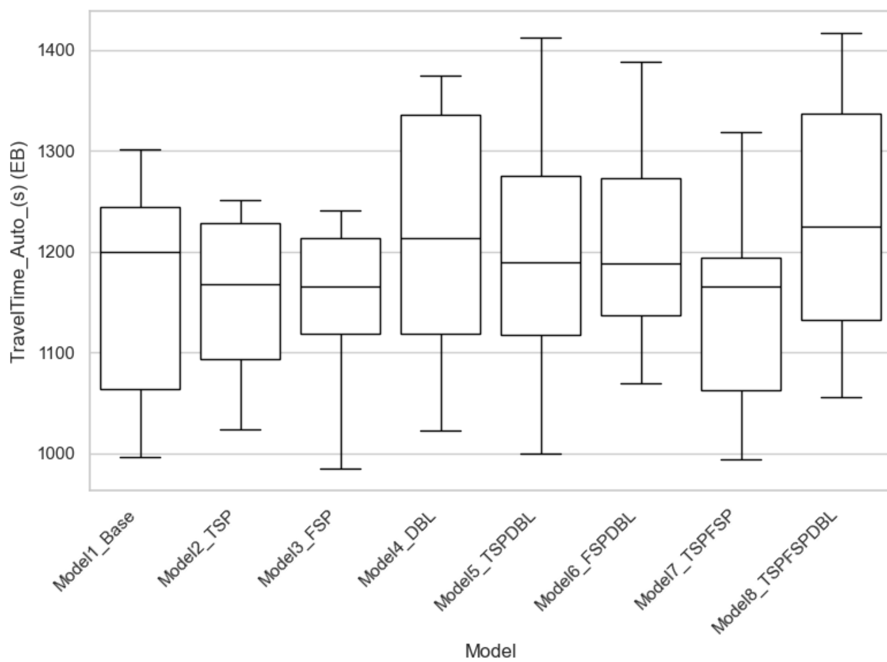



*Figure 21 - Cumulative average travel time for passenger vehicles in the eastbound movement along Queen Street*

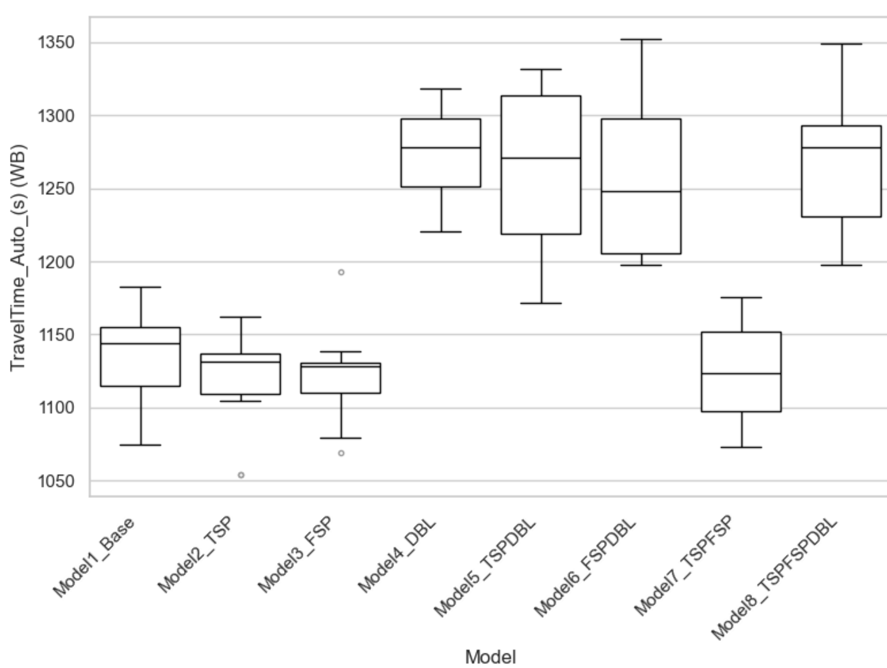



*Figure 22 - Cumulative average travel time for passenger vehicles in the westbound movement along Queen Street*

In Figure 21 and Figure 22, the total average travel time values for passenger vehicles in the eastbound (EB) and westbound (WB) directions are compared across all scenarios against the base case. In general, the results indicate that the implementation of a signal priority strategy (TSP or FSP) alone has a minimal impact on passenger vehicle travel times, while the introduction of DBL significantly increases delays for general traffic in both directions. The values in the figure represent the summed average travel time for passenger vehicles along the corridor in each scenario.

The results demonstrate that TSP-only leads to a slight increase in travel time for passenger vehicles, with EB increasing by 15s (+1.3%) and WB by 6s (+0.5%). This suggests that the prioritization of transit vehicles at intersections introduces minor additional delays for general traffic. A similar trend is observed in the FSP-only scenario, where EB travel time decreases slightly (-0.5%) and WB increases marginally (+1.0%). This minor fluctuation may be attributed to the relatively low frequency of freight vehicles triggering signal priority compared to transit vehicles, leading to negligible disruptions to passenger vehicle flow.

A key observation is that the introduction of DBL has the most significant impact on passenger vehicle travel times. In the DBL-only scenario, EB travel time increases to 1221s (+4.9%), while WB travel time rises substantially to 1276s (+12.6%). This suggests that the reallocation of a general-purpose lane for transit use results in considerable congestion for other road users. The WB direction experiences the largest increase, likely due to higher vehicle volumes and greater competition for the remaining lanes.

The scenarios that combine DBL with signal priority (TSP DBL and FSP DBL) further reinforce this trend, with WB travel time consistently exceeding 1250s, reflecting the compounded impact of both lane restrictions and intersection priority adjustments. While TSP and FSP marginally reduce the DBL-related travel time increases for EB passenger vehicles, the impact remains significant.

Interestingly, the TSP FSP scenario results in the lowest average travel time for passenger vehicles outside of the base case, with EB at 1139s (-2.1%) and WB at 1138s (+0.4%). This suggests that the combination of transit and freight signal priority allows for better traffic flow by reducing unnecessary delays at intersections. The mechanism behind this improvement is likely due to an increase in the frequency of priority requests, which extends green time at key intersections, indirectly benefiting passenger vehicles by reducing stop delays.

However, the TSP FSP & DBL scenario results in the highest overall travel times, with EB reaching 1232s (+5.8%) and WB at 1269s (+12.0%). This is likely due to two primary factors. First, the introduction of DBL removes one general-purpose lane, forcing passenger vehicles to compete for the remaining road space, leading to congestion and bottlenecks. Second, the simultaneous prioritization of transit and freight increases the frequency of green extensions, potentially leading to longer red-light durations for minor roadways. As a result, passenger vehicles attempting to enter or cross the major arterial experience increased delays, further contributing to the overall rise in travel time.

Overall, the findings indicate that TSP and FSP alone have minimal negative impacts on passenger vehicle travel time and, in some cases, may even improve flow by optimizing intersection efficiency. However, DBL significantly increases travel times, particularly in the WB direction, where the demand for road space is higher. The combination of DBL with signal priority strategies exacerbates these impacts, highlighting the trade-off between prioritizing sustainable transit solutions and maintaining acceptable levels of service for general traffic.

### 5.1.2. Average Travel Time for Freight

Table 10 and Figure 23 show the average travel time (in seconds) for the freight along the eastbound (EB) movement of Queen Street during the PM peak hours.

| **Road Segment** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Dr - Dixie EB** | 99.08 | 101.57 (+2.49) | 100.03 (+0.95) | 119.35 (+20.27) | 112.56 (+13.48) | 114.3 (+15.22) | 99.45 (+0.36) | 121.71 (+22.62) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| Dixie - Central Park EB | 80.76 | 79.87 (-0.90) | 78.08 (-2.69) | 89.08 (+8.32) | 94.22 (+13.47) | 89.98 (+9.22) | 78.74 (-2.03) | 86.49 (+5.74) |
| Central Park - Bramalea EB | 86.61 | 89.13 (+2.51) | 91.93 (+5.32) | 91.7 (+5.08) | 105.11 (+18.50) | 106.85 (+20.24) | 88.15 (+1.53) | 95.77 (+9.16) |
| Bramalea - Finchgate EB | 48.21 | 48.47 (+0.25) | 49.17 (+0.96) | 58.63 (+10.42) | 56.62 (+8.41) | 58.22 (+10.01) | 49.03 (+0.82) | 57.11 (+8.90) |
| Finchgate - Torbram Rd EB | 77.52 | 77.84 (+0.32) | 79.53 (+2.02) | 84.28 (+6.77) | 85.22 (+7.71) | 86.58 (+9.06) | 76.73 (-0.80) | 83.04 (+5.53) |
| Torbram Rd - Torbram Plaza (Walmart) EB | 30.50 | 29.79 (-0.73) | 29.48 (-1.04) | 32.66 (+2.16) | 32.04 (+1.54) | 32.65 (+2.14) | 29.08 (-1.44) | 32.07 (+1.57) |
| Torbram Plaza (Walmart) - Gateway EB | 40.32 | 43.13 (+2.81) | 42.6 (+2.28) | 41.62 (+1.30) | 41.35 (+1.03) | 42.1 (+1.78) | 42.24 (+1.92) | 41.45 (+1.13) |
| Gateway - Smart Centres (Tim Hortons) EB | 40.92 | 39.98 (-0.95) | 41.4 (+0.48) | 43.29 (+2.37) | 41.62 (+0.70) | 39.07 (-1.86) | 39.81 (-1.12) | 43.97 (+3.05) |
| Smart Centres - Airport Rd EB | 82.25 | 88.14 (+5.89) | 83.48 (+1.23) | 89.35 (+7.10) | 80.76 (-1.50) | 85.38 (+3.13) | 79.79 (-2.47) | 94.77 (+12.51) |
| Airport Rd - Delta Park EB | 101.81 | 114.66 (+12.85) | 98.5 (-3.32) | 108.34 (+6.53) | 100.85 (-0.98) | 99.51 (-2.31) | 96.39 (-5.44) | 119.68 (+17.86) |
| Delta Park - Auction Ln EB | 184.21 | 181.58 (-2.64) | 178.24 (-5.98) | 168.75 (-15.47) | 161.12 (-23.10) | 172.67 (-11.55) | 174.2 (-10.02) | 176.2 (-8.02) |
| Auction Ln - Goreway EB | 113.47 | 116.46 (+2.99) | 114.32 (+0.85) | 115.93 (+2.46) | 110.75 (-2.73) | 110.65 (-2.83) | 115.79 (+2.32) | 112.75 (-0.73) |
| Goreway - McVean EB | 85.77 | 85.12 (-0.66) | 85.2 (-0.58) | 89.55 (+3.78) | 90.31 (+4.54) | 90.06 (+4.29) | 84.51 (-1.27) | 89.13 (+3.36) |
| McVean - Cherrycrest EB | 28.20 | 29.25 (+1.05) | 29.01 (+0.81) | 33.2 (+5.00) | 33.25 (+5.05) | 32.47 (+4.27) | 27.41 (-0.80) | 32.21 (+4.01) |
| Cherrycrest - Beaumaris EB | 40.53 | 40.15 (-0.39) | 40.29 (-0.25) | 41.64 (+1.11) | 41.42 (+0.89) | 42.22 (+1.69) | 40.51 (-0.02) | 40.75 (+0.23) |
| Beaumaris - Gore Rd EB | 45.46 | 46.12 (+0.66) | 46.65 (+1.19) | 45.83 (+0.37) | 46.85 (+1.39) | 46.42 (+0.96) | 46.94 (+1.48) | 44.41 (-1.06) |
| Gore Rd EB | 24.80 | 24.84 (+0.04) | 24.88 (+0.08) | 24.94 (+0.14) | 25.01 (+0.22) | 24.84 (+0.05) | 24.93 (+0.13) | 24.81 (+0.01) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **EB Cumulative** | 1210.44 | 1236.02 (+25.58) | 1212.72 (+2.28) | 1278.08 (+67.64) | 1259.01 (+48.57) | 1273.9 (+63.46) | 1193.6 (-16.85) | 1296.25 (+85.81) |

*Table 10 - Average travel time for freight in the Eastbound direction for Queen St*

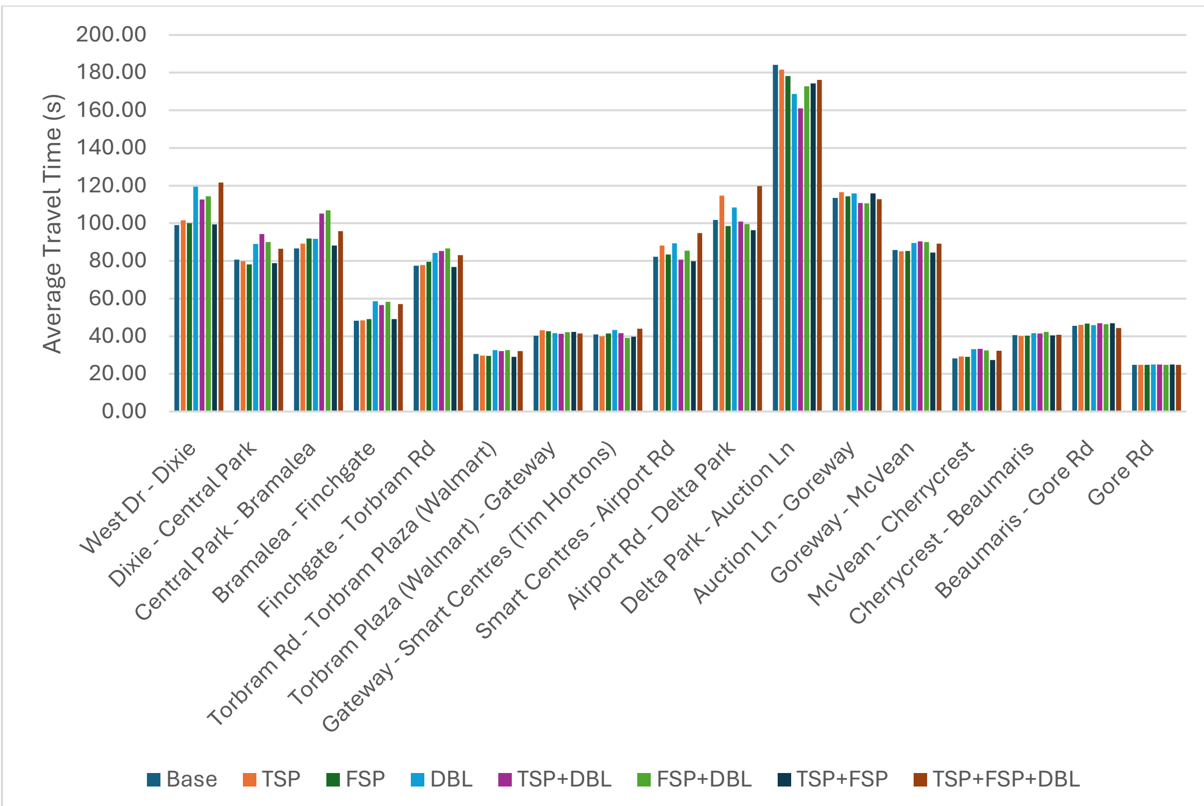



*Figure 23 - Average travel time for freight in the Eastbound direction for Queen St*

The analysis of eastbound (EB) freight travel times under different signal priority and DBL configurations reveals how prioritizing transit or freight vehicles, as well as establishing a bus-only lane, affects commercial traffic flow. In the Base scenario, the cumulative EB travel time for freight stands at 1210.44 seconds, serving as a benchmark against which subsequent scenarios are evaluated.

The introduction of Transit Signal Priority (TSP) leads to a slight increase in EB freight times, culminating in 1236.02s (+25.58s, +2.1%). Certain segments, such as Airport Rd - Delta Park EB (+12.85s,

+12.6%) and Central Park - Bramalea EB (+2.51s, +2.9%), experience marked delays, likely due to extended green phases for transit interrupting signal cycles that would otherwise accommodate freight. However, some improvements are noted, like Dixie - Central Park EB (−0.90s, −1.1%), indicating that TSP's effects can vary based on corridor geometry and intersection density.

By contrast, Freight Signal Priority (FSP) produces only a minor cumulative change, reaching 1212.72s (+2.28s, +0.2%). While certain links benefit significantly, e.g., Delta Park - Auction Ln EB (−5.98s, −3.3%), others see small increases, such as Bramalea - Finchgate EB (+0.42s, +0.9%). These results suggest that FSP effectively targets heavy vehicles at some intersections but does not uniformly reduce freight travel times, reflecting localized variations in traffic demand and signal settings.

The DBL scenario introduces the most substantial delay, increasing the overall EB freight time to 1278.08s (+67.64s, +5.6%). This surge can be attributed to the loss of a general-purpose lane, causing intensified congestion for commercial vehicles. Large increases occur on segments like West Dr - Dixie EB (+20.27s, +21.1%) and Central Park - Bramalea EB (+5.08s, +5.9%), which demonstrates that dedicating space for transit constrains freight operations, especially where traffic volumes are high and lane reallocation is significant.

Combining priority strategies with DBL yields somewhat mixed outcomes. TSP & DBL elevates EB freight times to 1259.01s (+48.57s, +4.0%), slightly less than DBL alone, indicating that transit-priority signaling can mitigate a portion of the extra delay. FSP & DBL also reduces overall times compared to DBL alone, with 1273.90s (+63.46s, +5.2%), though still far above the base. Notably, the TSP FSP scenario (absent DBL) lowers cumulative freight travel time to 1193.59s (−16.85s, −1.4%), suggesting that coordinating transit and freight signal requests can foster conditions beneficial for trucks. This synergy likely emerges from more frequent green phases along key arterial segments, offering heavy vehicles fewer stops.

However, once DBL is added to the TSP FSP configuration, EB freight times climb to 1296.25s (+85.81s, +7.1%), reflecting the overriding effects of lane reallocation on commercial vehicles. Even with coordinated signal priority, dedicating a lane to transit restricts road capacity, heightening congestion and diminishing the advantages of TSP and FSP for freight.

Overall, these findings demonstrate that DBL consistently produces the highest delays for freight, overshadowing the relatively small gains or neutral impacts from TSP and FSP. Nevertheless, combining TSP and FSP in a non-DBL context demonstrates a promising avenue for marginal improvements in freight movement, highlighting the importance of holistic signal coordination. Where physical bus lanes must be introduced, additional measures may be necessary to maintain freight efficiency.

To evaluate the average travel time in each scenario for the passenger vehicles along the eastbound and westbound of Queen Street, the average travel time is summed in each direction. Figure 24 and Figure 25 show the sum of average travel time in the eastbound and westbound for passenger vehicles per scenario.

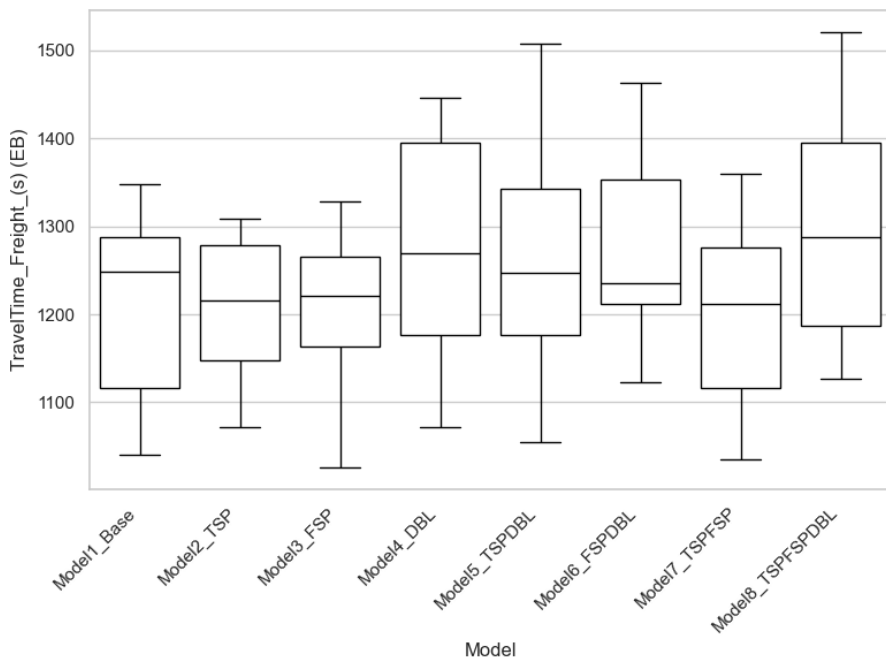



*Figure 24 - Cumulative average travel time for freight in eastbound movement along Queen Street*

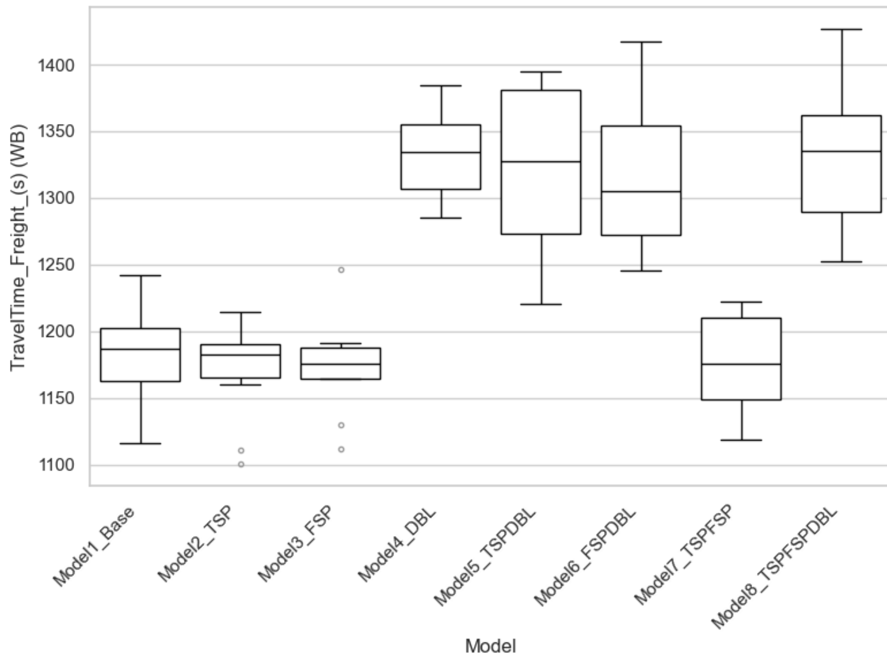



*Figure 25 - Cumulative average travel time for freight in westbound movement along Queen Street*

In Figure 24 and Figure 25, the total average travel times for freight vehicles in the eastbound (EB) and westbound (WB) directions are compared across multiple scenarios relative to the base case. The Base scenario, which represents conditions without any signal priority or DBL, yields a total average travel time of 1210s EB and 1182s WB, providing a Base to evaluate the effects of signal and lane management strategies on freight mobility.

The implementation of Transit Signal Priority (TSP) results in a slight increase in freight vehicle travel times, with EB rising to 1236s (+26s, +2.1%) and WB to 1191s (+9s, +0.8%). These increases suggest that while TSP benefits transit operations, it may cause additional delays for freight vehicles, particularly where transit priority interrupts green phases that would otherwise benefit through freight movements. This outcome is expected, as freight vehicles are not the target of TSP and are instead impacted by the changes in signal timing made to accommodate transit vehicles.

The Freight Signal Priority (FSP) scenario, as anticipated, yields a modest improvement in freight vehicle performance, with EB increasing only slightly to 1213s (+3s, +0.2%) and WB rising marginally to 1192s (+10s, +0.8%). Despite the signal system being adjusted to prioritize freight, the relatively small change from the base case suggests that either freight volumes are modest or signal responsiveness is conservative. Still, the results indicate that FSP generally maintains or improves flow for freight vehicles compared to other strategies.

Introducing DBL significantly increases freight travel times. In the DBL-only scenario, EB travel time increases to 1278s (+68s, +5.6%), while WB rises dramatically to 1334s (+152s, +12.9%). These increases are the highest across all scenarios. The primary reason for this outcome is the reduction in general-purpose lane capacity due to the introduction of dedicated bus-only lanes. As freight vehicles must share the remaining lanes with passenger vehicles, this leads to increased congestion and slower movement through the corridor. The WB direction is particularly impacted, likely due to higher freight or general traffic volumes and more constrained geometry.

The TSP & DBL scenario, which combines transit priority with DBL, results in freight travel times of 1259s EB and 1321s WB, continuing the trend of significant delay. The addition of TSP to an already congested DBL layout may further reduce green time available to freight, compounding the issue. Likewise, the FSP & DBL scenario shows elevated travel times of 1274s EB and 1318s WB, indicating that even prioritizing freight at signals cannot fully compensate for the delays introduced by lane reductions.

Interestingly, the TSP FSP scenario yields the best performance for freight, with EB travel time reduced to 1194s (-16s, -1.3%) and WB to 1189s (+7s, +0.6%). This scenario appears to strike a beneficial balance, as both priority strategies operate in tandem and likely coordinate signal operations in a way that smooths flow for multiple vehicle classes. The decrease in EB time suggests that signal coordination may allow freight to clear intersections more effectively, benefiting from more consistent green time even if indirectly.

Finally, the TSP FSP & DBL scenario results in some of the worst outcomes for freight, with EB reaching 1296s (+86s, +7.1%) and WB at 1330s (+148s, +12.5%). This scenario combines the restrictive effects of DBL removal with a high frequency of signal priority requests from both transit and freight vehicles. The elevated signal priority frequency can cause erratic signal phase adjustments, leading to more unpredictable delays and frequent interruptions for general traffic. Moreover, the loss of one general-purpose lane due to DBL significantly intensifies congestion, particularly affecting the large and slower-moving freight vehicles that require longer headways and acceleration times.

In summary, the findings reveal that FSP and TSP FSP scenarios are the most favorable for freight, with TSP FSP providing the best balance of signal responsiveness and corridor-wide flow. However, the introduction of DBL consistently leads to increased delays for freight, and when combined with signal priority treatments (TSP or FSP), these delays are exacerbated. The results emphasize the importance of carefully coordinating transit and freight signal priorities, especially when physical lane reallocation strategies such as DBL are introduced.

### 5.1.3. Average Travel Time for Transit

Table 11 and Figure 26 show the average travel time (in seconds) for the transit along the eastbound (EB) movement of Queen Street during the PM peak hours. The rows showing values of 0 indicate that this type of vehicle is not present in this road segment/intersection (i.e., the transit vehicles do not travel through the intersection).

| **Road Segment** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Dr - Dixie EB** | 113.44 | 115.42 (+1.98) | 114.28 (+0.84) | 119.11 (+5.67) | 112.94 (-0.52) | 113.97 (+0.53) | 114.49 (+1.05) | 114.67 (+1.23) |
| **Dixie - Central Park EB** | 130.99 | 129.7 (-1.30) | 123.97 (-7.02) | 127.32 (-3.68) | 117.44 (-13.56) | 114.25 (-16.75) | 120.83 (-10.17) | 114.07 (-16.93) |
| **Central Park - Bramalea EB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Bramalea - Finchgate EB** | 89.86 | 74.77 (-15.10) | 78.18 (-11.69) | 93.79 (+3.93) | 89.01 (-0.86) | 91.83 (+1.97) | 79.14 (-10.73) | 89.77 (-0.10) |
| **Finchgate - Torbram Rd EB** | 121.75 | 107.63 (-14.13) | 112.95 (-8.81) | 114.03 (-7.73) | 117.73 (-4.03) | 116.24 (-5.52) | 105.59 (-16.17) | 118.51 (-3.25) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **Torbram Rd - Torbram Plaza (Walmart) EB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Torbram Plaza (Walmart) - Gateway EB** | 77.92 | 65.75 (-12.18) | 67.75 (-10.19) | 76.98 (-0.96) | 77.54 (-0.39) | 77.25 (-0.68) | 66.23 (-11.70) | 74.33 (-3.60) |
| **Gateway - Smart Centres (Tim Hortons) EB** | 60.99 | 56.19 (-4.81) | 59.55 (-1.45) | 60.19 (-0.80) | 55.65 (-5.35) | 53.83 (-7.17) | 55.18 (-5.82) | 56.18 (-4.81) |
| **Smart Centres - Airport Rd EB** | 76.03 | 83.59 (+7.56) | 74.3 (-1.74) | 81.12 (+5.09) | 72.87 (-3.17) | 66.93 (-9.11) | 77.86 (+1.83) | 80.64 (+4.61) |
| **Airport Rd - Delta Park EB** | 134.76 | 130.23 (-4.54) | 119.78 (-14.99) | 129.64 (-5.12) | 120.43 (-14.33) | 118.27 (-16.49) | 114.64 (-20.13) | 125.69 (-9.08) |
| **Delta Park - Auction Ln EB** | 205.08 | 187.16 (-17.94) | 183.38 (-21.72) | 164.35 (-40.74) | 144 (-61.10) | 149.21 (-55.88) | 188.18 (-16.92) | 151.26 (-53.83) |
| **Auction Ln - Goreway EB** | 101.23 | 91.43 (-9.82) | 94.65 (-6.59) | 92.36 (-8.88) | 88.66 (-12.59) | 94.48 (-6.77) | 95.47 (-5.78) | 96.02 (-5.23) |
| **Goreway - McVean EB** | 124.20 | 117.47 (-6.75) | 109.95 (-14.26) | 131.46 (+7.26) | 126.47 (+2.27) | 124.53 (+0.33) | 106.21 (-18.01) | 134.85 (+10.65) |
| **McVean - Cherrycrest EB** | 31.08 | 27.9 (-3.19) | 30.83 (-0.26) | 36.04 (+4.96) | 32.08 (+1.00) | 32.69 (+1.61) | 30.27 (-0.82) | 32.82 (+1.74) |
| **Cherrycrest - Beaumaris EB** | 40.57 | 39.24 (-1.34) | 41.5 (+0.93) | 40.09 (-0.49) | 40.49 (-0.09) | 42.36 (+1.79) | 43.09 (+2.52) | 39.66 (-0.92) |
| **Beaumaris - Gore Rd EB** | 48.74 | 55.72 (+6.98) | 53.54 (+4.80) | 50.55 (+1.81) | 51.22 (+2.48) | 49.52 (+0.78) | 55.95 (+7.21) | 48.7 (-0.04) |
| **Gore Rd EB** | 61.25 | 44.88 (-16.39) | 45.42 (-15.85) | 61.53 (+0.28) | 61.26 (-0.01) | 62.28 (+1.03) | 44.78 (-16.48) | 61.46 (+0.20) |
| **EB Cumulative** | 1417.90 | 1327 (-90.91) | 1309.96 (-107.95) | 1378.5 (-39.41) | 1307.73 (-110.19) | 1307.58 (-110.33) | 1297.84 (-120.07) | 1338.56 (-79.35) |

*Table 11 - Average travel time for transit in the Eastbound direction for Queen St*

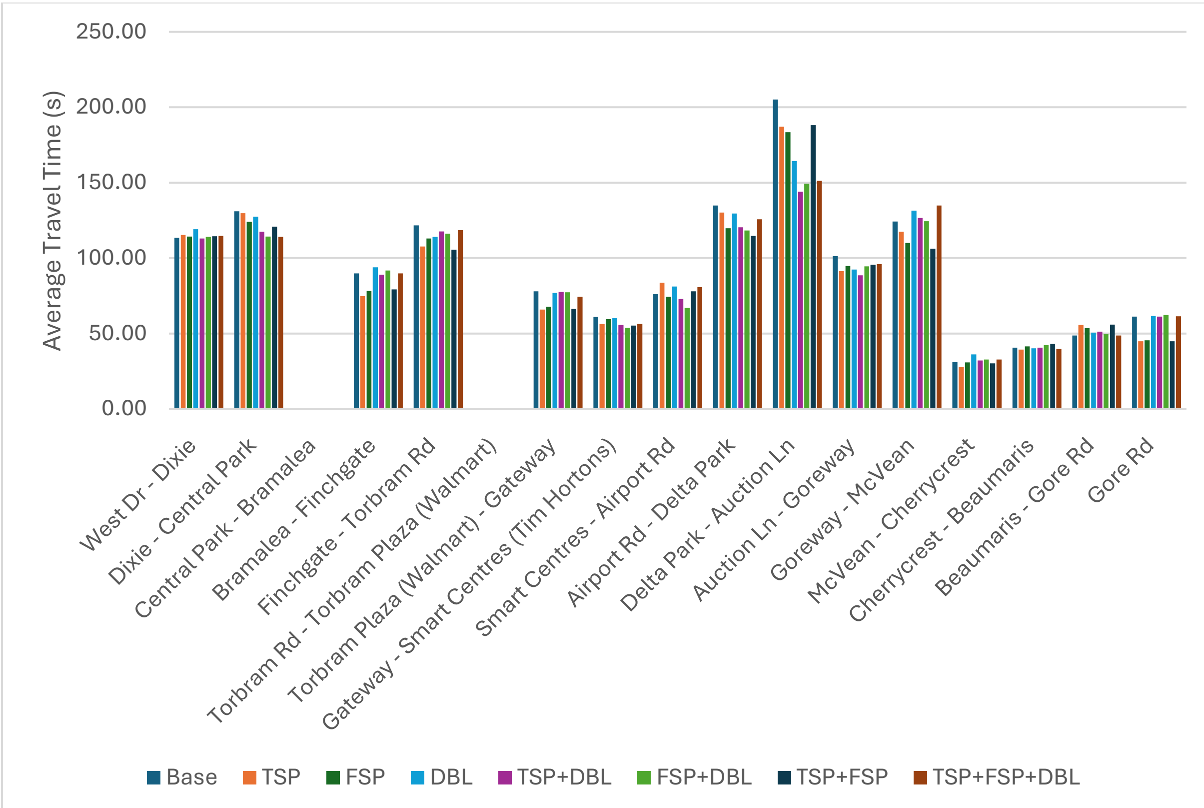



*Figure 26 - Average travel time for transit in the Eastbound direction for Queen St*

The assessment of eastbound (EB) transit travel times under various signal priority and DBL scenarios reveals how different strategies can enhance or hinder bus operations. In the Base scenario, EB transit requires 1417.90 seconds overall, forming a benchmark for subsequent evaluations.

Transit Signal Priority (TSP), which grants extended or early green phases to approaching buses, lowers the total EB travel time to 1327.70s (−90.91s, −6.4%) compared to the base. Although some segments observe modest time increases, such as West Dr - Dixie EB (+1.98s), others, like Cherrycrest - Beaumaris EB (−1.34s), experience noticeable improvements. These reductions suggest that TSP effectively streamlines bus progression on many sections of the corridor, though localized disruptions may still arise if additional green time for transit reduces throughput for other movements.

The Freight Signal Priority (FSP) scenario produces an even greater reduction, with EB transit travel dropping to 1309.96s (−107.95s, −7.6%). While FSP is designed primarily to favor heavy vehicles, certain corridor characteristics allow buses to share in these benefits, potentially through fewer intersection stops or more consistent signal phases. Key reductions can be seen at segments like Goreway - McVean EB (−14.26s), highlighting how minor phase adjustments for freight can also facilitate bus movement in mixed traffic contexts.

By contrast, DBL alone yields 1378.50s for EB transit (a relative improvement of −39.41s or −2.8% from the base). While dedicating a lane to transit typically boosts bus reliability, the net gains here appear less pronounced than with TSP or FSP. Possible explanations include constrained intersection approaches, geometric limitations, or conflicts at access points, which can offset the time savings from exclusive bus lanes.

When TSP is combined with DBL, overall travel time falls further to 1307.73s (−110.17s, −7.8%), suggesting that transit-prioritized signals can magnify the advantage of a dedicated lane by smoothing bus arrivals at intersections. A similar outcome emerges with FSP and DBL, yielding 1307.58s (−110.32s, −7.8%), though improvements are slightly less uniform across segments.

Interestingly, the TSP FSP scenario without DBL delivers the largest reduction, dropping travel time to 1297.84s (−120.06s, −8.5%), reflecting that synchronizing signal priorities for both transit and freight can create efficient green windows for buses when lane reallocation is not a factor. However, introducing DBL into this scenario (TSP FSP & DBL) raises EB transit time to 1338.56s (−79.35s, −5.6%) relative to the base. While still an improvement over not having any priority, the gains are tempered by corridor design constraints or interactions between transit vehicles in the bus lane and approaching intersections.

Overall, these results indicate that signal priority treatments (TSP or FSP) can provide significant benefits to EB transit, sometimes more so than a DBL alone. DBL offers moderate advantages but can be most effective when integrated with robust priority measures. Nevertheless, synergy between TSP and FSP proves especially potent in reducing bus travel times, unless offset by design or operational complexities introduced by DBL.

The analysis of total average travel time for transit across different priority scenarios reveals key trends in the effectiveness of Transit Signal Priority (TSP), Freight Signal Priority (FSP), DBL, and their combinations for both eastbound (EB) and westbound (WB) directions. The summarized average travel time results (in seconds) for transit are demonstrated is Figure 27 and Figure 28.

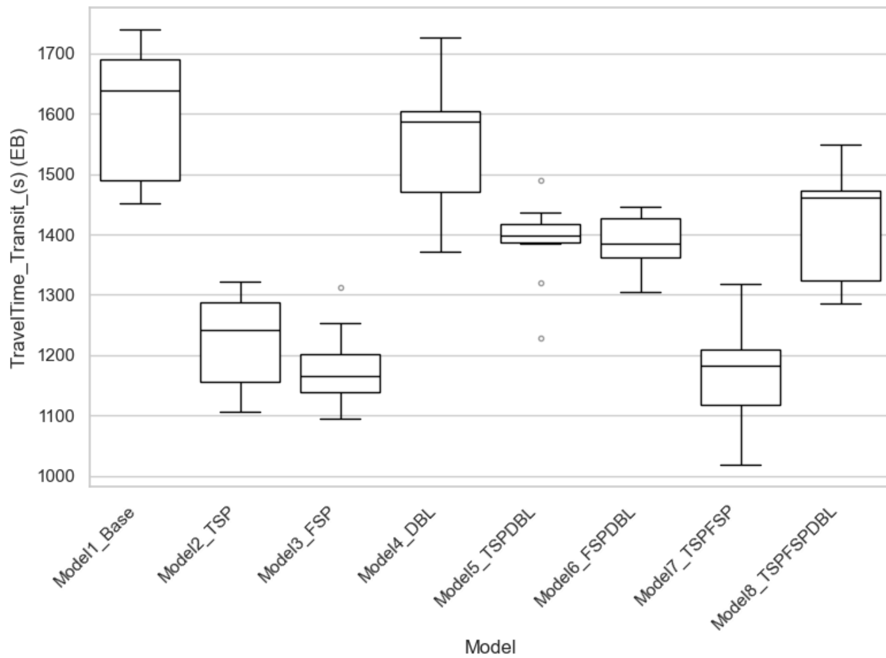



*Figure 27 - Cumulative average travel time for transit in the westbound movement along Queen Street*

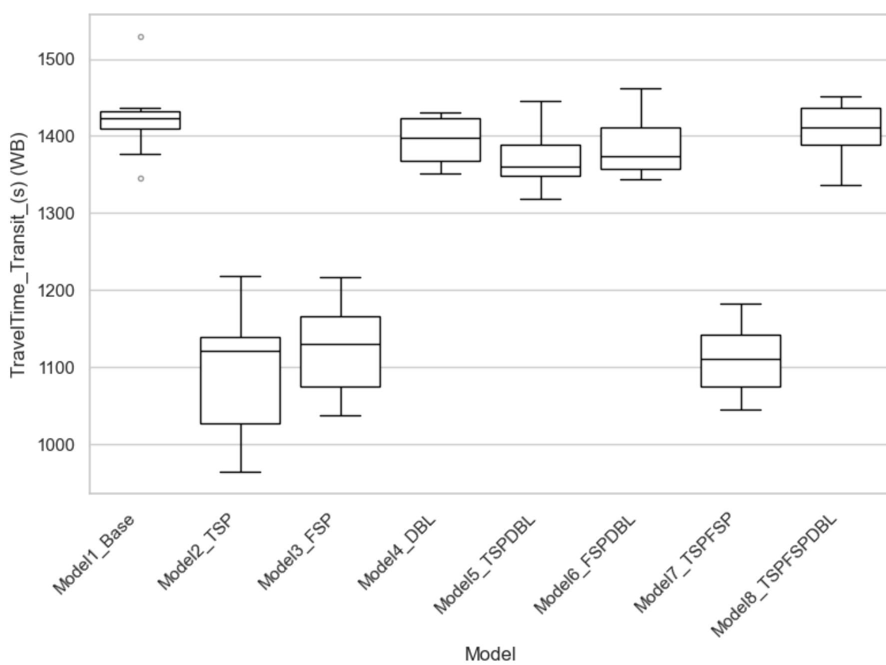



*Figure 28 - Cumulative average travel time for transit in the westbound movement along Queen Street*

In Figure 27 and Figure 28, the total average travel times for transit vehicles in the eastbound (EB) and westbound (WB) directions are compared across various scenarios. The Base scenario, representing current conditions without signal priority or bus-only lanes, shows transit travel times of 1418 seconds EB and 1272 seconds WB, reflecting the relatively high levels of congestion and delay experienced by buses under normal operations.

When Transit Signal Priority (TSP) is implemented, travel times improve notably, with EB travel time reduced to 1327s (-91s, -6.4%) and WB reduced to 1154s (-118s, -9.3%). These reductions demonstrate the effectiveness of TSP in facilitating smoother transit flow through intersections by extending green lights or reducing red-light delays in response to approaching buses. The WB direction benefits slightly more, likely due to higher signal delay sensitivity or better signal spacing.

The Freight Signal Priority (FSP) scenario also results in significant travel time reductions for transit, with EB dropping to 1310s (-108s, -7.6%) and WB to 1166s (-106s, -8.3%). Though designed to prioritize freight, the signal adjustments under FSP, such as extended green times, can also benefit transit vehicles. This crossover benefit is particularly notable in corridors where freight and transit routes overlap or share signalized intersections.

Surprisingly, the DBL-only scenario does not produce the expected improvements in transit performance. Instead, EB travel time increases to 1378s (+40s, +2.8%), while WB travel time decreases only modestly to 1237s (-35s, -2.7%). These results suggest that although a dedicated lane improves flow in theory, other factors, such as signal delays, access limitations, or geometric constraints, may still hinder performance. Moreover, the introduction of DBL could have induced greater conflicts at intersections or constrained bus access to stops due to physical barriers.

The TSP & DBL and FSP & DBL scenarios improve slightly over the DBL-only case, with EB travel times at 1308s for both scenarios, and WB at 1214s (TSP & DBL) and 1232s (FSP & DBL). These results show that combining signal priority with dedicated lanes produces better outcomes than BRT alone. The improvement is more prominent when DBL is combined with TSP, likely because transit-specific signal timing complements the spatial benefits of the dedicated lane.

The TSP FSP scenario yields the best performance across all non- DBL strategies, with EB travel time dropping to 1298s (-120s, -8.5%) and WB to 1161s (-111s, -8.7%). This significant improvement can be attributed to the greater number of signal priority requests generated by the combination of transit and freight vehicles. The increased frequency of priority calls likely helps maintain green bands for through movement along the corridor, allowing buses to clear intersections more efficiently.

Finally, the TSP FSP & DBL scenario, which combines both signal priority treatments and a DBL, results in EB travel time of 1339s (-79s, -5.6%) and WB travel time of 1251s (-21s, -1.6%). While this scenario still improves transit flow compared to the base case, it does not outperform the TSP-FSP-only scenario. This may be due to diminishing returns from combining multiple strategies or operational conflicts introduced by the DBL implementation. In particular, higher volumes of priority requests may cause excessive signal fluctuations, and the physical restrictions of the DBL may limit bus flexibility at certain locations.

Overall, the findings suggest that signal priority treatments (TSP and FSP), either individually or combined, produce the most consistent improvements for transit, especially when no physical lane reallocation occurs. While DBL is generally beneficial, it must be implemented carefully alongside signal strategies to avoid unintended constraints. The TSP FSP combination without DBL emerges as the most effective non-infrastructure-intensive option, offering substantial reductions in transit travel time with minimal disruption to the corridor geometry

## 5.2. Total Person's Delay Analysis

The total persons delay (hour) results are obtained directly from the VISSIM simulation output. The total persons delay results are reported as an average of averages for all vehicle classes combined, and as an average for each vehicle class on its own. The output from the VISSIM software application is programmed to produce it in hours for this MOE. All scenarios are modelled and included for the purpose of MOE comparison among the different scenarios. Total person-delay in hours, separated by direction and mode, highlights the cumulative burden experienced by all occupants of a vehicle, rather than just the vehicles themselves. This approach recognizes that a bus transporting multiple passengers potentially incurs far greater human cost when delayed than an equivalent wait in an underoccupied car. By expressing that delay in hours, stakeholders can compare it to operational metrics (e.g., workforce productivity or route scheduling)

### 5.2.1. Total Persons Delay for Passenger Vehicles

Table 12 and Figure 29 show the total persons delay (in hours) for the passenger vehicles (or autos) along the eastbound (EB) movement of Queen Street during the PM peak hours.

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Dr - Dixie EB** | 63.21 | 64.17 (+0.96) | 63.2 (-0.02) | 90.14 (+26.93) | 83.36 (+20.15) | 83.36 (+20.15) | 62.91 (-0.31) | 85.08 (+21.86) |
| **Dixie - Central Park EB** | 108.65 | 111.13 (+2.48) | 103.72 (-4.93) | 116.75 (+8.11) | 115.69 (+7.05) | 113.07 (+4.42) | 104.31 (-4.35) | 118.15 (+9.50) |
| **Central Park - Bramalea EB** | 52.01 | 52.9 (+0.90) | 55.15 (+3.14) | 57.66 (+5.65) | 71.94 (+19.93) | 69.12 (+17.11) | 51.27 (-0.75) | 62.84 (+10.83) |
| **Bramalea - Finchgate EB** | 110.07 | 106.37 (-3.72) | 107.36 (-2.72) | 107.3 (-2.79) | 109.71 (-0.38) | 112.82 (+2.74) | 108.88 (-1.20) | 105.21 (-4.87) |
| **Finchgate - Torbram Rd EB** | 25.89 | 28.4 (+2.50) | 28.71 (+2.81) | 35.08 (+9.18) | 33.24 (+7.34) | 32.88 (+6.99) | 29.15 (+3.26) | 32.84 (+6.95) |
| **Torbram Rd - Torbram Plaza (Walmart) EB** | 44.68 | 47.08 (+2.40) | 49.91 (+5.23) | 55.24 (+10.56) | 53.11 (+8.42) | 56.03 (+11.35) | 48.02 (+3.34) | 49.32 (+4.63) |
| **Torbram Plaza (Walmart) - Gateway EB** | 17.94 | 17.02 (-0.93) | 16.62 (-1.33) | 19.15 (+1.20) | 17.2 (-0.75) | 18.62 (+0.68) | 16.42 (-1.53) | 18.56 (+0.62) |
| **Gateway - Smart Centres (Tim Hortons) EB** | 31.26 | 36.05 (+4.79) | 35.96 (+4.70) | 36.08 (+4.82) | 34.49 (+3.24) | 34.74 (+3.48) | 33.84 (+2.58) | 35.2 (+3.95) |
| **Smart Centres - Airport Rd EB** | 35.34 | 33.43 (-1.93) | 37.96 (+2.62) | 37.21 (+1.87) | 33.57 (-1.78) | 30.61 (-4.74) | 32.48 (-2.87) | 37.81 (+2.47) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **Airport Rd - Delta Park EB** | 105.76 | 117.23 (+11.47) | 111.77 (+6.01) | 116.96 (+11.20) | 104.91 (-0.85) | 105.82 (+0.06) | 106.26 (+0.50) | 125.85 (+20.09) |
| **Delta Park - Auction Ln EB** | 143.69 | 157.6 (+13.91) | 136.99 (-6.71) | 145.96 (+2.27) | 142.11 (-1.59) | 143.75 (+0.06) | 137.58 (-6.12) | 162.35 (+18.66) |
| **Auction Ln - Goreway EB** | 164.78 | 162.73 (-2.06) | 160.78 (-4.01) | 149.65 (-15.14) | 140.07 (-24.72) | 146.83 (-17.97) | 159.96 (-4.83) | 148.69 (-16.10) |
| **Goreway - McVean EB** | 128.37 | 127.69 (-0.69) | 128.44 (+0.08) | 130.92 (+2.56) | 127.57 (-0.80) | 129.82 (+1.45) | 131.21 (+2.84) | 128.15 (-0.23) |
| **McVean - Cherrycrest EB** | 44.15 | 44.47 (+0.33) | 44.12 (-0.04) | 44.86 (+0.71) | 45.18 (+1.03) | 45.7 (+1.55) | 44.42 (+0.28) | 43.33 (-0.83) |
| **Cherrycrest - Beaumaris EB** | 27.95 | 28.77 (+0.82) | 28.43 (+0.48) | 34.39 (+6.44) | 34.06 (+6.11) | 34.69 (+6.74) | 27.03 (-0.93) | 33.18 (+5.23) |
| **Beaumaris - Gore Rd EB** | 10.86 | 10.59 (-0.28) | 11 (+0.15) | 10.97 (+0.11) | 11.15 (+0.29) | 11.69 (+0.83) | 10.88 (+0.02) | 10.37 (-0.50) |
| **Gore Rd EB** | 40.26 | 43.21 (+2.95) | 43.86 (+3.61) | 43.37 (+3.12) | 43.22 (+2.96) | 43.25 (+2.99) | 43.9 (+3.65) | 41.56 (+1.30) |
| **EB Cumulative** | 1154.87 | 1188.75 (+33.88) | 1163.92 (+9.05) | 1231.62 (+76.75) | 1200.5 (+45.63) | 1212.7 (+57.83) | 1148.44 (-6.44) | 1238.41 (+83.54) |

*Table 12 - Total Persons Delay for Autos in the Eastbound direction for Queen St*

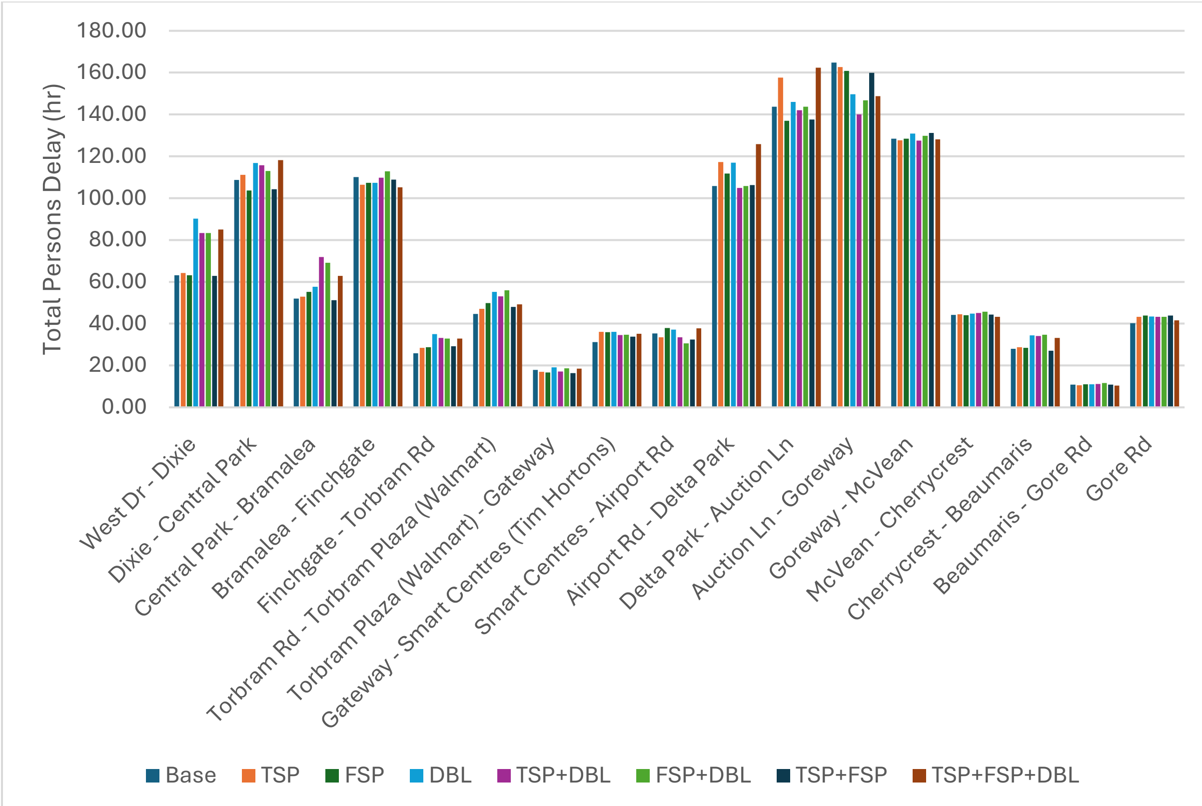



*Figure 29 - Total persons delay for passenger vehicle in the eastbound direction*

Under base conditions, the EB corridor records a total persons delay of 1154.87 hours, serving as the starting point for comparisons. The TSP scenario increases overall delay to 1188.75 hours (+33.88 hours), suggesting that granting extended green phases to transit vehicles can reduce intersection capacity for automobiles. Notable rises are observed on segments like Airport Rd - Delta Park EB (+11.47 hours) and Delta Park - Auction Ln EB (+13.91 hours), where buses may frequently trigger priority signals, leaving fewer opportunities for autos to clear intersections efficiently.

By contrast, FSP yields a more modest increase in cumulative delay, reaching 1163.92 hours (+9.05 hours). Certain links, such as Dixie - Central Park EB (−4.93 hours), exhibit improvements likely due to less stop-and-go motion when freight receives preferential treatment, indirectly benefiting adjacent traffic. However, other segments, like Delta Park - Auction Ln EB (+6.75 hours), still show added delays, indicating that freight-oriented priority can occasionally disrupt auto flow if heavy trucks trigger multiple green extensions.

The DBL scenario imposes the most significant surge in EB delay, climbing to 1231.62 hours (+76.75 hours). Removing a general-use lane for exclusive bus service intensifies congestion, as autos must compete for reduced space. Substantial increases, for instance at West Dr - Dixie EB (+26.93 hours) and Dixie - Central Park EB (+8.11 hours), highlight how lane reallocation can quickly exacerbate queue lengths and wait times for private vehicles.

When TSP and DBL are combined, total persons delay moderates somewhat to 1200.54 hours (+45.67 hours), illustrating that transit-priority signals can mitigate some, but not all, of the congestion introduced by lane reductions. A similar finding appears in FSP & DBL, which stands at 1212.72 hours (+57.85 hours). Although FSP improves certain truck-dominated segments, the net impact remains negative for general auto users under DBL constraints.

Interestingly, merging TSP and FSP without DBL leads to 1148.44 hours (−6.44 hours), signifying a small improvement relative to the base. Here, optimized signal phases for both transit and freight can create smoother traffic progression, indirectly lowering auto queues at intersections. However, once DBL is layered onto TSP FSP, delay escalates to 1238.41 hours (+83.54 hours), indicating that the reduction in lane capacity outweighs the gains from dual signal prioritization.

Overall, these results demonstrate that DBL consistently generates the most substantial increases in EB person-delay for automobiles, whereas TSP or FSP alone exert more modest impacts. The TSP FSP combination can slightly reduce total auto delay, provided bus lanes remain shared; however, introducing a DBL significantly compromises the benefits of any signal priority measures.

To evaluate total persons delay in each scenario for the passenger vehicles (autos) along the eastbound and westbound of Queen Street, the average travel time is summed in each direction. Figure 30 and Figure 31 show the cumulative total persons delay in the eastbound and westbound for passenger vehicles per scenario.

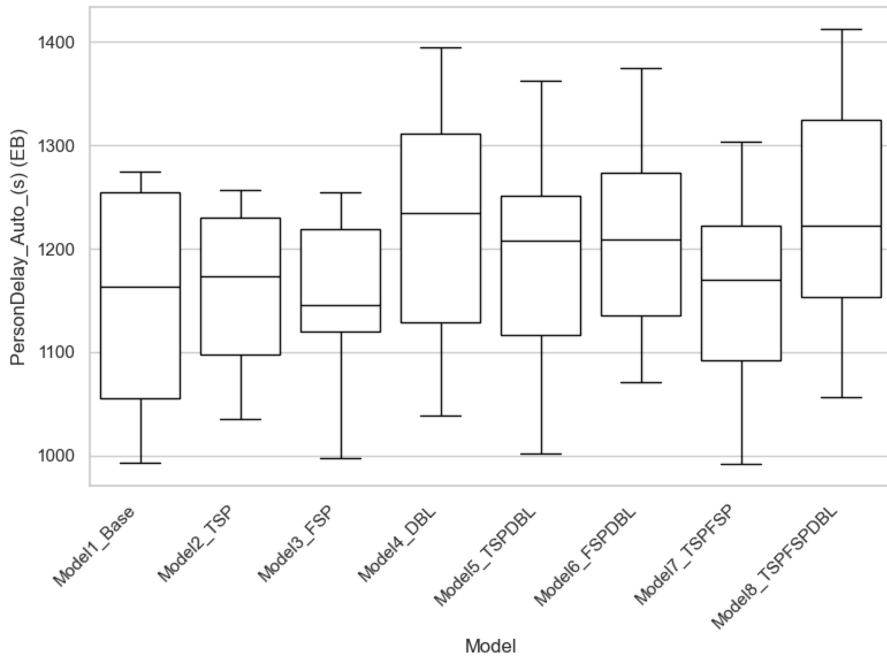



*Figure 30 - Cumulative total persons delay for autos in eastbound movement along Queen Street*

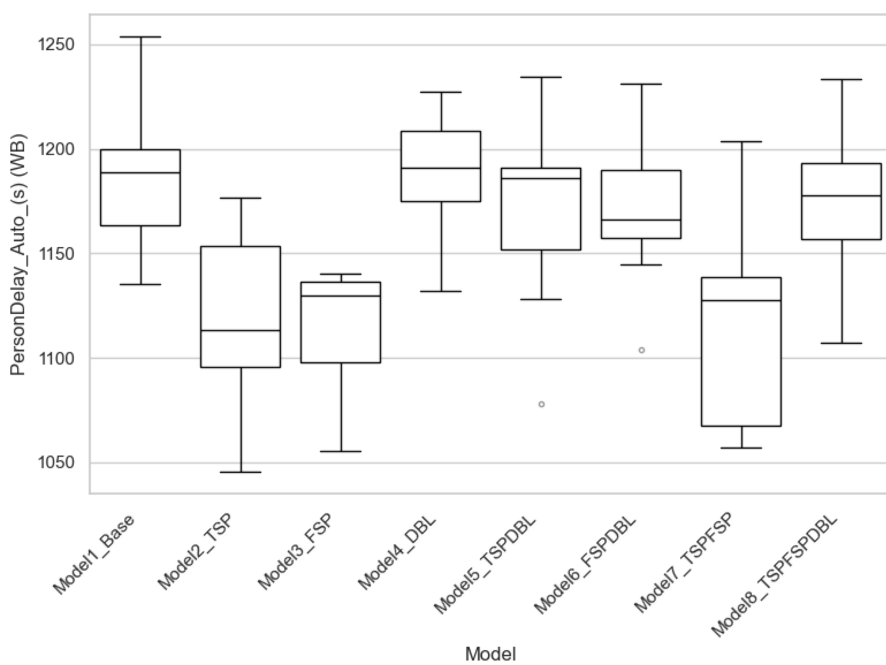



*Figure 31 - Cumulative total persons delay for autos in westbound movement along Queen Street*

In Figure 30 and Figure 31, the cumulative total person delay (in hours) for passenger vehicles in the eastbound (EB) and westbound (WB) directions is shown across different scenarios. These delays reflect the combined impacts of signal priority strategies and DBL implementation on passenger vehicle occupants, providing a more person-centric view of performance compared to average travel time alone. The Base scenario yields total delays of 1155 hours EB and 1186 hours WB, which serve as reference values representing existing conditions without any transit- or freight-focused interventions.

The TSP and FSP scenarios, when implemented individually, result in modest variations in delay. Under TSP, person delay slightly increases to 1189 hours WB (+3 hrs) but decreases marginally to 1179 hours WB (-7 hrs) compared to the base. Similarly, FSP produces a decrease in EB delay to 1164 hours (-9 hrs) and a very minor increase in WB delay to 1191 hours (+5 hrs). These relatively small changes suggest that signal priority strategies for transit or freight, when implemented alone, have limited impact on total delay experienced by passenger vehicle occupants, an expected result given these strategies are designed to benefit other modes.

In contrast, the DBL-only scenario results in the highest total person delay across all scenarios, with 1232 hours EB (+77 hrs) and 1289 hours WB (+103 hrs). This sharp increase reflects the considerable reduction in roadway capacity available to passenger vehicles due to the conversion of a general-purpose lane into a dedicated transit lane. With fewer lanes available and increased congestion, passenger vehicles experience more frequent delays, and the cumulative impact on person-hours is substantial, particularly in the WB direction.

The combination scenarios that include DBL with signal priority treatments (TSP & DBL and FSP & DBL) also show substantial increases in total delay. The TSP & DBL scenario results in 1200 hours EB and 1269 hours WB, while FSP & DBL results in 1213 hours EB and 1270 hours WB. Although these are marginally better than DBL alone, the values remain significantly higher than the base case, indicating that signal priority measures offer limited mitigation when DBL infrastructure reduces road capacity for autos.

Conversely, the TSP FSP scenario, without DBL, yields the lowest total delay of all scenarios, with 1148 hours EB (-7 hrs) and 1190 hours WB (+4 hrs) compared to the base. These results suggest that the coordinated implementation of TSP and FSP produces operational efficiencies that can reduce intersection delay for all road users, including passenger vehicles. This is likely due to improved signal progression and reduced cycle disruptions, which help general traffic move more smoothly through the corridor.

Finally, the TSP FSP & DBL scenario sees a return to higher delay values, with 1238 hours EB (+83 hrs) and 1274 hours WB (+88 hrs). These increases confirm that the benefit of signal coordination is outweighed by the capacity losses introduced by the DBL. This scenario closely mirrors the delay patterns observed in the DBL-only and DBL-combination scenarios, reaffirming that DBL has the most dominant effect on person-delay outcomes for autos.

In summary, the addition of DBL consistently results in the highest increases in total person delay for passenger vehicles, regardless of whether TSP or FSP is applied. The TSP FSP scenario without DBL emerges as the most effective strategy for minimizing person delay for general traffic. These results highlight the importance of carefully evaluating the trade-offs between transit-focused infrastructure investments and their broader impacts on the passenger vehicle network.

## 5.2.2. Total Persons Delay for Freight

Table 13 and Figure 32 show the total persons delay (in hours) for the freight along the eastbound (EB) movement of Queen Street during the PM peak hours.

| **Road Segment** | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **West Dr - Dixie EB** | 12.37 | 12.74 (+0.38) | 12.5 (+0.13) | 17.85 (+5.48) | 16.48 (+4.11) | 16.74 (+4.37) | 12.45 (+0.08) | 17.17 (+4.81) |
| **Dixie - Central Park EB** | 18.94 | 19.8 (+0.85) | 18.87 (-0.08) | 20.54 (+1.59) | 20.03 (+1.09) | 20.22 (+1.28) | 18.15 (-0.81) | 21.09 (+2.15) |
| **Central Park - Bramalea EB** | 0.00 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Bramalea - Finchgate EB** | 14.17 | 13.59 (-0.59) | 14.54 (+0.37) | 14.05 (-0.13) | 14.01 (-0.18) | 14.38 (+0.21) | 14.14 (-0.04) | 13.58 (-0.60) |
| **Finchgate - Torbram Rd EB** | 3.39 | 3.7 (+0.30) | 3.76 (+0.37) | 4.73 (+1.33) | 4.34 (+0.95) | 4.59 (+1.20) | 3.93 (+0.54) | 4.51 (+1.12) |
| **Torbram Rd - Torbram Plaza (Walmart) EB** | 5.62 | 5.78 (+0.16) | 5.88 (+0.26) | 6.46 (+0.84) | 6.5 (+0.88) | 6.93 (+1.31) | 5.63 (+0.01) | 6.59 (+0.97) |
| **Torbram Plaza (Walmart) - Gateway EB** | 2.42 | 2.21 (-0.22) | 2.08 (-0.35) | 2.65 (+0.23) | 2.43 (+0.01) | 2.55 (+0.13) | 2.09 (-0.34) | 2.64 (+0.22) |
| **Gateway - Smart Centres (Tim Hortons) EB** | 4.14 | 4.68 (+0.55) | 4.43 (+0.30) | 4.69 (+0.55) | 4.41 (+0.28) | 4.52 (+0.38) | 4.54 (+0.41) | 4.79 (+0.66) |
| **Smart Centres - Airport Rd EB** | 5.50 | 5.25 (-0.26) | 5.64 (+0.14) | 5.87 (+0.37) | 5.46 (-0.05) | 4.89 (-0.62) | 5.32 (-0.19) | 6.34 (+0.84) |
| **Airport Rd - Delta Park EB** | 15.38 | 16.59 (+1.21) | 16.12 (+0.73) | 17.34 (+1.95) | 15.34 (-0.05) | 15.84 (+0.46) | 15.45 (+0.06) | 19.36 (+3.97) |
| **Delta Park - Auction Ln EB** | 31.67 | 34.23 (+2.56) | 30.35 (-1.33) | 32.45 (+0.78) | 30.47 (-1.21) | 30.34 (-1.34) | 30.5 (-1.18) | 34.91 (+3.24) |
| **Auction Ln - Goreway EB** | 55.40 | 57.26 (+1.86) | 56 (+0.60) | 52.13 (-3.29) | 49.45 (-5.96) | 51.47 (-3.95) | 55.32 (-0.09) | 52.66 (-2.75) |
| **Goreway - McVean EB** | 47.31 | 46.68 (-0.64) | 45.78 (-1.54) | 47.27 (-0.05) | 46.11 (-1.21) | 45.69 (-1.63) | 46.19 (-1.13) | 47.34 (+0.03) |
| **McVean - Cherrycrest EB** | 16.54 | 16.24 (-0.31) | 15.83 (-0.72) | 16.13 (-0.42) | 16.17 (-0.38) | 16.58 (+0.05) | 15.73 (-0.82) | 15.45 (-1.10) |
| **Cherrycrest - Beaumaris EB** | 9.58 | 9.78 (+0.20) | 10.06 (+0.48) | 11.5 (+1.92) | 11.63 (+2.05) | 11.55 (+1.97) | 9.01 (-0.58) | 11.43 (+1.85) |
| **Beaumaris - Gore Rd EB** | 4.33 | 4.01 (-0.33) | 4.07 (-0.26) | 4.25 (-0.08) | 4.23 (-0.11) | 4.6 (+0.28) | 4.33 (-0.01) | 3.82 (-0.51) |
| **Gore Rd EB** | 14.55 | 14.61 (+0.06) | 15.36 (+0.81) | 14.79 (+0.24) | 15.39 (+0.84) | 14.94 (+0.40) | 15.5 (+0.95) | 13.91 (-0.65) |
| **EB Cumulative** | 261.31 | 267.08 (+5.77) | 261.19 (-0.12) | 272.61 (+11.31) | 262.37 (+1.06) | 265.75 (+4.44) | 258.19 (-3.13) | 275.53 (+14.22) |

*Table 13 - Total Persons Delay for freight in the Eastbound direction for Queen St*

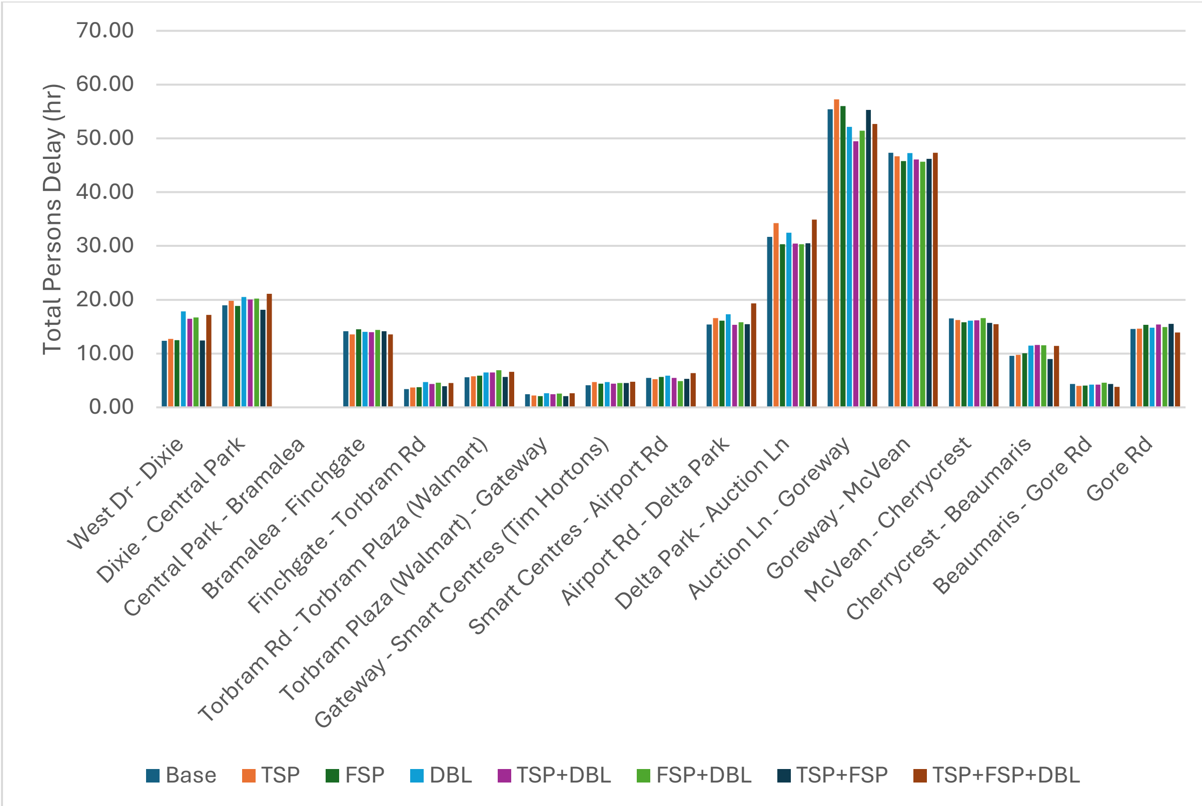



*Figure 32 - Total persons delay for freight in the eastbound direction*

Under Base conditions, the EB freight corridor exhibits a total person-delay of 261.31 hours, serving as the benchmark for evaluating each priority strategy. TSP increases this delay slightly to 267.08 hours (+5.77 hours), indicating that while transit receives extended greens at some intersections, freight may encounter added stops or shorter effective green time. Segments such as West Dr - Dixie EB (+0.38 hours) and Airport Rd - Delta Park EB (+1.21 hours) highlight these modest upticks in localized waiting.

The FSP scenario remains near the base level at 261.19 hours (−0.12 hours), implying that preferential signal phasing for heavy vehicles has little net effect, improvements on some links can offset mild slowdowns elsewhere. For instance, Delta Park - Auction Ln EB (−1.33 hours) benefits from decreased intersection queuing for trucks, while other segments record small gains in wait times.

By contrast, DBL implementation causes the highest increase, at 272.61 hours (+11.31 hours). Dedicating a general-purpose lane to buses intensifies congestion for remaining lanes, impeding freight vehicles in segments like West Dr - Dixie EB (+5.48 hours) and Airport Rd - Delta Park EB (+1.95 hours).

These changes demonstrate how physical lane reallocation can challenge commercial operations by limiting road space for larger, slower-accelerating freight traffic.

When TSP or FSP are combined with DBL, person-delay typically remains higher than in non-DBL scenarios, reflecting the overarching impact of lane reduction. For instance, TSP & DBL sees 281.09 hours (+19.78 hours), and FSP & DBL shows 265.75 hours (+4.45 hours), indicating that while signal priority may partially alleviate intersection congestion, it cannot fully overcome the loss of capacity.

A noteworthy exception is the TSP FSP scenario without DBL, yielding 258.19 hours (−3.13 hours), the lowest delay among all scenarios. This result suggests that synchronizing both transit and freight priority requests can streamline phase changes enough to benefit trucking interests alongside transit flow, even if inadvertently. However, once DBL is introduced to this dual-priority arrangement (TSP FSP & DBL), total person-delay increases to 275.53 hours (+14.22 hours), emphasizing that lane removal outweighs any synergy gained through integrated signal strategies.

Overall, these findings confirm that DBL consistently exerts the largest upward pressure on freight person-delay, due to fundamental lane capacity reductions. TSP and FSP alone have modest to minimal impacts, with TSP FSP improving freight delay relative to the base. This highlights the importance of coordinating signal priorities carefully to accommodate commercial traffic, especially when infrastructure changes such as DBL s are under consideration.

To evaluate total persons delay in each scenario for the freight along the eastbound and westbound of Queen Street, the average travel time is summed in each direction. Figure 33 and Figure 34 shows the cumulative total persons delay in the eastbound and westbound for freight per scenario.

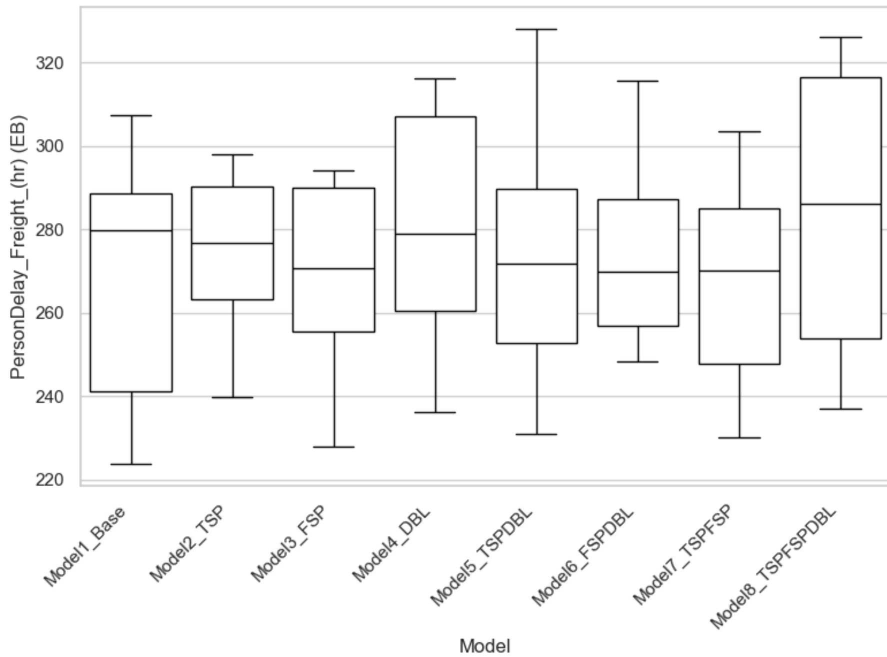



*Figure 33 - Cumulative total persons delay per scenario for freight in the eastbound movement*

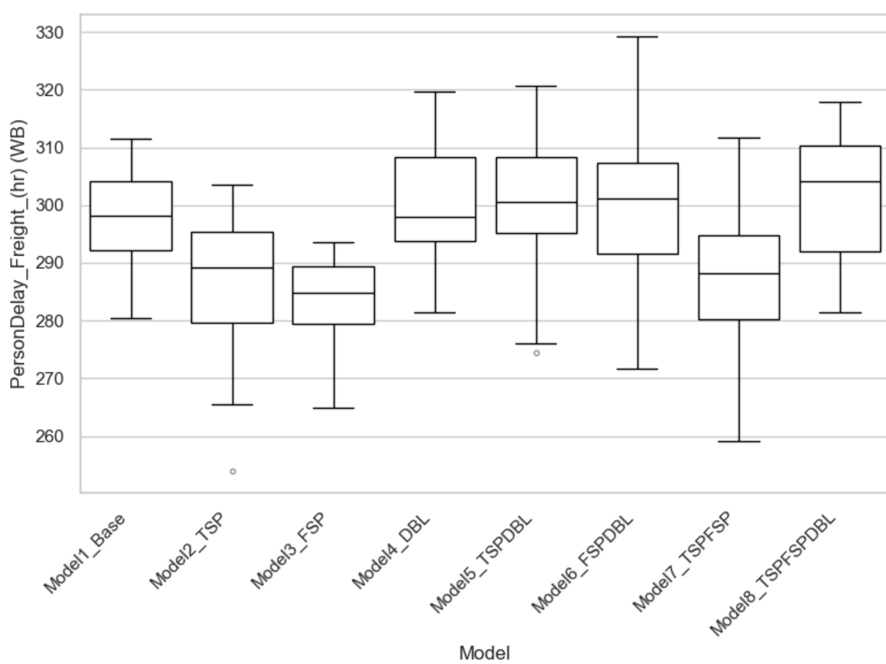



*Figure 34 - Cumulative total persons delay per scenario for freight in westbound movement*

In Figure 33 and Figure 34, the cumulative total person-delay (in hours) for freight vehicles is presented for the eastbound (EB) and westbound (WB) directions under various signal priority and DBL scenarios. These results offer a holistic perspective on freight-specific delay, capturing the total number of hours that freight occupants collectively spend waiting or traveling more slowly due to congestion and signal delays. The Base scenario shows 261 hours EB and 287 hours WB, serving as the benchmark for evaluating subsequent interventions.

The TSP scenario, which prioritizes transit vehicles at signalized intersections, leads to a slight increase in freight delay compared to the base. Specifically, EB rises to 267 hours (+6 hrs) and WB to 289 hours (+2 hrs), indicating that transit-preferential signal timings can slightly hamper freight flow. Nonetheless, these increases remain relatively modest, reflecting that TSP's impact on other vehicle classes is not excessively disruptive.

Under Freight Signal Priority (FSP), the EB delay remains at 261 hours (no change from base), while WB experiences a slight increase to 289 hours (+2 hrs). Given that FSP is designed to enhance the progression of freight vehicles at intersections, the minimal changes suggest that Base freight volumes or signal configurations might be limiting the full potential of FSP. However, these results also imply that FSP does not substantially disadvantage freight in either direction.

In contrast, the DBL scenario exhibits a noticeable rise in freight delays, with EB reaching 273 hours (+12 hrs) and WB climbing to 308 hours (+21 hrs). This outcome can be attributed to the reallocation of a general-purpose lane to bus-only traffic, reducing capacity for other vehicles, including freight. The WB direction experiences a more significant increase, indicating that lane constraints or volume imbalances may be particularly pronounced there.

When TSP and DBL are combined, EB delay dips to 262 hours and WB slightly declines to 307 hours from the DBL-only scenario, suggesting that transit signal priority might mitigate some of the delays introduced by DBL, albeit not enough to return to Base levels. A similar pattern emerges in the FSP & DBL scenario, where EB is 266 hours and WB is 308 hours, reflecting that even freight prioritization at intersections cannot fully overcome the congestion caused by reduced lane capacity.

Conversely, the TSP FSP scenario without DBL yields the lowest EB delay of all scenarios at 258 hours (-3 hrs from the base) and maintains WB delay at 289 hours (+2 hrs). This indicates that combining transit and freight signal priorities can, in certain configurations, benefit freight vehicles by streamlining overall signal operations. The improved EB performance may stem from more frequent or synergistic priority requests, effectively maintaining green phases for through movements.

Lastly, the TSP FSP & DBL scenario yields 276 hours EB (+15 hrs from base) and 309 hours WB (+22 hrs), one of the highest overall delays for freight. This aligns with the patterns seen in other DBL-inclusive scenarios: reducing lane availability intensifies congestion, and the resulting surge in priority requests (from both transit and freight) can lead to complex signal phases that compound delays.

Overall, these findings reinforce that DBL has the greatest potential to increase person-delays for freight, overshadowing the relatively small changes observed under TSP or FSP alone. The TSP FSP combination emerges as the best non- DBL strategy for minimizing freight delay, whereas scenarios involving DBL introduce capacity constraints that outpace the benefits offered by any form of signal priority.

### 5.2.3. Total Persons Delay for Transit

Table 14 and Figure 35 show the total persons delay (in hours) for the transit along the eastbound (EB) movement of Queen Street during the PM peak hours.

| **Road Segment** | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **West Dr - Dixie EB** | 13.36 | 12.38 (-0.99) | 14.38 (+1.02) | 12.68 (-0.69) | 13.08 (-0.28) | 13.64 (+0.28) | 12.85 (-0.52) | 14.03 (+0.67) |
| **Dixie - Central Park EB** | 11.99 | 12.6 (+0.61) | 11.64 (-0.36) | 11.41 (-0.59) | 10.79 (-1.21) | 10.04 (-1.96) | 12.1 (+0.11) | 10.33 (-1.67) |
| **Central Park - Bramalea EB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Bramalea - Finchgate EB** | 13.01 | 11.14 (-1.88) | 10.72 (-2.30) | 9.89 (-3.13) | 9.58 (-3.44) | 10.2 (-2.82) | 12.53 (-0.49) | 9.98 (-3.04) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Finchgate - Torbram Rd EB** | 9.99 | 7.08 (-2.91) | 8.29 (-1.71) | 10.05 (+0.06) | 8.67 (-1.33) | 9.2 (-0.80) | 8.68 (-1.32) | 8.76 (-1.24) |
| **Torbram Rd - Torbram Plaza (Walmart) EB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Torbram Plaza (Walmart) - Gateway EB** | 6.69 | 7.64 (+0.95) | 6.71 (+0.02) | 7.64 (+0.95) | 6.57 (-0.14) | 6.3 (-0.40) | 6.92 (+0.23) | 5.69 (-1.01) |
| **Gateway - Smart Centres (Tim Hortons) EB** | 14.68 | 14.3 (-0.39) | 14.62 (-0.07) | 14.29 (-0.40) | 14.56 (-0.13) | 14.2 (-0.49) | 14.82 (+0.14) | 13.05 (-1.63) |
| **Smart Centres - Airport Rd EB** | 11.75 | 10.6 (-1.16) | 12.12 (+0.37) | 12.18 (+0.42) | 10.94 (-0.83) | 10.18 (-1.58) | 10.43 (-1.34) | 11.07 (-0.69) |
| **Airport Rd - Delta Park EB** | 25.76 | 26.47 (+0.71) | 23.55 (-2.22) | 28.72 (+2.96) | 24.05 (-1.72) | 23.71 (-2.06) | 26.5 (+0.74) | 26 (+0.24) |
| **Delta Park - Auction Ln EB** | 42.93 | 42.57 (-0.37) | 35.89 (-7.06) | 33.45 (-9.49) | 30.05 (-12.89) | 33.41 (-9.54) | 36.95 (-6.00) | 33.25 (-9.69) |
| **Auction Ln - Goreway EB** | 34.67 | 28.95 (-5.73) | 31.07 (-3.61) | 30.64 (-4.04) | 27.35 (-7.33) | 28.25 (-6.43) | 33.79 (-0.89) | 26.81 (-7.87) |
| **Goreway - McVean EB** | 26.61 | 23.68 (-2.94) | 27.09 (+0.48) | 26.51 (-0.12) | 26.45 (-0.18) | 26.01 (-0.62) | 25.32 (-1.31) | 28.7 (+2.08) |
| **McVean - Cherrycrest EB** | 12.19 | 12.68 (+0.48) | 13.29 (+1.10) | 12.07 (-0.13) | 13.76 (+1.57) | 12.52 (+0.33) | 11.36 (-0.84) | 15.27 (+3.08) |
| **Cherrycrest - Beaumaris EB** | 2.93 | 2.31 (-0.63) | 2.85 (-0.09) | 3.84 (+0.90) | 3.19 (+0.26) | 3.25 (+0.32) | 2.87 (-0.07) | 3.21 (+0.28) |
| **Beaumaris - Gore Rd EB** | 1.36 | 1.22 (-0.15) | 1.49 (+0.13) | 1.06 (-0.31) | 1.15 (-0.21) | 1.41 (+0.05) | 1.83 (+0.48) | 1.02 (-0.35) |
| **Gore Rd EB** | 7.18 | 8.86 (+1.68) | 8.31 (+1.14) | 7.72 (+0.54) | 7.71 (+0.53) | 7.68 (+0.51) | 8.84 (+1.66) | 7.44 (+0.26) |
| **EB Cumulative** | 235.10 | 222.42 (-12.70) | 221.96 (-13.16) | 222.06 (-13.06) | 207.83 (-27.28) | 209.93 (-25.18) | 225.71 (-9.40) | 214.55 (-20.57) |

*Table 14 - Total Persons Delay for transit in the Eastbound direction for Queen St*

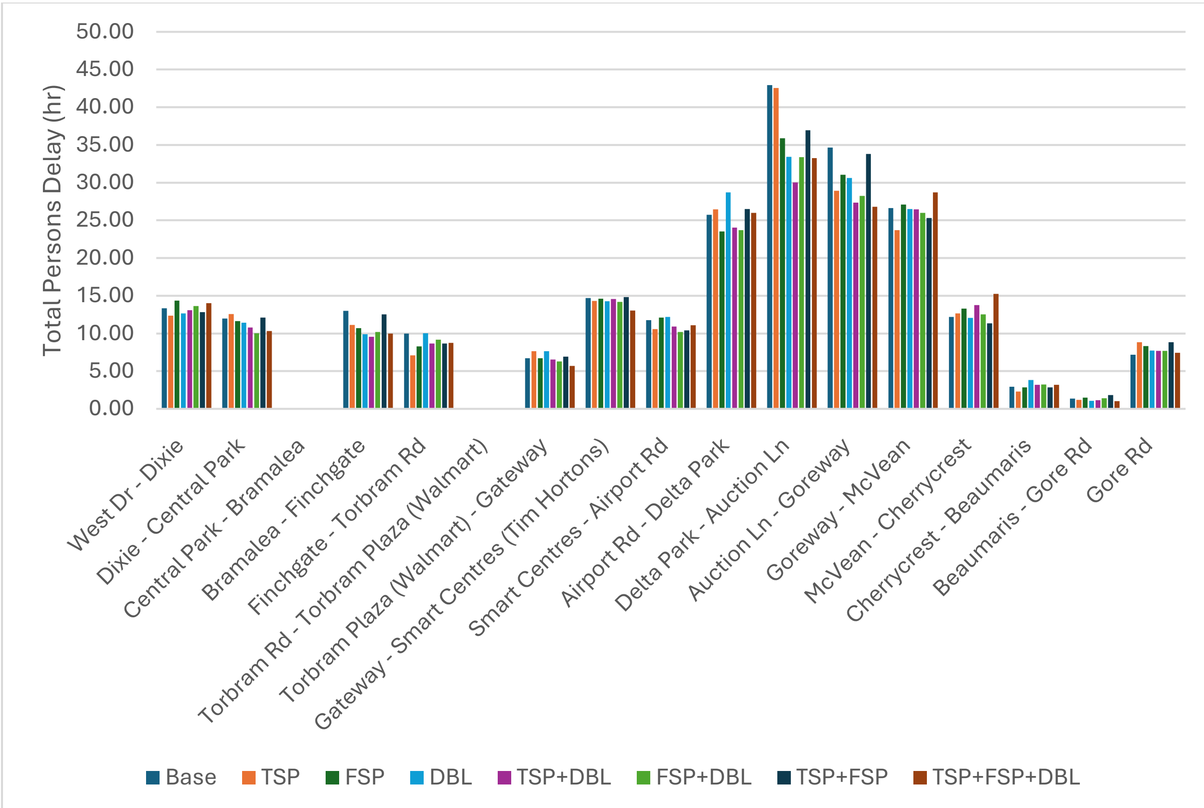



*Figure 35 - Total persons delay for transit in the eastbound direction*

Under Base conditions, transit in the EB direction incurs 235.10 hours of person-delay. Implementing TSP reduces this total to 222.42 hours (−12.70 hours, −5.4%), demonstrating that extending or adjusting green signals to accommodate buses can diminish passenger wait time. Numerous segments benefit, such as Bramalea - Finchgate EB (−1.88 hours) and Cherrycrest - Beaumaris EB (−0.63 hours), though a few links see modest increases, like Dixie - Central Park EB (+0.61 hours).

By contrast, FSP alone yields 221.96 hours (−13.14 hours, −5.6%), suggesting that while priority is designed for freight vehicles, it can also enhance transit flow in certain conditions, particularly where extended or more frequent green phases incidentally benefit buses. Some segments, including Bramalea - Central Park EB (−2.22 hours), highlight these indirect gains.

The DBL scenario alone decreases EB transit person-delay to 222.06 hours (−13.04 hours, −5.6%), indicating that dedicating a lane to buses facilitates smoother travel, though not universally. Segments such as Airport Rd - Delta Park EB (+2.26 hours) and Delta Park - Auction Ln EB (−7.06 hours) suggest that factors like intersection design and stop placements can create mixed outcomes along the corridor.

When TSP and DBL are combined, total delay falls to 207.83 hours (−27.28 hours, −11.6%), illustrating that coordinating signal timing in tandem with a bus-only lane can substantially reduce transit occupant delays. A similar trend emerges under FSP & DBL, where delay reaches 209.93 hours (−25.18 hours, −10.7%), reflecting moderate synergy between freight-based priority phases and the physical separation provided by DBL.

Notably, TSP FSP, without a dedicated lane, reduces total EB delay to 225.71 hours (−9.39 hours, −4.0%), showing that transit can still benefit from both priority types, though the gain is smaller than TSP alone in this particular scenario. Once DBL is added to TSP FSP (TSP FSP & DBL), transit delay drops to 214.55 hours (−20.57 hours, −8.7%), confirming that a DBL, combined with carefully tuned signal preferences, can further streamline passenger travel times.

Overall, these results indicate that signal priority measures (TSP, FSP) and DBL both substantially reduce transit passenger delays, often delivering the greatest advantages when employed together. However, the degree of improvement can vary by segment, reflecting how geometric design, intersection density, and operational characteristics interact with each strategy.

In Figure 36 and Figure 37, the cumulative total person-delay (in hours) for transit vehicles is displayed for the eastbound (EB) and westbound (WB) directions under various signal priority and DBL scenarios. This person-delay metric accounts for the total hours that transit occupants collectively spend in slower or stopped traffic, offering a more passenger-focused view than average travel time alone.

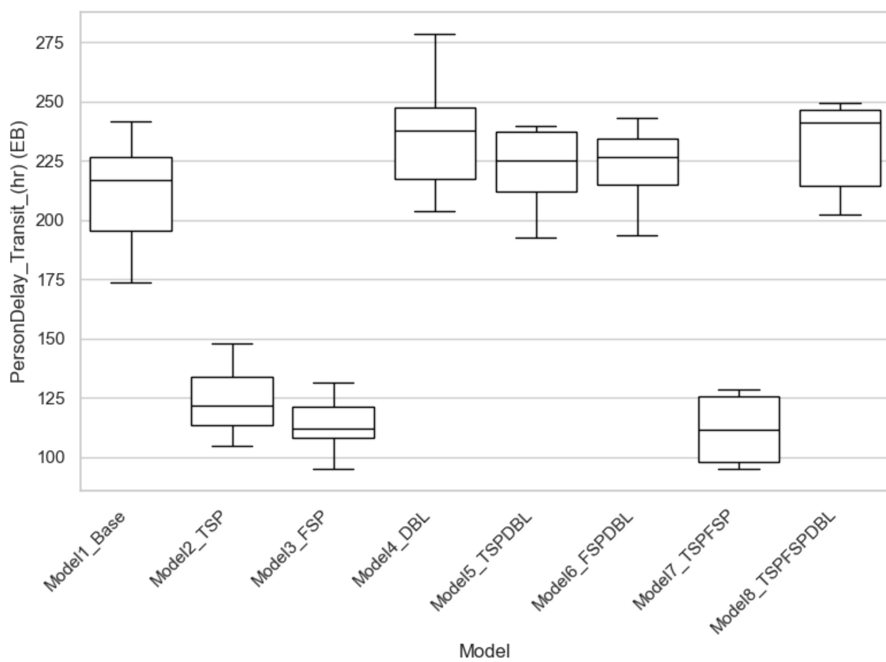



*Figure 36 - Cumulative total persons delay per scenario for transit in eastbound movement*

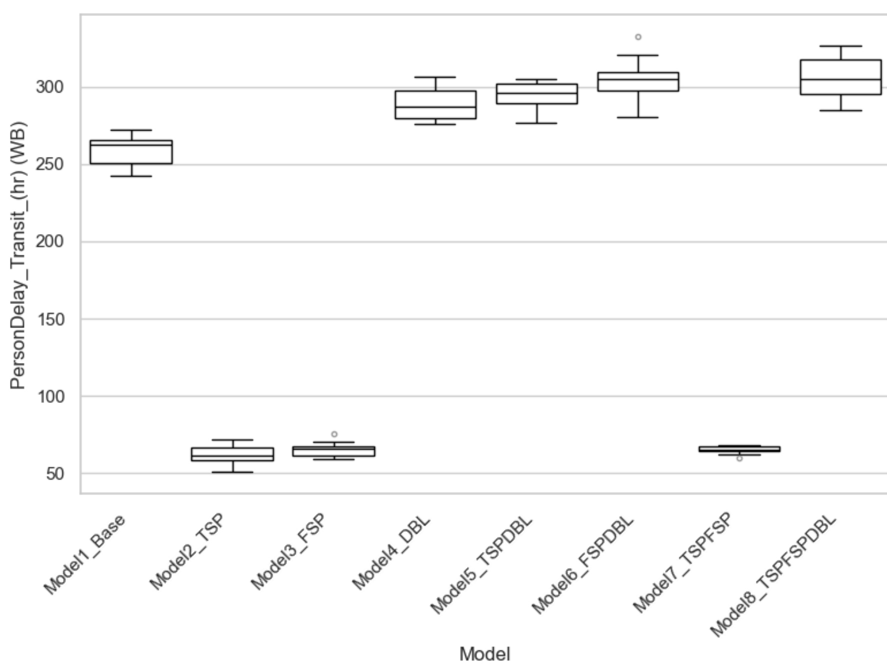



*Figure 37 - Cumulative total persons delay per scenario for transit in westbound movements*

Under the Base scenario, EB transit vehicles experience 235 hours of delay, while WB vehicles experience 262 hours. These values serve as the reference for subsequent comparisons. The introduction of

Transit Signal Priority (TSP) alone reduces EB delay to 222 hours (-13 hrs) yet slightly increases WB delay to 272 hours (+10 hrs). This pattern suggests that while TSP generally benefits transit, the direction-specific signal timing or roadway constraints in the WB direction may offset some of its potential advantages.

A similar outcome is observed in the Freight Signal Priority (FSP) alone scenario, where EB delay remains at 222 hours (-13 hrs) and WB delay increases to 275 hours (+13 hrs). Although FSP is designed for freight vehicles, the extended green phases can also help, or in some cases hinder, transit flow, depending on intersection spacing and traffic volumes in each direction.

By contrast, the DBL scenario yields 275 hours of delay EB (+40 hrs) and 281 hours WB (+19 hrs). While a dedicated lane is generally intended to improve transit operations, these results suggest that other factors, such as intersection conflicts, lane-access restrictions, or detours, may still pose challenges for buses. The net effect is higher total delay for transit passengers, especially in the EB direction.

When TSP and DBL are combined, EB delay falls notably to 208 hours (-27 hrs from base), whereas WB delay remains slightly elevated at 273 hours (+11 hrs). This outcome indicates that transit-prioritized signal phasing can help offset some of DBL's drawbacks in one direction but may be less effective where congestion or roadway design limits improvements. Similarly, the FSP & DBL scenario leads to 210 hours EB (-25 hrs) and 278 hours WB (+16 hrs), demonstrating small gains in EB at the cost of higher WB delay.

The TSP FSP combination, without DBL, produces 226 hours EB (-9 hrs) and 279 hours WB (+17 hrs). These mixed results imply that while adding freight priority to transit priority can smooth some aspects of corridor flow, the benefits are not uniform across directions. Finally, the TSP FSP & DBL scenario yields 215 hours EB (-20 hrs) and 279 hours WB (+17 hrs), signifying that, despite noteworthy improvements in EB delay, the cumulative DBL and priority strategies still elevate WB delay compared to the base.

Overall, the findings demonstrate the complexity of managing corridor-wide transit performance. DBL's physical constraints can undermine the benefits of signal priority, and different directions may experience disparate outcomes depending on intersection density, competing traffic demands, and lane configurations. While TSP and FSP individually can reduce transit delay (particularly eastbound), their effectiveness varies when combined with DBL, highlighting the importance of carefully coordinating infrastructure changes with operational strategies to optimize overall passenger travel conditions.

## 5.3. Emissions Analysis

Emissions (CO, NOx, VOC) and fuel consumption, recorded by direction but not disaggregated by mode, capture corridor-level environmental impacts. Since these pollutants disperse freely and affect the region's air quality broadly, what matters is the aggregate effect along each direction of travel; differentiating them by vehicle class could dilute the corridor-level picture, especially if data on mode-specific emissions factors are limited. Collecting these environmental MOEs at each node ensures that intersection-specific idling and speed variations, key determinants of emissions, are accounted for in assessing the overall environmental footprint.

### 5.3.1. CO Emissions

Table 15 and Figure 38 show the CO emissions (in grams) for all modes along the eastbound (EB) movement of Queen Street during the PM peak hours.

| **Road Segment** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Drive** | 3405.85 | 3392.43 (-13.43) | 3366.71 (-39.15) | 4267.48 (+861.63) | 3992.21 (+586.36) | 4002.33 (+596.48) | 3367.01 (-38.86) | 4120.03 (+714.17) |
| **Dixie Road** | 4843.23 | 4573.15 (-270.09) | 4451.46 (-391.78) | 4765.06 (-78.18) | 4885.31 (+42.08) | 4749.12 (-94.13) | 4548.98 (-294.27) | 4876.37 (+33.13) |
| **Central Park** | 2386.96 | 2461.81 (+74.85) | 2686.13 (+299.16) | 2671.82 (+284.86) | 3255.89 (+868.93) | 3157.07 (+770.11) | 2420.47 (+33.51) | 2858.4 (+471.44) |
| **Bramalea Road** | 4140.05 | 4155.2 (+15.14) | 4106.3 (-33.76) | 4098.75 (-41.31) | 4135.33 (-4.73) | 4213.31 (+73.26) | 4078.49 (-61.57) | 3967.43 (-172.64) |
| **Finchgate** | 1761.36 | 1827.29 (+65.93) | 1825.54 (+64.18) | 1938.49 (+177.13) | 1865.02 (+103.66) | 1874.12 (+112.76) | 1845.54 (+84.18) | 1869.46 (+108.10) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Torbram Road** | 2161.33 | 2329.08 (+167.75) | 2402.23 (+240.90) | 2527.53 (+366.20) | 2461.57 (+300.25) | 2554.26 (+392.93) | 2301.19 (+139.86) | 2379.83 (+218.50) |
| **Torbram Plaza** | 1295.24 | 1360.97 (+65.73) | 1310.2 (+14.97) | 1384.44 (+89.21) | 1303.26 (+8.02) | 1371.36 (+76.13) | 1308.18 (+12.94) | 1363.27 (+68.03) |
| **Gateway** | 1682.24 | 1724.27 (+42.02) | 1681.36 (-0.89) | 1784.3 (+102.06) | 1764.95 (+82.71) | 1756.2 (+73.96) | 1776.72 (+94.47) | 1763.32 (+81.07) |
| **Smart Centres** | 1633.79 | 1691.37 (+57.59) | 1747.7 (+113.91) | 1790.78 (+156.99) | 1633.23 (-0.57) | 1584.64 (-49.15) | 1662.86 (+29.07) | 1797.35 (+163.56) |
| **Airport Road** | 4486.21 | 4765.39 (+279.18) | 4763.28 (+277.07) | 5155.38 (+669.17) | 4843.05 (+356.84) | 4772.22 (+286.01) | 4888.97 (+402.76) | 5551.99 (+1065.78) |
| **Delta Park** | 8926.26 | 9642.98 (+716.72) | 9010.06 (+83.80) | 8979.28 (+53.02) | 9115.81 (+189.55) | 9409.58 (+483.32) | 9072.06 (+145.81) | 9641.97 (+715.71) |
| **Auction Lane** | 10711.17 | 11033.83 (+322.66) | 10297.65 (-413.53) | 9385.6 (-1325.58) | 8924.52 (-1786.66) | 9545.94 (-1165.24) | 10367.95 (-343.22) | 9354.41 (-1356.76) |
| **Goreway Drive** | 5785.13 | 5831.32 (+46.19) | 5769.16 (-15.97) | 5747.09 (-38.05) | 5700.53 (-84.61) | 5756.74 (-28.40) | 5760.88 (-24.26) | 5730.99 (-54.15) |
| **McVean** | 3810.04 | 3694.95 (-115.10) | 3690.7 (-119.35) | 3604.36 (-205.69) | 3633.68 (-176.37) | 3686 (-124.05) | 3736.66 (-73.39) | 3561.56 (-248.49) |
| **Cherrycrest** | 2495.55 | 2416.27 (-79.29) | 2488.74 (-6.83) | 2825.84 (+330.29) | 2772.58 (+277.03) | 2787.1 (+291.55) | 2490.76 (-4.80) | 2718.32 (+222.77) |
| **Beaumaris** | 1933.31 | 1948.59 (+15.27) | 1937.12 (+3.81) | 1903.22 (-30.10) | 1915.68 (-17.64) | 1955.98 (+22.66) | 1921.22 (-12.10) | 1847.02 (-86.31) |
| **Gore Road** | 3436.04 | 3453.4 (+17.36) | 3363.61 (-72.43) | 3411.76 (-24.29) | 3480.29 (+44.25) | 3414.96 (-21.08) | 3359.53 (-76.52) | 3273.61 (-162.43) |
| **EB Cumulative** | 64893.77 | 66302.19 (+1408.41) | 64897.89 (+4.12) | 66241.11 (+1347.34) | 65682.83 (+789.06) | 66590.87 (+1697.10) | 64907.39 (+13.62) | 66675.25 (+1781.47) |

*Table 15 - CO emissions for the eastbound along the EB in Queen Street (in grams)*

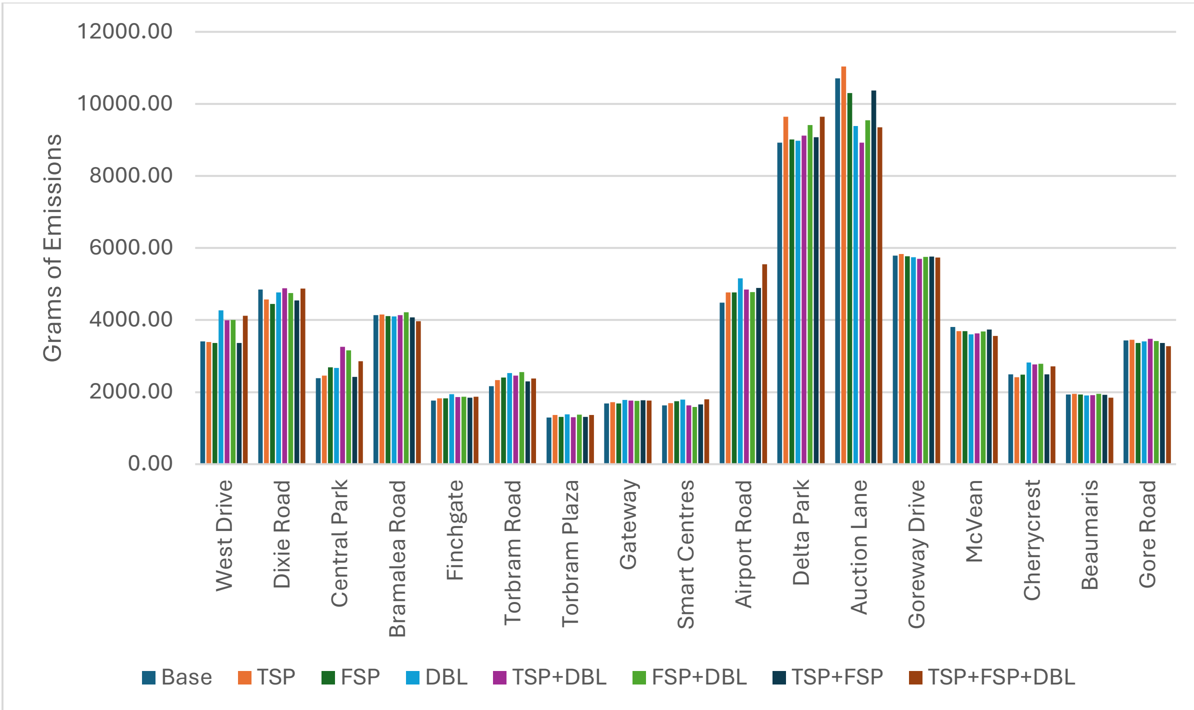



*Figure 38 - CO emissions in each intersection in the EB of Queen Street*

Under Base conditions, total EB CO emissions amount to 64,893.77 g. The TSP scenario raises this figure to 66,302.19 g (+1,408.42 g, +2.2%), with significant increases on links such as Torbram Road (+368.76 g) and McVean (+583.8 g). These rises suggest that extending green signals for transit can intensify congestion or idling for general traffic in certain areas. However, some segments, like Dixie Road (−270.05 g), record decreased emissions, indicating possible efficiency gains where TSP alleviates intersection bottlenecks.

By comparison, FSP yields 64,897.89 g (+4.12 g, +0.01%), nearly matching the base total. Although specific locations see marked increases, as with Delta Park (+1,010.06 g), others such as Gateway (−42.02 g) register reductions. These mixed results imply that prioritizing freight vehicles can curb stop-and-go traffic for heavy trucks in certain segments while marginally increasing it for other road users.

Conversely, DBL causes the most substantial escalation in emissions, reaching 66,241.11 g (+1,347.34 g, +2.1%). Large increases occur along high-volume arterials, for instance, Central Park (+284.8 g) and Airport Road (+1,027.6 g), reflecting how lane reallocation to buses can create more severe congestion for other vehicle classes. The heightened idling and slower travel speeds contribute to amplified CO outputs.

When TSP and DBL are implemented together, CO emissions reach 65,682.83 g (+789.06 g, +1.2%), indicating that transit signal priority partially mitigates, but does not eliminate, the adverse effects of dedicating a lane to bus traffic. The combination of FSP and DBL yields 66,590.87 g (+1,697.10 g, +2.6%), indicating that while freight priority can help reduce truck-based idling, DBL's capacity reduction remains the stronger influence on corridor-wide emissions.

Interestingly, the TSP FSP scenario (without DBL) lowers emissions to 64,907.39 g (+13.62 g, +0.02%), nearly matching the base outcome. Some segments, like Dixie Road (−98.76 g), show significant reductions, suggesting that coordinating transit and freight signals can stabilize traffic flow enough to mitigate overall CO production. However, adding DBL to this dual-priority setup (TSP FSP & DBL) pushes emissions upward to 66,675.25 g (+1,781.48 g, +2.7%), confirming that lane reallocation for buses exerts the most pronounced impact on air quality, regardless of signal strategies.

Overall, these results demonstrate that DBL consistently triggers the largest rises in CO emissions, overshadowing the smaller, and sometimes beneficial, impacts of TSP and FSP. By contrast, TSP and FSP, especially in tandem without DBL, have minimal net effects on CO, demonstrating their relatively modest influence compared to lane-capacity changes.

In Figure 39 and Figure 40, the cumulative carbon monoxide (CO) emissions (in grams) for eastbound (EB) and westbound (WB) traffic are presented under various signal priority and DBL scenarios. These results illustrate how modifications to lane configurations and signal timings influence overall vehicle emissions, serving as a proxy for environmental impact and air quality concerns.

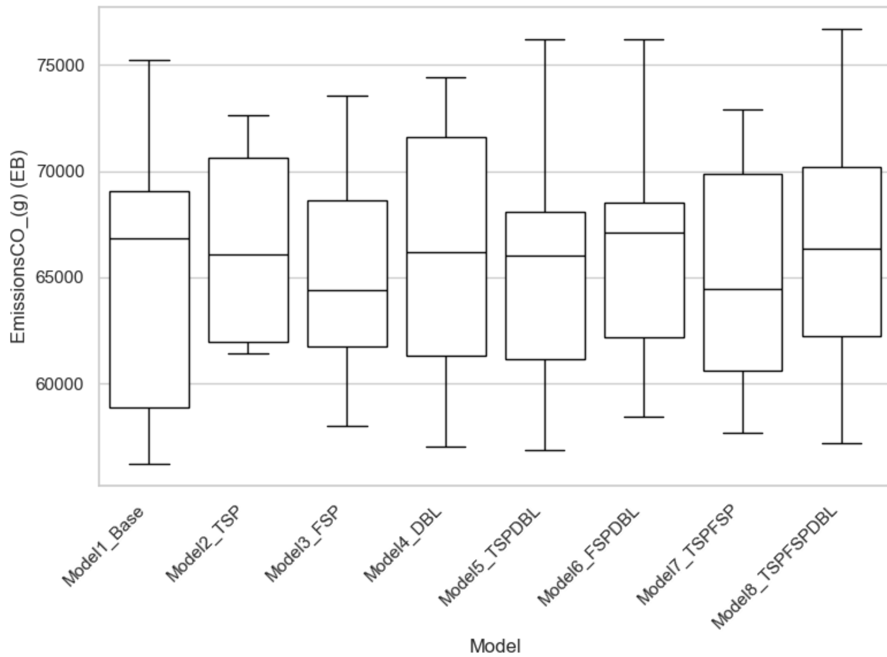



*Figure 39 - Cumulative CO emissions per scenario in the westbound movement in grams*

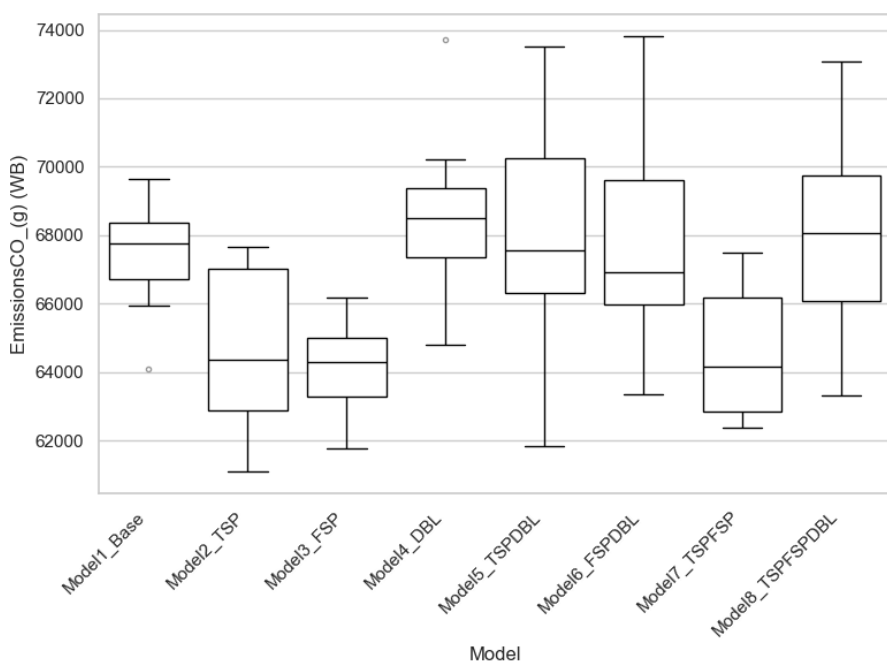



*Figure 40 - Cumulative CO emissions per scenario in the westbound movement in grams*

Under the Base scenario, total CO emissions reach 64,894 g in EB and 69,941 g in WB. These values provide a reference point for examining the effectiveness of priority measures in reducing or shifting emissions. The Transit Signal Priority (TSP) scenario shows 66,302 g EB (+1,408 g from base) and 68,044 g WB (-1,897 g), indicating that while TSP marginally increases emissions in the eastbound direction, it reduces them somewhat in the westbound direction, possibly due to fewer idling buses and smoother progression at signals.

Freight Signal Priority (FSP) yields 64,898 g EB (+4 g) and 67,587 g WB (-2,354 g), effectively maintaining near-base conditions eastbound and offering modest reductions westbound. This subtle shift may reflect FSP's limited frequency of activation and the potential secondary benefits for general traffic when freight flow is optimized.

Conversely, the DBL-only scenario results in an overall increase in emissions: 66,241 g EB (+1,347 g) and 71,922 g WB (+1,981 g). These rises can be attributed to the reallocation of a general-purpose lane to exclusive bus use, creating additional congestion for other vehicles and leading to more stop-and-go conditions that elevate CO output.

When TSP and DBL are combined, emissions in EB decline to 65,683 g (-558 g compared to DBL alone), and WB dips to 71,375 g (-547 g), suggesting that transit signal priority can partially mitigate the congestion induced by lane reconfiguration. A similar trend appears under FSP & DBL, which shows 66,591 g EB and 71,375 g WB, comparable westbound emissions to TSP & DBL but slightly higher eastbound emissions, implying that FSP is not as effective as TSP in offsetting DBL-related congestion on the EB corridor.

In contrast, the TSP FSP combination (without DBL) yields 64,907 g EB (+13 g from base) and 67,982 g WB (-1,959 g). While nearly matching the base in EB, this scenario achieves a notable reduction in WB emissions, underlining the benefits of integrated signal priority for both transit and freight. Finally, TSP FSP & DBL results in 66,675 g EB (+1,781 g) and 71,525 g WB (+1,584 g), indicating that while dual-priority measures help somewhat, the lane reduction imposed by DBL still elevates emissions in both directions.

Overall, the findings suggest that DBL consistently raises emissions due to decreased capacity for general traffic, while TSP or FSP alone yield modest improvements or small increases, depending on direction and volume. The TSP FSP scenario without DBL emerges as the most balanced configuration, closely matching base emissions eastbound and reducing them westbound. In contrast, any DBL-inclusive scenario sees net increases in CO, showing the importance of assessing the broader environmental trade-offs when introducing dedicated lanes.

## 5.3.2. NOx Emissions

Table 16 and Figure 41 show the NOx emissions (in grams) for all modes along the eastbound (EB) movement of Queen Street during the PM peak hours.

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Drive** | 662.66 | 660.05 (-2.62) | 655.04 (-7.62) | 830.3 (+167.65) | 776.74 (+114.09) | 778.71 (+116.06) | 655.1 (-7.56) | 801.61 (+138.96) |
| **Dixie Road** | 942.32 | 889.77 (-52.55) | 866.1 (-76.23) | 927.11 (-15.22) | 950.51 (+8.19) | 924.01 (-18.32) | 885.07 (-57.26) | 948.77 (+6.45) |
| **Central Park** | 464.42 | 478.98 (+14.57) | 522.63 (+58.21) | 519.84 (+55.43) | 633.48 (+169.07) | 614.26 (+149.84) | 470.94 (+6.52) | 556.15 (+91.73) |
| **Bramalea Road** | 805.50 | 808.45 (+2.95) | 798.94 (-6.57) | 797.47 (-8.04) | 804.59 (-0.92) | 819.76 (+14.26) | 793.53 (-11.98) | 771.92 (-33.59) |
| **Finchgate** | 342.70 | 355.53 (+12.83) | 355.19 (+12.49) | 377.16 (+34.47) | 362.87 (+20.17) | 364.64 (+21.94) | 359.08 (+16.38) | 363.73 (+21.04) |
| **Torbram Road** | 420.52 | 453.16 (+32.64) | 467.39 (+46.88) | 491.77 (+71.25) | 478.94 (+58.42) | 496.97 (+76.45) | 447.73 (+27.22) | 463.03 (+42.52) |
| **Torbram Plaza** | 252.01 | 264.8 (+12.79) | 254.92 (+2.92) | 269.37 (+17.36) | 253.57 (+1.56) | 266.82 (+14.82) | 254.53 (+2.52) | 265.25 (+13.24) |
| **Gateway** | 327.30 | 335.48 (+8.18) | 327.14 (-0.18) | 347.16 (+19.86) | 343.4 (+16.10) | 341.7 (+14.39) | 345.69 (+18.38) | 343.08 (+15.78) |
| **Smart Centres** | 317.88 | 329.08 (+11.21) | 340.04 (+22.17) | 348.42 (+30.55) | 317.77 (-0.11) | 308.32 (-9.57) | 323.54 (+5.66) | 349.7 (+31.83) |
| **Airport Road** | 872.85 | 927.17 (+54.32) | 926.77 (+53.91) | 1003.05 (+130.20) | 942.28 (+69.43) | 928.5 (+55.65) | 951.22 (+78.37) | 1080.22 (+207.37) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Delta Park** | 1736.73 | 1876.18 (+139.45) | 1753.03 (+16.31) | 1747.05 (+10.32) | 1773.61 (+36.88) | 1830.77 (+94.04) | 1765.1 (+28.37) | 1875.98 (+139.26) |
| **Auction Lane** | 2084.00 | 2146.79 (+62.78) | 2003.55 (-80.46) | 1826.1 (-257.91) | 1736.39 (-347.62) | 1857.3 (-226.72) | 2017.23 (-66.78) | 1820.03 (-263.98) |
| **Goreway Drive** | 1125.58 | 1134.57 (+8.99) | 1122.47 (-3.11) | 1118.18 (-7.41) | 1109.12 (-16.47) | 1120.06 (-5.53) | 1120.86 (-4.72) | 1115.05 (-10.54) |
| **McVean** | 741.30 | 718.91 (-22.40) | 718.08 (-23.22) | 701.28 (-40.02) | 706.99 (-34.32) | 717.17 (-24.14) | 727.02 (-14.28) | 692.95 (-48.35) |
| **Cherrycrest** | 485.54 | 470.12 (-15.43) | 484.22 (-1.33) | 549.81 (+64.27) | 539.45 (+53.90) | 542.27 (+56.73) | 484.62 (-0.94) | 528.89 (+43.35) |
| **Beaumaris** | 376.15 | 379.13 (+2.98) | 376.9 (+0.75) | 370.3 (-5.86) | 372.73 (-3.44) | 380.57 (+4.41) | 373.8 (-2.36) | 359.37 (-16.80) |
| **Gore Road** | 668.53 | 671.91 (+3.38) | 654.44 (-14.10) | 663.81 (-4.73) | 677.14 (+8.61) | 664.43 (-4.11) | 653.65 (-14.89) | 636.93 (-31.61) |
| **EB Cumulative** | 12625.97 | 12900 (+274.03) | 12626.78 (+0.81) | 12888.12 (+262.15) | 12779.5 (+153.53) | 12956.17 (+330.20) | 12628.62 (+2.65) | 12972.58 (+346.61) |

*Table 16 - NOx emissions for the eastbound along Queen Street (in grams)*

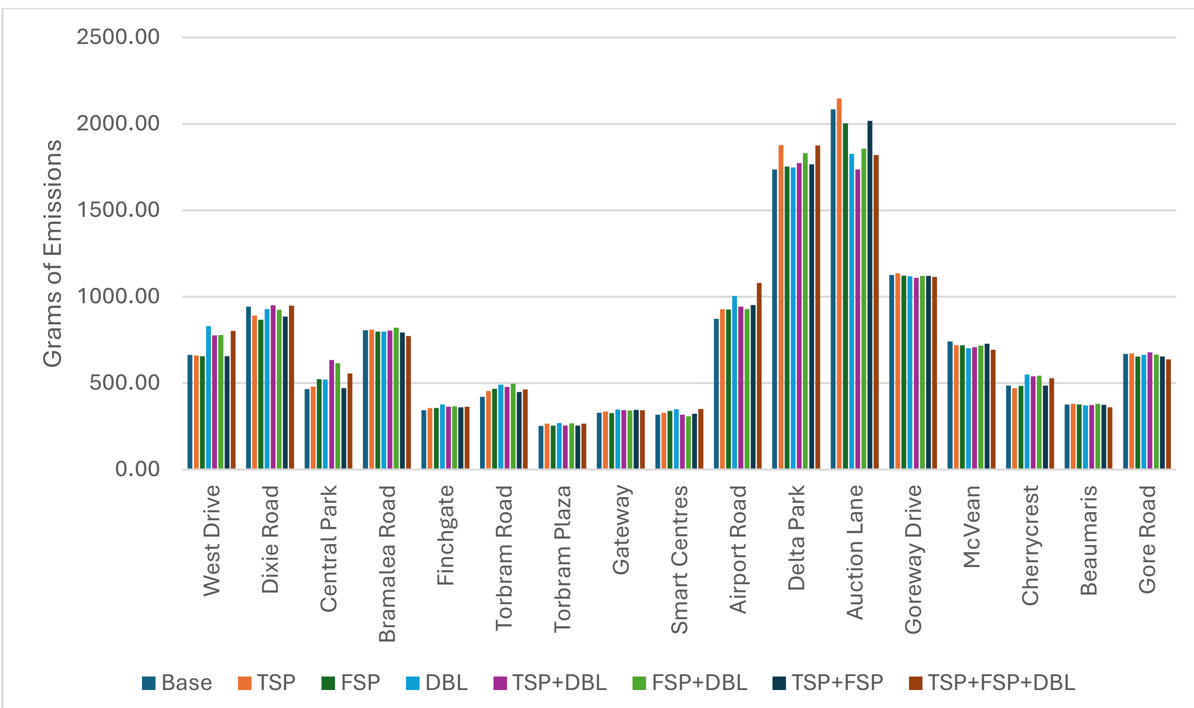



*Figure 41 - NOx emissions in each intersection in the EB*

Under Base conditions, total EB NOx emissions measure 12,625.97 g. The TSP scenario increases this figure to 12,900.20 g (+274.23 g, +2.2%), indicating that extended green times for transit vehicles can induce modest additional congestion or idling for other traffic. Specific links, such as Delta Park (+139.45

g) and Auction Lane (+68.28 g), show more pronounced spikes, while certain segments see minor dips in emissions.

By contrast, FSP yields 12,626.78 g (+0.81 g, +0.01%), effectively matching the base total. Although some areas, like Airport Road (+54.32 g), experience greater output, others, such as Bramalea Road (−1.28 g), balance these changes. This near-net-zero impact suggests that optimizations favoring heavy vehicles can, on the whole, hold corridor emissions near Base.

The DBL scenario pushes emissions to 12,888.28 g (+262.31 g, +2.1%), which demonstrates that lane reallocation tends to exacerbate congestion for non-bus traffic. Segments like West Drive (+167.65 g) and Airport Road (+130.24 g) highlight how bus-only lanes can force general traffic into fewer lanes, increasing stop-and-go conditions, and thus higher NOx output.

When TSP and DBL are combined, NOx emissions reach 12,779.55 g (+153.58 g, +1.2%), reflecting that transit-priority signaling can partially offset DBL-induced congestion. The FSP & DBL scenario rises to 12,956.17 g (+330.20 g, +2.6%), indicating that while freight-priority phasing can help trucks in isolated spots, lane reallocation remains the dominant factor shaping overall emissions.

Meanwhile, TSP FSP (without a DBL) generates 12,628.62 g (+2.65 g, +0.02%), mirroring FSP's minimal net change. Some segments benefit from reduced idling, while others encounter slight increases, resulting in a negligible overall shift from Base. However, once DBL is added to TSP FSP, TSP FSP & DBL, total emissions jump to 12,972.58 g (+346.61 g, +2.7%), confirming that lane capacity reduction for buses overwhelms minor gains from signal adjustments.

In summary, DBL consistently produces the largest increases in NOx, while TSP and FSP alone have limited net impact on corridor emissions. Though signal priorities can modestly mitigate DBL's effects, the lane reallocation needed for dedicated bus service remains the key driver in elevating NOx output.

In Figure 42 and Figure 43, the cumulative nitrogen oxides (NOx) emissions (in grams) for eastbound (EB) and westbound (WB) traffic are shown under various signal priority and DBL scenarios.

These results reveal how changes in lane allocation and signal timing can influence overall NOx output, providing a measure of potential air quality impacts.

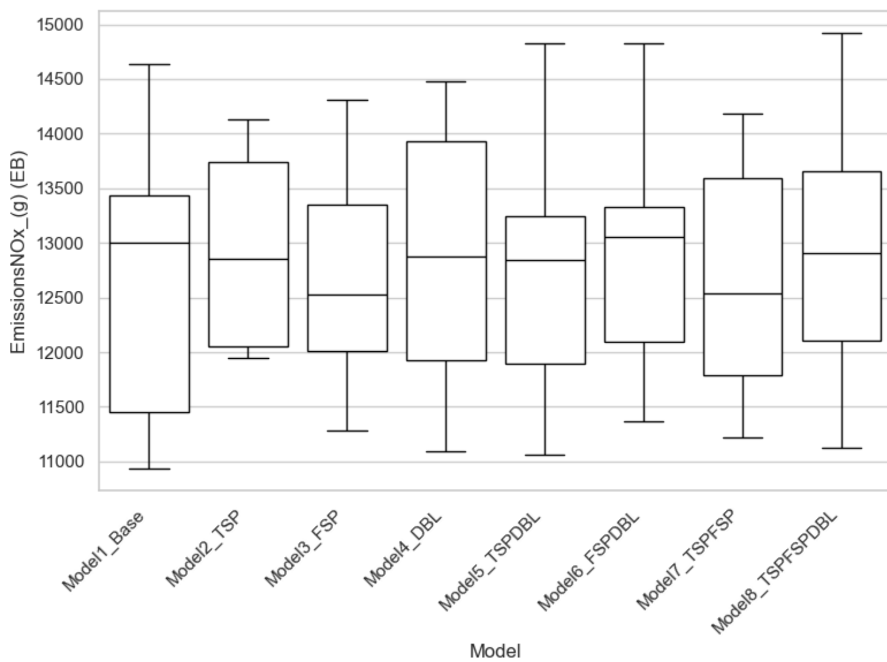



*Figure 42 - Cumulative NOx emissions per scenario in eastbound movement in grams*

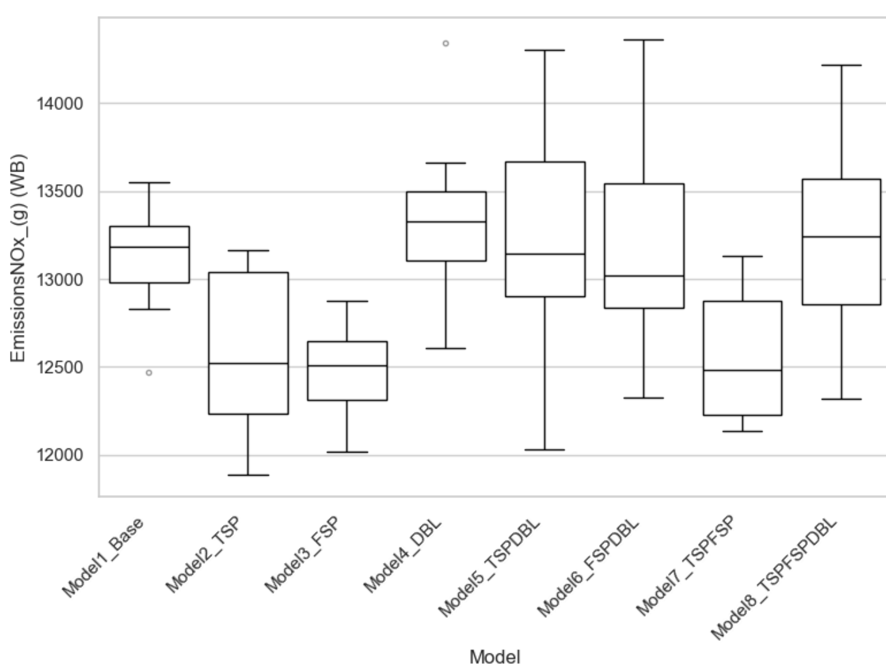


*Figure 43 - Cumulative NOx emissions per scenario in westbound movement in grams*

Under the Base scenario, EB NOx emissions total 12,626 g, while WB reaches 13,608 g, establishing the reference point. When Transit Signal Priority (TSP) is implemented, EB emissions increase to 12,900 g (+274 g), while WB emissions drop to 13,239 g (-369 g). This small net reduction for WB suggests that smoother bus flow might slightly reduce idling, even as EB sees a marginal uptick.

The Freight Signal Priority (FSP) scenario yields a near-Base result of 12,627 g EB and 13,150 g WB. These minimal changes indicate that FSP's adjustments, triggered by relatively fewer heavy vehicles, do not substantially alter NOx production in either direction.

By contrast, the DBL-only scenario shows higher emissions in both directions, with 12,888 g EB (+262 g) and 13,993 g WB (+385 g). This increase is attributed to the reallocation of a general-purpose lane for exclusive bus use, leading to more stop-and-go conditions for other vehicles, particularly in the busier WB corridor.

When TSP and DBL are combined, EB emissions drop slightly to 12,779 g compared to DBL alone, while WB emissions decrease to 13,887 g. This indicates that signal priority can partially counteract congestion-induced idling, but not enough to return to or below base conditions. A similar effect appears under FSP & DBL, which lowers EB emissions to 12,596 g, the lowest of any DBL-containing scenario, yet WB remains elevated at 13,887 g.

The TSP FSP combination (without DBL) yields nearly Base EB emissions (12,629 g) and modestly reduced WB emissions (13,227 g), signifying that coordinating transit and freight priorities can improve traffic flow enough to hold NOx near or just below the base scenario. Finally, in the TSP FSP & DBL scenario, EB climbs to 12,973 g (+344 g from base) and WB to 13,916 g (+308 g), highlighting that while dual-priority measures are beneficial, the capacity losses from dedicating a lane to DBL still increase emissions relative to the base.

Overall, the results demonstrate that DBL consistently increases NOx emissions unless partially mitigated by TSP or FSP. TSP and FSP alone produce minimal changes, with TSP FSP offering the most balanced approach near the Base. When lane reallocation is introduced, capacity constraints overshadow the incremental benefits of signal priority measures, increasing NOx in both directions.

### 5.3.3. VOC Emissions

Table 17 and Figure 44 show the VOC emissions (in grams) for all modes along the eastbound (EB) movement of Queen Street during the PM peak hours.

| **Road Segment** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Drive** | 789.34 | 786.23 (-3.12) | 780.27 (-9.08) | 989.03 (+199.69) | 925.24 (+135.90) | 927.58 (+138.24) | 780.34 (-9.01) | 954.86 (+165.52) |
| **Dixie Road** | 1122.47 | 1059.88 (-62.60) | 1031.67 (-90.80) | 1104.35 (-18.12) | 1132.22 (+9.76) | 1100.66 (-21.82) | 1054.27 (-68.20) | 1130.15 (+7.68) |
| **Central Park** | 553.20 | 570.55 (+17.35) | 622.54 (+69.34) | 619.22 (+66.02) | 754.59 (+201.39) | 731.69 (+178.48) | 560.97 (+7.77) | 662.47 (+109.26) |
| **Bramalea Road** | 959.50 | 963.01 (+3.51) | 951.68 (-7.83) | 949.93 (-9.58) | 958.41 (-1.10) | 976.48 (+16.98) | 945.23 (-14.27) | 919.49 (-40.01) |
| **Finchgate** | 408.21 | 423.5 (+15.28) | 423.09 (+14.88) | 449.27 (+41.05) | 432.24 (+24.03) | 434.35 (+26.14) | 427.72 (+19.51) | 433.27 (+25.06) |
| **Torbram Road** | 500.91 | 539.79 (+38.88) | 556.74 (+55.84) | 585.78 (+84.87) | 570.5 (+69.59) | 591.98 (+91.07) | 533.33 (+32.42) | 551.55 (+50.64) |
| **Torbram Plaza** | 300.18 | 315.42 (+15.24) | 303.66 (+3.47) | 320.86 (+20.68) | 302.05 (+1.86) | 317.83 (+17.65) | 303.19 (+3.00) | 315.96 (+15.77) |
| **Gateway** | 389.88 | 399.62 (+9.74) | 389.68 (-0.21) | 413.53 (+23.66) | 409.05 (+19.17) | 407.02 (+17.14) | 411.78 (+21.90) | 408.67 (+18.79) |
| **Smart Centres** | 378.65 | 392 (+13.35) | 405.05 (+26.40) | 415.03 (+36.39) | 378.52 (-0.14) | 367.26 (-11.40) | 385.39 (+6.74) | 416.56 (+37.91) |
| **Airport Road** | 1039.72 | 1104.43 (+64.71) | 1103.94 (+64.22) | 1194.81 (+155.09) | 1122.43 (+82.70) | 1106.01 (+66.29) | 1133.07 (+93.35) | 1286.73 (+247.01) |
| **Delta Park** | 2068.75 | 2234.86 (+166.11) | 2088.17 (+19.42) | 2081.04 (+12.29) | 2112.68 (+43.93) | 2180.77 (+112.02) | 2102.54 (+33.80) | 2234.62 (+165.88) |
| **Auction Lane** | 2482.42 | 2557.2 (+74.78) | 2386.58 (-95.84) | 2175.21 (-307.22) | 2068.35 (-414.08) | 2212.37 (-270.06) | 2402.88 (-79.55) | 2167.98 (-314.45) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **Goreway Drive** | 1340.76 | 1351.47 (+10.71) | 1337.06 (-3.71) | 1331.95 (-8.82) | 1321.16 (-19.61) | 1334.18 (-6.59) | 1335.14 (-5.63) | 1328.22 (-12.55) |
| **McVean** | 883.01 | 856.34 (-26.68) | 855.36 (-27.66) | 835.35 (-47.67) | 842.14 (-40.88) | 854.27 (-28.75) | 866.01 (-17.01) | 825.43 (-57.59) |
| **Cherrycrest** | 578.37 | 560 (-18.38) | 576.79 (-1.59) | 654.92 (+76.55) | 642.58 (+64.21) | 645.94 (+67.57) | 577.26 (-1.12) | 630 (+51.63) |
| **Beaumaris** | 448.06 | 451.61 (+3.54) | 448.95 (+0.89) | 441.09 (-6.98) | 443.98 (-4.09) | 453.32 (+5.26) | 445.27 (-2.81) | 428.07 (-20.01) |
| **Gore Road** | 796.33 | 800.36 (+4.03) | 779.55 (-16.79) | 790.71 (-5.63) | 806.59 (+10.26) | 791.45 (-4.89) | 778.61 (-17.74) | 758.7 (-37.65) |
| **EB Cumulative** | 15039.76 | 15366.18 (+326.42) | 15040.72 (+0.96) | 15352.02 (+312.26) | 15222.63 (+182.88) | 15433.08 (+393.32) | 15042.92 (+3.16) | 15452.64 (+412.88) |

*Table 17 - VOC emissions for the eastbound along Queen Street (in grams)*

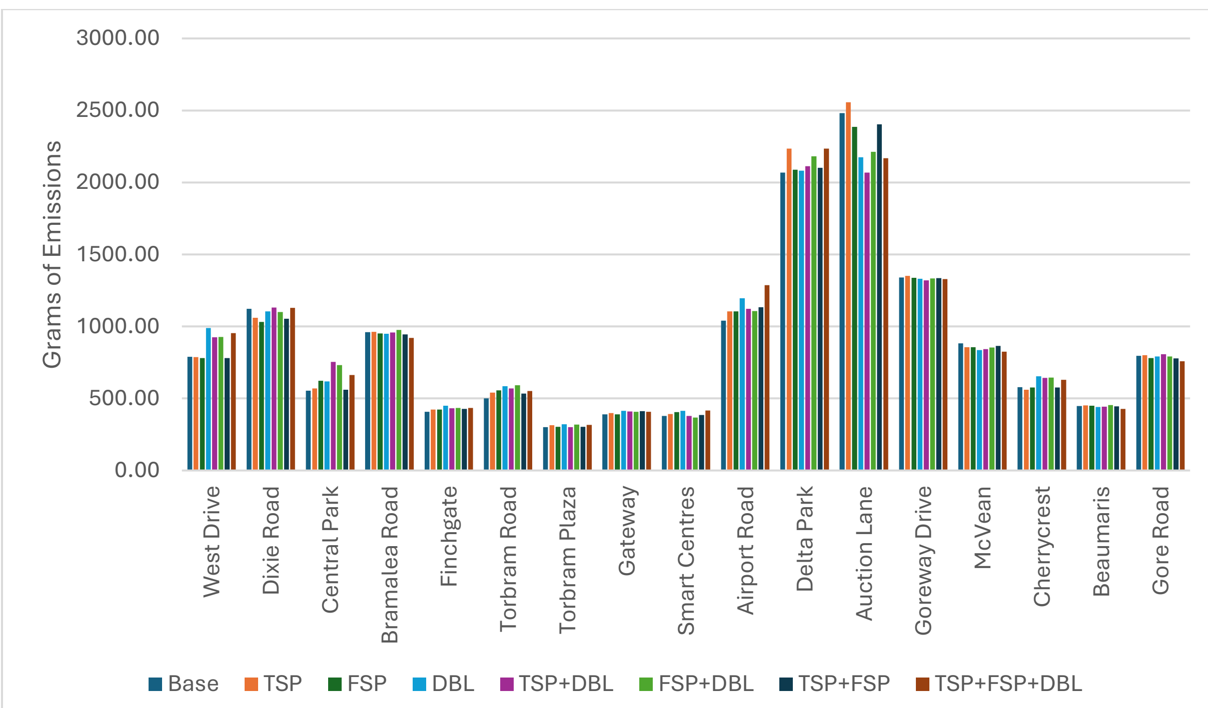



*Figure 44 - VOC emissions in each intersection in the EB*

Under Base conditions, total EB VOC emissions stand at 15,039.76 g. Introducing TSP increases this figure to 15,366.18 g (+326.42 g, +2.2%), suggesting that while extending green phases for transit improves bus throughput, it may also prolong idling for general traffic on certain links. Notable rises occur on Torbram Plaza (+185.73 g) and Airport Road (+64.71 g), though a few locations, such as Dixie Road (−62.60 g), see reductions.

Conversely, FSP leads to 15,040.20 g (+0.44 g, virtually unchanged). Segments like Bramalea Road (+53.99 g) or Beaumaris (no change) show minimal shifts, indicating that while freight-oriented green lights can alleviate stop-and-go conditions for heavy vehicles, overall VOC levels remain near Base.

The DBL scenario pushes total emissions to 15,532.02 g (+492.26 g, +3.3%), marking the largest single-strategy rise. Lane reallocation for buses intensifies congestion for autos, particularly in corridors such as Central Park (+65.74 g) and Torbram Road (+84.87 g), where narrower capacity fosters more frequent decelerations.

When TSP is combined with DBL, VOC emissions drop relative to DBL alone, reaching 15,222.63 g (+182.87 g, +1.2%), reflecting that transit-prioritized signals can partially mitigate the capacity loss. In the FSP & DBL combination, emissions total 15,453.08 g (+413.32 g, +2.7%), showing that freight-based priority similarly moderates, but does not offset, the impacts of dedicating a lane to buses.

Meanwhile, TSP FSP (in the absence of a bus-only lane) yields 15,042.92 g (+3.16 g, +0.02%), nearly matching the base scenario and demonstrating that carefully coordinated signal priority for both transit and freight does little to change overall corridor emissions. However, once DBL is overlaid on TSP FSP, total VOC jumps to 15,452.64 g (+412.88 g, +2.7%), confirming that restricted capacity from DBL emerges as the dominant factor driving emissions upward.

Overall, these findings show that DBL produces the most pronounced VOC increases, overshadowing the relatively minor impacts, positive or negative, from TSP and FSP. When no lanes are removed, TSP or FSP alone, or in tandem, generally keep VOC emissions near Base levels. However, once one lane is reserved for transit operations, any small benefits from signal priority pale before the congestion caused by reduced space for autos.

In Figure 45 and Figure 46, the cumulative volatile organic compounds (VOC) emissions (in grams) are presented for eastbound (EB) and westbound (WB) traffic under various scenarios. VOC emissions are a key indicator of air quality, as these compounds contribute to ground-level ozone formation and other environmental impacts.

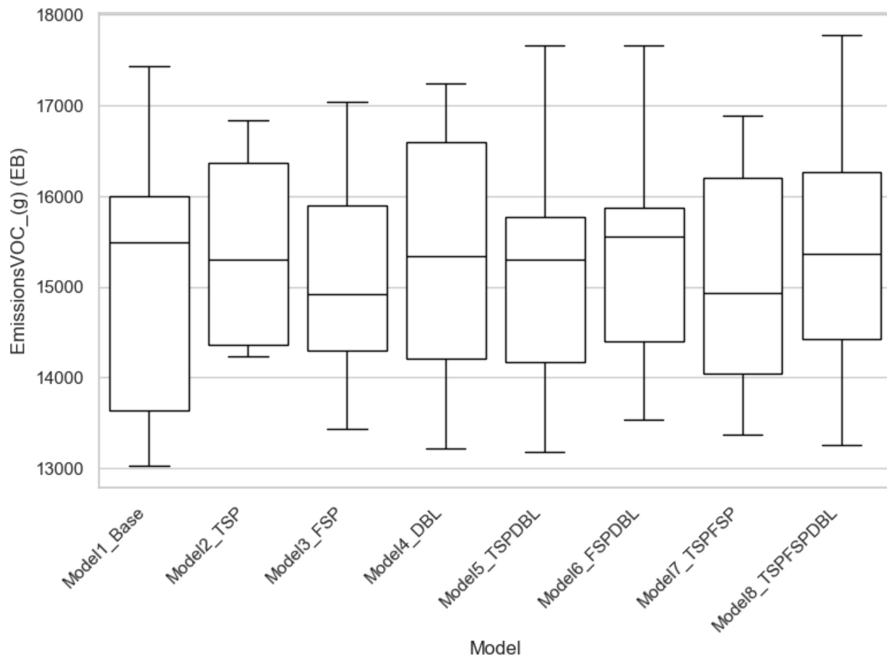



*Figure 45 - Cumulative VOC emissions per scenario in eastbound movement*

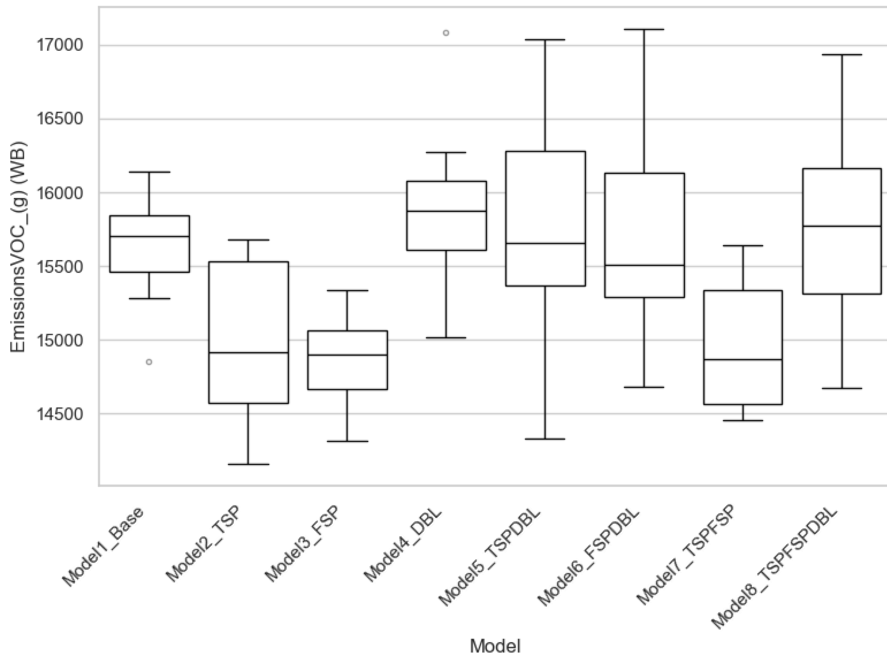



*Figure 46 - Cumulative VOC emissions per scenario in westbound movement in grams*

Under the Base scenario, EB VOC emissions total 15,040 g, whereas WB emissions reach 16,210 g. These values establish the Base for evaluating how reconfigured lanes or signal timings affect pollution levels.

In the TSP scenario, EB emissions increase slightly to 15,366 g (+326 g) relative to the base, while WB decreases to 15,770 g (-440 g). This outcome suggests that giving transit vehicles priority at intersections can reduce congestion-related idling in the WB direction but marginally increases stop-and-go conditions on EB segments. The FSP scenario produces a near-Base EB total of 15,041 g (+1 g) and a moderate drop in WB emissions to 15,664 g (-546 g), indicating that freight-prioritized signal phasing may also yield ancillary air quality benefits by smoothing traffic flow.

By contrast, the DBL-only scenario elevates VOC emissions for both EB (15,352 g, +312 g) and WB (16,669 g, +459 g). The lane reduction for general-purpose traffic and possible new congestion patterns appear to offset any efficiency gains for buses, resulting in more abrupt acceleration and deceleration for non-transit vehicles.

When TSP and DBL are combined, EB emissions decrease slightly from the DBL-only level to 15,223 g but remain above the base scenario by +183 g; WB totals 16,542 g, a small improvement compared to DBL alone but still higher than base. Similarly, FSP & DBL yields EB emissions of 15,433 g (+393 g) and WB emissions of 16,542 g (+332 g), reinforcing the pattern that while signal priority can mitigate some congestion, the net effect of lane removal for DBL is an overall rise in VOC emissions.

The TSP FSP scenario, without DBL, returns EB emissions to 15,043 g (+3 g) and WB to 15,755 g (-455 g), nearly matching or slightly improving on the base scenario. These finding highlights that combining transit and freight signal priority can enhance corridor efficiency enough to stabilize or reduce emissions in comparison to existing conditions. Finally, the TSP FSP & DBL scenario shows EB emissions of 15,453 g (+413 g) and WB of 16,577 g (+367 g), indicating that the lane constraints introduced by DBL continue to dominate, surpassing the limited gains from dual-priority measures.

Overall, these results demonstrate that DBL consistently elevates VOC emissions unless partially offset by TSP or FSP. TSP or FSP alone have modest and sometimes positive impacts on emissions, whereas their combination (TSP FSP) achieves near Base model or improved performance. However, adding DBL to any scenario pushes emissions above the base, signifying that the reduced road space for general traffic leads to more idling and speed fluctuations, thereby increasing VOC output.

### 5.3.4. Fuel Consumption

Table 18 and Figure 47 show the fuel consumption (in grams) for all modes along the eastbound (EB) movement of Queen Street during the PM peak hours.

| **Road Segment** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Drive** | 48.72 | 48.54 (-0.20) | 48.17 (-0.57) | 61.06 (+12.33) | 57.12 (+8.39) | 57.26 (+8.54) | 48.17 (-0.56) | 58.95 (+10.22) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Dixie Road** | 69.29 | 65.43 (-3.87) | 63.69 (-5.61) | 68.17 (-1.12) | 69.89 (+0.61) | 67.95 (-1.35) | 65.08 (-4.21) | 69.77 (+0.48) |
| **Central Park** | 34.15 | 35.22 (+1.08) | 38.43 (+4.28) | 38.23 (+4.08) | 46.58 (+12.44) | 45.17 (+11.02) | 34.63 (+0.48) | 40.9 (+6.75) |
| **Bramalea Road** | 59.23 | 59.45 (+0.22) | 58.75 (-0.49) | 58.64 (-0.60) | 59.17 (-0.07) | 60.28 (+1.05) | 58.35 (-0.89) | 56.76 (-2.47) |
| **Finchgate** | 25.20 | 26.15 (+0.95) | 26.12 (+0.92) | 27.74 (+2.54) | 26.69 (+1.49) | 26.82 (+1.62) | 26.41 (+1.21) | 26.75 (+1.55) |
| **Torbram Road** | 30.92 | 33.33 (+2.40) | 34.37 (+3.45) | 36.16 (+5.24) | 35.22 (+4.30) | 36.55 (+5.63) | 32.93 (+2.01) | 34.05 (+3.13) |
| **Torbram Plaza** | 18.53 | 19.48 (+0.95) | 18.75 (+0.22) | 19.81 (+1.28) | 18.65 (+0.12) | 19.62 (+1.09) | 18.72 (+0.19) | 19.51 (+0.98) |
| **Gateway** | 24.07 | 24.67 (+0.61) | 24.06 (-0.02) | 25.53 (+1.47) | 25.25 (+1.19) | 25.13 (+1.06) | 25.42 (+1.36) | 25.23 (+1.16) |
| **Smart Centres** | 23.37 | 24.2 (+0.83) | 25.01 (+1.63) | 25.62 (+2.25) | 23.37 (-0.01) | 22.68 (-0.71) | 23.79 (+0.42) | 25.72 (+2.34) |
| **Airport Road** | 64.18 | 68.18 (+4.00) | 68.15 (+3.97) | 73.76 (+9.58) | 69.29 (+5.11) | 68.28 (+4.10) | 69.95 (+5.77) | 79.43 (+15.25) |
| **Delta Park** | 127.70 | 137.96 (+10.26) | 128.9 (+1.20) | 128.46 (+0.76) | 130.42 (+2.72) | 134.62 (+6.92) | 129.79 (+2.09) | 137.94 (+10.24) |
| **Auction Lane** | 153.24 | 157.86 (+4.62) | 147.32 (-5.92) | 134.28 (-18.97) | 127.68 (-25.57) | 136.57 (-16.67) | 148.33 (-4.92) | 133.83 (-19.42) |
| **Goreway Drive** | 82.76 | 83.43 (+0.67) | 82.54 (-0.23) | 82.22 (-0.55) | 81.56 (-1.22) | 82.36 (-0.41) | 82.42 (-0.35) | 81.99 (-0.78) |
| **McVean** | 54.51 | 52.87 (-1.65) | 52.8 (-1.71) | 51.57 (-2.95) | 51.99 (-2.53) | 52.74 (-1.78) | 53.46 (-1.05) | 50.96 (-3.56) |
| **Cherrycrest** | 35.70 | 34.57 (-1.14) | 35.61 (-0.10) | 40.43 (+4.73) | 39.67 (+3.97) | 39.88 (+4.18) | 35.64 (-0.07) | 38.89 (+3.19) |
| **Beaumaris** | 27.66 | 27.88 (+0.22) | 27.72 (+0.06) | 27.23 (-0.44) | 27.41 (-0.26) | 27.99 (+0.33) | 27.49 (-0.18) | 26.43 (-1.24) |
| **Gore Road** | 49.16 | 49.41 (+0.25) | 48.13 (-1.04) | 48.81 (-0.35) | 49.79 (+0.64) | 48.86 (-0.31) | 48.07 (-1.10) | 46.84 (-2.33) |
| **EB Cumulative** | 928.38 | 948.53 (+20.15) | 928.44 (+0.06) | 947.66 (+19.28) | 939.67 (+11.29) | 952.66 (+24.28) | 928.58 (+0.20) | 953.87 (+25.49) |

*Table 18 - Fuel consumption for the eastbound along Queen Street (in grams)*

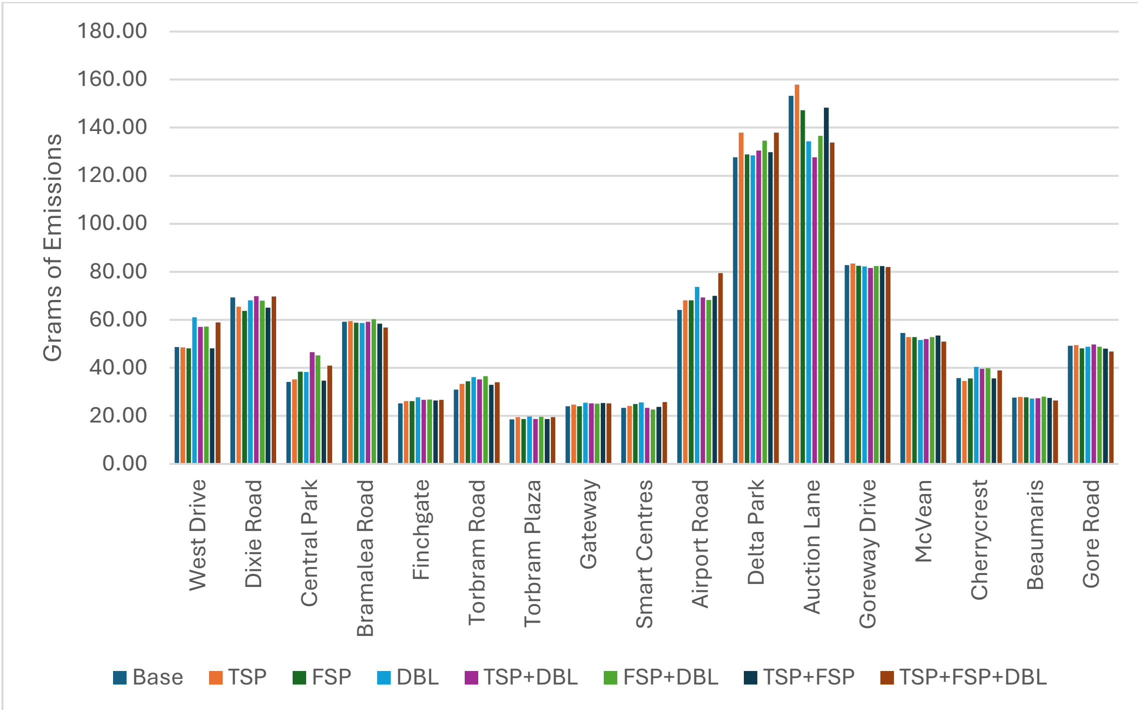



*Figure 47 - Fuel consumption in each intersection in the EB*

Under Base conditions, total EB fuel use is 928.38 g. Introducing TSP raises this figure to 948.53 g (+20.15 g, +2.2%), implying that extending green signals for transit can lead to additional idling or acceleration periods for other vehicles along some segments, such as Torbram Road (+2.40 g) and Smart Centres (+3.01 g). However, in a few areas, like West Drive (−0.20 g) and Dixie Road (−3.87 g), it appears that more synchronized signaling marginally reduces stop-and-go conditions.

In contrast, FSP yields 928.44 g (+0.06 g, effectively unchanged), suggesting that optimizing signal phases for freight vehicles has minimal overall impact on corridor fuel use. While certain segments, like Airport Road (+3.97 g), see slight increases, others, such as McVean (−1.65 g), record enough savings to keep the net effect near Base.

The DBL scenario prompts a notable rise to 947.66 g (+19.28 g, +2.1%), indicating that dedicating a lane to buses constrains capacity for general traffic, fostering additional acceleration and deceleration cycles. Segments such as Bramalea Road (+0.60 g) and Finchgate (+2.44 g) exemplify the modest yet cumulative gains in fuel consumption caused by reallocated lanes.

When TSP is combined with DBL, fuel consumption remains elevated at 939.67 g (+11.29 g, +1.2%), revealing that transit-priority signals can mitigate some negative effects but cannot fully offset capacity reductions. A similar pattern emerges in FSP & DBL, reaching 952.66 g (+24.28 g, +2.6%), showing that, while freight-priority phases ease truck movement at certain intersections, the net result still increases corridor-wide consumption due to fewer lanes for other vehicles.

Interestingly, TSP FSP, absent DBL, lowers EB fuel usage to 928.58 g (+0.20 g, +0.02%), virtually matching the Base. This result suggests that simultaneously favoring transit and freight can keep traffic flow reasonably smooth for general traffic. Once DBL is added, however, consumption climbs to 953.87 g (+25.49 g, +2.7%), confirming that lane reallocation remains the primary driver of fuel usage increases, exceeding the minor efficiency gains from coordinated signal priorities.

Overall, DBL tend to produce the largest surge in EB fuel consumption, overshadowing the smaller impact of TSP and FSP alone. When no lane is removed, the combination of TSP and FSP typically keeps consumption near Base, but any scenario with DBL sees a net uptick, emphasizing how reduced capacity for autos and trucks leads to more frequent speed changes and higher fuel demands.

In Figure 48 and Figure 49, cumulative fuel consumption (in grams) for EB and WB traffic is presented under various signal priority and DBL scenarios. Fuel consumption serves as an important indicator of both economic efficiency (operating costs) and environmental sustainability, since higher consumption is closely tied to elevated emissions.

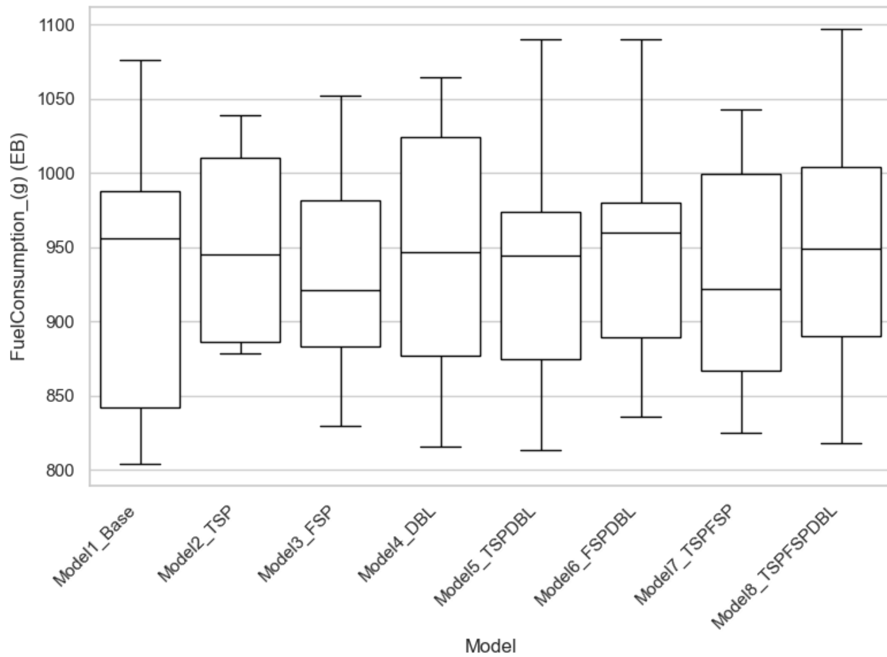



*Figure 48 - Cumulative fuel consumption per scenario for eastbound movement*

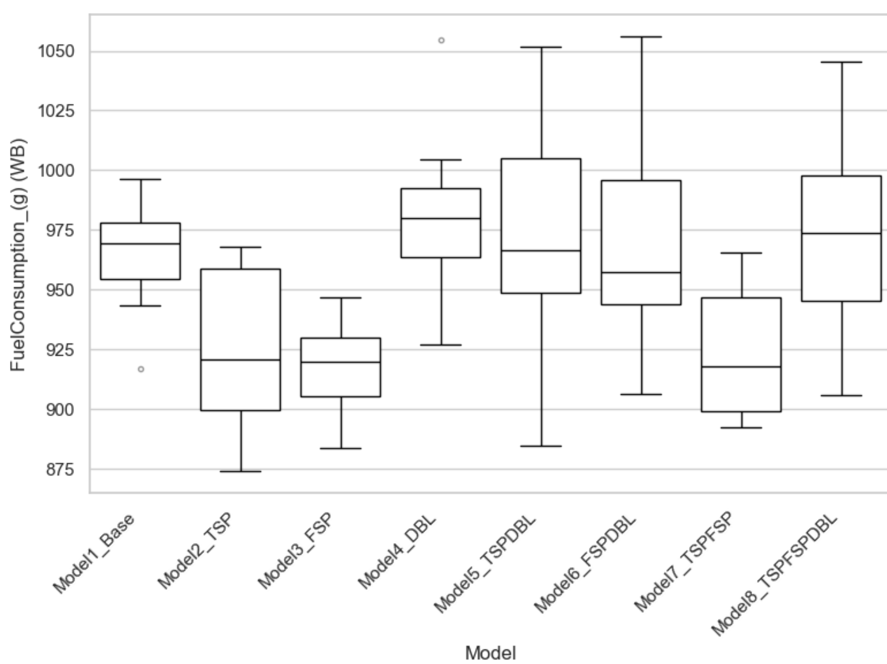



*Figure 49 - Cumulative fuel consumption per scenario for westbound movement*

Under the Base scenario, EB traffic consumes 928 g of fuel, whereas WB consumes 1001 g, establishing reference values for subsequent comparisons. The Transit Signal Priority (TSP) scenario increases EB consumption slightly to 949 g (+21 g) but reduces WB consumption to 973 g (-28 g). This suggests that while the extended or early green phases for transit vehicles may create mild disruptions for EB traffic, in the WB direction it helps smooth traffic flow enough to lower overall idling.

The Freight Signal Priority (FSP) scenario maintains EB consumption at 928 g (no change from base) while reducing WB consumption to 967 g (-34 g). These minimal changes imply that FSP, triggered less frequently than TSP (assuming fewer freight vehicles than transit buses), has negligible effects on EB operations but provides moderate efficiency gains in WB, likely due to more consistent signal progression for freight, which general traffic can also benefit from.

By contrast, the DBL-only scenario elevates both EB and WB consumption to 948 g (+20 g) and 1029 g (+28 g), respectively. Reallocating a general-purpose lane to bus-exclusive use reduces capacity for other vehicles, often resulting in more stop-and-go conditions and hence higher fuel consumption. The WB direction experiences a somewhat larger penalty, suggesting heavier congestion or higher vehicle volumes traveling westbound.

When TSP and DBL are combined, EB consumption decreases to 940 g (+12 g from base) relative to DBL alone, while WB falls to 1021 g (+20 g). These reductions indicate that transit-prioritized signals can partially mitigate fuel penalties introduced by DBL, though not enough to return to base levels. A similar pattern emerges with FSP & DBL, where EB consumption is 953 g (+25 g) and WB is 1021 g (+20 g), slightly higher than TSP & DBL eastbound but unchanged westbound, implying that TSP may be more effective than FSP at mitigating DBL’s impact on EB flow.

The TSP FSP scenario (without DBL) produces EB consumption of 929 g (+1 g), nearly matching the base, and WB of 973 g (-28 g). This outcome suggests that coordinating both transit and freight signal priority can preserve efficiency eastbound while reducing idling or sudden accelerations westbound. Finally, TSP FSP & DBL leads to 954 g EB (+26 g) and 1023 g WB (+22 g), confirming that any lane reallocation for DBL continues to drive up fuel consumption, even with dual signal priorities in place.

Overall, these results show that DBL consistently increases fuel usage due to lost capacity for general-purpose traffic, despite partial offsets from TSP or FSP. TSP and FSP alone each offer minor benefits or neutral impacts, particularly in the WB direction, and the TSP FSP combination achieves near-base or slightly improved efficiency. However, introducing DBL in any scenario raises consumption above the base, demonstrating the trade-offs between dedicating roadway space for buses and preserving operating efficiency for other vehicles.

## 5.4. Chapter Summary

This chapter presented a comparative evaluation of different priority strategies, Transit Signal Priority (TSP), Freight Signal Priority (FSP), and DBL, and their combinations, examining impacts on travel modes such as automobile, freight, and transit performance under both eastbound (EB) and westbound (WB) flows. The tables below summarize the percent changes in average travel time, total person-delay, and key emissions (CO, NOx, VOC) as well as fuel consumption. These results offer a concise overview of how each treatment (alone or in combination) shapes mobility and environmental outcomes along the Queen Street corridor.

In Table 19 , the results indicate that while Transit Signal Priority (TSP) and Freight Signal Priority (FSP) generally produce modest increases or decreases for autos and freight (on the order of ±1-2%), DBL alone tends to impose the largest spikes in automobile and freight travel times, particularly in the westbound direction, where capacity constraints often lead to higher congestion. Conversely, transit experiences the most substantial gains under TSP FSP & DBL, with average travel times improving more than with TSP or FSP alone. In several cases, combining TSP or FSP with DBL can mitigate some of the negative impacts on general traffic while enhancing the already substantial transit benefits.

| Percent Change in Average Travel Time | | TSP | FSP | DBL | TSP & DBL | FSP & DBL | TSP FSP | TSP FSP & DBL |
|---|---|---|---|---|---|---|---|---|
| Autos | EB | 1% | -0.5% | 5% | 3% | 4% | -2% | 6% |
| | WB | 0.5% | 1% | 12 % | 11 % | 11% | 0.5% | 12% |
| Freight | EB | 2% | 0.2% | 6% | 4.% | 5% | -1% | 7% |
| | WB | 1% | 1% | 13% | 12% | 12% | 1% | 13% |
| Transit | EB | -6% | -8% | -3% | -8% | -8% | -8% | -6% |
| | WB | -9% | -8% | -3% | -5% | -3% | -9% | -2% |

*Table 19 - Summary of percent change for average travel time for all modelled modes*

In Table 20, autos and freight typically incur moderate or minimal delay shifts when only TSP or FSP is applied. However, the introduction of DBL triggers more apparent delay increases, sometimes exceeding 6-8% for certain modes and directions. Transit, on the other hand, experiences reduced person-delay across most DBL-related scenarios, most specifically in TSP & FSP, reinforcing the notion that dedicating a lane to buses provides a major advantage for transit riders. Notably, combining TSP or FSP with DBL can lessen delays for modes other than transit (freight specifically) compared to DBL alone; however, the trade-off remains more apparent than TSP or FSP in isolation.

| Percent Change in Total Persons Delay | | TSP | FSP | DBL | TSP & DBL | FSP & DBL | TSP FSP | TSP FSP & DBL |
|---|---|---|---|---|---|---|---|---|
| Autos | EB | 3% | 1% | 7% | 4% | 5% | -1% | 7% |
| | WB | -1% | 0% | 9% | 7% | 7% | 0% | 7% |
| Freight | EB | 2% | 0% | 4% | 0% | 2% | -1% | 5% |
| | WB | 1% | 1% | 7% | 7% | 7% | 1% | 8% |
| Transit | EB | -5% | -6% | -6% | -12% | -11% | -4% | -9% |
| | WB | 4% | 5% | 7% | 4% | 6% | 6% | 7% |

*Table 20 - Summary of percent change for total persons delay for all modelled modes*

Table 21 summarizes the percent difference in emissions (CO, NOx, and VOC) and fuel consumption. Here, TSP and FSP alone often result in small changes, ranging from slight decreases to modest increases, suggesting that smoother signal operations do not dramatically shift corridor-wide environmental measures. However, DBL regularly yields 2-3% higher emissions and fuel usage, correlating with the additional congestion imposed on non-bus traffic. When TSP or FSP is combined with DBL, the net increases in emissions or fuel consumption still remain, though they can be somewhat lower than DBL unaccompanied by signal priority.

| Percent Change in Environmental Emissions | | TSP | FSP | DBL | TSP & DBL | FSP & DBL | TSP FSP | TSP FSP & DBL |
|---|---|---|---|---|---|---|---|---|
| CO Emissions | EB | 2% | 0% | 2% | 1% | 3% | 0% | 3% |
| | WB | 2% | 2% | 8% | 8% | 7% | 2% | 8% |
| NOx Emissions | EB | 2% | 0% | 2% | 1% | 3% | 0% | 3% |
| | WB | 2% | 2% | 8% | 8% | 7% | 2% | 8% |
| VOC Emissions | EB | 2% | 0% | 2% | 1% | 3% | 0% | 3% |
| | WB | 2% | 2% | 8% | 8% | 7% | 2% | 8% |
| Fuel Consumption | EB | 2% | 0% | 2% | 1% | 3% | 0% | 3% |
| | WB | 2% | 2% | 8% | 8% | 7% | 2% | 8% |

*Table 21 - Summary of percent change for environmental emissions for all modelled modes*

In the eastbound (EB) direction, the simulated results broadly align with the trends reported in the literature. Consistent with prior TSP studies that typically find bus travel-time reductions on the order of 5-15% with minimal effects on general traffic, EB transit in our scenarios improved by roughly 5-9% under TSP/FSP, while autos and freight changed by about ±1% and approximately 0-1%, respectively. Findings for FSP also mirror the limited evidence base, which generally reports corridor-level changes that are small and highly location-dependent; our EB results showed modest, mixed effects, with localized gains where truck arrivals are well captured by detection and signal phasing. With respect to DBL, the literature frequently documents substantial transit benefits accompanied by capacity penalties for non-transit modes; our EB outcomes fall at the conservative end of those ranges. As such, transit gains were moderate, and autos/freight experienced increases of roughly 5-6% in average travel time, likely reflecting the corridor's access friction, intersection spacing, and counter-peak EB demand during the PM period. Finally, environmental results are directionally consistent with prior work: signal priority alone produced near-baseline emissions and fuel consumption, whereas DBL induced small but systematic increases (approximately 2-3%) attributable to added stop-and-go in the remaining general-purpose lanes. Overall, the EB results align with the literature's main conclusions, that is, priority strategies yield measurable, mode-specific benefits with limited externalities, while lane reallocation via DBL produces the expected trade-off between transit gains and non-transit disbenefits.

Overall, these findings exhibit a clear trade-off between improving transit performance and introducing negative externalities (e.g., higher delays or emissions) for autos and freight, illustrating the importance of site-specific evaluations before adopting DBL.

# Chapter 6. Conclusions and Recommendations

Urban corridors often experience rising congestion due to mixed traffic flows of autos, freight vehicles, and public transit. To address capacity issues, agencies deploy signal priority strategies and dedicated lanes. While these measures can enhance one mode's performance (e.g., faster transit travel times), they may impose additional delays on other vehicles. Likewise, changes in traffic flow alter air quality indicators and fuel usage. An integrated understanding of these trade-offs is essential for planning balanced policies that support passenger, freight, and environmental objectives simultaneously.

## 6.1. Summary of the Study

This research has demonstrated that incorporating signal priority technologies (Transit Signal Priority - TSP, and Freight Signal Priority - FSP) and implementing a dedicated DBL can significantly influence the operational performance of an urban arterial corridor. Using PTV VISSIM microsimulation, the study quantified the effects of these strategies, individually and in various combinations, on travel times, total person-delay, and emissions for autos, freight, and transit modes. While TSP and FSP individually result in only modest travel-time impacts (often below ±3% for non-priority modes), their combined implementation (TSP FSP) frequently yields moderate corridor-wide benefits, such as slight reductions in automobile and freight travel times. These gains are attributable to more frequent green extensions and better coordination at intersections, collectively improving the overall traffic flow without incurring substantial penalties for any single mode.

In contrast, establishing a DBL produced the most pronounced changes in traffic dynamics. Transit vehicles experienced shorter travel times and reduced delays, confirming that lane reallocation is highly advantageous for bus reliability and scheduling. However, the same lane reduction increased congestion for automobiles and freight, leading to consistent travel-time increases and higher emissions across multiple scenarios. Despite minor variations when combining DBL with either TSP or FSP, the net effect on passenger vehicles and trucks remained notably negative compared to scenarios without DBL. These findings express the trade-off inherent in allocating road space to public transit: although a dedicated lane is remarkably effective at boosting bus performance, it redistributes congestion among other classes of vehicles and can elevate emissions due to intensified stop-and-go conditions in the remaining lanes.

Also, the results highlight that combining TSP and FSP without a DBL can serve as a balanced approach, offering moderate transit and freight benefits while preserving acceptable auto performance. From a policy perspective, this suggests that incremental or coordinated signal priority solutions may suffice when agencies aim to enhance bus and truck travel times without pursuing large-scale infrastructure reconfigurations. Conversely, in corridors with urgent transit needs and high passenger volumes, implementing a DBL can deliver transformative improvements for bus travel, even at the known cost of greater congestion for general traffic and commercial vehicles. Consequently, adopting a targeted approach, based on corridor-specific demands, geometric constraints, and travel behavior patterns, can help municipalities and transportation agencies decide whether a full DBL configuration is justified or whether signal-based interventions alone might achieve more balanced mobility outcomes.

The study corridor is a 9.9-km segment of Queen Street in Brampton, Ontario, which is an urban arterial with 17 closely spaced, coordinated, fully actuated signalized intersections. Most nodes are four-legged with auxiliary turn lanes at major cross streets (e.g., Dixie, Bramalea, Torbram, Airport, Goreway, McVean); commercial frontages and frequent driveways introduce notable access friction, especially near retail clusters (e.g., Smart Centres/Tim Hortons, Torbram Plaza/Walmart). Pedestrian activity around stops and shopping areas adds clearance time and occasional lost time to the signal plan.

Directional demand is asymmetric in the PM peak (4:00-6:00): westbound (WB) is the dominant home-bound flow and exhibits longer queues, tighter storage, and greater sensitivity to capacity or green-time reallocation; eastbound (EB) is the counter-peak and generally progresses more smoothly. Travel behavior blends through movements with short access-oriented trips, producing frequent lane changes near intersections and turn pockets that can constrain saturation flow when storage fills.

The corridor supports significant freight activity, particularly near Delta Park, Auction Lane, Airport Road, and Goreway, where medium-/heavy-duty trucks require reliable progression and protected turning. Freight performance is sensitive to lost green, stop-and-go conditions, and lane reallocation. Transit service is frequent (local and limited-stop), with mixed near-/far-side stops; right-turn queues and midblock access friction often impede curb-lane operations. TSP (modest early/extended green) improves schedule adherence where stop placement aligns with progression; FSP can stabilize truck platoons with limited corridor-wide disruption. A DBL can decouple buses from general traffic, but its benefits depend on intersection sequencing, queue-jump treatments, and turn-lane balance, and it reduces general-purpose capacity, especially impactful in the WB peak.

## 6.2. Conclusions

This study sought to evaluate the operational impacts of Transit Signal Priority (TSP), Freight Signal Priority (FSP), and Dedicated Bus Lanes (DBL), both individually and in combination, along the Queen Street corridor in Brampton, Ontario. The research aimed to provide insights for improving the mobility of people and goods in an urban arterial corridor with high congestion and competing travel demands.

With respect to the first objective, evaluating the impact of implementing TSP, FSP, and their combination, the analysis demonstrated that TSP and FSP individually provided moderate improvements in transit and freight operations, primarily through reduced travel times and person-delay, while maintaining a generally neutral impact on passenger vehicle performance. When these two strategies were combined, the results showed cumulative benefits, further enhancing transit and freight movement with minimal adverse effects on private vehicle traffic. This confirms that a coordinated signal priority approach can be a balanced solution for improving multi-modal operations in congested corridors.

For the second objective, to assess the effects of implementing DBL, both alone and in combination with TSP, FSP, and their integration, the results confirmed that DBL significantly improve transit performance by reducing travel times and variability. However, these improvements come at a cost to other vehicle classes, as passenger vehicles and freight experienced increased travel times and higher emissions due to lane reallocation. When DBL were paired with TSP and FSP, the benefits for transit were preserved, but the negative impacts on autos and freight remained substantial, emphasizing the need for careful consideration when reallocating road space in congested environments.

In aggregate, the eastbound (EB) direction performs better when the objective is corridor-wide efficiency and environmental outcomes across all modes, whereas the westbound (WB) direction tends to yield larger transit gains under priority treatments but at the cost of greater disbenefits to autos and freight. Quantitatively, autos and freight in WB experience the steepest penalties when a DBL is introduced (e.g., auto travel time increases are on the order of +12-13% WB versus approximately +5% EB; freight approximately +13% WB versus approximately +6% EB), and WB also shows the larger DBL-related increases in CO/NOx/VOC and fuel consumption. By contrast, transit travel time reductions from signal priority alone (TSP, FSP, or TSP+FSP) are often stronger WB (e.g., −9% WB versus −6% to −8% EB), reflecting greater room for improvement where baseline delay is higher. DBL effects on transit are mixed by direction: WB generally posts modest improvements with DBL and priority overlays, while EB can see smaller gains (or even slight increases under DBL-alone), again consistent with different baseline delay profiles.

These directional differences are plausibly explained by PM-peak commute patterns and asymmetric demand. During the modeled PM peak (4-6 PM), WB flows on Queen Street in Brampton more closely align with home-bound, auto-dominant traffic, producing heavier WB volumes, longer queues, and more frequent spillback. Under those conditions, DBL removes a general-purpose lane where demand is already high, intensifying WB congestion for non-transit modes and magnifying emissions and fuel-use penalties. EB, by contrast, carries comparatively lower peak auto/truck demand in the PM, so lane reallocation and signal-priority perturbations propagate less severely, yielding smaller travel-time and environmental impacts for non-priority modes.

Signal-system geometry and operational asymmetries also matter. The WB corridor appears to have tighter intersection spacing, higher turn volumes at select nodes, and more frequent bus-truck interactions, all of which amplify the payoffs of TSP/FSP for buses (larger WB transit reductions) but also the opportunity costs for autos and freight when green time is reallocated or a lane is reserved for DBL. EB's slightly smoother platoon progression and lower conflicting turning demand in the PM tend to moderate both the benefits (smaller transit gains) and the disbenefits (smaller auto/freight penalties), producing more balanced outcomes across MOEs.

In conclusion, this thesis addressed its overall goal of investigating the impacts of implementing DBL, TSP, FSP, and their combinations along a major urban arterial. The findings exhibit that while DBL offer the greatest improvements for transit reliability, they can negatively affect other road users in a multi-modal environment. Conversely, applying signal priority strategies such as TSP and FSP, either individually or together, delivers balanced operational benefits for both people and goods movement without disproportionately disadvantaging other traffic. These results highlight the importance of a context-sensitive approach to corridor treatments, ensuring that the operational trade-offs among transit, freight, and passenger vehicles are carefully weighed in planning and policy decisions aimed at enhancing the efficiency and sustainability of urban transportation networks.

## 6.3. Benefits of the Study

The findings of this study carry several practical benefits that extend beyond the immediate case of a single urban corridor. First, by focusing on three distinct transportation modes, autos, freight, and transit, this work demonstrates how integrated signal priority measures and DBL can be tailored to serve multiple user groups without disproportionately disadvantaging any one mode. Such a multimodal lens demonstrates the possibility of achieving more balanced roadway operations, thereby fostering conditions that accommodate a broader spectrum of travel demands. Second, the microsimulation-based approach is readily transferable to other corridors, enabling planners to replicate similar analyses elsewhere. By adjusting model inputs such as traffic volumes, geometric layouts, or bus frequency, transportation professionals can adapt the methodological framework to suit a variety of contexts, including suburban arterials, congested central business districts, or inter-municipal connectors.

From a policy-making standpoint, these results offer a structured means of gauging trade-offs. Cities grappling with limited right-of-way can draw on the study's evidence to evaluate whether modest interventions (like TSP or FSP alone) might suffice or if a more transformative measure (like DBL) is warranted. Policymakers can thus assess whether prioritizing transit to enhance regional mobility aligns with community and commercial needs. Additionally, stakeholders such as municipal traffic engineers, regional freight coordinators, and public transit agencies may use the study's findings to negotiate equitable solutions that address rising congestion without unduly impeding freight operations or undermining local business activity. The flexible design of TSP and FSP strategies, e.g., conditional vs. unconditional priority, or variable green-extension parameters, allows decision-makers to fine-tune treatments to local objectives, whether those entails improving transit reliability, cutting freight delays, or maintaining adequate service levels for autos. Ultimately, this study's integrative framework equips practitioners and policymakers with a robust evidence base for implementing context-appropriate traffic management strategies, paving the way for more efficient, equitable, and resilient transportation systems.

## 6.4. Recommendations for Future Work

Future work should advance both control logic and corridor design to deliver decision-ready, multi-objective results. On the control side, model conditional/threshold-based TSP and FSP that trigger only under situations of headway deviation, bus occupancy, or truck platoon size, and integrate adaptive or predictive coordination (e.g., split optimization by cycle, short-horizon arrival forecasts). Multi-objective controllers that explicitly balance person-throughput, schedule adherence, and cross-street delay rather than optimizing a single mode should be tested. On the geometric side, evaluate DBL design variants (median vs. curbside, offset, reversible or peak-only DBL, targeted "gap" segments at bottlenecks) and intersection treatments (consistent far-side stops, queue jumps, bus bypass lanes at right-turn pockets, protected bus merge phases). Since curb activity and compliance strongly influence corridor performance, future simulations should represent lane-use compliance, enforcement levels, and curb management (ride-hail services such as Uber and Lyft, or deliveries) as explicit scenarios.

Modeling a variety of operations should also be further explored for each mode. For Example, for transit, future work should incorporate stochastic dwell times, stop consolidation, dynamic holding/headway control, short-turning, and report reliability metrics (headway variability, on-time performance, 85th/95th percentile travel times, queues and buffer time) and person-throughput. For freight, future work should, for example, test dynamic FSP (time-of-day or queue-length triggers), truck-only lanes where feasible, platoon facilitation with delivery/curb lay-by design at industrial frontages; represent truck class mix, payload effects on acceleration, and driveway conflicts. Corridor friction should be addressed through access management (driveway consolidation, right-in/right-out, turn-bay lengthening, protected/permitted left-turn alternatives) and explicit modeling of parking maneuvers and pickup/drop-off. To reflect network context, future research should attempt to move beyond static peak inputs by introducing dynamic Origin-Destination demand to include off-peak activities, incident and work-zone scenarios, weather degradation, and land-use growth, and accompany microsimulation with a mesoscopic dynamic traffic assignment for a more robust route choice and diversion to parallel routes.

Finally, future work should additionally broaden the evaluation lens. Future work should attempt to add pedestrian and cycling flows with conflict modeling (protected phases, and LPIs) alongside operations. Furthermore, future work should include stronger calibration/validation with high-resolution signal logs, bus Automatic Passenger Counting (APC), GPS-backed travel times, and truck GPS and Electronic Logging Devices (ELD) traces to validate travel times, queue length distributions, and potential stop incidents. Moreover, future work should also replace aggregate emission factors with second-by-second, modal emissions/energy models, including cold-starts and grades, and report GHG and energy intensity per passenger-km and freight-ton-km. Incorporate equity, accessibility, and economics (person-weighted access to jobs, distributional impacts, full cost-benefit with capital and operations and maintenance estimations, reliability value, emissions monetization, and health externalities). Finally, future work should explore technology such as partial penetration of connected/automated vehicles, connected bus priority, headways, truck platooning, eco-driving, and conduct sensitivity analyses to arrival variance, saturation, compliance, dwell variability, and demand growth, so recommendations reflect performance under an acceptable level of uncertainty and variance.

# References


Abbasi, M., Hosseinlou, M.H., Sarreshtehdari, A. & Mandzuka, S. (2021) ‘Evaluation of transit signal priority for bus rapid transit in heterogeneous traffic flow’, Tehnički Vjesnik - Technical Gazette, 28(6), pp. 2080-2087.

Ahn, K. et al. (2016) ‘Multimodal Intelligent Traffic Signal System Simulation Model Development and assessment’, Transportation Research Record: Journal of the Transportation Research Board, 2558(1), pp. 92-102. doi:10.3141/2558-09.

Alam, A., Diab, E., El-Geneidy, A.M. & Hatzopoulou, M. (2014) ‘A simulation of transit bus emissions along an urban corridor: Evaluating changes under various service improvement strategies’, Transportation Research Part D: Transport and Environment, 31, pp. 189-198.

Albright, E., and Figliozzi, M. (2012) 'Competence of Bus Rapid Transit Systems Coupled with Transit Signal Priority at Signalized Junctions', Transportation Research Record, 2311, pp. 186-194. doi: 10.3141/2311-17.

Ali, M.S., Kodi, J., Alluri, P., Sando, T. (2022) 'Exploring the operational benefits of transit signal priority', International Journal of Transportation Science and Technology, 12(2023), pp. 1080-1092. doi: 10.1016/j.ijtst.2023.01.003.

Alzubaidi, H., Pirdavani, A. and Brijs, T. (2017) 'The impact of transit signal priority: Case study in Dubai, UAE', MATEC Web of Conferences, 2017, 81, 07009. doi: 10.1051/matecconf/201708107009.

Ashby, B. TTS 2016 Data, University of Toronto. 2018.

Byrne-Nearing, Sharyn, and Daniela Aubry. Let’s Get Ready to Ride. 2022.

Callan, I. (2021) Part 2: Regional Transportation-GTA Students Need Integrated Transit System, The Pointer.

Cesme, B., Altun, S.Z. and Lane, B. (2015) ‘Queue jump lane, Transit Signal Priority, and stop location evaluation of transit preferential treatments using microsimulation’, Transportation Research Record: Journal of the Transportation Research Board, 2533(1), pp. 39-49. doi:10.3141/2533-05.

City of Brampton, 2024. 2025 Federal Election Priorities. [pdf] Available at: https://www.brampton.ca/EN/City-Hall/Relations/Documents/2025-Federal-Election-Priorities.pdf [Accessed 22 Jun. 2025].

City of Brampton (2022) Employment and Industrial Land Study. City of Brampton Planning Department.

Chimba, D. and Ikiriko, S. (no date) ‘Evaluation of Transit Priority Treatments in Tennessee’, Transportation Research Center for Livable Communities.

Chowdhury, M., et al. (2022) 'Operational Impact of the Through Traffic Signal Prioritization for Heavy Commercial Vehicle', Journal of Transportation Safety & Security. Available at: https://doi.org/10.1080/19439962.2022.2067654 (Accessed: 22 June 2024).

Chung, Y., Kim, S., and Han, D. (2023) 'Transferability of a calibrated microscopic simulation model parameters for operational assessment of transit signal priority', Journal of Advanced Transportation, 2023, Article ID 7039145. doi: 10.1007/s12469-023-00329-4.

Desta, R. and Tóth, J. (2022) 'Competence of bus rapid transit systems coupled with transit signal priority at signalized junctions', Transport and Telecommunication Journal, 23(1), pp. 81-92. doi:10.2478/ttj-2022-0008.

Environment and Climate Change Canada (2023). National Inventory Report 1990-2021: Greenhouse Gas Sources and Sinks in Canada. Government of Canada.

Federal Highway Administration (FHWA), 2008. Chapter 9 - Transit Signal Priority. [online] U.S. Department of Transportation. Available at: https://ops.fhwa.dot.gov/publications/fhwahop08024/chapter9.htm [Accessed 22 Jun. 2025].Hertel, Sean, et al. "Next Stop: Equity Routes to Fairer Transit Access in GTHA: EUC: York Uni." Faculty of Environmental and Urban Change, 24 Jan. 2022.

Goods Movement Intensification Assessment Report. Region of Peel. 2024.

Huan, L., et al. (2022) 'Providing priority to public transit in the absence of dedicated lanes: an exploratory experiment', Journal of Public Transportation. Available at: https://doi.org/10.5038/2375-0901.9.3.7 (Accessed: 22 June 2024).

Ink, S. (2016) Active transit signal priority, National Association of City Transportation Officials.

INRIX (2022) INRIX 2022 Global Traffic Scorecard. Available at: https://inrix.com/scorecard-2022/ (Accessed: 28 March 2025).

Iqbal, S. et al. (2021) 'Developing guidelines for Implementing Transit Signal Priority and freight signal priority using simulation modeling and a decision tree algorithm', Transportation Research Record: Journal of the Transportation Research Board, 2676(4), pp. 133-144. doi:10.1177/03611981211057528.

Kim, J., Kim, S. and Chung, Y. (2022) 'Transit Signal Priority for an Integrated Traffic Signal System', Journal of Advanced Transportation, 2022, Article ID 8181041. doi: 10.1155/2022/8181041.

Lee, J., Kim, D. and Kim, H. (2022) 'Signalized intersection delay analysis using transit signal priority (TSP) and dedicated short-range communication (DSRC) system for bus rapid transit (BRT)', Journal of Intelligent Transportation Systems, 2022, pp. 1-13. doi: 10.1007/s41062-022-00892-y.

Litman, T. (2021). Evaluating Transportation Equity. Victoria Transport Policy Institute

Mai, C., McDaniel-Wilson, C. and Noval, D. (2014) PROTOCOL FOR VISSIM SIMULATION, WSDOT VISSIM.

Metrolinx Annual Report 2021-2022. 2022.

Metrolinx Board Meeting Annual Report 2021. 2022.

Metrolinx (2018) Regional Mobility Review.

Mohamed, M., Elmitiny, N. and Talaat, H. (2022) 'A simulation-based evaluation of BRT systems in over-crowded travel corridors: A case study of cairo, Egypt', Journal of Engineering and Applied Science, 69(1). doi:10.1186/s44147-022-00088-2.

Ontario Ministry of the Environment, Conservation and Parks (2022). Ontario Greenhouse Gas Emissions Summary.

Ontario Ministry of Transportation (2021) Published Plans and Annual Reports 2020-2021. Available at: https://www.ontario.ca/page/published-plans-and-annual-reports-2024-2025-ministry-transportation (Accessed: 28 March 2025).

Osorio, C. & Nanduri, K. (2015) 'Urban transportation emissions mitigation: Coupling high-resolution vehicular emissions and traffic models for traffic signal optimization', Transportation Research Part B: Methodological, 81, pp. 520-538. doi: 10.1016/j.trb.2014.12.007

Park, S., Ahn, K. & Rakha, H.A. (2019) 'Environmental impact of freight signal priority with connected trucks', Sustainability, 11(23), 6819. doi: 10.3390/su11236819

Planning for the future. Planning for the Future. City of Brampton 2021.

Queen Street Rapid Transit LRT or BRT Benefits Case. Metrolinx. 2013.

Shaheen, S.A. & Lipman, T.E. (2007) 'Reducing greenhouse emissions and fuel consumption: Sustainable approaches for surface transportation', IATSS Research, 31(1), pp. 6-20.

Smith, H.R., Hemily, P.B. and Ivanovic, M. (2005) Transit Signal Priority (TSP): A planning and implementation handbook. Washington, DC: ITS America.

Song, Y., Zlatkovic, M. and Porter, R.J. (2016) 'A Corridor-Level Evaluation of GPS-Based Transit Signal Priority', International Conference on Transportation and Development 2016, ASCE, pp. 455-462.

Statistics Canada (2022) [Title of the Publication, if known]. Available at: https://www150.statcan.gc.ca/n1/pub/12-581-x/12-581-x2022001-eng.pdf (Accessed: 28 March 2025).

The Big Move: Transforming Transportation in the Greater Toronto and Hamilton Area, Metrolinx. 2008.

Toronto Region Board of Trade. Next Stop: Building Universal Transit Access. 2021.

Transit access and social equity - Metrolinx. 2018.

Transit needs and opportunities - Metrolinx. 2016.

Transit Signal Priority. TSMO. 2022.

Transport Canada (2020). Canada’s Transportation System: Freight and Supply Chains.

TRB (2016). Highway Capacity Manual, 6th ed., Chapters 1, 2, and 19, Transportation Research Board, Washington, D.C.

Truong, L.T., Currie, G., and Wallace, M. (2017) 'Transit Priority Multiplier Effect', Transportation Research Record: Journal of the Transportation Research Board, 2649, pp. 10-18. doi: 10.3141/2649-02.

Wijayaratna, K., Dixit, V., Mao, T. & Waller, S.T. (2013) ‘Emissions impacts of transit signal prioritisation’, in Australasian Transport Research Forum (ATRF) 2013, 2-4 October, Brisbane, Australia.

Xiaodan, W. and Junhao, H. (2014) ‘Traffic simulation modeling and analysis of BRT based on vissim’, 2014 7th International Conference on Intelligent Computation Technology and Automation [Preprint]. doi:10.1109/icicta.2014.210.

Yanbo, Z., Ioannou, P., (2016) 'A Traffic Light Signal Control System with Truck Priority', Journal of Transportation Engineering. Available at: https://doi.org/10.1016/j.jtreng.2016.08.007 (Accessed: 22 June 2024).

Zhao, X., Yu, L. and Zhu, D. (2020) 'Modeling and optimizing bus transit priority along an arterial', Transportation Research Part A: Policy and Practice, 139, pp. 45-60. doi: 10.1016/j.tra.2020.08.003.

Zhao, Y. and Ioannou, P. (2019) ‘A co-simulation, optimization, control approach for traffic light control with Truck priority’, Annual Reviews in Control, 48, pp. 283-291. doi:10.1016/j.arcontrol.2019.09.006.

# Appendices

## Appendix A - Signal Timing Plans (STP)

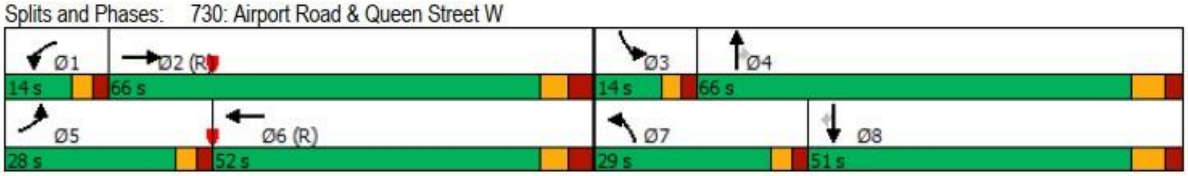
The following section lists the signal timing plans for the existing conditions (Base model) that are used in this study. They are for the PM peak in 2017, obtained from the Region of Peel.

| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | | 1 | 6 | | 7 | 4 | 4 | 3 | 8 | 8 |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 8.0 | 12.0 | | 8.0 | 12.0 | | 8.0 | 12.0 | 12.0 | 8.0 | 12.0 | 12.0 |
| Minimum Split (s) | 13.0 | 49.5 | | 13.0 | 49.5 | | 13.0 | 49.2 | 49.2 | 13.0 | 49.2 | 49.2 |
| Total Split (s) | 28.0 | 66.0 | | 14.0 | 52.0 | | 29.0 | 66.0 | 66.0 | 14.0 | 51.0 | 51.0 |
| Total Split (%) | 17.5% | 41.3% | | 8.8% | 32.5% | | 18.1% | 41.3% | 41.3% | 8.8% | 31.9% | 31.9% |
| Maximum Green (s) | 23.0 | 58.5 | | 9.0 | 44.5 | | 24.0 | 58.8 | 58.8 | 9.0 | 43.8 | 43.8 |
| Yellow Time (s) | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.6 | 4.6 | 3.0 | 4.6 | 4.6 |
| All-Red Time (s) | 2.0 | 3.5 | | 2.0 | 3.5 | | 2.0 | 2.6 | 2.6 | 2.0 | 2.6 | 2.6 |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total Lost Time (s) | 5.0 | 7.5 | | 5.0 | 7.5 | | 5.0 | 7.2 | 7.2 | 5.0 | 7.2 | 7.2 |
| Lead/Lag | Lead | Lag | | Lead | Lag | | Lead | Lag | Lag | Lead | Lag | Lag |
| Lead-Lag Optimize? | | | | | | | | | | | | |
| Vehicle Extension (s) | 3.0 | 5.0 | | 3.0 | 5.0 | | 4.0 | 5.0 | 5.0 | 4.0 | 5.0 | 5.0 |
| Recall Mode | None | C-Min | | None | C-Min | | None | None | None | None | None | None |
| Walk Time (s) | | 12.0 | | | 12.0 | | | 12.0 | 12.0 | | 12.0 | 12.0 |
| Flash Dont Walk (s) | | 30.0 | | | 30.0 | | | 30.0 | 30.0 | | 30.0 | 30.0 |
| Pedestrian Calls (#/hr) | | 0 | | | 0 | | | 0 | 0 | | 0 | 0 |
| Act Effct Green (s) | 23.0 | 58.5 | 160.0 | 9.0 | 44.5 | 160.0 | 24.0 | 58.8 | 58.8 | 9.0 | 43.8 | 43.8 |
| Actuated g/C Ratio | 0.14 | 0.37 | 1.00 | 0.06 | 0.28 | 1.00 | 0.15 | 0.37 | 0.37 | 0.06 | 0.27 | 0.27 |
| v/c Ratio | 1.39 | 1.12 | 0.22 | 1.23 | 0.78 | 0.11 | 1.15 | 1.22 | 0.40 | 1.29 | 0.48 | 0.28 |
| Control Delay | 240.3 | 105.4 | 0.3 | 187.5 | 79.7 | 0.1 | 147.7 | 147.1 | 16.6 | 221.7 | 50.0 | 3.1 |
| Queue Delay | 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 | 240.3 | 105.4 | 0.3 | 187.5 | 79.7 | 0.1 | 147.7 | 147.1 | 16.6 | 221.7 | 50.0 | 3.1 |
| LOS | F | F | A | F | E | A | F | F | B | F | D | A |
| Approach Delay | | 123.7 | | | 86.3 | | | 137.1 | | | 83.2 | |
| Approach LOS | | F | | | F | | | F | | | F | |

Intersection Summary

Area Type: Other
Cycle Length: 160
Actuated Cycle Length: 160
Offset: 103 (64%), Referenced to phase 2:EBT and 6:WBT, Start of Green
Natural Cycle: 145
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 1.39
Intersection Signal Delay: 117.4 Intersection LOS: F
Intersection Capacity Utilization 121.1% ICU Level of Service H
Analysis Period (min) 15

Splits and Phases: 730: Airport Road & Queen Street W

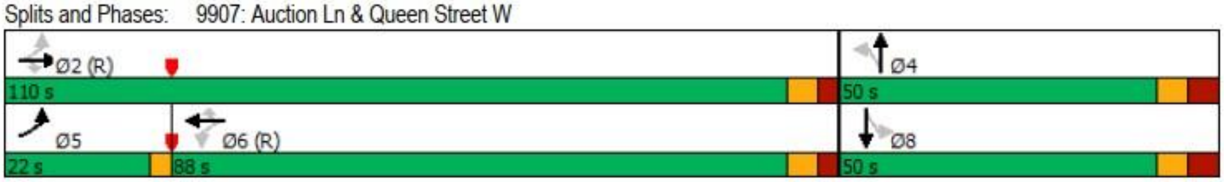


| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Minimum Split (s) | 9.0 | 36.8 | 36.8 | 36.8 | 36.8 | 36.8 | 46.4 | 46.4 | | 46.4 | 46.4 | |
| Total Split (s) | 22.0 | 110.0 | 110.0 | 88.0 | 88.0 | 88.0 | 50.0 | 50.0 | | 50.0 | 50.0 | |
| Total Split (%) | 13.8% | 68.8% | 68.8% | 55.0% | 55.0% | 55.0% | 31.3% | 31.3% | | 31.3% | 31.3% | |
| Maximum Green (s) | 19.0 | 103.2 | 103.2 | 81.2 | 81.2 | 81.2 | 41.6 | 41.6 | | 41.6 | 41.6 | |
| Yellow Time (s) | 3.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | | 4.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 4.4 | 4.4 | | 4.4 | 4.4 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 3.0 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 8.4 | 8.4 | | 8.4 | 8.4 | |
| Lead/Lag | Lead | | | Lag | Lag | Lag | | | | | | |
| Lead-Lag Optimize? | Yes | | | Yes | Yes | Yes | | | | | | |
| Vehicle Extension (s) | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | C-Max | C-Max | C-Max | C-Max | None | None | | None | None | |
| Walk Time (s) | | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Flash Dont Walk (s) | | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 30.0 | 30.0 | | 30.0 | 30.0 | |
| Pedestrian Calls (#/hr) | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | |
| Act Effct Green (s) | 117.3 | 113.5 | 113.5 | 95.9 | 95.9 | 95.9 | 31.3 | 31.3 | | 31.3 | 31.3 | |
| Actuated g/C Ratio | 0.73 | 0.71 | 0.71 | 0.60 | 0.60 | 0.60 | 0.20 | 0.20 | | 0.20 | 0.20 | |
| v/c Ratio | 0.62 | 0.61 | 0.03 | 0.05 | 0.65 | 0.09 | 0.81 | 0.26 | | 0.42 | 0.33 | |
| Control Delay | 48.1 | 7.9 | 2.6 | 22.5 | 21.2 | 5.5 | 86.9 | 45.0 | | 60.2 | 12.7 | |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Delay | 48.1 | 7.9 | 2.6 | 22.5 | 21.2 | 5.5 | 86.9 | 45.0 | | 60.2 | 12.7 | |
| LOS | D | A | A | C | C | A | F | D | | E | B | |
| Approach Delay | | 9.8 | | | 20.8 | | | 74.1 | | | 32.9 | |
| Approach LOS | | A | | | C | | | E | | | C | |

**Intersection Summary**

Area Type: Other
Cycle Length: 160
Actuated Cycle Length: 160
Offset: 0 (0%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green
Natural Cycle: 95
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 0.81
Intersection Signal Delay: 19.0 Intersection LOS: B
Intersection Capacity Utilization 88.7% ICU Level of Service E
Analysis Period (min) 15

Splits and Phases: 9907: Auction Ln & Queen Street W



| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Minimum Split (s) | 33.8 | 33.8 | 33.8 | 33.8 | 33.8 | 33.8 | 44.5 | 44.5 | | 44.5 | 44.5 | |
| Total Split (s) | 113.0 | 113.0 | 113.0 | 113.0 | 113.0 | 113.0 | 47.0 | 47.0 | | 47.0 | 47.0 | |
| Total Split (%) | 70.6% | 70.6% | 70.6% | 70.6% | 70.6% | 70.6% | 29.4% | 29.4% | | 29.4% | 29.4% | |
| Maximum Green (s) | 106.2 | 106.2 | 106.2 | 106.2 | 106.2 | 106.2 | 38.5 | 38.5 | | 38.5 | 38.5 | |
| Yellow Time (s) | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | | 4.0 | 4.0 | |
| All-Red Time (s) | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 4.5 | 4.5 | | 4.5 | 4.5 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 8.5 | 8.5 | | 8.5 | 8.5 | |
| Lead/Lag | | | | | | | | | | | | |
| Lead-Lag Optimize? | | | | | | | | | | | | |
| Vehicle Extension (s) | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | C-Max | C-Max | C-Max | C-Max | C-Max | C-Max | Min | Min | | Min | Min | |
| Walk Time (s) | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Flash Dont Walk (s) | 19.0 | 19.0 | 19.0 | 19.0 | 19.0 | 19.0 | 28.0 | 28.0 | | 28.0 | 28.0 | |
| Pedestrian Calls (#/hr) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | |
| Act Effct Green (s) | | 132.2 | 132.2 | 132.2 | 132.2 | | 12.5 | 12.5 | | | | |
| Actuated g/C Ratio | | 0.83 | 0.83 | 0.83 | 0.83 | | 0.08 | 0.08 | | | | |
| v/c Ratio | | 0.52 | 0.01 | 0.19 | 0.60 | | 0.41 | 0.43 | | | | |
| Control Delay | | 5.0 | 0.0 | 4.1 | 6.3 | | 81.1 | 51.5 | | | | |
| Queue Delay | | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | | | | |
| Total Delay | | 5.0 | 0.0 | 4.1 | 6.3 | | 81.1 | 51.5 | | | | |
| LOS | | A | A | A | A | | F | D | | | | |
| Approach Delay | | 5.0 | | | 6.3 | | | 63.3 | | | | |
| Approach LOS | | A | | | A | | | E | | | | |

| Intersection Summary | |
|---|---|
| Area Type: Other | |
| Cycle Length: 160 | |
| Actuated Cycle Length: 160 | |
| Offset: 65 (41%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green | |
| Natural Cycle: 100 | |
| Control Type: Actuated-Coordinated | |
| Maximum v/c Ratio: 0.60 | |
| Intersection Signal Delay: 6.9 | Intersection LOS: A |
| Intersection Capacity Utilization 69.1% | ICU Level of Service C |
| Analysis Period (min) 15 | |

Splits and Phases: 9903: Beaumaris Dr & Queen Street W

| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | | 1 | 6 | | 7 | 4 | | 8 | 8 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | | 5.0 | 8.0 | | 5.0 | 8.0 | | 8.0 | 8.0 | |
| Minimum Split (s) | 8.0 | 26.5 | | 8.0 | 26.5 | | 8.0 | 40.7 | | 40.7 | 40.7 | |
| Total Split (s) | 16.0 | 80.0 | | 16.0 | 80.0 | | 12.0 | 64.0 | | 52.0 | 52.0 | |
| Total Split (%) | 10.0% | 50.0% | | 10.0% | 50.0% | | 7.5% | 40.0% | | 32.5% | 32.5% | |
| Maximum Green (s) | 13.0 | 73.5 | | 13.0 | 73.5 | | 9.0 | 56.3 | | 44.3 | 44.3 | |
| Yellow Time (s) | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.0 | | 4.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 2.5 | | 0.0 | 2.5 | | 0.0 | 3.7 | | 3.7 | 3.7 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 3.0 | 6.5 | | 3.0 | 6.5 | | 3.0 | 7.7 | | 7.7 | 7.7 | |
| Lead/Lag | Lead | Lag | | Lead | Lag | | Lead | | | Lag | Lag | |
| Lead-Lag Optimize? | Yes | Yes | | Yes | Yes | | Yes | | | Yes | Yes | |
| Vehicle Extension (s) | 5.0 | 5.0 | | 3.0 | 5.0 | | 3.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 8.0 | | | 8.0 | | | 8.0 | | 8.0 | 8.0 | |
| Flash Dont Walk (s) | | 12.0 | | | 12.0 | | | 25.0 | | 25.0 | 25.0 | |
| Pedestrian Calls (#/hr) | | 0 | | | 0 | | | 0 | | 0 | 0 | |
| Act Effct Green (s) | 99.5 | 73.5 | 160.0 | 99.5 | 73.5 | 160.0 | 51.5 | 46.8 | 160.0 | 34.8 | 34.8 | 160.0 |
| Actuated g/C Ratio | 0.62 | 0.46 | 1.00 | 0.62 | 0.46 | 1.00 | 0.32 | 0.29 | 1.00 | 0.22 | 0.22 | 1.00 |
| v/c Ratio | 0.89 | 0.85 | 0.11 | 0.78 | 1.05 | 0.06 | 0.92 | 0.79 | 0.17 | 0.62 | 0.54 | 0.02 |
| Control Delay | 72.9 | 63.3 | 0.1 | 78.0 | 56.9 | 0.0 | 84.7 | 57.7 | 0.2 | 92.4 | 57.4 | 0.0 |
| Queue Delay | 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 | 72.9 | 63.3 | 0.1 | 78.0 | 56.9 | 0.0 | 84.7 | 57.7 | 0.2 | 92.4 | 57.4 | 0.0 |
| LOS | E | E | A | E | E | A | F | E | A | F | E | A |
| Approach Delay | | 60.0 | | | 56.9 | | | 51.3 | | | 56.4 | |
| Approach LOS | | E | | | E | | | D | | | E | |

| Intersection Summary | |
|---|---|
| Area Type: Other | |
| Cycle Length: 160 | |
| Actuated Cycle Length: 160 | |
| Offset: 83 (52%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green | |
| Natural Cycle: 145 | |
| Control Type: Actuated-Coordinated | |
| Maximum v/c Ratio: 1.05 | |
| Intersection Signal Delay: 56.8 | Intersection LOS: E |
| Intersection Capacity Utilization 109.0% | ICU Level of Service G |
| Analysis Period (min) 15 | |

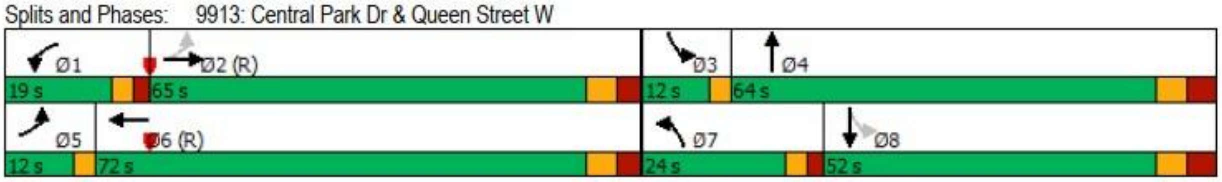
Splits and Phases: 9912: Bramalea Road & Queen Street W

| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | | 1 | 6 | | 7 | 4 | | 3 | 8 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | | 5.0 | 8.0 | |
| Minimum Split (s) | 8.0 | 40.3 | | 13.0 | 40.3 | | 13.0 | 46.0 | | 8.0 | 46.0 | |
| Total Split (s) | 12.0 | 65.0 | | 19.0 | 72.0 | | 24.0 | 64.0 | | 12.0 | 52.0 | |
| Total Split (%) | 7.5% | 40.6% | | 11.9% | 45.0% | | 15.0% | 40.0% | | 7.5% | 32.5% | |
| Maximum Green (s) | 9.0 | 57.7 | | 14.0 | 64.7 | | 19.0 | 56.0 | | 9.0 | 44.0 | |
| Yellow Time (s) | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 3.3 | | 2.0 | 3.3 | | 2.0 | 4.0 | | 0.0 | 4.0 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 3.0 | 7.3 | | 5.0 | 7.3 | | 5.0 | 8.0 | | 3.0 | 8.0 | |
| Lead/Lag | Lead | Lag | | Lead | Lag | | Lead | Lag | | Lead | Lag | |
| Lead-Lag Optimize? | Yes | Yes | | Yes | Yes | | Yes | Yes | | Yes | Yes | |
| Vehicle Extension (s) | 3.0 | 5.0 | | 3.0 | 5.0 | | 3.0 | 5.0 | | 3.0 | 5.0 | |
| Recall Mode | None | C-Max | | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 8.0 | | | 8.0 | | | 8.0 | | | 8.0 | |
| Flash Dont Walk (s) | | 25.0 | | | 25.0 | | | 30.0 | | | 30.0 | |
| Pedestrian Calls (#/hr) | | 0 | | | 0 | | | 0 | | | 0 | |
| Act Effct Green (s) | 105.9 | 72.2 | 160.0 | 27.4 | 70.6 | 160.0 | 18.1 | 28.1 | 160.0 | 30.9 | 17.0 | |
| Actuated g/C Ratio | 0.66 | 0.45 | 1.00 | 0.17 | 0.44 | 1.00 | 0.11 | 0.18 | 1.00 | 0.19 | 0.11 | |
| v/c Ratio | 0.57 | 0.66 | 0.09 | 0.59 | 0.80 | 0.12 | 0.86 | 0.71 | 0.14 | 0.50 | 0.46 | |
| Control Delay | 26.1 | 39.4 | 0.1 | 89.7 | 15.1 | 0.0 | 103.9 | 68.3 | 0.2 | 53.1 | 70.4 | |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Total Delay | 26.1 | 39.4 | 0.1 | 89.7 | 15.1 | 0.0 | 103.9 | 68.3 | 0.2 | 53.1 | 70.4 | |
| LOS | C | D | A | F | B | A | F | E | A | D | E | |
| Approach Delay | | 34.9 | | | 19.9 | | | 57.6 | | | 63.8 | |
| Approach LOS | | C | | | B | | | E | | | E | |

**Intersection Summary**

Area Type: Other
Cycle Length: 160
Actuated Cycle Length: 160
Offset: 125 (78%), Referenced to phase 2:EBTL and 6:WBT, Start of Green
Natural Cycle: 135
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 0.86
Intersection Signal Delay: 33.8 Intersection LOS: C
Intersection Capacity Utilization 102.6% ICU Level of Service G
Analysis Period (min) 15

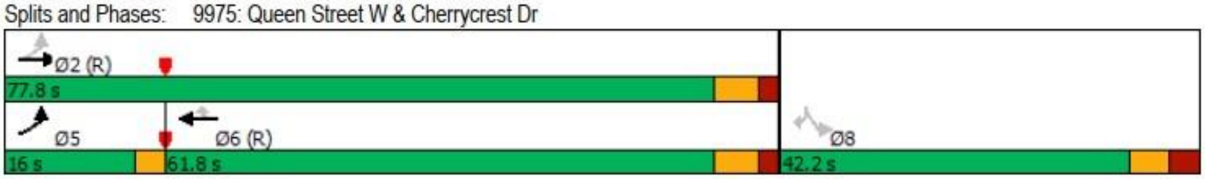
Splits and Phases: 9913: Central Park Dr & Queen Street W

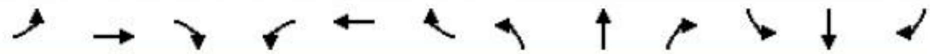


| Lane Group | EBL | EBT | WBT | WBR | SBL | SBR |
|---|---|---|---|---|---|---|
| Switch Phase | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Minimum Split (s) | 8.0 | 20.0 | 31.6 | 31.6 | 42.2 | 42.2 |
| Total Split (s) | 16.0 | 77.8 | 61.8 | 61.8 | 42.2 | 42.2 |
| Total Split (%) | 13.3% | 64.8% | 51.5% | 51.5% | 35.2% | 35.2% |
| Maximum Green (s) | 13.0 | 71.2 | 55.2 | 55.2 | 35.0 | 35.0 |
| Yellow Time (s) | 3.0 | 4.6 | 4.6 | 4.6 | 4.0 | 4.0 |
| All-Red Time (s) | 0.0 | 2.0 | 2.0 | 2.0 | 3.2 | 3.2 |
| Lost Time Adjust (s) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total Lost Time (s) | 3.0 | 6.6 | 6.6 | 6.6 | 7.2 | 7.2 |
| Lead/Lag | Lead | | Lag | Lag | | |
| Lead-Lag Optimize? | Yes | | Yes | Yes | | |
| Vehicle Extension (s) | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Recall Mode | None | C-Max | C-Max | C-Max | None | None |
| Walk Time (s) | | | 8.0 | 8.0 | 8.0 | 8.0 |
| Flash Dont Walk (s) | | | 17.0 | 17.0 | 27.0 | 27.0 |
| Pedestrian Calls (#/hr) | | | 0 | 0 | 0 | 0 |
| Act Effct Green (s) | 100.4 | 96.8 | 79.0 | 79.0 | 9.4 | 9.4 |
| Actuated g/C Ratio | 0.84 | 0.81 | 0.66 | 0.66 | 0.08 | 0.08 |
| v/c Ratio | 0.71 | 0.44 | 0.69 | 0.07 | 0.06 | 0.50 |
| Control Delay | 41.3 | 4.0 | 15.4 | 6.3 | 50.7 | 17.0 |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total Delay | 41.3 | 4.0 | 15.4 | 6.3 | 50.7 | 17.0 |
| LOS | D | A | B | A | D | B |
| Approach Delay | | 7.8 | 15.1 | | 19.5 | |
| Approach LOS | | A | B | | B | |

| Intersection Summary | |
|---|---|
| Area Type: Other | |
| Cycle Length: 120 | |
| Actuated Cycle Length: 120 | |
| Offset: 0 (0%), Referenced to phase 2:EBTL and 6:WBT, Start of Green | |
| Natural Cycle: 105 | |
| Control Type: Actuated-Coordinated | |
| Maximum v/c Ratio: 0.71 | |
| Intersection Signal Delay: 12.0 | Intersection LOS: B |
| Intersection Capacity Utilization 76.1% | ICU Level of Service D |
| Analysis Period (min) 15 | |

Splits and Phases: 9975: Queen Street W & Cherrycrest Dr





| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 2 | 2 | 2 | 1 | 6 | 6 | 4 | 4 | | 3 | 8 | 8 |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 12.0 | 12.0 | 12.0 | 5.0 | 12.0 | 12.0 | 8.0 | 8.0 | | 5.0 | 8.0 | 8.0 |
| Minimum Split (s) | 41.0 | 41.0 | 41.0 | 8.0 | 41.0 | 41.0 | 53.6 | 53.6 | | 8.0 | 53.6 | 53.6 |
| Total Split (s) | 84.4 | 84.4 | 84.4 | 13.0 | 97.4 | 97.4 | 51.6 | 51.6 | | 11.0 | 62.6 | 62.6 |
| Total Split (%) | 52.8% | 52.8% | 52.8% | 8.1% | 60.9% | 60.9% | 32.3% | 32.3% | | 6.9% | 39.1% | 39.1% |
| Maximum Green (s) | 77.4 | 77.4 | 77.4 | 10.0 | 90.4 | 90.4 | 44.0 | 44.0 | | 8.0 | 55.0 | 55.0 |
| Yellow Time (s) | 4.0 | 4.0 | 4.0 | 3.0 | 4.0 | 4.0 | 4.0 | 4.0 | | 3.0 | 4.0 | 4.0 |
| All-Red Time (s) | 3.0 | 3.0 | 3.0 | 0.0 | 3.0 | 3.0 | 3.6 | 3.6 | | 0.0 | 3.6 | 3.6 |
| 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 |
| Total Lost Time (s) | 7.0 | 7.0 | 7.0 | 3.0 | 7.0 | 7.0 | 7.6 | 7.6 | | 3.0 | 7.6 | 7.6 |
| Lead/Lag | Lag | Lag | Lag | Lead | | | Lag | Lag | | Lead | | |
| Lead-Lag Optimize? | Yes | Yes | Yes | Yes | | | Yes | Yes | | Yes | | |
| Vehicle Extension (s) | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | | 5.0 | 5.0 | 5.0 |
| Recall Mode | C-Max | C-Max | C-Max | None | C-Max | C-Max | None | None | | None | None | None |
| Walk Time (s) | 12.0 | 12.0 | 12.0 | | 12.0 | 12.0 | 8.0 | 8.0 | | | 8.0 | 8.0 |
| Flash Dont Walk (s) | 22.0 | 22.0 | 22.0 | | 22.0 | 22.0 | 38.0 | 38.0 | | | 38.0 | 38.0 |
| Pedestrian Calls (#/hr) | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | | | 0 | 0 |
| Act Effct Green (s) | 77.4 | 77.4 | 77.4 | 95.7 | 91.7 | 91.7 | 42.7 | 42.7 | | 58.3 | 53.7 | 53.7 |
| Actuated g/C Ratio | 0.48 | 0.48 | 0.48 | 0.60 | 0.57 | 0.57 | 0.27 | 0.27 | | 0.36 | 0.34 | 0.34 |
| v/c Ratio | 1.04 | 0.78 | 0.09 | 0.95 | 0.72 | 0.14 | 0.26 | 0.96 | | 0.96 | 0.11 | 0.11 |
| Control Delay | 105.0 | 48.5 | 12.2 | 101.3 | 34.7 | 9.9 | 48.0 | 74.5 | | 107.6 | 36.8 | 10.2 |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | 0.0 |
| Total Delay | 105.0 | 48.5 | 12.2 | 101.3 | 34.7 | 9.9 | 48.0 | 74.5 | | 107.6 | 36.8 | 10.2 |
| LOS | F | D | B | F | C | A | D | E | | F | D | B |
| Approach Delay | | 48.8 | | | 38.0 | | | 70.2 | | | 70.1 | |
| Approach LOS | | D | | | D | | | E | | | E | |

| Intersection Summary | |
|---|---|
| Area Type: Other | |
| Cycle Length: 160 | |
| Actuated Cycle Length: 160 | |
| Offset: 0 (0%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green | |
| Natural Cycle: 145 | |
| Control Type: Actuated-Coordinated | |
| Maximum v/c Ratio: 1.04 | |
| Intersection Signal Delay: 47.4 | Intersection LOS: D |
| Intersection Capacity Utilization 97.8% | ICU Level of Service F |
| Analysis Period (min) 15 | |

Splits and Phases: 9906: Delta Park Blvd/Maritime Ontario Blvd & Queen Street W

| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | | 1 | 6 | | 7 | 4 | | 3 | 8 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | | 5.0 | 8.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Minimum Split (s) | 10.0 | 40.3 | | 10.0 | 40.3 | | 13.0 | 41.7 | | 13.0 | 41.7 | |
| Total Split (s) | 22.0 | 67.3 | | 23.0 | 68.3 | | 28.0 | 56.7 | | 13.0 | 41.7 | |
| Total Split (%) | 13.8% | 42.1% | | 14.4% | 42.7% | | 17.5% | 35.4% | | 8.1% | 26.1% | |
| Maximum Green (s) | 17.0 | 60.0 | | 18.0 | 61.0 | | 23.0 | 49.0 | | 8.0 | 34.0 | |
| Yellow Time (s) | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.0 | |
| All-Red Time (s) | 2.0 | 3.3 | | 2.0 | 3.3 | | 2.0 | 3.7 | | 2.0 | 3.7 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 5.0 | 7.3 | | 5.0 | 7.3 | | 5.0 | 7.7 | | 5.0 | 7.7 | |
| Lead/Lag | Lead | Lag | | Lead | Lag | | Lead | Lag | | Lead | Lag | |
| Lead-Lag Optimize? | Yes | Yes | | Yes | Yes | | Yes | Yes | | Yes | Yes | |
| Vehicle Extension (s) | 3.0 | 5.0 | | 3.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 8.0 | | | 8.0 | | | 8.0 | | | 8.0 | |
| Flash Dont Walk (s) | | 25.0 | | | 25.0 | | | 26.0 | | | 26.0 | |
| Pedestrian Calls (#/hr) | | 0 | | | 0 | | | 0 | | | 0 | |
| Act Effct Green (s) | 17.0 | 60.4 | 160.0 | 17.6 | 61.0 | 160.0 | 23.0 | 49.0 | 160.0 | 8.0 | 34.0 | 160.0 |
| Actuated g/C Ratio | 0.11 | 0.38 | 1.00 | 0.11 | 0.38 | 1.00 | 0.14 | 0.31 | 1.00 | 0.05 | 0.21 | 1.00 |
| v/c Ratio | 0.97 | 0.85 | 0.18 | 0.87 | 0.98 | 0.39 | 0.98 | 0.90 | 0.08 | 0.81 | 0.60 | 0.09 |
| Control Delay | 110.6 | 51.4 | 0.3 | 104.5 | 44.2 | 0.6 | 101.5 | 82.5 | 0.1 | 108.2 | 59.6 | 0.1 |
| Queue Delay | 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 | 110.6 | 51.4 | 0.3 | 104.5 | 44.2 | 0.6 | 101.5 | 82.5 | 0.1 | 108.2 | 59.6 | 0.1 |
| LOS | F | D | A | F | D | A | F | F | A | F | E | A |
| Approach Delay | | 54.1 | | | 41.8 | | | 82.6 | | | 57.7 | |
| Approach LOS | | D | | | D | | | F | | | E | |

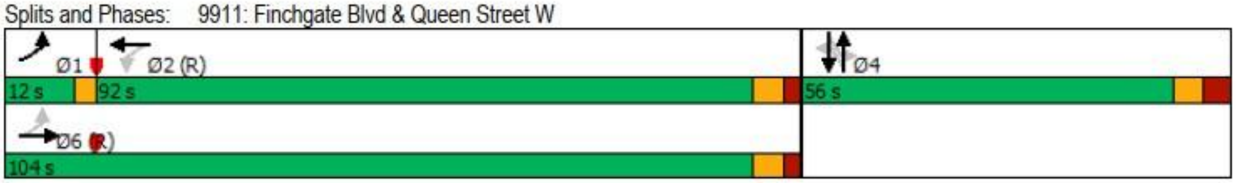
| Intersection Summary | |
|---|---|
| Area Type: Other | |
| Cycle Length: 160 | |
| Actuated Cycle Length: 160 | |
| Offset: 20 (13%), Referenced to phase 2:EBT and 6:WBT, Start of Green | |
| Natural Cycle: 145 | |
| Control Type: Actuated-Coordinated | |
| Maximum v/c Ratio: 0.98 | |
| Intersection Signal Delay: 57.5 | Intersection LOS: E |
| Intersection Capacity Utilization 98.3% | ICU Level of Service F |
| Analysis Period (min) 15 | |

Splits and Phases: 458: Dixie Road & Queen Street W

| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 1 | 6 | | 2 | 2 | | 4 | 4 | | 4 | 4 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Minimum Split (s) | 8.0 | 24.4 | | 24.4 | 24.4 | | 44.7 | 44.7 | | 44.7 | 44.7 | |
| Total Split (s) | 12.0 | 104.0 | | 92.0 | 92.0 | | 56.0 | 56.0 | | 56.0 | 56.0 | |
| Total Split (%) | 7.5% | 65.0% | | 57.5% | 57.5% | | 35.0% | 35.0% | | 35.0% | 35.0% | |
| Maximum Green (s) | 9.0 | 97.6 | | 85.6 | 85.6 | | 48.3 | 48.3 | | 48.3 | 48.3 | |
| Yellow Time (s) | 3.0 | 4.0 | | 4.0 | 4.0 | | 4.0 | 4.0 | | 4.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 2.4 | | 2.4 | 2.4 | | 3.7 | 3.7 | | 3.7 | 3.7 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | | 0.0 | | | 0.0 | |
| Total Lost Time (s) | 3.0 | 6.4 | | 6.4 | 6.4 | | | 7.7 | | | 7.7 | |
| Lead/Lag | Lead | | | Lag | Lag | | | | | | | |
| Lead-Lag Optimize? | Yes | | | Yes | Yes | | | | | | | |
| Vehicle Extension (s) | 5.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | | C-Max | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 8.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Flash Dont Walk (s) | | 10.0 | | 10.0 | 10.0 | | 29.0 | 29.0 | | 29.0 | 29.0 | |
| Pedestrian Calls (#/hr) | | 0 | | 0 | 0 | | 0 | 0 | | 0 | 0 | |
| Act Effct Green (s) | 122.9 | 119.5 | 160.0 | 101.0 | 101.0 | 160.0 | | 26.4 | | | 26.4 | |
| Actuated g/C Ratio | 0.77 | 0.75 | 1.00 | 0.63 | 0.63 | 1.00 | | 0.16 | | | 0.16 | |
| v/c Ratio | 0.59 | 0.43 | 0.07 | 0.25 | 0.83 | 0.04 | | 0.71 | | | 0.27 | |
| Control Delay | 48.0 | 10.9 | 0.1 | 13.4 | 20.9 | 0.1 | | 70.5 | | | 38.0 | |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | | | 0.0 | |
| Total Delay | 48.0 | 10.9 | 0.1 | 13.4 | 20.9 | 0.1 | | 70.5 | | | 38.0 | |
| LOS | D | B | A | B | C | A | | E | | | D | |
| Approach Delay | | 12.9 | | | 20.3 | | | 70.5 | | | 38.0 | |
| Approach LOS | | B | | | C | | | E | | | D | |

| Intersection Summary | |
|---|---|
| Area Type: Other | |
| Cycle Length: 160 | |
| Actuated Cycle Length: 160 | |
| Offset: 71 (44%), Referenced to phase 2:WBTL and 6:EBTL, Start of Green | |
| Natural Cycle: 120 | |
| Control Type: Actuated-Coordinated | |
| Maximum v/c Ratio: 0.83 | |
| Intersection Signal Delay: 21.2 | Intersection LOS: C |
| Intersection Capacity Utilization 96.0% | ICU Level of Service F |
| Analysis Period (min) 15 | |

Splits and Phases: 9911: Finchgate Blvd & Queen Street W



| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | | 1 | 6 | | 7 | 4 | | 3 | 8 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | | 5.0 | 8.0 | | 5.0 | 8.0 | | 5.0 | 8.0 | |
| Minimum Split (s) | 8.0 | 35.8 | | 8.0 | 35.8 | | 8.0 | 39.4 | | 9.0 | 39.4 | |
| Total Split (s) | 13.0 | 93.6 | | 8.0 | 88.6 | | 18.0 | 39.4 | | 19.0 | 40.4 | |
| Total Split (%) | 8.1% | 58.5% | | 5.0% | 55.4% | | 11.3% | 24.6% | | 11.9% | 25.3% | |
| Maximum Green (s) | 10.0 | 86.8 | | 5.0 | 81.8 | | 15.0 | 32.0 | | 16.0 | 33.0 | |
| Yellow Time (s) | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 2.8 | | 0.0 | 2.8 | | 0.0 | 3.4 | | 0.0 | 3.4 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 3.0 | 6.8 | | 3.0 | 6.8 | | 3.0 | 7.4 | | 3.0 | 7.4 | |
| Lead/Lag | Lead | Lag | | Lead | Lag | | Lead | Lag | | Lead | Lag | |
| Lead-Lag Optimize? | Yes | Yes | | Yes | Yes | | Yes | Yes | | Yes | Yes | |
| Vehicle Extension (s) | 3.0 | 5.0 | | 3.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 8.0 | | | 8.0 | | | 8.0 | | | 8.0 | |
| Flash Dont Walk (s) | | 21.0 | | | 21.0 | | | 24.0 | | | 24.0 | |
| Pedestrian Calls (#/hr) | | 0 | | | 0 | | | 0 | | | 0 | |
| Act Effct Green (s) | 101.2 | 94.2 | 160.0 | 94.1 | 85.0 | 160.0 | 49.1 | 29.7 | | 50.6 | 30.4 | |
| Actuated g/C Ratio | 0.63 | 0.59 | 1.00 | 0.59 | 0.53 | 1.00 | 0.31 | 0.19 | | 0.32 | 0.19 | |
| v/c Ratio | 0.75 | 0.53 | 0.00 | 0.11 | 0.85 | 0.07 | 0.68 | 0.81 | | 0.75 | 0.39 | |
| Control Delay | 64.1 | 21.6 | 0.0 | 8.1 | 36.5 | 0.1 | 53.5 | 70.7 | | 61.9 | 31.7 | |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Delay | 64.1 | 21.6 | 0.0 | 8.1 | 36.7 | 0.1 | 53.5 | 70.7 | | 61.9 | 31.7 | |
| LOS | E | C | A | A | D | A | D | E | | E | C | |
| Approach Delay | | 23.9 | | | 35.0 | | | 65.1 | | | 43.7 | |
| Approach LOS | | C | | | C | | | E | | | D | |

Intersection Summary

Area Type: Other

Cycle Length: 160

Actuated Cycle Length: 160

Offset: 0 (0%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green

Natural Cycle: 115

Control Type: Actuated-Coordinated

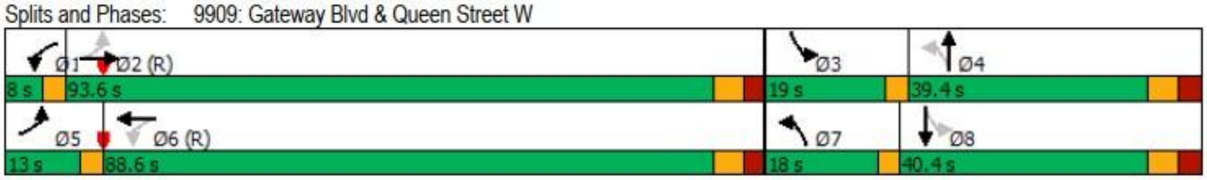
Maximum v/c Ratio: 0.85

Intersection Signal Delay: 36.5 Intersection LOS: D

Intersection Capacity Utilization 87.6% ICU Level of Service E

Analysis Period (min) 15

Splits and Phases: 9909: Gateway Blvd & Queen Street W



| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | | 1 | 6 | | 4 | 4 | | 3 | 3 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 12.0 | | 5.0 | 12.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Minimum Split (s) | 8.0 | 44.9 | | 8.0 | 44.9 | | 45.1 | 45.1 | | 45.1 | 45.1 | |
| Total Split (s) | 12.0 | 79.0 | | 9.0 | 76.0 | | 46.0 | 46.0 | | 26.0 | 26.0 | |
| Total Split (%) | 7.5% | 49.4% | | 5.6% | 47.5% | | 28.8% | 28.8% | | 16.3% | 16.3% | |
| Maximum Green (s) | 9.0 | 72.1 | | 6.0 | 69.1 | | 38.9 | 38.9 | | 18.9 | 18.9 | |
| Yellow Time (s) | 3.0 | 4.6 | | 3.0 | 4.6 | | 4.0 | 4.0 | | 4.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 2.3 | | 0.0 | 2.3 | | 3.1 | 3.1 | | 3.1 | 3.1 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 3.0 | 6.9 | | 3.0 | 6.9 | | 7.1 | 7.1 | | 7.1 | 7.1 | |
| Lead/Lag | Lead | Lag | | Lead | Lag | | Lag | Lag | | Lead | Lead | |
| Lead-Lag Optimize? | Yes | Yes | | Yes | Yes | | Yes | Yes | | Yes | Yes | |
| Vehicle Extension (s) | 5.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 12.0 | | | 12.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Flash Dont Walk (s) | | 26.0 | | | 26.0 | | 30.0 | 30.0 | | 30.0 | 30.0 | |
| Pedestrian Calls (#/hr) | | 0 | | | 0 | | 0 | 0 | | 0 | 0 | |
| Act Effct Green (s) | 101.3 | 92.8 | 160.0 | 81.0 | 69.1 | 160.0 | 24.6 | 24.6 | | 17.0 | 17.0 | 160.0 |
| Actuated g/C Ratio | 0.63 | 0.58 | 1.00 | 0.51 | 0.43 | 1.00 | 0.15 | 0.15 | | 0.11 | 0.11 | 1.00 |
| v/c Ratio | 0.89 | 0.63 | 0.09 | 0.07 | 0.91 | 0.25 | 0.64 | 0.57 | | 0.51 | 0.62 | 0.12 |
| Control Delay | 70.1 | 25.9 | 0.1 | 9.7 | 40.0 | 0.4 | 68.7 | 66.0 | | 72.7 | 75.7 | 0.2 |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | 0.0 |
| Total Delay | 70.1 | 25.9 | 0.1 | 9.7 | 40.0 | 0.4 | 68.7 | 66.0 | | 72.7 | 75.7 | 0.2 |
| LOS | E | C | A | A | D | A | E | E | | E | E | A |
| Approach Delay | | 30.2 | | | 33.2 | | | 67.4 | | | 51.1 | |
| Approach LOS | | C | | | C | | | E | | | D | |

| Intersection Summary | |
|---|---|
| Area Type: Other | |
| Cycle Length: 160 | |
| Actuated Cycle Length: 160 | |
| Offset: 15 (9%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green | |
| Natural Cycle: 145 | |
| Control Type: Actuated-Coordinated | |
| Maximum v/c Ratio: 0.91 | |
| Intersection Signal Delay: 38.0 | Intersection LOS: D |
| Intersection Capacity Utilization 101.5% | ICU Level of Service G |
| Analysis Period (min) 15 | |

Splits and Phases: 804: Gore Road & Queen Street W

| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | | 1 | 6 | | 7 | 4 | | 3 | 8 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 8.0 | 12.0 | | 5.0 | 12.0 | | 8.0 | 12.0 | | 8.0 | 12.0 | |
| Minimum Split (s) | 13.0 | 43.8 | | 10.0 | 43.8 | | 13.0 | 46.8 | | 13.0 | 46.8 | |
| Total Split (s) | 24.0 | 70.0 | | 18.0 | 64.0 | | 34.0 | 55.0 | | 17.0 | 38.0 | |
| Total Split (%) | 15.0% | 43.8% | | 11.3% | 40.0% | | 21.3% | 34.4% | | 10.6% | 23.8% | |
| Maximum Green (s) | 19.0 | 63.2 | | 13.0 | 57.2 | | 29.0 | 48.2 | | 12.0 | 31.2 | |
| Yellow Time (s) | 3.0 | 4.6 | | 3.0 | 4.6 | | 3.0 | 4.2 | | 3.0 | 4.2 | |
| All-Red Time (s) | 2.0 | 2.2 | | 2.0 | 2.2 | | 2.0 | 2.6 | | 2.0 | 2.6 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 5.0 | 6.8 | | 5.0 | 6.8 | | 5.0 | 6.8 | | 5.0 | 6.8 | |
| Lead/Lag | Lead | Lag | | Lead | Lag | | Lead | Lag | | Lead | Lag | |
| Lead-Lag Optimize? | Yes | Yes | | Yes | Yes | | Yes | Yes | | Yes | Yes | |
| Vehicle Extension (s) | 5.0 | 5.0 | | 3.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 12.0 | | | 12.0 | | | 12.0 | | | 12.0 | |
| Flash Dont Walk (s) | | 25.0 | | | 25.0 | | | 28.0 | | | 28.0 | |
| Pedestrian Calls (#/hr) | | 0 | | | 0 | | | 0 | | | 0 | |
| Act Effct Green (s) | 19.0 | 63.2 | 160.0 | 13.0 | 57.2 | 160.0 | 29.0 | 48.2 | 160.0 | 12.0 | 31.2 | 160.0 |
| Actuated g/C Ratio | 0.12 | 0.40 | 1.00 | 0.08 | 0.36 | 1.00 | 0.18 | 0.30 | 1.00 | 0.08 | 0.20 | 1.00 |
| v/c Ratio | 1.59 | 0.93 | 0.12 | 0.92 | 1.72 | 0.45 | 0.94 | 1.41 | 0.12 | 1.74 | 0.65 | 0.10 |
| Control Delay | 327.8 | 49.2 | 0.2 | 113.9 | 357.1 | 1.0 | 88.2 | 227.4 | 0.2 | 389.7 | 63.1 | 0.1 |
| Queue Delay | 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 | 327.8 | 49.2 | 0.2 | 113.9 | 357.1 | 1.0 | 88.2 | 227.4 | 0.2 | 389.7 | 63.1 | 0.1 |
| LOS | F | D | A | F | F | A | F | F | A | F | E | A |
| Approach Delay | | 83.5 | | | 283.4 | | | 186.6 | | | 171.1 | |
| Approach LOS | | F | | | F | | | F | | | F | |

**Intersection Summary**

Area Type: Other
Cycle Length: 160
Actuated Cycle Length: 160
Offset: 20 (13%), Referenced to phase 2:EBT and 6:WBT, Start of Green
Natural Cycle: 150
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 1.74
Intersection Signal Delay: 198.9 Intersection LOS: F
Intersection Capacity Utilization 137.7% ICU Level of Service H
Analysis Period (min) 15

Splits and Phases: 9905: Goreway Dr & Queen Street W

| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 8.0 | 8.0 | | 5.0 | 8.0 | |
| Minimum Split (s) | 10.0 | 44.0 | 44.0 | 44.0 | 44.0 | 44.0 | 45.3 | 45.3 | | 10.0 | 45.3 | |
| Total Split (s) | 16.0 | 83.0 | 83.0 | 67.0 | 67.0 | 67.0 | 37.3 | 37.3 | | 19.7 | 57.0 | |
| Total Split (%) | 11.4% | 59.3% | 59.3% | 47.9% | 47.9% | 47.9% | 26.6% | 26.6% | | 14.1% | 40.7% | |
| Maximum Green (s) | 11.0 | 76.0 | 76.0 | 60.0 | 60.0 | 60.0 | 30.0 | 30.0 | | 14.7 | 49.7 | |
| Yellow Time (s) | 3.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | | 3.0 | 4.0 | |
| All-Red Time (s) | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.3 | 3.3 | | 2.0 | 3.3 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 5.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.0 | 7.3 | 7.3 | | 5.0 | 7.3 | |
| Lead/Lag | Lead | | | Lag | Lag | Lag | Lag | Lag | | Lead | | |
| Lead-Lag Optimize? | Yes | | | Yes | Yes | Yes | Yes | Yes | | Yes | | |
| Vehicle Extension (s) | 3.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | C-Max | C-Max | C-Max | C-Max | None | None | | None | None | |
| Walk Time (s) | | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 8.0 | 8.0 | | | 8.0 | |
| Flash Dont Walk (s) | | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 30.0 | 30.0 | | | 30.0 | |
| Pedestrian Calls (#/hr) | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 0 | |
| Act Effct Green (s) | 21.4 | 86.4 | 86.4 | 60.0 | 60.0 | 60.0 | 19.6 | 19.6 | | 14.7 | 39.3 | |
| Actuated g/C Ratio | 0.15 | 0.62 | 0.62 | 0.43 | 0.43 | 0.43 | 0.14 | 0.14 | | 0.10 | 0.28 | |
| v/c Ratio | 1.07 | 0.56 | 0.08 | 0.10 | 1.38 | 0.61 | 0.11 | 0.62 | | 0.78 | 0.77 | |
| Control Delay | 113.7 | 17.2 | 2.9 | 27.5 | 205.2 | 9.6 | 52.3 | 65.7 | | 77.0 | 36.7 | |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Delay | 113.7 | 17.2 | 2.9 | 27.5 | 205.2 | 9.6 | 52.3 | 65.7 | | 77.0 | 36.7 | |
| LOS | F | B | A | C | F | A | D | E | | E | D | |
| Approach Delay | | 40.0 | | | 172.5 | | | 64.9 | | | 52.4 | |
| Approach LOS | | D | | | F | | | E | | | D | |

| Intersection Summary | |
|---|---|
| Area Type: Other | |
| Cycle Length: 140 | |
| Actuated Cycle Length: 140 | |
| Offset: 0 (0%), Referenced to phase 2:EBT and 6:WBTL, Start of Green | |
| Natural Cycle: 150 | |
| Control Type: Actuated-Coordinated | |
| Maximum v/c Ratio: 1.38 | |
| Intersection Signal Delay: 110.7 | Intersection LOS: F |
| Intersection Capacity Utilization 123.0% | ICU Level of Service H |
| Analysis Period (min) 15 | |

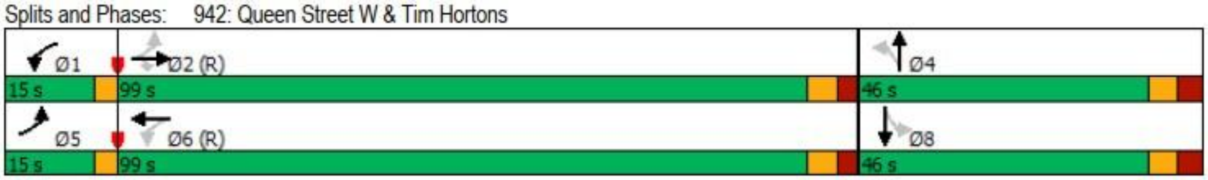
Splits and Phases: 9904: Queen Street W & McVean dr

| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | 2 | 1 | 6 | | 4 | 4 | | 8 | 8 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | 8.0 | 5.0 | 8.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Minimum Split (s) | 9.0 | 38.8 | 38.8 | 9.0 | 38.8 | | 39.5 | 39.5 | | 39.5 | 39.5 | |
| Total Split (s) | 15.0 | 99.0 | 99.0 | 15.0 | 99.0 | | 46.0 | 46.0 | | 46.0 | 46.0 | |
| Total Split (%) | 9.4% | 61.9% | 61.9% | 9.4% | 61.9% | | 28.8% | 28.8% | | 28.8% | 28.8% | |
| Maximum Green (s) | 12.0 | 92.2 | 92.2 | 12.0 | 92.2 | | 38.5 | 38.5 | | 38.5 | 38.5 | |
| Yellow Time (s) | 3.0 | 4.0 | 4.0 | 3.0 | 4.0 | | 4.0 | 4.0 | | 4.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 2.8 | 2.8 | 0.0 | 2.8 | | 3.5 | 3.5 | | 3.5 | 3.5 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | | | 0.0 | |
| Total Lost Time (s) | 3.0 | 6.8 | 6.8 | 3.0 | 6.8 | | 7.5 | 7.5 | | | 7.5 | |
| Lead/Lag | Lead | Lag | Lag | Lead | Lag | | | | | | | |
| Lead-Lag Optimize? | Yes | Yes | Yes | Yes | Yes | | | | | | | |
| Vehicle Extension (s) | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | C-Max | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 8.0 | 8.0 | | 8.0 | | 8.0 | 8.0 | | 8.0 | 8.0 | |
| Flash Dont Walk (s) | | 24.0 | 24.0 | | 24.0 | | 24.0 | 24.0 | | 24.0 | 24.0 | |
| Pedestrian Calls (#/hr) | | 0 | 0 | | 0 | | 0 | 0 | | 0 | 0 | |
| Act Effct Green (s) | 131.3 | 127.5 | | | 112.6 | | | | | | 18.2 | |
| Actuated g/C Ratio | 0.82 | 0.80 | | | 0.70 | | | | | | 0.11 | |
| v/c Ratio | 0.60 | 0.44 | | | 0.76 | | | | | | 0.75 | |
| Control Delay | 37.2 | 15.0 | | | 24.4 | | | | | | 52.6 | |
| Queue Delay | 0.0 | 0.0 | | | 0.0 | | | | | | 0.0 | |
| Total Delay | 37.2 | 15.0 | | | 24.4 | | | | | | 52.6 | |
| LOS | D | B | | | C | | | | | | D | |
| Approach Delay | | 16.3 | | | 24.4 | | | | | | 52.6 | |
| Approach LOS | | B | | | C | | | | | | D | |

Intersection Summary

Area Type: Other
Cycle Length: 160
Actuated Cycle Length: 160
Offset: 124 (78%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green
Natural Cycle: 120
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 0.76
Intersection Signal Delay: 22.4 Intersection LOS: C
Intersection Capacity Utilization 83.6% ICU Level of Service E
Analysis Period (min) 15

Splits and Phases: 942: Queen Street W & Tim Hortons

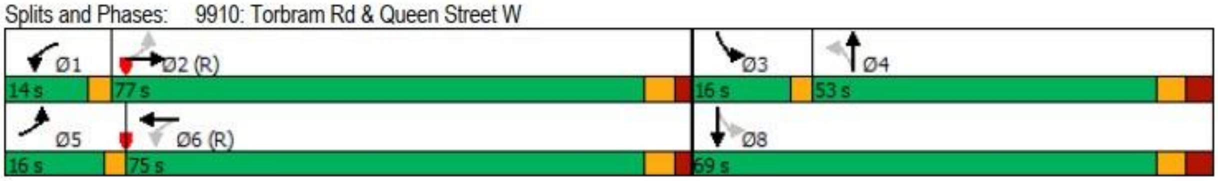


| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | | 1 | 6 | | 4 | 4 | | 3 | 8 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | | 5.0 | 8.0 | | 8.0 | 8.0 | | 5.0 | 8.0 | |
| Minimum Split (s) | 8.0 | 26.5 | | 8.0 | 26.5 | | 40.7 | 40.7 | | 8.0 | 40.7 | |
| Total Split (s) | 16.0 | 77.0 | | 14.0 | 75.0 | | 53.0 | 53.0 | | 16.0 | 69.0 | |
| Total Split (%) | 10.0% | 48.1% | | 8.8% | 46.9% | | 33.1% | 33.1% | | 10.0% | 43.1% | |
| Maximum Green (s) | 13.0 | 70.5 | | 11.0 | 68.5 | | 45.3 | 45.3 | | 13.0 | 61.3 | |
| Yellow Time (s) | 3.0 | 4.0 | | 3.0 | 4.0 | | 4.0 | 4.0 | | 3.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 2.5 | | 0.0 | 2.5 | | 3.7 | 3.7 | | 0.0 | 3.7 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 3.0 | 6.5 | | 3.0 | 6.5 | | 7.7 | 7.7 | | 3.0 | 7.7 | |
| Lead/Lag | Lead | Lag | | Lead | Lag | | Lag | Lag | | Lead | | |
| Lead-Lag Optimize? | Yes | Yes | | Yes | Yes | | Yes | Yes | | Yes | | |
| Vehicle Extension (s) | 3.0 | 5.0 | | 3.0 | 5.0 | | 5.0 | 5.0 | | 3.0 | 5.0 | |
| Recall Mode | None | C-Max | | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 8.0 | | | 8.0 | | 8.0 | 8.0 | | | 8.0 | |
| Flash Dont Walk (s) | | 12.0 | | | 12.0 | | 25.0 | 25.0 | | | 25.0 | |
| Pedestrian Calls (#/hr) | | 0 | | | 0 | | 0 | 0 | | | 0 | |
| Act Effct Green (s) | 88.4 | 72.7 | 160.0 | 81.6 | 68.5 | 160.0 | 45.2 | 45.2 | 160.0 | 65.2 | 60.5 | 160.0 |
| Actuated g/C Ratio | 0.55 | 0.45 | 1.00 | 0.51 | 0.43 | 1.00 | 0.28 | 0.28 | 1.00 | 0.41 | 0.38 | 1.00 |
| v/c Ratio | 0.95 | 0.63 | 0.06 | 0.52 | 0.68 | 0.12 | 0.77 | 0.92 | 0.10 | 0.76 | 0.35 | 0.09 |
| Control Delay | 87.0 | 40.9 | 0.1 | 18.9 | 25.0 | 0.1 | 74.5 | 70.0 | 0.2 | 60.2 | 36.4 | 0.1 |
| Queue Delay | 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 | 87.0 | 40.9 | 0.1 | 18.9 | 25.0 | 0.1 | 74.5 | 70.0 | 0.2 | 60.2 | 36.4 | 0.1 |
| LOS | F | D | A | B | C | A | E | E | A | E | D | A |
| Approach Delay | | 45.1 | | | 21.9 | | | 62.9 | | | 34.4 | |
| Approach LOS | | D | | | C | | | E | | | C | |

**Intersection Summary**

Area Type: Other
Cycle Length: 160
Actuated Cycle Length: 160
Offset: 18 (11%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green
Natural Cycle: 85
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 0.95
Intersection Signal Delay: 40.6 Intersection LOS: D
Intersection Capacity Utilization 87.0% ICU Level of Service E
Analysis Period (min) 15

Splits and Phases: 9910: Torbram Rd & Queen Street W

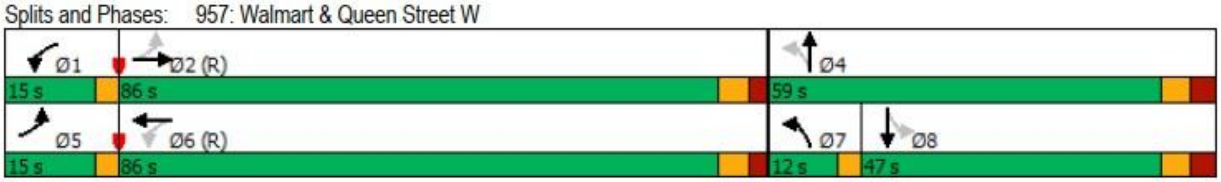


| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | | 1 | 6 | | 7 | 4 | | 8 | 8 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | | 5.0 | 8.0 | | 5.0 | 8.0 | | 8.0 | 8.0 | |
| Minimum Split (s) | 9.0 | 29.6 | | 9.0 | 29.6 | | 9.0 | 36.5 | | 36.5 | 36.5 | |
| Total Split (s) | 15.0 | 86.0 | | 15.0 | 86.0 | | 12.0 | 59.0 | | 47.0 | 47.0 | |
| Total Split (%) | 9.4% | 53.8% | | 9.4% | 53.8% | | 7.5% | 36.9% | | 29.4% | 29.4% | |
| Maximum Green (s) | 12.0 | 79.4 | | 12.0 | 79.4 | | 9.0 | 51.5 | | 39.5 | 39.5 | |
| Yellow Time (s) | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.0 | | 4.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 2.6 | | 0.0 | 2.6 | | 0.0 | 3.5 | | 3.5 | 3.5 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 3.0 | 6.6 | | 3.0 | 6.6 | | 3.0 | 7.5 | | 7.5 | 7.5 | |
| Lead/Lag | Lead | Lag | | Lead | Lag | | Lead | | | Lag | Lag | |
| Lead-Lag Optimize? | Yes | Yes | | Yes | Yes | | Yes | | | Yes | Yes | |
| Vehicle Extension (s) | 5.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 8.0 | | | 8.0 | | | 8.0 | | 8.0 | 8.0 | |
| Flash Dont Walk (s) | | 15.0 | | | 15.0 | | | 21.0 | | 21.0 | 21.0 | |
| Pedestrian Calls (#/hr) | | 0 | | | 0 | | | 0 | | 0 | 0 | |
| Act Effct Green (s) | 104.5 | 90.4 | 160.0 | 104.7 | 90.5 | 160.0 | 46.4 | 41.9 | | 29.9 | 29.9 | |
| Actuated g/C Ratio | 0.65 | 0.56 | 1.00 | 0.65 | 0.57 | 1.00 | 0.29 | 0.26 | | 0.19 | 0.19 | |
| v/c Ratio | 0.51 | 0.61 | 0.10 | 0.48 | 0.73 | 0.04 | 0.85 | 0.54 | | 0.86 | 0.28 | |
| Control Delay | 34.5 | 32.5 | 0.1 | 31.5 | 21.8 | 0.0 | 71.5 | 26.9 | | 101.7 | 32.2 | |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.9 | 0.0 | | 0.0 | 0.1 | |
| Total Delay | 34.5 | 32.5 | 0.1 | 31.5 | 21.8 | 0.0 | 75.4 | 26.9 | | 101.7 | 32.3 | |
| LOS | C | C | A | C | C | A | E | C | | F | C | |
| Approach Delay | | 30.0 | | | 21.6 | | | 51.7 | | | 74.0 | |
| Approach LOS | | C | | | C | | | D | | | E | |

**Intersection Summary**

Area Type: Other
Cycle Length: 160
Actuated Cycle Length: 160
Offset: 104 (65%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green
Natural Cycle: 105
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 0.86
Intersection Signal Delay: 31.2 Intersection LOS: C
Intersection Capacity Utilization 87.7% ICU Level of Service E
Analysis Period (min) 15

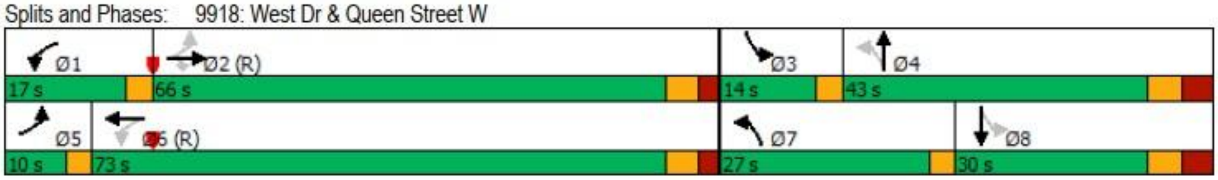
Splits and Phases: 957: Walmart & Queen Street W



| Lane Group | EBL | EBT | EBR | WBL | WBT | WBR | NBL | NBT | NBR | SBL | SBT | SBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Detector Phase | 5 | 2 | 2 | 1 | 6 | | 7 | 4 | | 3 | 8 | |
| Switch Phase | | | | | | | | | | | | |
| Minimum Initial (s) | 5.0 | 8.0 | 8.0 | 5.0 | 8.0 | | 5.0 | 8.0 | | 5.0 | 8.0 | |
| Minimum Split (s) | 8.0 | 27.6 | 27.6 | 8.0 | 27.6 | | 8.0 | 41.7 | | 9.0 | 41.7 | |
| Total Split (s) | 10.0 | 66.0 | 66.0 | 17.0 | 73.0 | | 27.0 | 43.0 | | 14.0 | 30.0 | |
| Total Split (%) | 7.1% | 47.1% | 47.1% | 12.1% | 52.1% | | 19.3% | 30.7% | | 10.0% | 21.4% | |
| Maximum Green (s) | 7.0 | 59.4 | 59.4 | 14.0 | 66.4 | | 24.0 | 35.3 | | 11.0 | 22.3 | |
| Yellow Time (s) | 3.0 | 4.0 | 4.0 | 3.0 | 4.0 | | 3.0 | 4.0 | | 3.0 | 4.0 | |
| All-Red Time (s) | 0.0 | 2.6 | 2.6 | 0.0 | 2.6 | | 0.0 | 3.7 | | 0.0 | 3.7 | |
| Lost Time Adjust (s) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Lost Time (s) | 3.0 | 6.6 | 6.6 | 3.0 | 6.6 | | 3.0 | 7.7 | | 3.0 | 7.7 | |
| Lead/Lag | Lead | Lag | Lag | Lead | Lag | | Lead | Lag | | Lead | Lag | |
| Lead-Lag Optimize? | Yes | Yes | Yes | Yes | Yes | | Yes | Yes | | Yes | Yes | |
| Vehicle Extension (s) | 3.0 | 5.0 | 5.0 | 3.0 | 5.0 | | 3.0 | 5.0 | | 5.0 | 5.0 | |
| Recall Mode | None | C-Max | C-Max | None | C-Max | | None | None | | None | None | |
| Walk Time (s) | | 8.0 | 8.0 | | 8.0 | | | 8.0 | | | 8.0 | |
| Flash Dont Walk (s) | | 13.0 | 13.0 | | 13.0 | | | 26.0 | | | 26.0 | |
| Pedestrian Calls (#/hr) | | 0 | 0 | | 0 | | | 0 | | | 0 | |
| Act Effct Green (s) | 72.5 | 59.4 | 59.4 | 82.5 | 66.4 | 140.0 | 51.5 | 35.9 | | 34.7 | 19.8 | |
| Actuated g/C Ratio | 0.52 | 0.42 | 0.42 | 0.59 | 0.47 | 1.00 | 0.37 | 0.26 | | 0.25 | 0.14 | |
| v/c Ratio | 0.94 | 0.96 | 0.31 | 0.98 | 0.97 | 0.02 | 1.16 | 0.84 | | 0.34 | 0.57 | |
| Control Delay | 85.9 | 52.2 | 4.4 | 92.6 | 47.9 | 0.0 | 131.8 | 51.4 | | 33.9 | 41.1 | |
| Queue Delay | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 0.0 | 0.0 | |
| Total Delay | 85.9 | 52.2 | 4.4 | 92.6 | 47.9 | 0.0 | 131.8 | 51.4 | | 33.9 | 41.1 | |
| LOS | F | D | A | F | D | A | F | D | | C | D | |
| Approach Delay | | 50.4 | | | 51.4 | | | 82.6 | | | 39.8 | |
| Approach LOS | | D | | | D | | | F | | | D | |

| Intersection Summary | |
|---|---|
| Area Type: Other | |
| Cycle Length: 140 | |
| Actuated Cycle Length: 140 | |
| Offset: 0 (0%), Referenced to phase 2:EBTL and 6:WBTL, Start of Green | |
| Natural Cycle: 130 | |
| Control Type: Actuated-Coordinated | |
| Maximum v/c Ratio: 1.16 | |
| Intersection Signal Delay: 56.4 | Intersection LOS: E |
| Intersection Capacity Utilization 120.8% | ICU Level of Service H |
| Analysis Period (min) 15 | |

Splits and Phases: 9918: West Dr & Queen Street W



# Appendix B - Travel Time Coordinates

The following section includes the coordinates used to obtain the existing travel time from the Google O-D API (2022-2023).

| Intersections | OD | Latitude | Longitude | Direction | Intersections | OD | Latitude | Longitude | Direction |
|---|---|---|---|---|---|---|---|---|---|
| West Dr. to Dixie Rd. | Origin | 43.70898543 | -79.73438354 | EB | Gore Rd. to Beaumaris Dr. | Origin | 43.76608326 | -79.65574754 | WB |
| | Destination | 43.71480086 | -79.72796711 | EB | | Destination | 43.76523718 | -79.661047 | WB |
| Dixie Rd. to Central Pk. | Origin | 43.71479621 | -79.72795906 | EB | Beaumaris Dr. to Cherrycrest Dr. | Origin | 43.76521687 | -79.66108923 | WB |
| | Destination | 43.72044222 | -79.72175671 | EB | | Destination | 43.76326445 | -79.66953581 | WB |
| Central Pk. to Bramalea Rd. | Origin | 43.7204795 | -79.72172727 | EB | Cherrycrest Dr. to McVean Dr. | Origin | 43.76324551 | -79.66956865 | WB |
| | Destination | 43.72440012 | -79.71736998 | EB | | Destination | 43.76179455 | -79.67308112 | WB |
| Bramalea Rd. to Finchgate Blvd. | Origin | 43.72441889 | -79.71734199 | EB | McVean Dr. to Goreway Dr. | Origin | 43.76177559 | -79.67310946 | WB |
| | Destination | 43.72807321 | -79.71329109 | EB | | Destination | 43.75322439 | -79.68458383 | WB |
| Finchgate Blvd. to Torbram Rd. | Origin | 43.72806161 | -79.71329107 | EB | Goreway Dr. to Auction Ln. | Origin | 43.75315522 | -79.68462489 | WB |
| | Destination | 43.73398111 | -79.70662641 | EB | | Destination | 43.75055641 | -79.68769553 | WB |
| Torbram Rd. to Torbram Plaza | Origin | 43.73400602 | -79.70664263 | EB | Auction Ln. to Delta Pk. | Origin | 43.75053453 | -79.68771481 | WB |
| | Destination | 43.73642925 | -79.70389598 | EB | | Destination | 43.7462524 | -79.69280341 | WB |
| Torbram Plaza to Gateway Blvd. | Origin | 43.73643532 | -79.70383848 | EB | Delta Pk. to Airport Rd. | Origin | 43.74620593 | -79.69282912 | WB |
| | Destination | 43.73871621 | -79.70119636 | EB | | Destination | 43.74362836 | -79.69591819 | WB |
| Gateway Blvd. to Smart Centres | Origin | 43.73873528 | -79.70120232 | EB | Airport Rd. to Smart Centres | Origin | 43.74360526 | -79.69596278 | WB |
| | Destination | 43.74083338 | -79.69878845 | EB | | Destination | 43.74103013 | -79.69889203 | WB |
| Smart Centres to Airport Rd. | Origin | 43.74089476 | -79.69871524 | EB | Smart Centres Gateway Blvd. | Origin | 43.74099084 | -79.69891895 | WB |
| | Destination | 43.74341551 | -79.69575251 | EB | | Destination | 43.73886532 | -79.70135667 | WB |
| Airport Rd. to Delta Pk. | Origin | 43.74343397 | -79.69573547 | EB | Gateway Blvd. to Torbram Plaza | Origin | 43.73883966 | -79.70139436 | WB |
| | Destination | 43.74607189 | -79.69267913 | EB | | Destination | 43.73656794 | -79.70402553 | WB |
| Delta Pk. to Auction Ln. | Origin | 43.74613545 | -79.69262106 | EB | Torbram Plaza to Torbram Rd. | Origin | 43.73653462 | -79.70407166 | WB |
| | Destination | 43.75036861 | -79.68760882 | EB | | Destination | 43.73416946 | -79.70678543 | WB |
| Auction Ln. to Goreway Dr. | Origin | 43.75041879 | -79.68755015 | EB | Torbram Rd. to Finchgate Blvd. | Origin | 43.73413495 | -79.70680273 | WB |
| | Destination | 43.75298122 | -79.68442238 | EB | | Destination | 43.72818479 | -79.71346665 | WB |
| Goreway Dr. to McVean Dr. | Origin | 43.75302212 | -79.68438754 | EB | Finchgate Blvd. to Bramalea Rd. | Origin | 43.7281418 | -79.71353498 | WB |
| | Destination | 43.76157618 | -79.67298873 | EB | | Destination | 43.72455393 | -79.7175253 | WB |
| McVean Dr. to Cherrycrest Dr. | Origin | 43.76159999 | -79.67293598 | EB | Bramalea Rd. to Central Pk. | Origin | 43.72451662 | -79.7175596 | WB |
| | Destination | 43.76310096 | -79.66944721 | EB | | Destination | 43.72057939 | -79.7219502 | WB |
| Cherrycrest Dr. to Beaumaris Dr. | Origin | 43.7630947 | -79.66939912 | EB | Central Pk. to Dixie Rd. | Origin | 43.72053257 | -79.72196748 | WB |
| | Destination | 43.76500316 | -79.66102638 | EB | | Destination | 43.71497345 | -79.72813833 | WB |
| Beaumaris Dr. to Gore Rd. | Origin | 43.76502041 | -79.66095254 | EB | Dixie Rd. to West Dr. | Origin | 43.71491294 | -79.72815528 | WB |
| | Destination | 43.76585206 | -79.65576088 | EB | | Destination | 43.70908747 | -79.73457512 | WB |

# Appendix C - Westbound Analysis Results

## Appendix C-1: Average Travel Time Supplementary Analysis for Westbound

Table C- 1 shows the average travel time (in seconds) for passenger vehicles in each segment per scenario in the westbound (WB) direction for all scenarios. Figure C- 1 is provided as a graphical representation for the values presented in Table C- 1.

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **West Dr WB** | 16.90 | 17.01 (+0.11) | 17.07 (+0.17) | 16.99 (+0.09) | 16.96 (+0.06) | 16.95 (+0.05) | 16.97 (+0.07) | 16.93 (+0.03) |
| **Dixie - West Dr WB** | 77.12 | 77.58 (+0.47) | 77.69 (+0.58) | 91.15 (+14.03) | 93.01 (+15.89) | 91.2 (+14.09) | 77.11 (-0.01) | 89.13 (+12.01) |
| **Central Park - Dixie WB** | 110.63 | 108.93 (-1.71) | 112.77 (+2.14) | 106.32 (-4.32) | 107.32 (-3.32) | 106.86 (-3.79) | 110.69 (+0.06) | 107.06 (-3.59) |
| **Bramalea - Central Park WB** | 63.78 | 65.26 (+1.48) | 66.15 (+2.38) | 70.27 (+6.49) | 70.54 (+6.77) | 70.48 (+6.71) | 65.39 (+1.62) | 70.68 (+6.90) |
| **Finchgate - Bramalea WB** | 75.18 | 73.19 (-2.00) | 74.2 (-0.99) | 105.99 (+30.81) | 99.59 (+24.41) | 102.95 (+27.77) | 76.45 (+1.27) | 102.33 (+27.15) |
| **Torbram Rd - Finchgate WB** | 64.07 | 64.51 (+0.44) | 64.08 (-0.01) | 94.89 (+30.82) | 83.89 (+19.82) | 88.42 (+24.34) | 65.48 (+1.40) | 85.72 (+21.65) |
| **Torbram Plaza - Torbram Rd WB** | 58.73 | 57.33 (-1.41) | 58.04 (-0.70) | 58.65 (-0.09) | 59.02 (+0.29) | 57.06 (-1.68) | 57.9 (-0.83) | 59.06 (+0.33) |
| **Gateway - Torbram Plaza (Walmart) WB** | 32.16 | 31.27 (-0.90) | 30.34 (-1.83) | 32.72 (+0.56) | 32.42 (+0.26) | 31.51 (-0.66) | 30.32 (-1.85) | 32.39 (+0.23) |
| **Smart Centres - Gateway WB** | 46.21 | 43.17 (-3.04) | 45.82 (-0.40) | 46.55 (+0.34) | 44.58 (-1.64) | 44.14 (-2.07) | 44.43 (-1.78) | 45.19 (-1.03) |
| **Airport Rd - Smart Centres (Tim Hortons) WB** | 42.87 | 43.18 (+0.31) | 42.78 (-0.09) | 44.8 (+1.94) | 44.38 (+1.51) | 42.43 (-0.44) | 42.28 (-0.59) | 45.58 (+2.72) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **Delta Park - Airport Rd WB** | 87.50 | 83.11 (-4.40) | 84 (-3.52) | 84.79 (-2.72) | 84.09 (-3.43) | 83.89 (-3.63) | 82.35 (-5.16) | 84.6 (-2.91) |
| **Auction Ln - Delta Park WB** | 48.76 | 54.64 (+5.88) | 54.58 (+5.82) | 56.83 (+8.07) | 57.89 (+9.13) | 57.89 (+9.13) | 54.69 (+5.92) | 56.41 (+7.65) |
| **Goreway - Auction Ln WB** | 45.55 | 47.37 (+1.81) | 44.57 (-1.00) | 48.15 (+2.59) | 46.82 (+1.27) | 49.66 (+4.11) | 46.12 (+0.56) | 48.56 (+3.01) |
| **McVean - Goreway WB** | 221.89 | 233.13 (+11.24) | 232.47 (+10.58) | 246.79 (+24.90) | 251.32 (+29.43) | 244.03 (+22.14) | 227.41 (+5.52) | 254.26 (+32.36) |
| **Cherrycrest - McVean WB** | 63.59 | 62.5 (-1.10) | 62.28 (-1.32) | 75.32 (+11.74) | 74.14 (+10.55) | 73.49 (+9.90) | 62.37 (-1.23) | 74.04 (+10.45) |
| **Beaumaris - Cherrycrest WB** | 52.39 | 51.23 (-1.17) | 51.36 (-1.04) | 68.98 (+16.59) | 69.83 (+17.44) | 70.47 (+18.08) | 51.49 (-0.91) | 70.36 (+17.97) |
| **Gore Rd - Beaumaris WB** | 26.15 | 26.11 (-0.05) | 25.8 (-0.36) | 26.71 (+0.56) | 26.6 (+0.45) | 26.85 (+0.70) | 26.41 (+0.26) | 26.73 (+0.58) |
| **WB Cumulative** | 1133.47 | 1139.44 (+5.97) | 1143.91 (+10.44) | 1275.82 (+142.35) | 1262.32 (+128.85) | 1258.2 (+124.73) | 1137.78 (+4.30) | 1268.94 (+135.47) |

*Table C- 1 - Average travel time for passenger vehicles in the Westbound direction for Queen St*

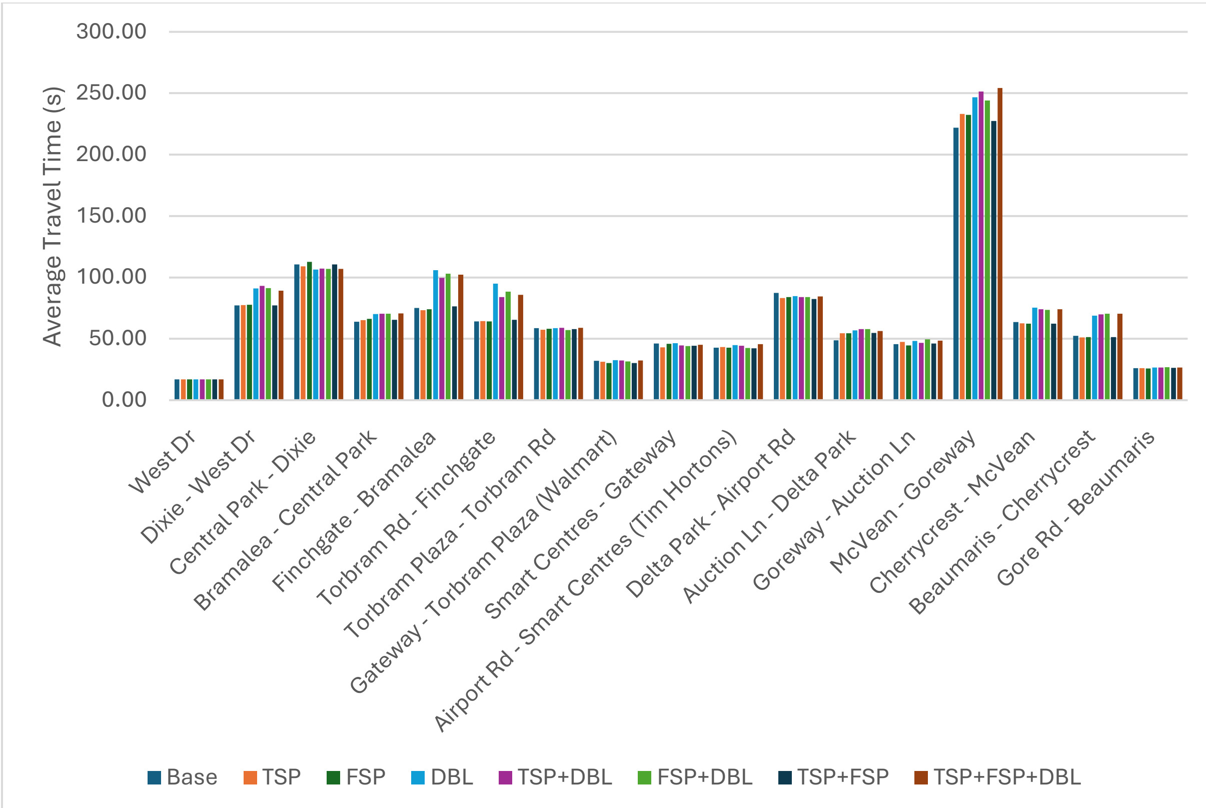



*Figure C- 1 - Average travel time for passenger vehicles in the Westbound direction for Queen St*

The evaluation of westbound (WB) automobile travel times under different priority strategies and dedicated bus laneconfigurations offers further insight into how transit and freight signal priority measures, as well as dedicated bus lanes, affect general traffic. In the Base scenario, which reflects existing operating conditions, the cumulative WB auto travel time stands at 1133.47 seconds, serving as a point of reference for comparative analysis.

The introduction of Transit Signal Priority (TSP) generates a slight increase in WB auto travel time, rising to 1139.44s (+5.97s, +0.5%). While some segments show minor delays, for example, McVean - Goreway WB grows from 221.89s to 233.13s (+11.24s, +5.1%), others benefit from incremental reductions, such as Central Park - Dixie WB (−1.71s, −1.5%) and Finchgate - Bramalea WB (−2.00s, −2.7%). These localized improvements suggest that the extended green phases for transit at certain intersections do not universally disrupt traffic flow and may occasionally reduce unnecessary stops for autos.

By contrast, Freight Signal Priority (FSP) produces a modest rise in cumulative WB travel time, reaching 1143.91s (+10.44s, +0.9%). Although some routes, such as Dixie - West Dr WB (−0.58s, −0.8%), demonstrate slight time savings, others see more pronounced delays, for instance, McVean - Goreway WB climbs from 221.89s to 232.47s (+10.58s, +4.8%), indicating that the selective extension of green signals for freight might periodically impede general traffic progression.

In contrast, the dedicated bus lanescenario triggers a substantial jump in WB auto travel times, rising to 1275.82s (+142.34s, +12.6%). This significant increase can be largely attributed to the reallocation of the lane that favors buses, thereby reducing the capacity available for other vehicles. Substantial slowdowns are evident in segments like Bramalea - Central Park WB (+24.41s, +38.3%) and McVean - Goreway WB (+24.90s, +11.2%), which highlights how dedicated bus lanecorridors can exacerbate congestion in corridors with substantial general-purpose traffic volumes.

The combined scenarios of TSP and dedicated bus lane, FSP and dedicated bus lanepartially mitigate dedicated bus lane-induced delays yet remain considerably higher than the base, with overall WB times of 1262.32s (+128.85s, +11.4%) and 1258.24s (+124.78s, +11.0%), respectively. These results suggest that while signal priority helps reduce some intersection-level bottlenecks, the loss of a general-purpose lane remains the dominant factor restricting vehicular throughput.

Notably, TSP FSP, implemented without a dedicated bus lane, produces one of the smallest increases in WB travel time, at 1137.78s (+4.31s, +0.4%). This finding implies that combining transit and freight priorities can streamline signal operations sufficiently to preserve near-base conditions for autos, even if individual segments (e.g., Bramalea - Central Park WB at +2.86s, +4.5%) experience mild disruptions. However, once dedicated bus laneis added to both TSP and FSP, travel time escalates to 1268.94s (+135.47s, +12.0%), reinforcing that capacity constraints from dedicating a lane to transit overshadow signal optimization benefits.

Overall, these observations highlight that while TSP and FSP alone exert only minimal or mixed effects on WB auto travel, dedicated bus lane implementation consistently imposes significant delays due to diminished lane availability. Integrating TSP or FSP with dedicated bus laneyields marginal amelioration but cannot fully offset dedicated bus lane-driven congestion. Consequently, the relative gains of signal priorities in the WB direction are dwarfed by the more substantial lane reallocation impacts associated with bus rapid transit.

Table C- 2 and Figure C- 2 show the average travel time (in seconds) for the freight along the westbound (WB) movement of Queen Street during the PM peak hours.

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **West Dr WB** | 17.04 | 17.19 (+0.15) | 17.25 (+0.21) | 17.08 (+0.04) | 17.07 (+0.03) | 17.07 (+0.03) | 17.09 (+0.05) | 17.04 (-0.01) |
| **Dixie - West Dr WB** | 78.72 | 78.74 (+0.02) | 79.64 (+0.92) | 94.06 (+15.34) | 95.49 (+16.77) | 94.23 (+15.50) | 78.48 (-0.25) | 91.75 (+13.03) |
| **Central Park - Dixie WB** | 114.96 | 113.95 (-1.03) | 116.36 (+1.40) | 111.78 (-3.20) | 112.26 (-2.71) | 111.72 (-3.26) | 114.41 (-0.56) | 112.52 (-2.45) |
| **Bramalea - Central Park WB** | 64.87 | 66.3 (+1.43) | 67.44 (+2.56) | 71.7 (+6.83) | 73.28 (+8.40) | 72.32 (+7.45) | 66.69 (+1.82) | 73.11 (+8.23) |
| **Finchgate - Bramalea WB** | 78.04 | 75.63 (-2.42) | 76.98 (-1.07) | 109.82 (+31.79) | 102.91 (+24.87) | 105.74 (+27.70) | 79.25 (+1.21) | 105.52 (+27.49) |
| **Torbram Rd - Finchgate WB** | 65.54 | 65.71 (+0.17) | 65.24 (-0.31) | 97.58 (+32.04) | 86.57 (+21.03) | 90.63 (+25.10) | 66.92 (+1.38) | 87.73 (+22.19) |
| **Torbram Plaza - Torbram Rd WB** | 61.33 | 59.9 (-1.44) | 60.1 (-1.24) | 61.13 (-0.20) | 61.23 (-0.11) | 59.47 (-1.87) | 61.05 (-0.29) | 61.36 (+0.03) |
| **Gateway - Torbram Plaza (Walmart) WB** | 33.98 | 33.05 (-0.94) | 31.69 (-2.29) | 34.16 (+0.18) | 34.13 (+0.15) | 33.28 (-0.71) | 32.25 (-1.74) | 34 (+0.03) |
| **Smart Centres - Gateway WB** | 49.33 | 45.51 (-3.83) | 49.07 (-0.27) | 50.43 (+1.10) | 46.63 (-2.71) | 47.99 (-1.35) | 47.21 (-2.13) | 48.57 (-0.77) |
| **Airport Rd - Smart Centres (Tim Hortons) WB** | 44.01 | 45.2 (+1.18) | 43.97 (-0.05) | 45.54 (+1.53) | 45.11 (+1.10) | 44.35 (+0.34) | 43.34 (-0.68) | 47.7 (+3.69) |
| **Delta Park - Airport Rd WB** | 89.18 | 86.45 (-2.74) | 87.6 (-1.60) | 88.7 (-0.49) | 87.67 (-1.52) | 87.35 (-1.84) | 88.17 (-1.02) | 89.82 (+0.63) |
| **Auction Ln - Delta Park WB** | 54.15 | 59 (+4.84) | 59.41 (+5.26) | 61.71 (+7.56) | 63.17 (+9.01) | 62.62 (+8.46) | 59.44 (+5.28) | 61.37 (+7.22) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Goreway - Auction Ln WB** | 47.79 | 49.84 (+2.05) | 47.05 (-0.74) | 50.82 (+3.03) | 49.55 (+1.76) | 52.24 (+4.46) | 48.46 (+0.68) | 50.75 (+2.97) |
| **McVean - Goreway WB** | 229.52 | 242.61 (+13.09) | 240.85 (+11.32) | 256.79 (+27.26) | 261.91 (+32.39) | 255.16 (+25.63) | 235.84 (+6.32) | 265.09 (+35.56) |
| **Cherrycrest - McVean WB** | 68.40 | 67.37 (-1.03) | 66.29 (-2.12) | 79.41 (+11.01) | 79.68 (+11.28) | 78.35 (+9.96) | 66.4 (-2.01) | 78.84 (+10.45) |
| **Beaumaris - Cherrycrest WB** | 56.71 | 55.74 (-0.98) | 55.47 (-1.25) | 74.11 (+17.40) | 75.44 (+18.73) | 75.93 (+19.22) | 55.46 (-1.25) | 75.35 (+18.65) |
| **Gore Rd - Beaumaris WB** | 28.52 | 28.5 (-0.03) | 28.03 (-0.50) | 29.58 (+1.06) | 29.37 (+0.85) | 29.69 (+1.17) | 28.93 (+0.41) | 29.58 (+1.06) |
| **WB Cumulative** | 1182.09 | 1190.6 (+8.51) | 1192.36 (+10.27) | 1334.31 (+152.22) | 1321.37 (+139.28) | 1318.06 (+135.97) | 1189.33 (+7.24) | 1330.03 (+147.94) |

*Table C- 2- Average travel time for freight in the Westbound direction for Queen St*

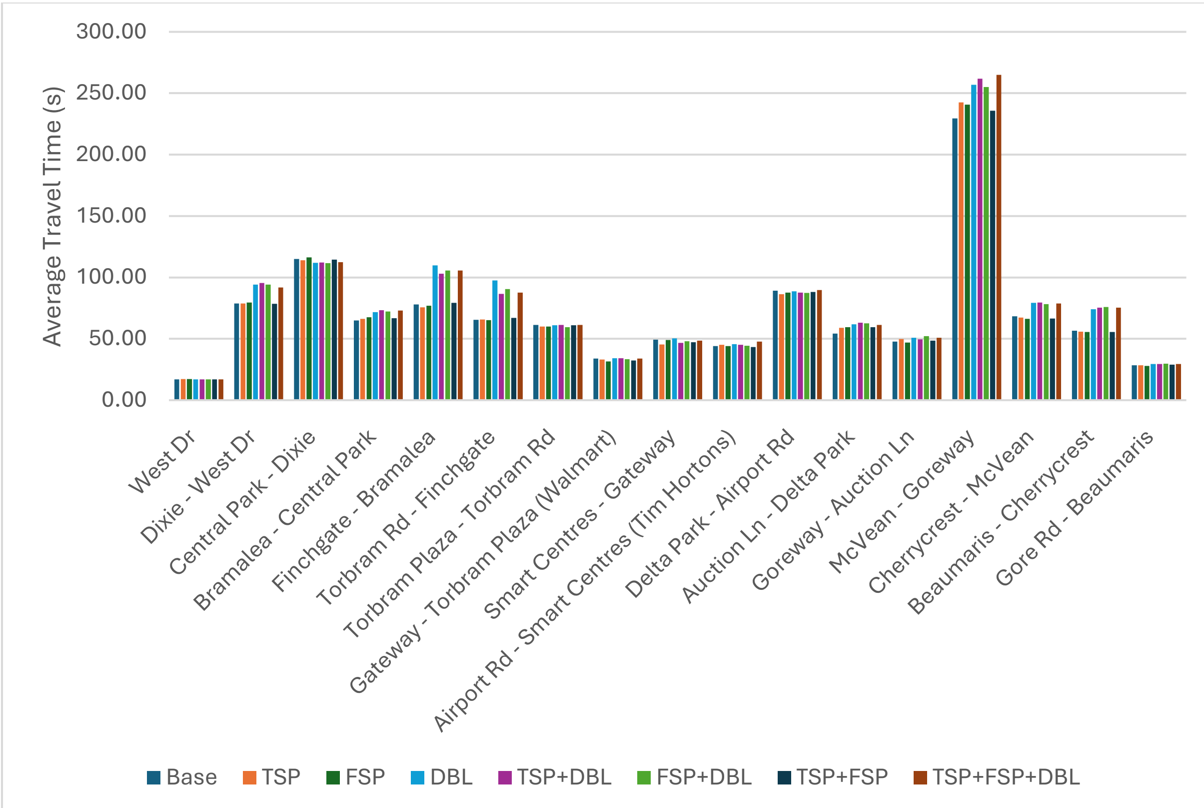



*Figure C- 2 - Average travel time for freight in the Westbound direction for Queen St*

The analysis of westbound (WB) freight travel times across various transit and freight priority strategies, as well as dedicated bus lane deployments, provides insight into how signal adjustments and dedicated lanes affect commercial vehicle movement. Under Base conditions, freight traffic collectively requires 1182.09 seconds along the WB corridor, establishing the reference for subsequent comparisons.

The introduction of Transit Signal Priority (TSP) elevates this total to 1190.6s (+8.51s, +0.7%), signifying a minor overall delay for freight. Certain segments, including Goreway - Auction Ln WB (rising from 47.85s to 49.84s, +2s) and McVean - Goreway WB (from 229.52s to 242.61s, +13.09s), exhibit notable slowdowns, suggesting that extending green signals for transit can displace freight vehicles' optimal progression. However, there are instances of improvement, such as Central Park - Dixie WB (−1.03s, −0.9%), which demonstrates that TSP does not uniformly impede freight traffic.

By contrast, Freight Signal Priority (FSP) produces a small increase in cumulative time, reaching 1192.36s (+10.27s, +0.9%) relative to the base. While specific links, like Delta Park - Airport Rd WB

(−2.74s, −3.1%), demonstrate benefits from freight-oriented green extensions, others, e.g., Bramalea - Central Park WB (+1.43s, +2.2%), suggest localized trade-offs where adjusted signal phases for trucks might hinder flow at certain intersections.

In the dedicated bus lane scenario, travel time surges to 1334.31s (+152.22s, +12.9%), representing the largest overall impact on WB freight. Removing a general-purpose lane in favor of buses spurs significant congestion, as seen in Finchgate - Bramalea WB (soaring from 78.07s to 109.82s, +31.75s) and Beaumaris - Cherrycrest WB (+17.40s, +30.7%). These results emphasize that lane reallocation poses fundamental challenges to commercial vehicles when capacity becomes constrained.

Combining signal priority with dedicated bus lane alleviates some congestion but remains substantially above Base. TSP & dedicated bus lane yields 1321.37s (+139.28s, +11.8%), whereas FSP & dedicated bus lane results in 1318.06s (+135.97s, +11.5%). Even though both scenarios modestly outperform dedicated bus lane alone, the net effect for freight stays unfavorable because lane reductions overshadow any intersection-level efficiencies. Conversely, TSP FSP without dedicated bus lane actually lowers WB freight times to 1189.33s (+7.24s, +0.6%), almost matching the base scenario, highlighting that synergistic signal adjustments for both transit and trucks can foster more efficient corridor flow under normal lane allocations.

However, once dedicated bus lane is added to TSP FSP, total freight travel time rises sharply to 1330.03s (+147.94s, +12.5%), confirming that the capacity constraints of dedicated bus lanes outweigh the gains from carefully coordinated signal priorities. Overall, these findings corroborate a pattern observed elsewhere: dedicated bus lane consistently imposes the most substantial delay for heavy vehicles, while TSP and FSP on their own incur smaller, more localized impacts. The TSP FSP combination stands out for its ability to maintain or slightly improve freight flow in a non-dedicated bus lane environment, which demonstrates the importance of choosing holistic strategies that account for commercial as well as passenger movements.

Table C- 3 and Figure C- 3 show the average travel time (in seconds) for the transit along the westbound (WB) movement of Queen Street during the PM peak hours.

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **West Dr WB** | 39.04 | 37.82 (-1.23) | 38.21 (-0.84) | 37.4 (-1.66) | 37.89 (-1.17) | 37.57 (-1.48) | 38.95 (-0.10) | 37.87 (-1.18) |
| **Dixie - West Dr WB** | 98.59 | 97.34 (-1.27) | 98.39 (-0.22) | 95.87 (-2.73) | 92.39 (-6.21) | 97.2 (-1.40) | 97.75 (-0.86) | 92.16 (-6.45) |
| **Central Park - Dixie WB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Bramalea - Central Park WB** | 107.41 | 101.34 (-6.08) | 95.71 (-11.71) | 99.84 (-7.58) | 96.84 (-10.58) | 97.73 (-9.69) | 99.9 (-7.52) | 101.51 (-5.91) |
| **Finchgate - Bramalea WB** | 142.66 | 101.79 (-40.88) | 100.95 (-41.72) | 131.18 (-11.49) | 121.06 (-21.61) | 122.65 (-20.02) | 99.15 (-43.52) | 122.81 (-19.86) |
| **Torbram Rd - Finchgate WB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Torbram Plaza - Torbram Rd WB** | 102.78 | 91.34 (-11.45) | 92.48 (-10.31) | 117.64 (+14.86) | 110.66 (+7.87) | 115 (+12.22) | 92.53 (-10.26) | 113.73 (+10.94) |
| **Gateway - Torbram Plaza (Walmart) WB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Smart Centres - Gateway WB** | 47.30 | 41.78 (-5.53) | 46.69 (-0.62) | 44.97 (-2.33) | 43.64 (-3.67) | 44.12 (-3.19) | 43.98 (-3.33) | 48.59 (+1.30) |
| **Airport Rd - Smart Centres (Tim Hortons) WB** | 79.53 | 64.16 (-15.38) | 59.94 (-19.60) | 75.01 (-4.53) | 75.49 (-4.05) | 79.09 (-0.44) | 64.86 (-14.68) | 81.17 (+1.64) |
| **Delta Park - Airport Rd WB** | 91.16 | 86.36 (-4.81) | 95.53 (+4.37) | 84.62 (-6.55) | 80.32 (-10.84) | 88.46 (-2.71) | 88.65 (-2.52) | 92.17 (+1.02) |
| **Auction Ln - Delta Park WB** | 58.90 | 55.36 (-3.55) | 60.4 (+1.51) | 59.99 (+1.09) | 63.08 (+4.18) | 59.41 (+0.51) | 58.5 (-0.40) | 61.15 (+2.26) |
| **Goreway - Auction Ln WB** | 77.54 | 67.98 (-9.57) | 63.22 (-14.33) | 80.23 (+2.69) | 74.81 (-2.75) | 78.24 (+0.70) | 67.08 (-10.47) | 79.04 (+1.50) |
| **McVean - Goreway WB** | 270.59 | 255.22 (-15.38) | 264.2 (-6.40) | 244.88 (-25.72) | 248.3 (-22.30) | 243.38 (-27.22) | 254.86 (-15.74) | 253.57 (-17.03) |
| **Cherrycrest - McVean WB** | 70.51 | 65.29 (-5.23) | 59.8 (-10.72) | 73.4 (+2.89) | 76.39 (+5.89) | 75.74 (+5.23) | 68.11 (-2.41) | 75.65 (+5.14) |
| **Beaumaris - Cherrycrest WB** | 57.60 | 58.92 (+1.32) | 61.9 (+4.31) | 63.92 (+6.32) | 63.65 (+6.05) | 65.85 (+8.25) | 56.11 (-1.50) | 62.71 (+5.11) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| Gore Rd - Beaumaris WB | 28.10 | 29.54 (+1.44) | 29.15 (+1.05) | 27.89 (-0.22) | 29.22 (+1.12) | 27.69 (-0.43) | 30.34 (+2.24) | 29.11 (+1.01) |
| WB Cumulative | 1271.70 | 1154.18 (-117.53) | 1166.5 (-105.21) | 1236.75 (-34.96) | 1213.65 (-58.06) | 1232.05 (-39.66) | 1160.7 (-111.01) | 1251.18 (-20.54) |

*Table C- 3 - Average travel time for transit in the Westbound direction for Queen St*

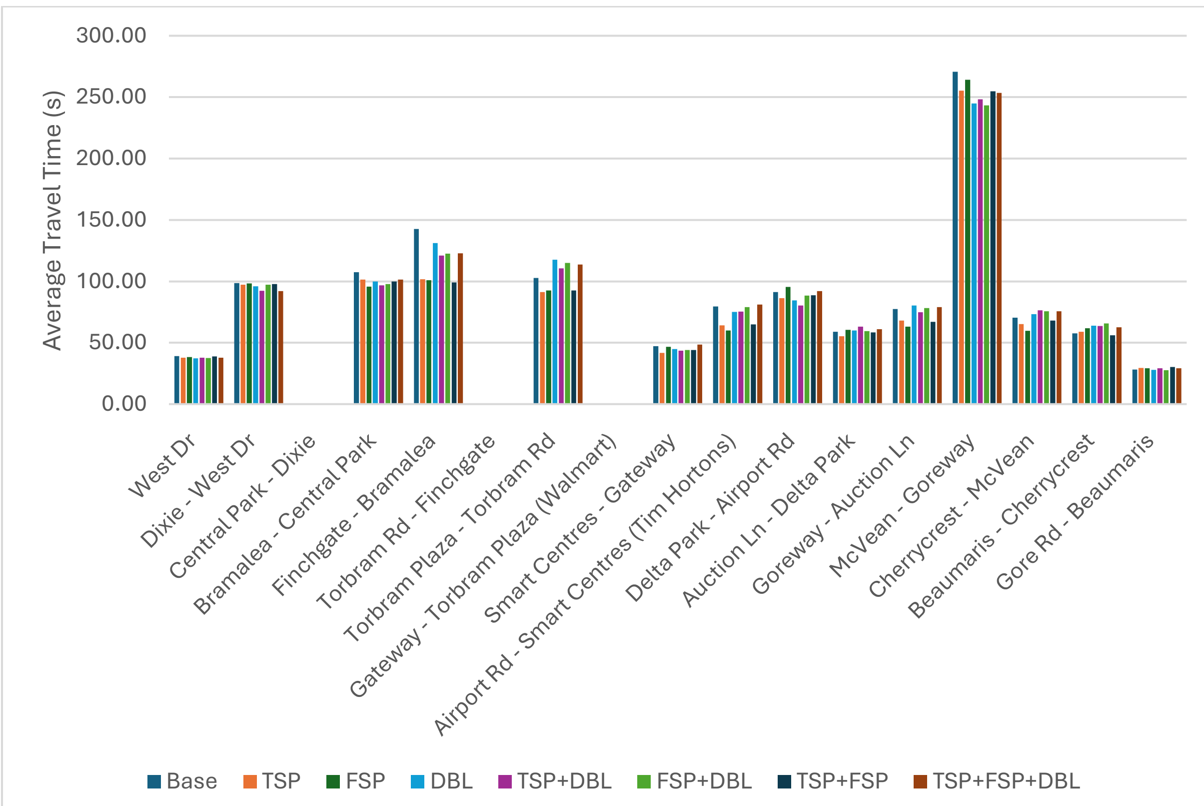



*Figure C- 3 - Average travel time for transit in the Westbound direction for Queen St*

The TSP scenario resulted in a substantial reduction of 117.52 seconds (-9.2%) in WB transit travel time, highlighting its effectiveness in improving travel efficiency for buses. The largest improvements were observed in Airport Rd - Smart Centres (Tim Hortons) WB (-15.38s) and Torbram Rd - Finchgate WB (-

6.08s), suggesting that TSP was particularly effective in mitigating intersection delays in these areas. However, in some segments, such as Beaumaris - Cherrycrest WB (+1.42s), there was a slight increase in travel time, which may be due to reallocated green time or operational constraints.

The FSP scenario produced a comparable reduction in travel time, with an overall decrease of 105.21 seconds (-8.3%). This suggests that prioritizing freight vehicles also leads to indirect benefits for transit by reducing congestion and optimizing intersection performance. The largest reductions were observed in Delta Park - Airport Rd WB (-4.81s) and Auction Ln - Delta Park WB (-6.85s), demonstrating that freight optimization strategies can enhance traffic flow in corridors where transit and freight movements are interdependent.

The dedicated bus lane scenario, which introduced a dedicated bus lane, yielded a smaller reduction of 34.96 seconds (-2.7%) in WB transit travel time. While dedicated bus lanes are generally expected to improve efficiency, the results indicate that other factors, such as intersection delays and interactions with other road users, may limit their effectiveness. Some segments, such as Central Park - Dixie WB (-7.58s), experienced notable improvements, while others, like Beaumaris - Cherrycrest WB (+4.37s), saw increases in travel time, suggesting that dedicated bus lane benefits are highly corridor-dependent.

The TSP and dedicated bus lane combination resulted in a significant reduction of 58.06 seconds (-4.6%), reinforcing the idea that TSP can enhance the effectiveness of dedicated bus lane by reducing intersection delays. The most substantial improvements were recorded in Bramalea - Central Park WB (-7.58s) and Gateway - Torbram Plaza (Walmart) WB (-3.67s). However, the fact that the reduction was smaller than with TSP alone suggests that the benefits of dedicated bus lanes may be offset by other operational constraints.

The FSP and dedicated bus lane combination produced the largest overall travel time reduction among the dual-treatment scenarios, with a decrease of 111.01 seconds (-8.7%). The most notable reductions were seen in Auction Ln - Delta Park WB (-9.22s) and West Dr - Dixie WB (-1.48s), reinforcing the idea that freight optimization can complement transit improvements.

The TSP and FSP combination yielded the most significant overall improvement, reducing WB transit travel time by 111.00 seconds (-8.7%). This aligns with the findings from the EB direction, demonstrating that integrating transit and freight priority strategies is highly effective in reducing travel time. The most substantial improvements were observed in Cherrycrest - McVean WB (-3.52s) and Beaumaris - Cherrycrest WB (-4.24s), suggesting that this combination helps streamline traffic operations at key intersections.

When TSP, FSP, and dedicated bus lane were applied together, the reduction in travel time was slightly smaller at 20.54 seconds (-1.6%), which is notably less than the improvements observed for TSP-FSP alone. This suggests that excessive prioritization across multiple modes may introduce inefficiencies, possibly due to conflicting green time allocations between transit and freight movements or operational complexities introduced by the dedicated bus lane system.

The results indicate that TSP and FSP are the most effective strategies for reducing WB transit travel time, with the greatest benefits observed when these two strategies are combined. dedicated bus lane alone provided modest improvements, and its effectiveness varied across corridor segments, suggesting that the benefits of dedicated bus lanes depend heavily on local traffic conditions and intersection design. Overall, the findings suggest that a balanced combination of TSP and FSP offers the greatest benefits for WB transit operations, while dedicated bus lane should be implemented with careful consideration of corridor-specific constraints.

## Appendix C-2: Total Persons Delay Supplementary Analysis for Westbound

Table C- 4 and Figure C- 4 show the total persons delay (in hours) for the passenger vehicles (or autos) along the westbound (WB) movement of Queen Street during the PM peak hours.

| **Road Segment** | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **West Dr WB** | 69.68 | 71.31 (+1.62) | 71.41 (+1.73) | 80.96 (+11.27) | 80.88 (+11.20) | 81.38 (+11.70) | 69.81 (+0.13) | 79.14 (+9.46) |
| **Dixie - West Dr WB** | 135.77 | 134.45 (-1.33) | 140.82 (+5.04) | 123.6 (-12.18) | 126.61 (-9.17) | 126.25 (-9.53) | 136.54 (+0.77) | 125.81 (-9.97) |
| **Central Park - Dixie WB** | 56.22 | 56.65 (+0.43) | 58.37 (+2.15) | 56.48 (+0.26) | 57.59 (+1.37) | 57.5 (+1.27) | 56.59 (+0.37) | 57.78 (+1.56) |
| **Bramalea - Central Park WB** | 98.28 | 95.82 (-2.47) | 97.55 (-0.74) | 122.57 (+24.29) | 118.53 (+20.25) | 121.38 (+23.10) | 102.6 (+4.32) | 118.98 (+20.70) |
| **Finchgate - Bramalea WB** | 38.95 | 39.19 (+0.25) | 38.52 (-0.43) | 81.68 (+42.73) | 68.22 (+29.28) | 74.95 (+36.01) | 41.93 (+2.99) | 72.71 (+33.76) |
| **Torbram Rd - Finchgate WB** | 46.50 | 44.27 (-2.23) | 45.45 (-1.05) | 45.76 (-0.74) | 46.69 (+0.19) | 43.64 (-2.87) | 44.86 (-1.65) | 46.62 (+0.12) |
| **Torbram Plaza - Torbram Rd WB** | 37.07 | 33.52 (-3.56) | 32.72 (-4.37) | 36.95 (-0.13) | 36.85 (-0.24) | 35.53 (-1.55) | 32.97 (-4.11) | 36.17 (-0.92) |
| **Gateway - Torbram Plaza (Walmart) WB** | 42.98 | 36.92 (-6.07) | 42.02 (-0.97) | 42.53 (-0.46) | 39.43 (-3.56) | 38.8 (-4.19) | 39.8 (-3.19) | 40.45 (-2.54) |
| **Smart Centres - Gateway WB** | 40.97 | 41.2 (+0.22) | 40.94 (-0.05) | 44.05 (+3.08) | 42.02 (+1.05) | 39.81 (-1.17) | 40.54 (-0.45) | 44.38 (+3.41) |
| **Airport Rd - Smart Centres (Tim Hortons) WB** | 98.78 | 93.14 (-5.65) | 92.27 (-6.53) | 92.97 (-5.82) | 91.35 (-7.44) | 90.07 (-8.72) | 90.19 (-8.60) | 92.74 (-6.05) |
| **Delta Park - Airport Rd WB** | 45.24 | 58.92 (+13.68) | 59.32 (+14.08) | 57 (+11.76) | 59.55 (+14.30) | 59.22 (+13.98) | 59.29 (+14.05) | 55.84 (+10.60) |
| **Auction Ln - Delta Park WB** | 44.62 | 47.59 (+2.97) | 43.57 (-1.06) | 50.45 (+5.83) | 47.93 (+3.31) | 52.49 (+7.87) | 45.08 (+0.46) | 50.37 (+5.75) |
| **Goreway - Auction Ln WB** | 221.29 | 220.37 (-0.93) | 222.86 (+1.57) | 202.34 (-18.95) | 202.8 (-18.49) | 198.44 (-22.86) | 223.24 (+1.95) | 202.1 (-19.19) |
| **McVean - Goreway WB** | 97.70 | 95.23 (-2.48) | 95 (-2.71) | 115.79 (+18.08) | 114.11 (+16.40) | 112.81 (+15.10) | 95.57 (-2.14) | 113.15 (+15.44) |
| **Cherrycrest - McVean WB** | 44.72 | 42.47 (-2.26) | 42.93 (-1.80) | 60.99 (+16.27) | 61.46 (+16.74) | 61.44 (+16.72) | 42.91 (-1.82) | 61.34 (+16.62) |
| **Beaumaris - Cherrycrest WB** | 18.83 | 18.89 (+0.06) | 18.06 (-0.78) | 24.8 (+5.96) | 25.06 (+6.23) | 26.56 (+7.73) | 19.45 (+0.62) | 25.86 (+7.03) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Gore Rd - Beaumaris WB** | 48.24 | 49.44 (+1.20) | 49.02 (+0.78) | 49.68 (+1.45) | 49.82 (+1.58) | 49.95 (+1.71) | 49.16 (+0.93) | 50.33 (+2.10) |
| **WB Cumulative** | 1185.85 | 1179.3 (-6.56) | 1190.75 (+4.90) | 1288.53 (+102.68) | 1268.81 (+82.96) | 1270.15 (+84.30) | 1190.46 (+4.61) | 1273.7 (+87.85) |

*Table C- 4 - Total Persons Delay for autos in the westbound direction for Queen St*

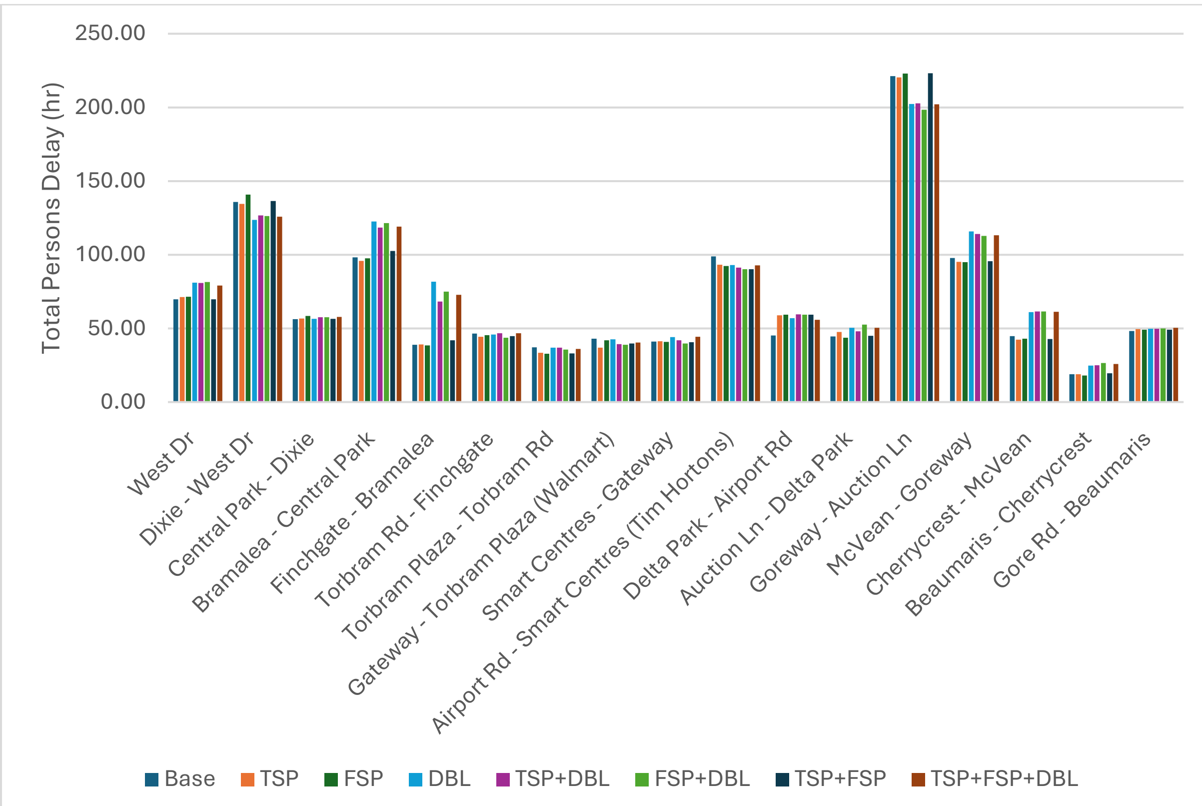



*Figure C- 4 - Total persons delay for passenger vehicle in the westbound direction*

Under Base conditions, the WB corridor has a total persons delay of 1185.85 hours, forming the reference for subsequent comparisons. When Transit Signal Priority (TSP) is implemented, the delay slips slightly to 1179.34 hours (−6.56 hours, −0.6%), indicating a mild benefit in some segments. For example, Bramalea - Central Park WB (−2.47 hours) and McVean - Goreway WB (−2.48 hours) show improvement, possibly due to fewer stops when buses extend green signals that also benefit autos. However, other segments see small rises, West Dr WB (+1.62 hours), suggesting localized disruptions where priority phases may briefly constrain general traffic.

By contrast, Freight Signal Priority (FSP) results in a minor net increase, reaching 1190.75 hours (+4.90 hours, +0.4%) compared to the base. While some routes profit from the smoother flow (e.g., Central Park - Dixie WB (+0.43 hours) remains fairly stable, and McVean - Goreway WB (−2.48 hours) improves further), others, like Delta Park - Airport Rd WB (+13.68 hours), incur extra delay when freight signals occasionally restrict green time for auto-dominated movements.

The dedicated bus lane scenario generates a significant escalation, with total WB delay rising to 1288.53 hours (+102.68 hours, +8.7%). Converting a general-purpose lane to a bus-only facility intensifies congestion among remaining lanes, as seen in Finchgate - Bramalea WB (+42.73 hours) and Bramalea - Central Park WB (+27.42 hours). These spikes highlight the challenges for autos when lane capacity is reduced in areas already prone to queuing.

When TSP and dedicated bus lane are combined, overall WB delay stabilizes slightly at 1268.81 hours (+82.96 hours, +7.0%), an improvement over dedicated bus lane alone but still markedly above the base. Similarly, FSP & dedicated bus lane produces 1270.15 hours (+84.30 hours, +7.1%), which shows that while signal priority can alleviate some bottlenecks, dedicated bus lane reduction effect dominates corridor-wide outcomes. The TSP FSP arrangement (without dedicated bus lane) achieves 1190.46 hours (+4.61 hours, +0.4%), implying that simultaneously accommodating transit and freight needs does not drastically impede autos in a conventional corridor. However, the addition of dedicated bus lane to both TSP and FSP raises WB delay to 1273.72 hours (+87.87 hours, +7.4%), reaffirming that lane reallocation for exclusive bus use overshadows any efficiency gains from coordinated signal priorities.

Overall, these data suggest that dedicated bus lane consistently causes the largest surge in person-delay for WB automobiles, while TSP or FSP alone impose relatively minor corridor-wide effects. Combinations of TSP and FSP often maintain near-base conditions for general traffic, but once dedicated bus lane is introduced, the loss of lane capacity becomes the driving force behind increased delays.

Table C- 5 and Figure C- 5 show the total persons delay (in hours) for the freight along the westbound (WB) movement of Queen Street during the PM peak hours.

| **Road Segment** | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **West Dr WB** | 9.65 | 9.6 (-0.06) | 9.97 (+0.32) | 11.56 (+1.91) | 11.6 (+1.95) | 11.53 (+1.87) | 9.65 (-0.01) | 11.22 (+1.57) |
| **Dixie - West Dr WB** | 20.09 | 20.47 (+0.38) | 21.1 (+1.01) | 18.55 (-1.54) | 19.19 (-0.91) | 18.9 (-1.20) | 20.85 (+0.77) | 19.15 (-0.94) |
| **Central Park - Dixie WB** | 0.00 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| **Bramalea - Central Park WB** | 18.17 | 17.84 (-0.34) | 18.09 (-0.08) | 22.23 (+4.06) | 21.68 (+3.52) | 22.36 (+4.19) | 19.16 (+0.99) | 21.6 (+3.43) |
| **Finchgate - Bramalea WB** | 7.88 | 8.02 (+0.14) | 7.79 (-0.10) | 15.74 (+7.87) | 13.73 (+5.85) | 15.09 (+7.21) | 8.69 (+0.81) | 14.7 (+6.82) |
| **Torbram Rd - Finchgate WB** | 12.95 | 12.75 (-0.21) | 12.67 (-0.28) | 12.68 (-0.27) | 13.11 (+0.17) | 12.23 (-0.72) | 13.03 (+0.08) | 13.15 (+0.21) |
| **Torbram Plaza - Torbram Rd WB** | 11.34 | 10.59 (-0.76) | 10.07 (-1.27) | 11.19 (-0.15) | 11.24 (-0.11) | 11.13 (-0.22) | 10.27 (-1.07) | 11.12 (-0.22) |
| **Gateway - Torbram Plaza (Walmart) WB** | 12.62 | 10.9 (-1.73) | 12.63 (+0.01) | 12.74 (+0.12) | 11.15 (-1.48) | 11.97 (-0.65) | 11.58 (-1.04) | 12.15 (-0.48) |
| **Smart Centres - Gateway WB** | 14.28 | 15.02 (+0.74) | 14.28 (-0.02) | 14.73 (+0.45) | 14.25 (-0.05) | 14.01 (-0.28) | 13.62 (-0.67) | 15.57 (+1.28) |
| **Airport Rd - Smart Centres (Tim Hortons) WB** | 32.60 | 31.02 (-1.59) | 31.07 (-1.54) | 29.96 (-2.65) | 30.46 (-2.15) | 30.11 (-2.50) | 31.1 (-1.51) | 30.43 (-2.18) |
| **Delta Park - Airport Rd WB** | 15.73 | 19.52 (+3.78) | 19.81 (+4.08) | 19.11 (+3.38) | 20.04 (+4.30) | 19.95 (+4.21) | 19.74 (+4.01) | 19.31 (+3.58) |
| **Auction Ln - Delta Park WB** | 12.42 | 13.41 (+0.99) | 12.42 (-0.01) | 14.02 (+1.60) | 13.32 (+0.90) | 14.61 (+2.18) | 12.67 (+0.24) | 14.13 (+1.70) |
| **Goreway - Auction Ln WB** | 57.50 | 58.67 (+1.18) | 59.07 (+1.57) | 53.4 (-4.11) | 53.97 (-3.54) | 53.57 (-3.94) | 57.85 (+0.35) | 53.84 (-3.67) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **McVean - Goreway WB** | 25.54 | 25.17 (-0.38) | 24.9 (-0.66) | 29.79 (+4.25) | 29.88 (+4.33) | 29.46 (+3.92) | 24.83 (-0.72) | 29.45 (+3.90) |
| **Cherrycrest - McVean WB** | 12.87 | 12.42 (-0.46) | 12.35 (-0.53) | 16.89 (+4.02) | 17.29 (+4.42) | 17.06 (+4.19) | 12.18 (-0.70) | 17.25 (+4.39) |
| **Beaumaris - Cherrycrest WB** | 6.25 | 6.26 (+0.01) | 5.95 (-0.31) | 8.23 (+1.98) | 8.28 (+2.03) | 8.78 (+2.53) | 6.53 (+0.28) | 8.4 (+2.15) |
| **Gore Rd - Beaumaris WB** | 17.06 | 17.44 (+0.38) | 17.38 (+0.32) | 17.64 (+0.58) | 17.51 (+0.44) | 17.71 (+0.64) | 17.38 (+0.32) | 17.94 (+0.87) |
| **WB Cumulative** | 286.95 | 289.02 (+2.07) | 289.47 (+2.52) | 308.4 (+21.45) | 306.63 (+19.68) | 308.39 (+21.44) | 289.08 (+2.13) | 309.34 (+22.39) |

*Table C- 5 - Total Persons Delay for freight in the westbound direction for Queen St*

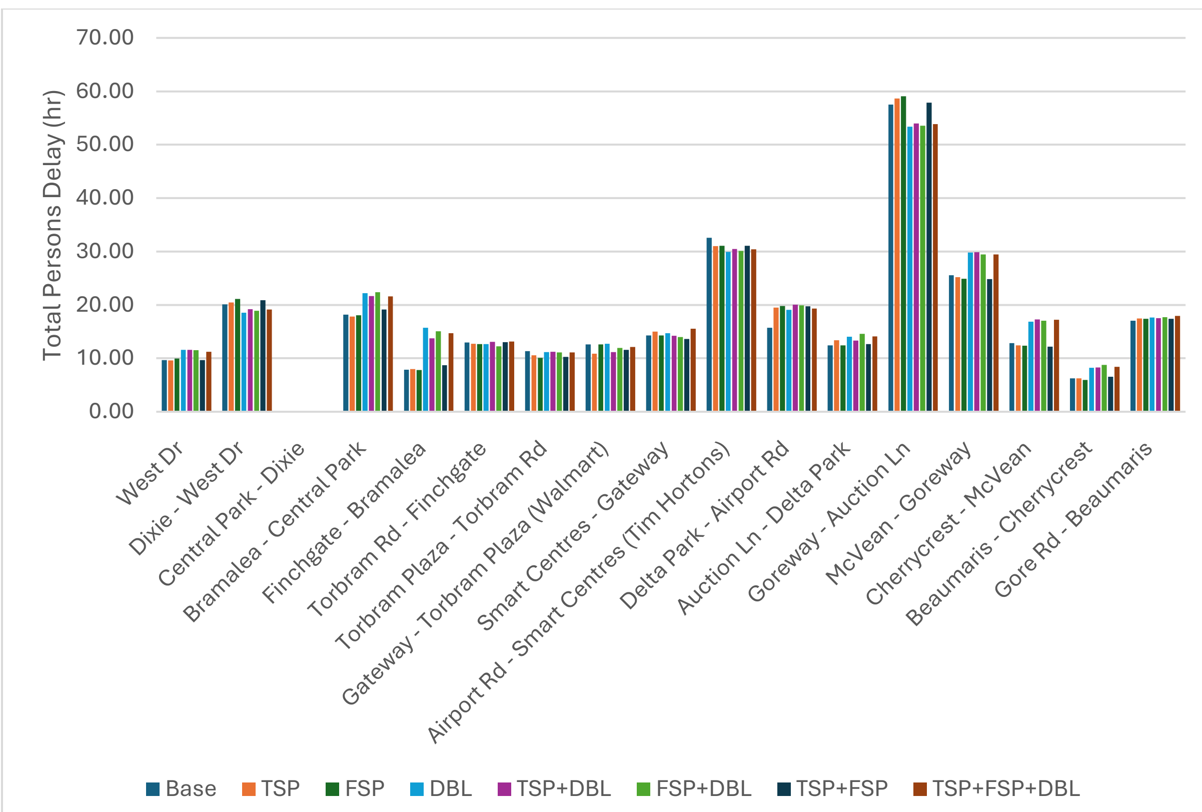



*Figure C- 5 - Total persons delay for freight in the westbound direction*

Under Base conditions, the WB freight corridor registers 286.95 hours of total person-delay. Introducing TSP elevates this value slightly to 289.02 hours (+2.07 hours, +0.7%), indicating that while transit vehicles gain extended or early green phases, freight vehicles may face marginally increased waiting in some segments (e.g., Goreway - Auction Ln WB at +1.18 hours). Nonetheless, certain links, like Dixie - West Dr WB (+0.38 hours), see minimal changes, highlighting the localized nature of TSP's impacts on commercial traffic.

In contrast, FSP yields 289.47 hours (+2.52 hours, +0.9%), remaining fairly close to the base. Although some segments benefit from fewer stops due to freight-oriented green extensions, e.g., Bramalea - Central Park WB (−0.08 hours), Torbram Plaza - Torbram Rd WB (−0.76 hours), others, such as Delta Park - Airport Rd WB (+3.78 hours), see increased queues. These mixed effects suggest that FSP can help freight flow at specific intersections but may not uniformly reduce overall corridor delay.

The dedicated bus lane scenario imposes a more substantial increase in WB person-delay, reaching 308.40 hours (+21.45 hours, +7.5%). Dedicating a lane to buses reduces available road space for heavy vehicles, intensifying congestion and wait times. Segments like Finchgate - Bramalea WB (+7.87 hours) and Airport Rd - Smart Centres (Tim Hortons) WB (−1.59 hours, indicating slight improvement in that particular stretch) highlight the uneven distribution of dedicated bus lane impacts.

When TSP or FSP is paired with dedicated bus lane, total delay remains higher than Base, reflecting the dominant role of lane reallocation in driving freight slowdowns. Specifically, TSP & dedicated bus lane brings the total to 306.63 hours (+19.68 hours) and FSP & dedicated bus lane to 308.39 hours (+21.44 hours), both modest improvements over dedicated bus lane alone yet still substantially above the base scenario. By contrast, combining TSP and FSP in a non-dedicated bus lane environment yields 289.08 hours (+2.13 hours, +0.7%), indicating that simultaneously prioritizing transit and freight does not significantly harm freight operations, nor does it produce major corridor-wide gains. However, once a dedicated bus lane is added to TSP FSP, the cumulative delay rises to 309.34 hours (+22.39 hours, +7.8%), which demonstrates that capacity constraints overshadow any signal-based optimizations.

Overall, these results confirm that dedicated bus lane causes the most substantial surge in person-delay for WB freight, while TSP and FSP alone produce minimal to moderate changes. Although priority strategies can temper some intersection-level inefficiencies, lane reallocation under dedicated bus lane remains the chief factor elevating freight delay in the westbound corridor.

Table C- 6 and Figure C- 6 show the total persons delay (in hours) for the transit along the westbound (WB) movement of Queen Street during the PM peak hours.

| **Road Segment** | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **West Dr WB** | 15.99 | 15.52 (-0.48) | 16.78 (+0.79) | 13.76 (-2.24) | 13.39 (-2.61) | 14.58 (-1.42) | 16.86 (+0.87) | 13.65 (-2.35) |
| **Dixie - West Dr WB** | 26.93 | 24.99 (-1.94) | 22.11 (-4.83) | 24.18 (-2.76) | 22.96 (-3.97) | 23.82 (-3.11) | 23.96 (-2.98) | 24.36 (-2.58) |
| **Central Park - Dixie WB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Bramalea - Central Park WB** | 30.26 | 41.13 (+10.86) | 39.33 (+9.07) | 35.97 (+5.71) | 35.68 (+5.42) | 36.55 (+6.29) | 37.67 (+7.41) | 37.71 (+7.45) |
| **Finchgate - Bramalea WB** | 19.82 | 22.73 (+2.90) | 22.65 (+2.82) | 29.7 (+9.87) | 24.65 (+4.83) | 28.22 (+8.40) | 23.29 (+3.46) | 24.85 (+5.03) |
| **Torbram Rd - Finchgate WB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Torbram Plaza - Torbram Rd WB** | 17.95 | 18.09 (+0.14) | 18.2 (+0.25) | 18.29 (+0.34) | 18.98 (+1.03) | 18.3 (+0.35) | 17.38 (-0.58) | 17.77 (-0.19) |
| **Gateway - Torbram Plaza (Walmart) WB** | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Smart Centres - Gateway WB** | 12.73 | 12.39 (-0.35) | 11 (-1.74) | 10.89 (-1.85) | 10.89 (-1.85) | 11.97 (-0.78) | 13.01 (+0.28) | 12.9 (+0.17) |
| **Airport Rd - Smart Centres (Tim Hortons) WB** | 20.54 | 18.3 (-2.25) | 21.93 (+1.39) | 20.23 (-0.33) | 16.65 (-3.90) | 19.13 (-1.43) | 19.55 (-1.00) | 20.15 (-0.41) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Delta Park - Airport Rd WB** | 13.11 | 11.55 (-1.58) | 13.95 (+0.84) | 13.57 (+0.46) | 15.31 (+2.20) | 12.75 (-0.37) | 13.33 (+0.22) | 13.94 (+0.83) |
| **Auction Ln - Delta Park WB** | 12.85 | 14.66 (+1.82) | 13.32 (+0.48) | 15.71 (+2.87) | 13.35 (+0.50) | 13.67 (+0.82) | 13.66 (+0.81) | 13.6 (+0.76) |
| **Goreway - Auction Ln WB** | 47.16 | 48.2 (+1.03) | 51.98 (+4.82) | 51.71 (+4.55) | 52.21 (+5.05) | 50.51 (+3.35) | 55.47 (+8.31) | 52.26 (+5.10) |
| **McVean - Goreway WB** | 20.12 | 18.25 (-1.87) | 16.41 (-3.72) | 21.09 (+0.97) | 22.28 (+2.16) | 21.72 (+1.60) | 19.33 (-0.79) | 21.95 (+1.84) |
| **Cherrycrest - McVean WB** | 8.67 | 9.1 (+0.42) | 10.57 (+1.89) | 9.98 (+1.31) | 9.54 (+0.87) | 9.85 (+1.18) | 8.08 (-0.60) | 9.27 (+0.60) |
| **Beaumaris - Cherrycrest WB** | 3.91 | 4.5 (+0.59) | 4.16 (+0.25) | 4.2 (+0.29) | 4.82 (+0.91) | 4.57 (+0.66) | 4.84 (+0.93) | 4.88 (+0.98) |
| **Gore Rd - Beaumaris WB** | 11.94 | 12.78 (+0.84) | 13.05 (+1.11) | 11.85 (-0.10) | 11.91 (-0.04) | 12.41 (+0.47) | 12.22 (+0.29) | 11.79 (-0.16) |
| **WB Cumulative** | 261.98 | 272.11 (+10.13) | 275.36 (+13.38) | 281.04 (+19.06) | 272.57 (+10.59) | 277.98 (+16.00) | 278.6 (+16.62) | 279.03 (+17.05) |

*Table C- 6 - Total Persons Delay for transit in the westbound direction for Queen St*

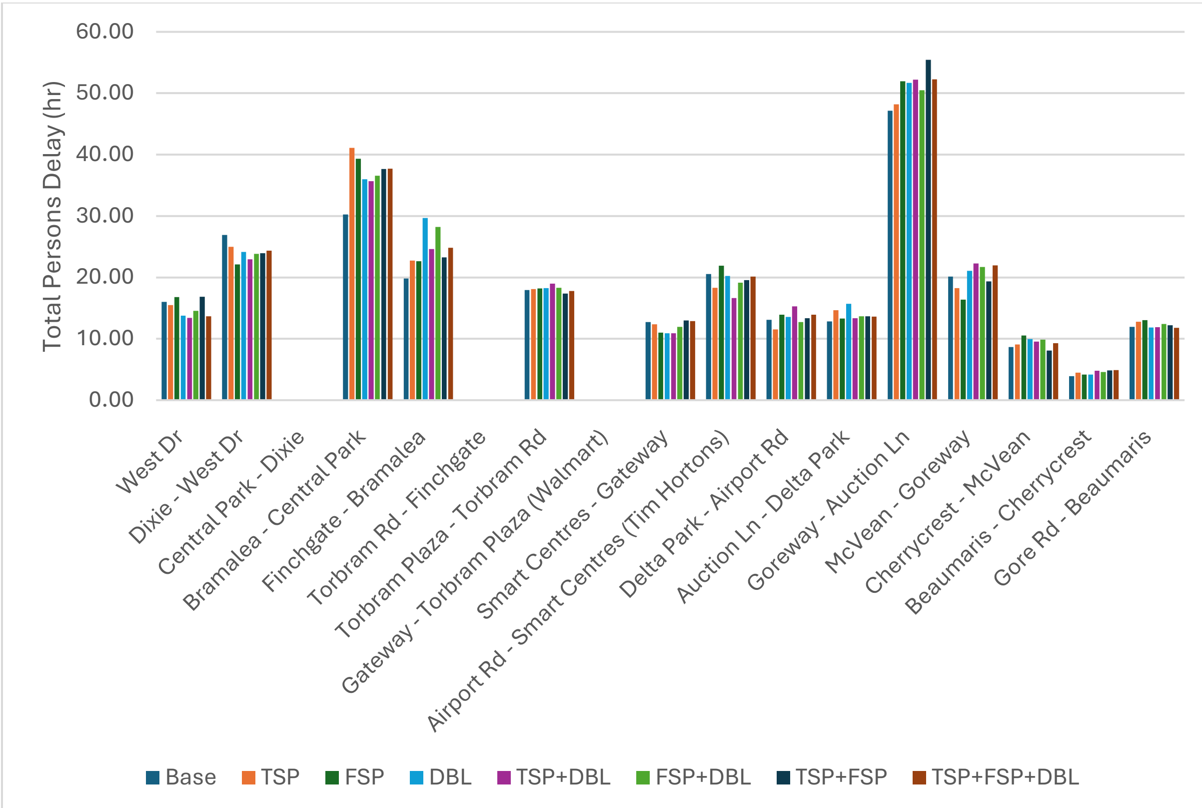



*Figure C- 6 - Total persons delay for transit in the westbound direction*

Under Base conditions, WB transit passengers experience 261.98 hours of cumulative delay. With the introduction of TSP, that value rises slightly to 272.11 hours (+10.13 hours, +3.9%), suggesting that extending green phases for transit modestly benefits some segments but may also increase dwell times where corridor geometry, intersections, or turning movements are not fully aligned with priority signals. For instance, Bramalea - Central Park WB registers a jump of +10.86 hours, whereas Dixie - West Dr WB sees a mild reduction of −1.94 hours, indicating localized variability in TSP effectiveness.

Implementing FSP elevates WB transit delay further to 275.36 hours (+13.38 hours, +5.1%), implying that freight-preferential signals do not necessarily translate into better conditions for buses. Some sections, such as Bramalea - Central Park WB (+9.33 hours), reveal how longer green times for trucks can displace ideal phasing for transit. However, minor savings elsewhere, like Delta Park - Airport Rd WB (−1.58 hours), demonstrate that freight signals can occasionally synchronize advantageously for buses.

The dedicated bus lane scenario produces the largest net increase among single-factor interventions, pushing total delay to 281.04 hours (+19.06 hours, +7.3%). While dedicating a lane typically helps buses bypass mixed-traffic congestion, other factors, such as stop access, intersection conflicts, or lane mergers appear to outweigh potential gains in this corridor. Segments like Finchgate - Bramalea WB (+9.87 hours) and Bramalea - Central Park WB (+5.71 hours) demonstrate that the operational constraints and partial geometry modifications can dilute the benefits of a dedicated lane.

When TSP is combined with dedicated bus lane (TSP & dedicated bus lane), total WB transit delay settles at 272.57 hours (+10.59 hours, +4.0%), showing that transit signal priority can mitigate some dedicated bus lane -related inefficiencies. A similar pattern emerges under FSP & dedicated bus lane (277.98 hours, +16.00), though the net delay remains higher than the base, likely due to capacity and geometric issues that overshadow partial signal optimization. Meanwhile, TSP FSP, without a dedicated lane, yields 278.60 hours (+16.62 hours, +6.3%), suggesting that jointly prioritizing buses and trucks does not necessarily produce robust corridor-wide improvements for transit in the WB direction.

Finally, layering dedicated bus lane onto TSP FSP leads to 279.03 hours (+17.05 hours, +6.5%), confirming that while signal coordination can help, the underlying lane reallocation constraints often drive higher person-delays. Overall, these observations indicate that dedicated bus lane alone introduces the most significant increases in WB transit delay, despite the conceptual benefit of bus-only lanes, while TSP and FSP in isolation also tend to raise total passenger wait times slightly. Coordinating signals can partially alleviate these impacts, but the interplay of corridor design and multiple competing priorities still challenges transit performance.

## Appendix C-3: Emission Supplementary Analysis for Westbound

Table C- 7 and Figure C- 7 show the CO emissions (in grams) for all modes along the westbound (WB) movement of Queen Street during the PM peak hours.

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Drive** | 3550.12 | 3688.82 (+138.70) | 3653.05 (+102.93) | 3930.62 (+380.50) | 3937.5 (+387.38) | 3910.48 (+360.36) | 3643.32 (+93.20) | 3865.14 (+315.02) |
| **Dixie Road** | 5667.63 | 5930.33 (+262.70) | 5729.39 (+61.76) | 5359 (-308.64) | 5473.68 (-193.96) | 5451.66 (-215.98) | 5870.01 (+202.38) | 5404.5 (-263.15) |
| **Central Park** | 2818.28 | 2806.27 (-12.03) | 2821.26 (+2.97) | 2779.3 (-39.00) | 2821.99 (+3.71) | 2817.6 (-0.69) | 2821.56 (+3.28) | 2822.43 (+4.15) |
| **Bramalea Road** | 780.23 | 781.43 (+1.20) | 786.86 (+6.63) | 795.25 (+15.02) | 793.11 (+12.88) | 789.53 (+9.30) | 783.68 (+3.45) | 791.8 (+11.57) |
| **Finchgate** | 2992.61 | 2903.53 (-89.09) | 2998.42 (+5.81) | 4659.59 (+1666.98) | 4067.11 (+1074.50) | 4409.77 (+1417.15) | 3084.89 (+92.27) | 4341.79 (+1349.18) |
| **Torbram Road** | 2254.49 | 2182.69 (-71.81) | 2278.62 (+24.13) | 2185.84 (-68.66) | 2197.38 (-57.12) | 2117.52 (-136.98) | 2227.96 (-26.54) | 2221.07 (-33.43) |
| **Torbram Plaza** | 2338.97 | 2344.4 (+5.43) | 2326.48 (-12.50) | 2576.14 (+237.18) | 2617.15 (+278.18) | 2562.3 (+223.33) | 2327.41 (-11.57) | 2571.04 (+232.07) |
| **Gateway** | 2333.29 | 2280.96 (-52.34) | 2423.2 (+89.91) | 2359.47 (+26.18) | 2222.52 (-110.78) | 2202.79 (-130.51) | 2270.4 (-62.90) | 2290.63 (-42.67) |
| **Smart Centres** | 2697.28 | 2732.88 (+35.61) | 2760.6 (+63.33) | 2752.05 (+54.77) | 2667.65 (-29.64) | 2577.88 (-119.40) | 2686.92 (-10.37) | 2743.5 (+46.22) |
| **Airport Road** | 3619.22 | 3614.27 (-4.96) | 3510.61 (-108.63) | 3454.42 (-164.81) | 3444.5 (-174.73) | 3397.95 (-221.28) | 3538.02 (-81.21) | 3498.86 (-120.37) |
| **Delta Park** | 4095.41 | 5063.97 (+968.56) | 4913.12 (+817.70) | 4590.82 (+495.40) | 4754.56 (+659.15) | 4734.16 (+638.75) | 5126.9 (+1031.49) | 4516.03 (+420.62) |
| **Auction Lane** | 3523.17 | 3669.98 (+146.81) | 3645.38 (+122.21) | 3539.63 (+16.46) | 3400.39 (-122.79) | 3654.77 (+131.60) | 3626.56 (+103.39) | 3522.2 (-0.98) |
| **Goreway Drive** | 10105.60 | 9990.52 (-115.09) | 10000.98 (-104.62) | 9850.58 (-255.02) | 9840.97 (-264.64) | 9690.94 (-414.67) | 10009.68 (-95.93) | 9810.48 (-295.12) |
| **McVean** | 6175.75 | 6121.18 (-54.58) | 6148.5 (-27.26) | 7585.74 (+1409.99) | 7672.51 (+1496.76) | 7418.65 (+1242.89) | 6327.81 (+152.05) | 7439.28 (+1263.53) |
| **Cherrycrest** | 3645.02 | 4120.94 (+475.92) | 3715.05 (+70.03) | 5018.48 (+1373.46) | 5043.02 (+1398.00) | 5080.41 (+1435.39) | 3821.59 (+176.58) | 5050.61 (+1405.60) |
| **Beaumaris** | 6034.27 | 6050.05 (+15.78) | 6107.18 (+72.92) | 6652.96 (+618.69) | 6604.8 (+570.54) | 6726.22 (+691.95) | 6044.33 (+10.06) | 6745.81 (+711.54) |
| **Gore Road** | 3774.66 | 3761.92 (-12.75) | 3768.16 (-6.51) | 3831.85 (+57.19) | 3815.92 (+41.26) | 3832.9 (+58.24) | 3770.6 (-4.07) | 3889.63 (+114.97) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| WB Cumulative | 66406.00 | 68044.07 (+1638.07) | 67586.81 (+1180.80) | 71921.67 (+5515.66) | 71374.68 (+4968.68) | 71375.43 (+4969.43) | 67981.54 (+1575.54) | 71524.75 (+5118.74) |

*Table C- 7 - CO emissions for the westbound along Queen Street (in grams)*

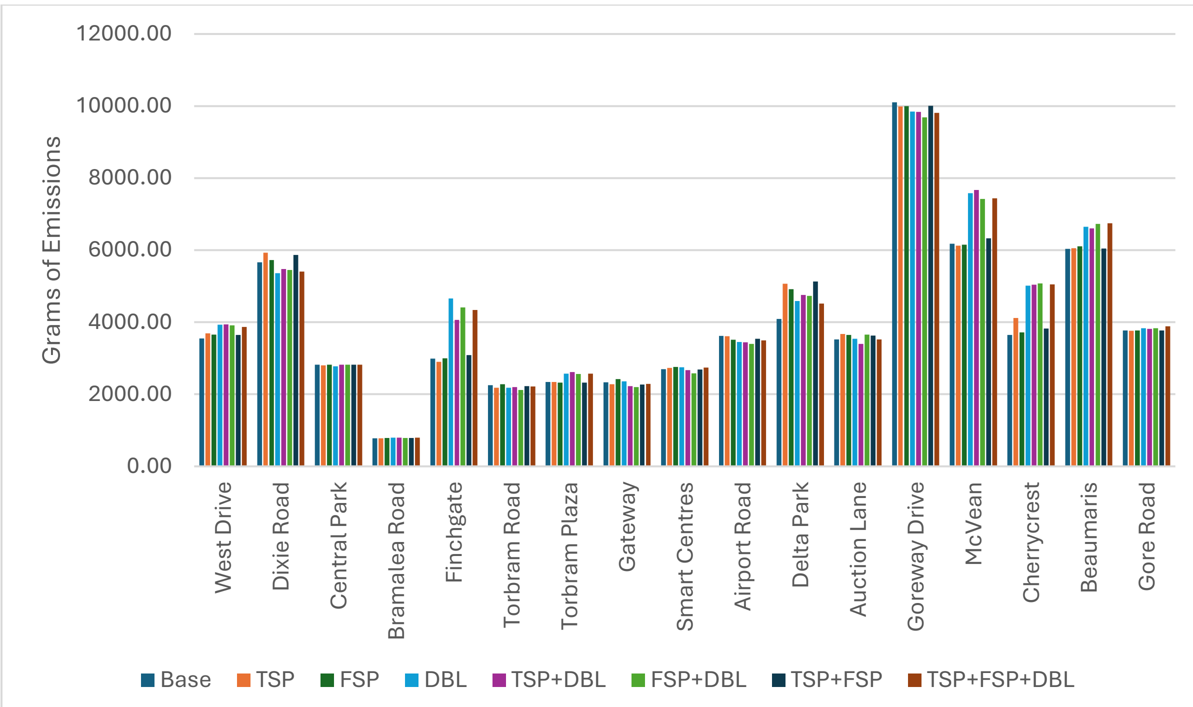



*Figure C- 7 - CO emissions in each intersection in the WB*

The westbound (WB) carbon monoxide (CO) emissions analysis evaluates the environmental impacts of transit and freight signal priority strategies, both independently and in combination with a Dedicated Bus Lane (DBL). CO emissions are a key indicator of traffic operating conditions, as higher emissions are typically associated with increased idling, stop-and-go behavior, and congestion. Under baseline conditions (Model 1), cumulative WB CO emissions along the corridor total 66,406.00 g, serving as the reference case for comparison.

The implementation of Transit Signal Priority (TSP) in Model 2 results in an increase in WB CO emissions to 68,043.07 g (+1,638.07 g, +2.5%). Several roadway segments experience notable increases, including Dixie Road (+262.70 g), Finchgate (+890.09 g), and Delta Park (+968.56 g). These increases suggest that while TSP improves transit progression, it can disrupt coordinated signal timing for general traffic in the westbound direction, leading to increased idling and acceleration-related emissions. Nonetheless, minor reductions observed on links such as Goreway Drive (−115.09 g) indicate localized benefits where signal priority aligns more closely with prevailing traffic demand.

Under Freight Signal Priority (FSP) (Model 3), cumulative WB CO emissions increase to 67,586.81 g (+1,180.80 g, +1.8%), representing a smaller increase than that observed under TSP. Emission reductions on segments such as Bramalea Road (−6.63 g) and Gore Road (−6.51 g) suggest that prioritizing freight vehicles can reduce emissions by minimizing stop-and-go conditions for heavy vehicles. However, increases on links such as Airport Road (+108.63 g) and Delta Park (+817.70 g) indicate that freight-oriented signal timing adjustments can still introduce inefficiencies for general traffic, resulting in net emission increases at the corridor level.

The introduction of a Dedicated Bus Lane (DBL) without signal priority (Model 4) produces the most substantial increase in WB CO emissions, with cumulative emissions rising to 71,921.67 g (+5,515.66 g, +8.3%). Significant increases are observed on major roadway segments such as Finchgate (+1,666.98 g), McVean (+1,409.99 g), and Cherrycrest (+1,373.46 g). These results are consistent with expectations, as reallocating a general-purpose lane to exclusive transit use reduces available capacity for other vehicles, intensifying congestion and increasing idling time, which directly contributes to higher CO emissions.

When TSP is combined with a DBL (Model 5), cumulative WB CO emissions remain elevated at 71,374.68 g (+4,968.68 g, +7.5%). Although transit signal priority provides some operational benefits for buses, it does not sufficiently mitigate the emissions impacts introduced by reduced roadway capacity. A similar outcome is observed in the FSP + DBL scenario (Model 6), which yields 71,375.43 g (+4,969.43 g, +7.5%), reinforcing the conclusion that the capacity reduction associated with the DBL dominates the emissions response, regardless of the type of signal priority applied.

The combined TSP + FSP scenario without a DBL (Model 7) results in cumulative WB CO emissions of 67,981.54 g (+1,575.54 g, +2.4%), indicating moderate emissions increases relative to the base case but substantially better performance compared to DBL scenarios. This suggests that coordinated signal priority for both transit and freight can improve traffic flow stability and limit excessive idling when roadway capacity is preserved. However, when a DBL is introduced alongside both signal priority strategies (TSP + FSP + DBL, Model 8), cumulative emissions increase again to 71,524.75 g (+5,118.74 g, +7.7%), confirming that even optimized signal coordination cannot fully offset the environmental impacts associated with lane reallocation.

Overall, the WB CO emissions results demonstrate that signal priority strategies alone, whether TSP, FSP, or their combination, result in relatively modest changes in emissions, whereas the introduction of a Dedicated Bus Lane consistently leads to substantial increases in CO emissions. These findings demonstrate the importance of accounting for roadway capacity constraints and multimodal trade-offs when evaluating transit priority strategies from an environmental performance perspective.

Table C- 8 and Figure C- 8 show the NOx emissions (in grams) for all modes along the westbound (WB) movement of Queen Street during the PM peak hours.

| **Road Segment** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Drive** | 690.72 | 717.71 (+26.99) | 710.76 (+20.03) | 764.76 (+74.04) | 766.1 (+75.37) | 760.84 (+70.12) | 708.86 (+18.14) | 752.02 (+61.30) |
| **Dixie Road** | 1102.72 | 1153.83 (+51.12) | 1114.74 (+12.02) | 1042.67 (-60.05) | 1064.98 (-37.74) | 1060.7 (-42.03) | 1142.09 (+39.38) | 1051.52 (-51.20) |
| **Central Park** | 548.34 | 546 (-2.34) | 548.92 (+0.58) | 540.75 (-7.59) | 549.06 (+0.73) | 548.21 (-0.14) | 548.98 (+0.64) | 549.15 (+0.81) |
| **Bramalea Road** | 151.30 | 152.04 (+0.74) | 153.1 (+1.80) | 154.73 (+3.43) | 154.32 (+3.02) | 153.62 (+2.32) | 152.48 (+1.18) | 154.06 (+2.76) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Finchgate** | 582.25 | 564.93 (-17.34) | 583.39 (+1.13) | 906.59 (+324.34) | 791.32 (+209.06) | 857.98 (+275.73) | 600.21 (+17.96) | 844.76 (+262.50) |
| **Torbram Road** | 438.64 | 424.68 (-13.97) | 443.34 (+4.70) | 425.29 (-13.36) | 427.53 (-11.12) | 412 (-26.66) | 433.48 (-5.17) | 432.14 (-6.51) |
| **Torbram Plaza** | 455.08 | 456.14 (+1.06) | 452.65 (-2.44) | 501.23 (+46.15) | 509.21 (+54.13) | 498.53 (+43.46) | 452.83 (-2.26) | 500.23 (+45.16) |
| **Gateway** | 453.97 | 443.8 (-10.19) | 471.47 (+17.50) | 459.07 (+5.10) | 432.43 (-21.56) | 428.59 (-25.40) | 441.74 (-12.24) | 445.68 (-8.31) |
| **Smart Centres** | 524.79 | 531.72 (+6.93) | 537.12 (+12.32) | 535.45 (+10.66) | 519.03 (-5.77) | 501.57 (-23.24) | 522.78 (-2.02) | 533.79 (+9.00) |
| **Airport Road** | 704.17 | 703.21 (-0.97) | 683.04 (-21.14) | 672.11 (-32.07) | 670.18 (-34.00) | 661.12 (-43.06) | 688.37 (-15.81) | 680.76 (-23.42) |
| **Delta Park** | 796.82 | 985.27 (+188.45) | 955.92 (+159.10) | 893.21 (+96.39) | 925.07 (+128.25) | 921.1 (+124.28) | 997.51 (+200.69) | 878.66 (+81.84) |
| **Auction Lane** | 685.48 | 714.05 (+28.57) | 709.26 (+23.78) | 688.69 (+3.21) | 661.6 (-23.89) | 711.09 (+25.61) | 705.6 (+20.12) | 685.3 (-0.19) |
| **Goreway Drive** | 1966.18 | 1943.8 (-22.40) | 1945.83 (-20.36) | 1916.57 (-49.62) | 1914.7 (-51.49) | 1885.51 (-80.68) | 1947.52 (-18.67) | 1908.77 (-57.42) |
| **McVean** | 1201.58 | 1190.96 (-10.62) | 1196.28 (-5.31) | 1475.91 (+274.34) | 1492.8 (+291.22) | 1443.4 (+241.83) | 1231.17 (+29.59) | 1447.42 (+245.84) |
| **Cherrycrest** | 709.19 | 801.79 (+92.60) | 722.82 (+13.63) | 976.42 (+267.23) | 981.19 (+272.00) | 988.47 (+279.28) | 743.55 (+34.36) | 982.67 (+273.48) |
| **Beaumaris** | 1174.05 | 1177.12 (+3.07) | 1188.24 (+14.19) | 1294.43 (+120.38) | 1285.06 (+111.01) | 1308.68 (+134.63) | 1176.01 (+1.96) | 1312.49 (+138.44) |
| **Gore Road** | 734.41 | 731.94 (-2.48) | 733.15 (-1.27) | 745.54 (+11.13) | 742.44 (+8.03) | 745.75 (+11.34) | 733.62 (-0.80) | 756.78 (+22.37) |
| **WB Cumulative** | 12919.69 | 13238.91 (+319.22) | 13149.94 (+230.25) | 13993.35 (+1073.66) | 13886.92 (+967.23) | 13887.07 (+967.38) | 13226.74 (+307.05) | 13916.12 (+996.43) |

*Table C- 8 - NOx emissions for the westbound along Queen Street (in grams)*

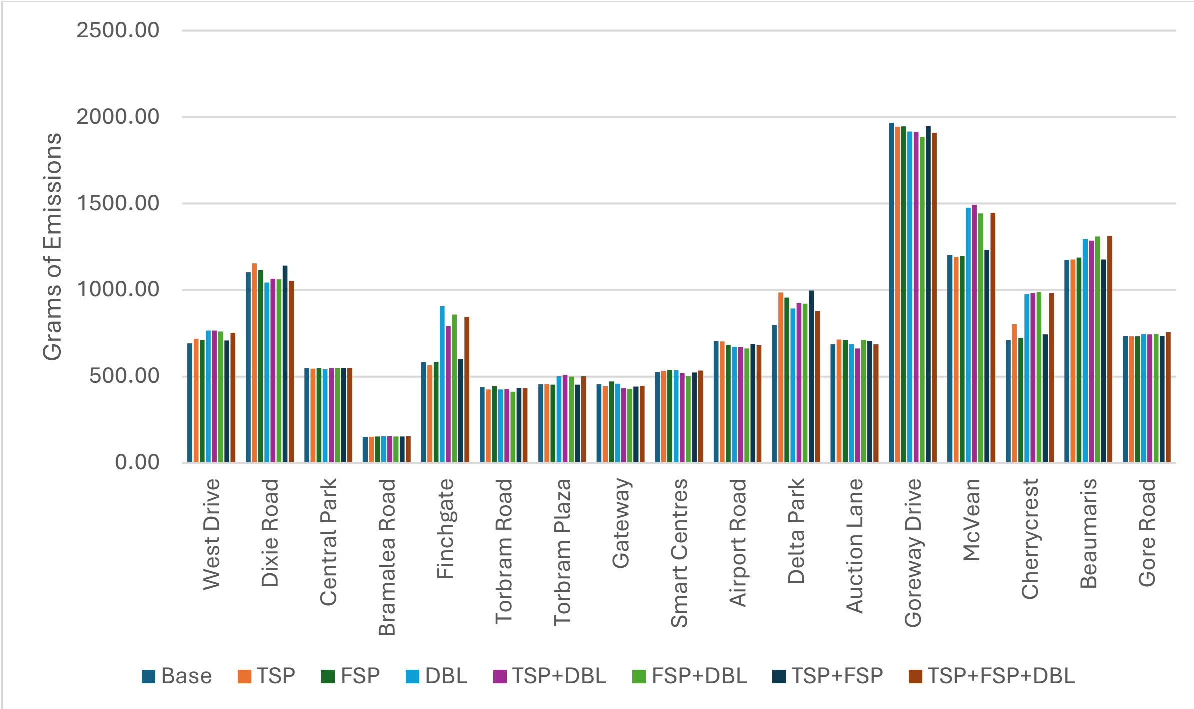



*Figure C- 8 - NOx emissions in each intersection in the WB*

The westbound (WB) nitrogen oxides (NOx) emissions analysis evaluates the environmental impacts of transit and freight signal priority strategies, both independently and in combination with a Dedicated Bus Lane (DBL). NOx emissions are particularly sensitive to stop-and-go traffic conditions, prolonged idling, and heavy-duty vehicle operations, making them a critical indicator of corridor-level environmental performance. Under baseline conditions (Model 1), cumulative WB NOx emissions along the corridor total 12,919.69 g, which serves as the reference case for comparison across scenarios.

The implementation of Transit Signal Priority (TSP) (Model 2) results in an increase in WB NOx emissions to 13,238.91 g (+319.22 g, +2.5%). Several roadway segments experience notable increases, including Dixie Road (+51.12 g), Delta Park (+188.45 g), and Cherrycrest (+92.60 g). These increases suggest that while TSP improves transit progression, it can disrupt coordinated signal operations for westbound general traffic, leading to increased idling and acceleration events that elevate NOx emissions. Nonetheless, localized reductions on segments such as Goreway Drive (−22.40 g) indicate that TSP can be beneficial where signal timing adjustments align more effectively with prevailing traffic patterns.

Under Freight Signal Priority (FSP) (Model 3), cumulative WB NOx emissions increase to 13,149.94 g (+230.25 g, +1.8%), representing a smaller increase than that observed under TSP. Emission reductions on freight-dominant links such as Airport Road (−21.14 g) and Goreway Drive (−20.36 g) suggest that prioritizing freight movements can reduce stop-and-go behavior for heavy vehicles, which are major contributors to NOx emissions. However, increases on segments such as Delta Park (+159.10 g) and Finchgate (+1.13 g) indicate that freight-priority signal adjustments can still introduce localized inefficiencies for other traffic streams.

The introduction of a Dedicated Bus Lane (DBL) without signal priority (Model 4) produces the most substantial increase in WB NOx emissions, with cumulative emissions rising to 13,993.35 g (+1,073.66 g, +8.3%). Significant increases are observed on major roadway segments such as Finchgate (+324.34 g), McVean (+274.34 g), and Cherrycrest (+267.23 g). These results are consistent with expectations, as reallocating a general-purpose lane to exclusive transit use reduces roadway capacity for remaining traffic, exacerbating congestion and increasing idling time, conditions that are particularly detrimental for NOx emissions.

When TSP is combined with a DBL (Model 5), cumulative WB NOx emissions decrease slightly relative to the DBL-only scenario but remain elevated at 13,886.92 g (+967.23 g, +7.5%). This indicates that while transit signal priority can partially mitigate DBL-related congestion, it does not fully offset the emissions impacts associated with reduced roadway capacity. A similar outcome is observed in the FSP + DBL scenario (Model 6), which yields 13,887.07 g (+967.38 g, +7.5%), reinforcing the conclusion that DBL-related capacity constraints dominate corridor-level NOx emissions regardless of the signal priority strategy employed.

The combined TSP + FSP scenario without a DBL (Model 7) results in cumulative WB NOx emissions of 13,226.74 g (+307.05 g, +2.4%), indicating a moderate increase relative to the base case but substantially better performance than scenarios involving a DBL. This suggests that coordinated signal priority for both transit and freight can improve traffic flow stability and limit excessive NOx generation when roadway capacity is preserved. However, when a DBL is added to this combined priority strategy

(TSP + FSP + DBL, Model 8), cumulative WB NOx emissions increase to 13,916.12 g (+996.43 g, +7.7%), confirming that even optimized signal coordination cannot fully counteract the emissions impacts of lane reallocation.

Overall, the WB NOx emissions results demonstrate that signal priority strategies alone, whether TSP, FSP, or their combination, produce relatively modest changes in emissions, while the introduction of a Dedicated Bus Lane consistently results in substantial increases in NOx emissions. These findings highlight the strong relationship between roadway capacity reductions, congestion, and NOx production, showing the importance of carefully evaluating environmental trade-offs when implementing DBL infrastructure on high-demand corridors.

Table C- 9 and Figure C- 9 show the VOC emissions (in grams) for all modes along the westbound (WB) movement of Queen Street during the PM peak hours.

| **Road Segment** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Drive** | 822.77 | 854.92 (+32.15) | 846.63 (+23.86) | 910.96 (+88.19) | 912.56 (+89.78) | 906.29 (+83.52) | 844.38 (+21.60) | 895.79 (+73.01) |
| **Dixie Road** | 1313.53 | 1374.42 (+60.89) | 1327.85 (+14.32) | 1242 (-71.53) | 1268.58 (-44.96) | 1263.48 (-50.06) | 1360.44 (+46.91) | 1252.55 (-60.99) |
| **Central Park** | 653.16 | 650.38 (-2.79) | 653.86 (+0.69) | 644.13 (-9.04) | 654.03 (+0.86) | 653.01 (-0.16) | 653.93 (+0.76) | 654.13 (+0.97) |
| **Bramalea Road** | 1000.14 | 181.11 (-819.05) | 182.37 (-817.79) | 184.31 (-815.84) | 183.82 (-816.34) | 182.98 (-817.17) | 181.63 (-818.52) | 183.51 (-816.64) |
| **Finchgate** | 693.57 | 672.93 (-20.65) | 694.92 (+1.35) | 1079.91 (+386.34) | 942.6 (+249.03) | 1022.01 (+328.44) | 714.96 (+21.39) | 1006.26 (+312.69) |
| **Torbram Road** | 522.50 | 505.86 (-16.65) | 528.1 (+5.60) | 506.59 (-15.92) | 509.27 (-13.24) | 490.76 (-31.75) | 516.35 (-6.16) | 514.76 (-7.75) |
| **Torbram Plaza** | 542.08 | 543.34 (+1.26) | 539.19 (-2.90) | 597.05 (+54.97) | 606.55 (+64.47) | 593.84 (+51.76) | 539.4 (-2.69) | 595.87 (+53.79) |
| **Gateway** | 540.76 | 528.64 (-12.13) | 561.6 (+20.84) | 546.83 (+6.07) | 515.09 (-25.68) | 510.52 (-30.25) | 526.19 (-14.58) | 530.88 (-9.89) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **Smart Centres** | 625.12 | 633.38 (+8.26) | 639.8 (+14.68) | 637.82 (+12.70) | 618.26 (-6.87) | 597.45 (-27.68) | 622.72 (-2.41) | 635.84 (+10.72) |
| **Airport Road** | 838.79 | 837.65 (-1.15) | 813.62 (-25.18) | 800.6 (-38.20) | 798.3 (-40.50) | 787.51 (-51.29) | 819.97 (-18.83) | 810.9 (-27.90) |
| **Delta Park** | 949.15 | 1173.63 (+224.48) | 1138.67 (+189.51) | 1063.97 (+114.82) | 1101.92 (+152.77) | 1097.19 (+148.04) | 1188.21 (+239.06) | 1046.64 (+97.49) |
| **Auction Lane** | 816.53 | 850.56 (+34.03) | 844.86 (+28.33) | 820.35 (+3.82) | 788.08 (-28.46) | 847.03 (+30.50) | 840.49 (+23.97) | 816.31 (-0.23) |
| **Goreway Drive** | 2342.07 | 2315.4 (-26.68) | 2317.83 (-24.25) | 2282.97 (-59.11) | 2280.74 (-61.34) | 2245.97 (-96.11) | 2319.84 (-22.24) | 2273.68 (-68.40) |
| **McVean** | 1431.29 | 1418.65 (-12.65) | 1424.98 (-6.32) | 1758.07 (+326.78) | 1778.18 (+346.89) | 1719.35 (+288.06) | 1466.53 (+35.24) | 1724.13 (+292.84) |
| **Cherrycrest** | 844.77 | 955.07 (+110.30) | 861 (+16.24) | 1163.08 (+318.32) | 1168.77 (+324.00) | 1177.44 (+332.67) | 885.69 (+40.93) | 1170.53 (+325.76) |
| **Beaumaris** | 1398.50 | 1402.16 (+3.66) | 1415.4 (+16.90) | 1541.89 (+143.39) | 1530.73 (+132.23) | 1558.87 (+160.37) | 1400.83 (+2.34) | 1563.41 (+164.91) |
| **Gore Road** | 874.81 | 871.87 (-2.96) | 873.31 (-1.51) | 888.07 (+13.26) | 884.38 (+9.57) | 888.32 (+13.50) | 873.88 (-0.95) | 901.46 (+26.65) |
| **WB Cumulative** | 15389.94 | 15769.87 (+379.94) | 15663.9 (+273.96) | 16668.54 (+1278.61) | 16541.78 (+1151.84) | 16541.95 (+1152.01) | 15755.38 (+365.45) | 16576.55 (+1186.62) |

*Table C- 9 - VOC emissions for the westbound along Queen Street (in grams)*

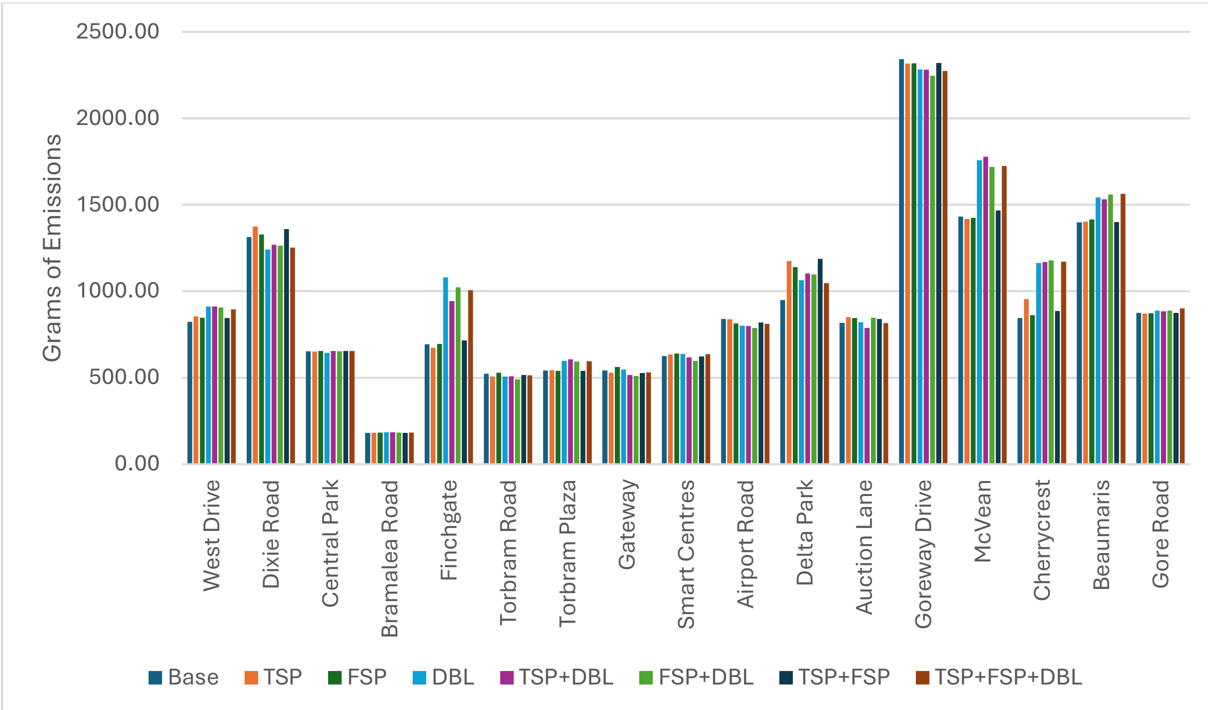



*Figure C- 9 - VOC emissions in each intersection in the WB*

The westbound (WB) volatile organic compounds (VOC) emissions analysis assesses the environmental implications of transit and freight signal priority strategies, both independently and in combination with a Dedicated Bus Lane (DBL). VOC emissions are closely associated with vehicle acceleration, idling, and congestion, and are particularly sensitive to capacity constraints and stop-and-go traffic conditions. Under baseline conditions (Model 1), cumulative WB VOC emissions along the corridor total 15,389.94 g, which serves as the reference case for comparison across all scenarios.

The implementation of Transit Signal Priority (TSP) (Model 2) results in a modest increase in WB VOC emissions to 15,769.87 g (+379.94 g, +2.5%). Emission increases are observed across several roadway links, including West Drive (+32.15 g), Dixie Road (+60.89 g), and Delta Park (+224.48 g). These increases suggest that while TSP improves transit progression, it can disrupt signal coordination for westbound general traffic, leading to increased idling and acceleration events that contribute to higher VOC emissions. Nevertheless, reductions on select segments such as Goreway Drive (−26.68 g) indicate localized improvements where signal priority aligns effectively with prevailing traffic patterns.

Under Freight Signal Priority (FSP) (Model 3), cumulative WB VOC emissions increase further to 15,663.90 g (+273.96 g, +1.8%), representing a smaller increase relative to TSP. Some segments, such as Airport Road (−25.18 g) and Goreway Drive (−24.25 g), experience emission reductions, suggesting improved freight progression and reduced stop-and-go behavior for heavy vehicles. However, notable increases on links such as Delta Park (+189.51 g) and Finchgate (+1.35 g) indicate that freight-priority signal adjustments can still introduce inefficiencies for general traffic, resulting in net VOC emission increases at the corridor level.

The introduction of a Dedicated Bus Lane (DBL) without signal priority (Model 4) leads to the most pronounced increase in WB VOC emissions, with cumulative emissions rising to 16,668.54 g (+1,278.61 g, +8.3%). Substantial increases are observed on high-demand roadway segments such as Finchgate (+386.34 g), McVean (+326.78 g), and Cherrycrest (+318.32 g). These results are consistent with expectations, as reallocating a general-purpose lane to exclusive transit use reduces available capacity for other vehicles, exacerbating congestion and increasing acceleration and idling events, key contributors to elevated VOC emissions.

When TSP is combined with a DBL (Model 5), cumulative WB VOC emissions decrease slightly relative to the DBL-only case but remain elevated at 16,541.78 g (+1,151.84 g, +7.5%). This suggests that transit signal priority can partially mitigate the operational inefficiencies introduced by the DBL, though it cannot fully offset the impacts of reduced roadway capacity. A similar pattern is observed in the FSP + DBL scenario (Model 6), which yields 16,541.95 g (+1,152.01 g, +7.5%), reinforcing the conclusion that DBL-related capacity constraints dominate the emissions response regardless of the signal priority strategy applied.

The combined TSP + FSP scenario without a DBL (Model 7) results in cumulative WB VOC emissions of 15,755.38 g (+365.45 g, +2.4%), indicating a moderate increase relative to the base case but substantially better performance than scenarios involving a DBL. This suggests that coordinated signal priority for both transit and freight can improve traffic flow stability and limit excessive VOC emissions when roadway capacity is preserved. However, when a DBL is added to this combined priority strategy

(TSP + FSP + DBL, Model 8), cumulative emissions increase to 16,576.55 g (+1,186.62 g, +7.7%), confirming that the emissions impacts associated with lane reallocation outweigh the benefits of optimized signal coordination.

Overall, the WB VOC emissions results demonstrate that signal priority strategies alone, whether TSP, FSP, or their combination, produce relatively modest increases in VOC emissions, whereas the introduction of a Dedicated Bus Lane consistently results in substantial emission increases. These findings highlight the strong sensitivity of VOC emissions to congestion and capacity reductions and emphasize the importance of considering environmental trade-offs when implementing DBL infrastructure on high-demand corridors.

Table C- 10 and Figure C- 10 show the fuel consumption (in grams) for all modes along the westbound (WB) movement of Queen Street during the PM peak hours.

| **Road Segment** | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** | **Model 6** | **Model 7** | **Model 8** |
|---|---|---|---|---|---|---|---|---|
| | **Base** | **Transit Signal Priority** | **Freight Signal Priority** | **Dedicated Bus Lane** | **Transit Signal Priority + Dedicated Bus Lane** | **Freight Signal Priority + Dedicated Bus Lane** | **Transit Signal Priority + Freight Signal Priority** | **Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane** |
| **West Drive** | 50.79 | 52.78 (+1.99) | 52.27 (+1.48) | 56.24 (+5.45) | 56.34 (+5.55) | 55.95 (+5.16) | 52.13 (+1.34) | 55.3 (+4.51) |
| **Dixie Road** | 81.08 | 84.85 (+3.76) | 81.97 (+0.89) | 76.67 (-4.42) | 78.31 (-2.78) | 78 (-3.09) | 83.98 (+2.90) | 77.32 (-3.77) |
| **Central Park** | 40.32 | 40.15 (-0.18) | 40.37 (+0.05) | 39.77 (-0.56) | 40.38 (+0.06) | 40.31 (-0.01) | 40.37 (+0.05) | 40.38 (+0.06) |
| **Bramalea Road** | 61.74 | 11.18 (-50.56) | 11.26 (-50.49) | 11.38 (-50.37) | 11.35 (-50.40) | 11.3 (-50.45) | 11.22 (-50.53) | 11.33 (-50.41) |
| **Finchgate** | 42.81 | 41.54 (-1.28) | 42.9 (+0.09) | 66.67 (+23.85) | 58.19 (+15.38) | 63.09 (+20.28) | 44.14 (+1.32) | 62.12 (+19.31) |
| **Torbram Road** | 32.25 | 31.23 (-1.03) | 32.6 (+0.35) | 31.28 (-0.99) | 31.44 (-0.82) | 30.3 (-1.96) | 31.88 (-0.38) | 31.78 (-0.48) |
| **Torbram Plaza** | 33.46 | 33.54 (+0.08) | 33.29 (-0.18) | 36.86 (+3.40) | 37.45 (+3.98) | 36.66 (+3.20) | 33.3 (-0.17) | 36.79 (+3.32) |
| **Gateway** | 33.38 | 32.64 (-0.75) | 34.67 (+1.29) | 33.76 (+0.38) | 31.8 (-1.59) | 31.52 (-1.87) | 32.49 (-0.90) | 32.77 (-0.62) |

| Road Segment | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 |
|---|---|---|---|---|---|---|---|---|
| | Base | Transit Signal Priority | Freight Signal Priority | Dedicated Bus Lane | Transit Signal Priority + Dedicated Bus Lane | Freight Signal Priority + Dedicated Bus Lane | Transit Signal Priority + Freight Signal Priority | Transit Signal Priority + Freight Signal Priority + Dedicated Bus Lane |
| **Smart Centres** | 38.59 | 39.1 (+0.51) | 39.5 (+0.91) | 39.38 (+0.79) | 38.17 (-0.43) | 36.88 (-1.71) | 38.44 (-0.15) | 39.25 (+0.67) |
| **Airport Road** | 51.78 | 51.71 (-0.08) | 50.23 (-1.56) | 49.42 (-2.36) | 49.28 (-2.50) | 48.62 (-3.17) | 50.62 (-1.17) | 50.06 (-1.73) |
| **Delta Park** | 58.59 | 72.45 (+13.86) | 70.29 (+11.70) | 65.68 (+7.09) | 68.02 (+9.43) | 67.73 (+9.14) | 73.35 (+14.76) | 64.61 (+6.02) |
| **Auction Lane** | 50.40 | 52.51 (+2.11) | 52.16 (+1.75) | 50.64 (+0.24) | 48.65 (-1.76) | 52.29 (+1.89) | 51.89 (+1.48) | 50.39 (-0.02) |
| **Goreway Drive** | 144.57 | 142.93 (-1.65) | 143.08 (-1.50) | 140.93 (-3.65) | 140.79 (-3.79) | 138.64 (-5.94) | 143.2 (-1.38) | 140.36 (-4.23) |
| **McVean** | 88.35 | 87.58 (-0.79) | 87.97 (-0.39) | 108.53 (+20.18) | 109.77 (+21.42) | 106.14 (+17.79) | 90.53 (+2.18) | 106.43 (+18.08) |
| **Cherrycrest** | 52.15 | 58.96 (+6.81) | 53.15 (+1.01) | 71.8 (+19.65) | 72.15 (+20.00) | 72.69 (+20.54) | 54.68 (+2.53) | 72.26 (+20.11) |
| **Beaumaris** | 86.33 | 86.56 (+0.23) | 87.38 (+1.05) | 95.18 (+8.86) | 94.49 (+8.17) | 96.23 (+9.90) | 86.48 (+0.15) | 96.51 (+10.18) |
| **Gore Road** | 54.00 | 53.82 (-0.19) | 53.91 (-0.10) | 54.82 (+0.82) | 54.6 (+0.60) | 54.84 (+0.84) | 53.95 (-0.06) | 55.65 (+1.65) |
| **WB Cumulative** | 949.88 | 973.45 (+23.57) | 966.91 (+17.03) | 1028.93 (+79.04) | 1021.1 (+71.22) | 1021.11 (+71.23) | 972.56 (+22.68) | 1023.25 (+73.37) |

*Table C- 10 - Fuel consumption for the westbound along Queen Street (in grams)*

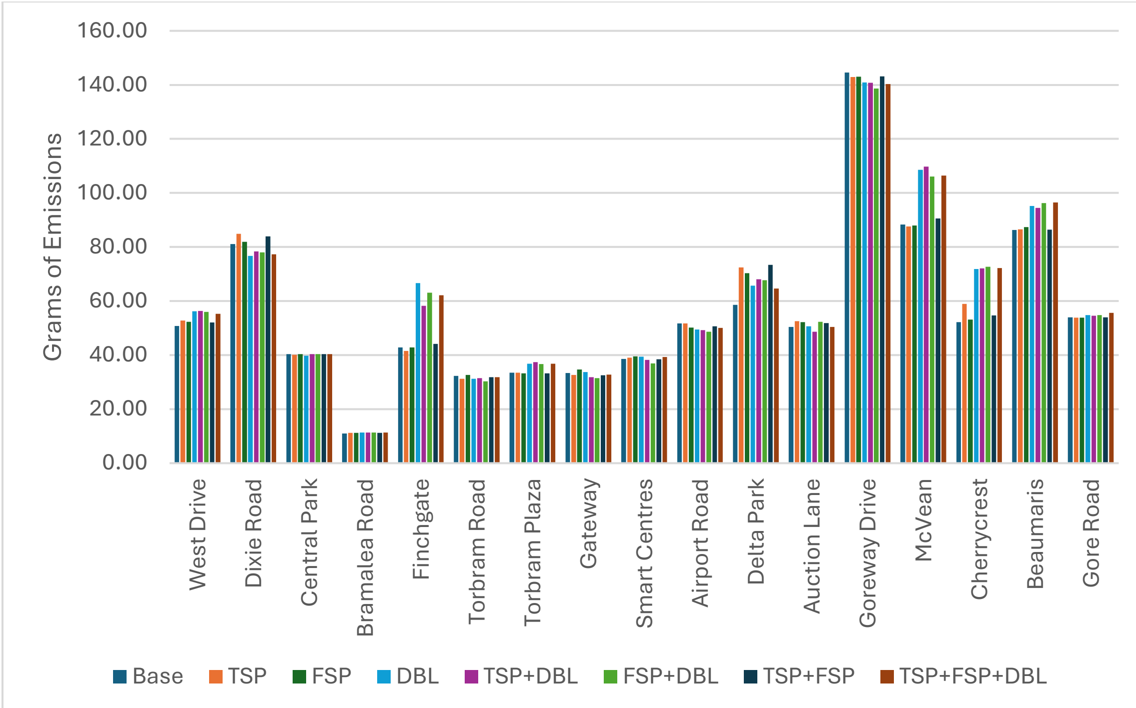



*Figure C- 10 - Fuel consumption in each intersection in the WB*

The westbound (WB) fuel consumption analysis evaluates the operational and environmental impacts of transit and freight signal priority strategies, both independently and in combination with a Dedicated Bus Lane (DBL). Fuel consumption is a direct indicator of traffic efficiency, as higher values are generally associated with increased congestion, idling, and stop-and-go conditions. Under baseline conditions (Model 1), cumulative WB fuel consumption along the corridor is 949.89 g, which serves as the reference case for assessing the impacts of alternative strategies.

The implementation of Transit Signal Priority (TSP) (Model 2) results in a modest increase in WB fuel consumption to 973.45 g (+23.57 g, +2.5%). Increases are observed on several key roadway links, including Dixie Road (+3.76 g), Delta Park (+13.86 g), and Cherrycrest (+6.81 g). These increases suggest that while TSP improves transit progression, it can disrupt coordinated signal timing for westbound general traffic, leading to additional acceleration and idling events that increase fuel use. Minor reductions on segments such as Goreway Drive (−1.65 g) indicate that TSP can still provide localized efficiency gains where signal timing better aligns with traffic demand.

Under Freight Signal Priority (FSP) (Model 3), cumulative WB fuel consumption increases slightly to 966.91 g (+17.03 g, +1.8%), representing a smaller increase compared to TSP. Reductions on links such as Airport Road (−1.56 g) and Goreway Drive (−1.50 g) suggest that prioritizing freight vehicles can reduce stop-and-go conditions for heavy vehicles, improving fuel efficiency in certain locations. However, increases on segments like Delta Park (+11.70 g) indicate that freight-priority signal adjustments may still introduce inefficiencies for general traffic, resulting in a net increase in corridor-level fuel consumption.

The introduction of a Dedicated Bus Lane (DBL) without signal priority (Model 4) leads to the most substantial increase in WB fuel consumption, with cumulative fuel use rising to 1,028.93 g (+79.04 g, +8.3%). Large increases occur on high-demand roadway segments such as Finchgate (+23.85 g), McVean (+20.18 g), and Cherrycrest (+19.65 g). These results are consistent with expectations, as reallocating a general-purpose lane to exclusive transit use reduces roadway capacity for other vehicles, intensifying congestion and increasing idling and acceleration events, which directly increase fuel consumption.

When TSP is combined with a DBL (Model 5), cumulative WB fuel consumption decreases slightly relative to the DBL-only scenario but remains elevated at 1,021.10 g (+71.22 g, +7.5%). This indicates that transit signal priority can partially mitigate DBL-induced inefficiencies but cannot fully offset the fuel consumption impacts associated with reduced roadway capacity. A similar pattern is observed in the FSP + DBL scenario (Model 6), which yields 1,021.11 g (+71.23 g, +7.5%), reinforcing the conclusion that DBL-related capacity constraints dominate fuel consumption outcomes regardless of the signal priority strategy applied.

The combined TSP + FSP scenario without a DBL (Model 7) results in cumulative WB fuel consumption of 972.56 g (+22.68 g, +2.4%), indicating a moderate increase relative to the base case but substantially better performance than scenarios involving a DBL. This suggests that coordinated signal priority for both transit and freight can improve traffic flow stability and limit excessive fuel use when roadway capacity is preserved. However, when a DBL is introduced alongside both signal priority strategies (TSP + FSP + DBL, Model 8), cumulative fuel consumption increases to 1,023.25 g (+73.37 g, +7.7%), confirming that the fuel penalties associated with lane reallocation outweigh the benefits of optimized signal coordination.

Overall, the WB fuel consumption results demonstrate that signal priority strategies alone, whether TSP, FSP, or their combination, result in relatively modest increases in fuel use, whereas the introduction of a Dedicated Bus Lane consistently produces substantial increases in fuel consumption. These findings highlight the close relationship between roadway capacity, congestion, and energy use, emphasizing the importance of carefully evaluating fuel and emissions trade-offs when implementing DBL infrastructure on high-demand corridors.