

Development of a Dynamic, Feedback-based and Self-Calibrating Tolling Algorithm for a High Occupancy/Toll Lane

By

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Abstract

Traffic congestion problems affect major urban centers across Canada and around the world. In many cases it is impossible to mitigate congestion problems by simply adding additional infrastructure. HOV lanes can utilize existing infrastructure to provide motorists, who travel with multiple occupants in the vehicle, with a congestion free route. However, HOV lanes were found to be inefficient in many cases primarily due to the significant underutilization of available capacity. HOT lanes optimize the HOV lane concept by selling off the excess capacity to solo motorists. This research focuses on the development of a tolling algorithm that can determine the ideal toll rate dynamically and based on feedback collected from the facility. The innovation in this research is the application of a self calibration mechanism that will further optimize the HOT lane operations. The approach of this study is to combine principles of traffic microsimulation, discrete choice models, feedback control theory and other statistical tools to form an effective tolling algorithm.

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Glossary of Acronyms and Terms

ANPR	Automatic Number Plate Recognition
ATLANTIC	A Thematic Long-Term Approach to Networking for the Telematics and ITS Communities
CAD	Computer Assisted Drafting
CCTV	Closed Circuit Television
CNR	Canadian National Railroad
COM	Component Object Model
DMS	Dynamic Message Sign
DOT	Department of Transportation
DSRC	Direct Short Range Communication
FHWA	Federal Highway Administration
GHG	Green House Gas
GIS	Geographic Information Systems
GPL	General Purpose Lane
GPS	Global Positioning System
HGV	Heavy Goods Vehicle
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
I-##	Interstate ##
IIA	Independence from Irrelevant Alternatives
IPCC	Intergovernmental Panel on Climate Change
ITS	Intelligent Transportation Systems
ME	Mean Error
MLE	Maximum Likelihood Estimation
MNL	Multinomial Logit
MOE	Measure of Effectiveness
MPE	Mean Percent Error
MSE	Mean Squared Error
MTO	Ministry of Transportation of Ontario
MTQ	Ministere des Transports Du Quebec
NCC	National Capital Commission
OD	Origin – Destination
RFID	Radio Frequency Identification
RMSE	Root Mean Squared Error
RMSPE	Root Mean Square Percent Error
RP	Revealed Preference
SOV	Single Occupant Vehicle
SP	Stated Preference
SPSS	Statistical Package for Social Sciences
SR - ##	State Route ##
TRB	Transportation Research Board
UNFCCC	United Nations Framework Convention on Climate Change
VAP	Vehicle Actuated Programming
VIP	Video Image Processing
VISSIM	Verkehr In Stadten – SIMulation

Chapter 1

Introduction

1.1 Mobility Issues

Congestion is widely cited as a major social and environmental problem in most urban communities. Congestion is generally defined based on individual experiences. Impacts such as delay and fuel consumption are the most commonly cited effects of congestion from the private citizen's perspective. However, there are additional social costs associated with congestion such as increased stress levels or noise pollution. Officially there is no formal definition of urban roadway congestion. Transport Canada, after consultation with provincial and urban transportation experts, adopted the view that: "Congestion is the inconvenience and increased cost that travellers impose on each other while using their vehicles, attempting to use the road network at the same time, because of this relationship that exists between traffic density and speed (with due consideration for capacity)" (Transport Canada, 2006).

To properly study the effects of congestion, two different types of congestion must be discerned: recurrent congestion and non-recurrent congestion (Transport Canada, 2006). Recurrent congestion is most common and will be the focus of this discussion. Recurrent congestion occurs mainly during the morning peak period and the afternoon peak period when the majority of people are going to work and returning home from work respectively. Although these are the most common times, major highways across the country experience congestion at other times as well (Transport Canada, 2006). This phenomenon reflects the fact that there is significant growth in off-peak travel. This rise

in congestion may be attributed to the rapid growth of the populations of the 27 major urban areas in Canada (Transport Canada, 2006). Non-recurrent congestion is associated with random conditions or special events. The four major causes of non-recurrent congestion are: traffic incidents, work zones, weather and special events (Transport Canada, 2006). Due to its random and unpredictable nature, non-recurrent congestion is much more difficult to address.

1.2 Cost of Congestion

Urban traffic congestion is extremely difficult to quantify, due in part to the fact that it is made up of many different components, some of which carry no real costs. The major components that should be considered when quantifying urban congestion are (Kriger et al. 2007):

- Delay Costs: the cost of time lost during congestion;
- Fuel Costs: the cost of fuel wasted due to congested conditions; and
- Green-House Gas Emissions: an assumed cost for GHG emissions released as a result of traffic congestion.

Since the socio-economic components of the cost attributed to urban congestion are difficult to quantify, the study conducted by Kriger et al. (2007) proposes the use of thresholds. The threshold method draws from recent research conducted by the MTQ (Ministere des Transports du Quebec) where the concept of thresholds was used in a travel demand forecasting model for the Montreal region. The threshold represents the percentage of the capacity at which congestion becomes apparent and is deemed unacceptable. In that study the threshold values of 50%, 60% and 70% were chosen. The

range in the accepted values can be attributed to the lack of consensus among urban areas as to what is the threshold which represents the local conditions. (Kriger et al 2007).

The key findings of the study indicate that the total annual cost of urban congestion is in the range of \$2.3 billion (at the 50% threshold) to \$3.7 billion (at the 70% threshold), where the cost is expressed in 2002 dollars. The costs attributed to delay are in the range of \$2.0 billion (at the 50% threshold) to \$3.4 billion (at the 70% threshold), constituting the greatest fraction of the total cost of urban congestion. The costs attributed to wasted fuel are in the range of \$176 million (at the 50% threshold) to \$213 million (at the 70% threshold). The costs attributed to GHG emissions are in the range of \$38 million (at the 50% threshold) to \$46 million (at the 70% threshold), constituting the smallest portion of the total costs of congestion. (Kriger et al 2007) Most of the components of the total cost of urban congestion are socio-economic, which are difficult to quantify, therefore portions attributed to delay, wasted fuel and emissions should not be taken at face value. Instead, they should all be treated as important factors constituting the problem of urban congestion.

1.3 Environmental Concerns

Over the years there has been much controversy regarding climate change, primarily the link between GHG emissions and climate change. In 2007 the Intergovernmental Panel on Climate Change (IPCC) released a document that was prepared by scientists from all over the world, which ended the discussions and placed the reality of human induced climate change beyond any doubt (UNFCCC, http://unfccc.int/kyoto_protocol).

The Kyoto protocol was adopted at the 3rd Conference of the Parties to the UNFCCC in Kyoto Japan, on 11 December 1997. The Kyoto protocol committed the participating nations to stabilize their GHG emissions to a level at least 5% below the 1990 baseline levels. This target must be met within a five year time frame between 2008 and 2012 (UNFCCC, http://unfccc.int/kyoto_protocol).

As of 2005, Canada's GHG emissions are 32.7% above the Kyoto target (See Figure 1). There are various different sectors that contribute to the GHG emissions in Canada including: energy industries, the transportation sector, the industrial process sector, the agricultural sector and the waste sector. In this particular study, transportation is the primary concern. According to Environment Canada the emissions in the transportation sector grew by 48.8 Mt or 32.8% from 1990 to 2005 (Environment Canada, www.ec.gc.ca). It should be noted that the emissions from light duty gasoline trucks and heavy duty diesel vehicles grew the most of all modes in the transportation sector. This may be attributed to the growing popularity of sport utility vehicles, as well as the growth in truck transport. (Environment Canada, www.ec.gc.ca)

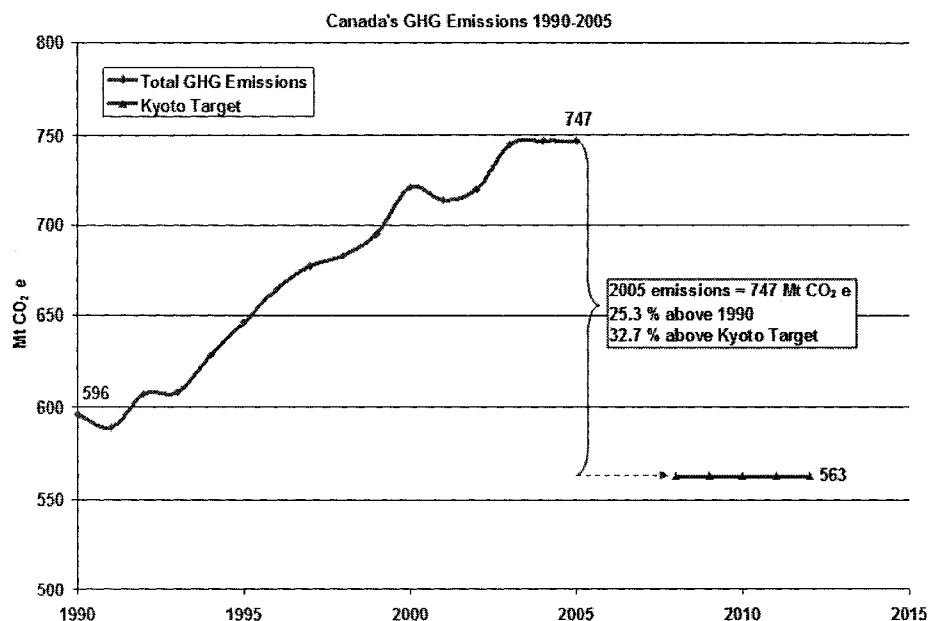


Figure 1.1: Canada's GHG Emissions 1990-2005 (Image Courtesy of Environment Canada, www.ec.gc.ca)

In recent years, some developed countries including Canada have announced their intentions to replace the Kyoto Protocol with their own GHG reduction targets and schedules. Also, some countries are going beyond Kyoto Protocol and have developed targets with 2030 and 2050 horizons. Emissions created by the transportation sector are a major detriment to the environment at large. Due to traffic congestion, GHG emissions are growing in most countries around the world.

1.4 Managed Lanes

In many urban centers traffic congestion has escalated to the point where traditional transportation engineering techniques cannot keep up. Expanding any given roadway may be impossible due to any number of reasons including: lack of space to expand the right of way as well as concerns over environmental quality. This has led engineers and planners to develop new techniques of managing traffic. Managed lanes can come in a variety of types; most common are the high occupancy vehicle (HOV) lane and the high

occupancy toll (HOT) lane. HOV lanes are used to reduce solo travel and thereby reduce traffic demand. Generally HOV lanes operate by allowing only vehicles with some minimum occupancy (often 2 or 3 persons) to utilize the facility. Whereas HOT lanes operate on a similar premise as HOV lanes, they also sell off additional capacity to solo vehicles. As a result, multiple occupant vehicles can travel for free on an HOT lane while, a solo motorist has the option to pay the toll in order to use the facility (Murray et al. 2000). HOT as well as HOV lanes will be discussed in greater detail in chapter 2.

1.5 Problem Definition

Currently there are many high occupancy toll lanes in North America with others either in construction or planning phases. Each HOT facility has its own rules and regulations as well as its own pricing structure or algorithm. There is much research on the subject of HOT lanes regarding many aspects including: implementation, motorist's perceptions of the facility and how to attract more users and how to model various aspects of HOT facilities. There is, however, currently very little research regarding pricing algorithm development, more specifically; no research that examines the development of a pricing algorithm that is feedback based, dynamic and self calibrating.

This study will attempt to develop a feedback based, dynamic and self calibrating tolling algorithm for an HOT lane. In addition to algorithm development the study will also examine the efficiency and practicality of implementing such a tolled facility in a medium sized urban area such as Ottawa, Ontario, Canada.

1.6 Research Objectives

The first objective of this research is to expand the knowledge base on the subject of HOT lane pricing algorithm development. This is to be achieved by developing a feedback based, dynamic and self-calibrating tolling algorithm. The algorithm will be developed using a variety of mathematical and computer simulation techniques. To accomplish this objective the process for algorithm development will be outlined, discussing all major elements, such as: model calibration, data collection, logit model development based on a stated preference survey, modelling HOT lanes and the development of the actual algorithm.

The second objective of this research is to examine the positive and negative effects of implementing an HOT lane in a medium sized city. Since the study area for this project is in the City of Ottawa the research can, in addition to the first objective, examine how traffic will be changed with the addition of an HOT lane in a highly traveled corridor.

The aim of the research is to have a working tolling algorithm that is feedback based, dynamic and self calibrating, while examining how an HOT lane will affect traffic in a medium sized city. Given the objectives, this study should produce information that is not currently available. By utilizing stated preference survey techniques as well as computer traffic simulation techniques the study will combine real world data and mathematical techniques to gain a better understanding of how motorists behave in the presence of an HOT facility. Also, this research should be able to provide a better understanding of whether it is practical and efficient to implement an HOT lane in a medium sized city.

1.7 Thesis Organization

In this chapter the problems associated with urban transportation were introduced and a potential solution, HOT lanes, was briefly presented. The problem was defined and the research objectives were then presented and described. In Chapter 2 background information will be presented in detail and previous research on the subject will be examined. Chapter 3 will describe the research by outlining the methodology of the study, the scope of the study and the various models that will be utilized in the study. The various data requirements and how they will be coded into the microsimulation model will be discussed in Chapter 4. In Chapter 5 the calibration and validation process for the computer simulation model will be outlined. Chapter 6 will describe the process of developing a logit model that will be used to model driver's choice behaviour. Chapter 7 will discuss how the tolling algorithm was developed using feedback control theory, the logit model and a self calibration mechanism. In Chapter 8 the process for validating or testing the effectiveness of the tolling algorithm was described. Chapter 9 will present the results of the validation process as well as other results found through the study and discuss each of the findings. Chapter 10 will conclude the study and provide recommendations for future research.

Chapter 2: Background

2.1 Introduction

Every morning, in any given city in any given country, hundreds of thousands of people climb into their vehicles and head for work. When the business day comes to a close the whole process is repeated in the opposite direction. In most cities the primary form of commuter transportation is the automobile. While public transit and non-motorized modes are growing in popularity, they have yet to reach the breadth of the market that private vehicles hold at this time.

The amounts of vehicles that populate our transportation networks place a strain on the environment, the economy and our day to day way of life. Congestion is a serious issue whether it is from a city planner's perspective, an environmentalist's perspective or a politician's perspective. All must work together to reduce the strain that congestion induces on society.

From the realms of engineering, informatics, economics and public policy, people have conjured ingenious ideas regarding transportation, more specifically congestion mitigation. HOT lanes have been shown to be effective means of reducing congestion, increasing throughput and increasing efficiency of many highways in North America.

2.2 HOV Lanes

High occupancy vehicle (HOV) lanes are lanes on a highway facility that permit only vehicles with some specified minimum occupancy. Generally this means that vehicles with two or more occupants may utilize the lane, however some jurisdictions require a

minimum of three occupants in the vehicle. Minimum occupancy is set according to local travel conditions, levels of congestion and projected use of the lane (FHWA, www.ops.fhwa.dot.gov/freewaymgmt/). The Ministry of Transportation of Ontario has implemented many HOV lanes throughout the province with more on the way. The MTO characterize HOV lanes as lanes that are designed to help move more people through congested areas (MTO, www.mto.gov.on.ca/english/traveller/hov/).

HOV lanes on freeway facilities are generally placed on the leftmost lane, so as to cause the least amount of conflicts with users of interchanges. HOV lanes are delineated from the general purpose lane by a striped buffer zone, crossing the buffer is illegal. Access points are placed at regular intervals to allow vehicles to enter and exit the HOV lanes. HOV lane regulations are enforced by local authorities and the penalty for the improper use of an HOV in Ontario is a fine of \$110 and three demerit points (MTO, www.mto.gov.on.ca/english/traveller/hov/).

Many different organizations, MTO and FHWA to name a few, report numerous benefits of HOV lanes. They are said to reduce congestion because more people are moved. Since an HOV lane requires at least two people per vehicle they could potentially move at least twice as many people for same number of single occupant vehicles (MTO, 2007). Also, HOV lanes are said to encourage the formation of carpools and vanpools as well as the use of public transportation (MTO, 2007). Users of carpools, vanpools and transit vehicles are said to: save time, have a more reliable commute, save money, conserve fuel and feel less stressed on their commutes (MTO, 2007). Reduced vehicle emissions and reduced congestion are some social benefits attributed to HOV lanes. Although the use of

HOV lane is a more efficient use of the road infrastructure than a general purpose lane, there are many problems that lead to questions of whether HOV lanes are truly the most effective way to manage congestion and use the available infrastructure.



Figure 2.1 Striped buffer on an HOV lane in Mississauga, Ontario (Image Courtesy of: www.onthighways.com).

The effectiveness of HOV lanes has been questioned by academics, engineers and the general public. Most people's perceptions of the HOV lanes are that they are a poor use of the infrastructure; since it seems to them that the lanes are underutilized. Government agencies report that even though they may seem underutilized, HOV lanes move more people than the general purpose lanes. Researchers have questioned the effectiveness of HOV lanes from a theoretical perspective. While the mathematics behind the ineffectiveness of HOV lanes is outside of the scope of this thesis, some of the highlights will be presented.

There are three phases associated with the implementation of an HOV lane (Mallinckrodt, 1993):

- Phase 1: pre-HOV;
- Phase 2: immediately after implementation of HOV; and
- Phase 3: long term.

In phase 1, there is a congestion problem on some freeway with some number of lanes, average occupancy per vehicle, number of high occupancy vehicles, and flow. The level of service would be around E or F to warrant the implementation of an HOV lane. (Mallinckrodt, 1993) Level of Service (LOS) is a “qualitative measure that incorporates the collective factors of speed, travel time, traffic interruptions, freedom to manoeuvre, safety, driving comfort and convenience, and operating costs provided by a highway facility under a particular volume condition.” (Homburger et al. 1982) Level of Service A refers to free flow conditions, whereas level of service F refers to the complete breakdown of traffic flow on the roadway.

In phase 2, single occupant and high occupant diversion occurs between lanes and parallel arterials. Already existing carpools from other lanes and arterials divert to the carpool lane to take advantage of its better speed. Most solo drivers divert from the HOV lane to obey the law. At this stage no new carpools or vanpools are formed, unless an adequate marketing program was launched beforehand to address the problem of the congestion and present the HOV lane solution, this is however uncommon. In this phase three things occur that are detrimental to the capacity of the roadway as well as to congestion (Mallinckrodt, 1993):

- The HOV lane is relatively empty, carrying fewer vehicles than the general purpose lane was in phase 1;

- That capacity deficiency is forced onto the other lanes, so both the speed and flow in the general purpose lanes are less than that in phase 1; and
- Weaving of high occupant vehicles across the freeway to access the HOV lane causes further congestion and degradation to capacity.

In phase 3, more carpools and vanpools will have formed to take advantage of the HOV facility. It is only in this phase that some benefits are realized, since ridesharing increases; the person carrying capacity also increases and congestion is reduced as compared to phase 2. If the additional capacity created by the formation of the new carpools and vanpools in phase 3 exceeds that lost in phase 2, then the capacity will increase and the benefits mentioned earlier may be realized. (Mallinckrodt, 1993)

HOV lanes may cause a reduction in capacity in the immediate period after the implementation; this period may be prolonged if enough carpools and vanpools are not formed. It is during this period that most people argue that the lane is underutilized. Even when equilibrium is eventually reached, the potential of the HOV lane is never maximized. So, to make the lane more effective other techniques are often utilized.

2.3 Congestion Pricing

Many industries such as airlines, cell phone providers and electrical companies have successfully employed variable pricing schemes based on demand. Demand for transportation facilities is exceeded everyday in countless cities worldwide. Most economists agree that when some resource is in short supply there are two main options: increase supply or restrict access (Kindleysides, 2006). Road space is limited, and it is impossible to increase the size of the networks to completely eradicate congestion, so

restricting access to road facilities may be necessary. However, restricting access to road facilities must be done in a way that is both politically correct and equitable. Congestion pricing provides a means to restrict access to roadway facilities that is effective, profitable and politically correct.

Congestion pricing, sometimes referred to as value pricing, demand pricing or transportation pricing, is a way of harnessing the power of the market to reduce the waste associated with traffic congestion (FHWA, 2006). By charging users a fee, congestion pricing forces users to make changes to their travel mode, travel time or route (if they refuse to pay the fee), which as a result should alleviate some of the congestion on the roadways. There are four main types of congestion charging strategies: variably priced lanes, variable tolls on entire roadways, cordon charges, and area wide charges (FHWA, 2006). In this study the focus is on variably priced lanes, but the theory behind congestion pricing is the same in all four cases.

The concept of congestion pricing is illustrated in Figure 2.2. Two functions are shown in the diagram: the average cost function and the marginal cost function. The average cost function represents the perceived cost of travel incurred by a particular driver on the roadway. These private costs include, among other things, travel time, fuel cost and maintenance cost. The decision whether to use a particular roadway facility is determined by these private costs. However, the decision to use a particular roadway facility also affects other travellers. The marginal cost function represents the incremental cost effect of adding each vehicle to the roadway facility. That is, beyond point A each additional vehicle slows the entire stream of traffic causing the operating costs of each driver on the

facility to increase. To adequately harness the power of congestion pricing to reduce the demand on the facility, drivers should be made aware of the marginal cost function. To make drivers more aware of the marginal cost function a toll should be charged as the difference between the marginal cost function and the average cost function. (Gryz et al. 2007)

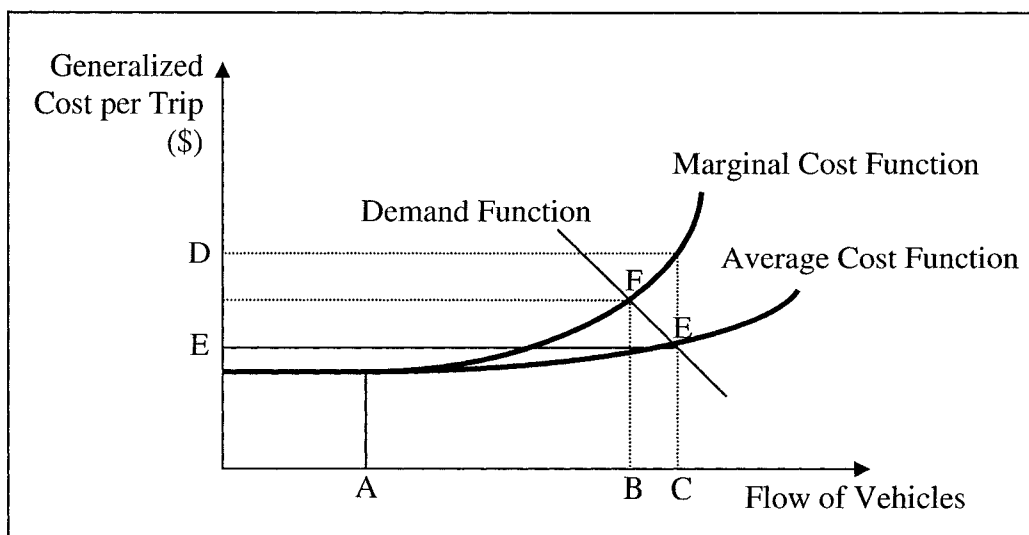


Figure 2.2: The concept of Congestion Pricing. (Image Courtesy of Gryz et al. 2007)

If a congestion toll is not charged, drivers perceive their generalized cost per trip as the average cost function and the equilibrium of the demand and price-volume function will result in the traffic level shown by C. If a congestion toll of the value $\$(D - E)$ is charged the demand will begin to decrease. When the equilibrium level is reached, i.e. where the demand function meets the marginal cost function, a toll of the value $\$(F - E)$ can then be charged. The reduction in the traffic stream increases efficiency for all travelers on the roadway. Those drivers who are unwilling to pay the toll can divert to a parallel toll-free route, shift the mode of transportation, shift to a shoulder or off peak time of travel, or forgo the trip entirely. (Gryz et al, 2007)

Congestion pricing schemes worldwide have been shown to impact travel behaviour both in the short term and in the long term. Short term impacts include adjustments to the time of travel, mode choice, trip frequency and route choice primarily where a free alternative exists. Long term effects include trip making decisions as well as decisions regarding automobile ownership and residence location. (Wolff et al. 2007)

There are various ways that a congestion charging scheme can be implemented. The following sections describe some of the possible ways that congestion pricing is used.

2.3.1 Cordon Based

In a cordon based congestion pricing scheme; drivers are required to pay a toll to go into or out of a specific area. A cordon based system is good for diverting traffic to areas which are not as plagued with congestion or for discouraging commuters from using private automobiles to go to work. Paying per crossing discourages shorter or unnecessary trips (Kindleysides, 2006). Generally a screen-line is an imaginary line placed on a map where the movements can be monitored. Vehicle and pedestrian movements can be monitored as they cross the screen-line. A cordon is similar to a screen-line, except that it encircles an entire area. So, a cordon would be an imaginary line that encircles an area of high interest (generally the central business district) in a city. Using a congestion charge that is cordon based requires setting up screening points along all routes entering a specific area, where entering and exiting vehicles can be charged. A dynamic pricing scheme or a static pricing scheme may be used with a cordon based pricing system.

Cordon tolls have many advantages over other road pricing systems: they are transparent and easy to understand, they are relatively easy to implement and the technology has been tested worldwide and is widely available. However, cordon based road pricing has been criticized for being inflexible (i.e. tolling locations cannot be easily changed), for being inefficient (since short and long trips that contribute differently to congestion are charged the same toll), for causing an increase in congestion outside of the cordon and for adversely affecting the economic activity within the boundary (Safirova et al 2007).

This type of congestion pricing scheme would require some complex technologies to operate properly. One option is to install automated number plate recognition cameras and software. This way every vehicle entering or exiting the cordon would be charged by mail. Another possibility is the use of electronic payment systems where people wishing to enter the area would have to buy a smart card or transponder and fill their account with money before they can enter the cordoned area. The ideal strategy would be to use a combination of both systems so that occasional users do not have to buy or lease equipment and daily users can use the facility with greater ease.

2.3.2 Zone Based

A zone based congestion pricing system refers to a system where drivers pay for movements within a certain area. A zone based system is good for reducing traffic within the area and depending on the charging structure discouraging short local trips (Kindleysides, 2006). As opposed to the cordon system, discussed in the previous section, where vehicles are charged when passing through the borders of the cordoned area, the

zone based approach involves charging motorists for any movements made within the charging zone.

Generally speaking, the zone based system would appear to be the same as the cordon based system to those motorists accessing the charging zone from a suburb or an area outside of the charging zone. However, the zone based system also applies to residents residing within the congestion charging zone. In this case, the residents of the charging zone are generally charged less than the motorists commuting from locations outside of the zone.

2.3.3 HOT Lanes

Despite the fact that HOV lanes offer some benefits, poor public perception and in some cases severe inefficiency lead researchers to the conclusion that HOV lanes can be improved upon. The concept of the high occupancy toll (HOT) lane attempts to improve the efficiency of a standard HOV lane while experiencing the same benefits and in some cases turning some revenue over to the municipality. The HOT lanes operate similarly to the HOV lane in that vehicles with some minimum occupancy (usually 2 persons) utilize the lane free of charge; however on an HOT lane solo drivers are also permitted to use the lane if they choose to pay the specified toll. The tolling mechanism is used to limit access to the lane so that free flow conditions are maintained while more people can be moved than a traditional HOV lane. HOT Lanes will be discussed in greater detail in Section 2.4.

2.3.4 Other Congestion Pricing Uses

An access based toll limits entry into a small area or specific route by restricting identified vehicles. The identified vehicles can be private automobiles, freight vehicles or any other type of vehicle established by the operating party. An access based congestion pricing scheme can be used in conjunction with toll collection or simply by refusing entry to specified vehicles. This type of system works well for smaller towns or suburban areas that have a serious congestion problem in a small localized area. (Kindleysides, 2006)

A distance based congestion pricing scheme charges motorists depending on how far they have driven. This approach has yet to be used as a congestion management method. Instead it has been used in Europe for charging freight vehicle drivers for road usage on a per-use basis and as an optional tolled route in major metropolitan areas (such as highway 407 in Toronto). (Kindleysides, 2006)

Infrastructure based congestion charging schemes involve charging drivers for use of a specific piece of infrastructure or route. This method is useful in that it helps cover the investment on certain infrastructure projects, such as large bridges. Also, infrastructure based tolls are good for managing driver behaviour with regard to specific routes. (Kindleysides, 2006)

2.4 HOT Lanes

HOT lanes provide an un-congested lane for high occupant vehicles and offer solo travellers the option of using an un-congested lane for a variable fee. The fee is set according to the traffic in the HOT lane as well as the general purpose lanes and can rise or fall in real time. The tolls are “market based” which means that they vary according to

the demand for the facility (Nookala, 2006). Traditionally, a tolled facility was physically separated from the general purpose lanes, however innovations in technology have allowed for an HOT lane to be placed adjacent to general purpose lanes and separated only by a painted buffer. It is both unsafe and illegal to cross the painted buffer, and law enforcement agencies should regularly monitor the facility to ensure there are no “cheaters.”

The majority of HOT lanes in North America are HOV lane conversions. This means that planners or engineers have studied the existing HOV lane system and decided that it is underutilized and there is excess capacity, while the general purpose lanes and parallel routes remain severely congested. Generally the decision to convert to HOT lanes is made based on poor public opinion regarding the HOV lanes and under-utilization of the facility.

In North America there are currently nine HOT lanes with more on the way. There are three HOT facilities in California, one in Minnesota, one in Colorado, one in Utah, one in Florida and one in Washington State. Each of the HOT lanes in the US have successfully used a dynamic pricing scheme combined with a facility that offers un-congested travel for carpools, vanpools and transit vehicles while offering solo drivers the option to pay for an un-congested trip (FHWA, 2007). The following sections describe some of the HOT lanes located in North America.

2.4.1 Minneapolis, Minnesota

The MnPASS project in Minnesota is one of the most recent HOT lanes to be built in North America. It is located in the Minneapolis – St. Paul region and is operated and

maintained by the Minnesota department of transportation (MnDOT). This project is particularly interesting, seeing as some the innovation had not previously been attempted elsewhere. These innovative efforts include (Nookala, 2006):

- Implementation and infrastructure development through public-private partnerships;
- Tolling on lanes directly adjacent to non-barrier separated lanes with multiple access and egress points;
- Dynamic pricing applications on multiple consecutive segments; and
- Technology applications to assist enforcement.

Figure 2.3 illustrates an access/egress area on an HOT lane. Access points are regularly spaced and must be a minimum of one quarter mile (402 meters) long (Nookala, 2006). Tolls are collected electronically by means of a dedicated short range communication (DSRC) system and smart tag technology.

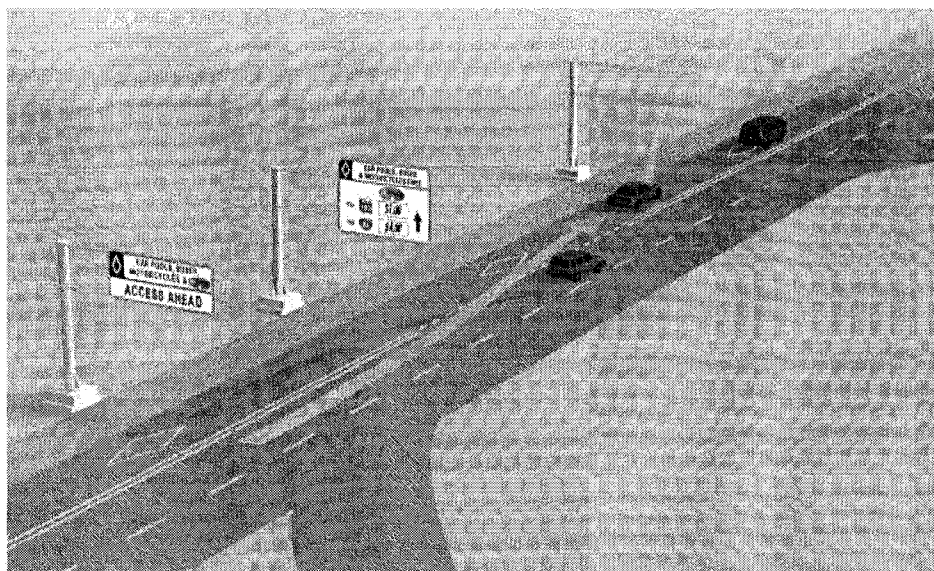


Figure 2.3 Depiction of an access area on an HOT lane adjacent to two general purpose lanes (Image courtesy of MnDOT)

Enforcement of regulations of an HOT lane is essential to successful operations and efficient transportation. The MnPASS project boasts some of the most innovative means of enforcing HOT regulations in North America. Police cruisers patrolling the HOT facility are equipped with transponders that issue an audio tone, which indicates whether the driver has paid the toll, when the officer is trailing a solo driver. If no tone is heard, the officer knows to pull this motorist over and issue a citation. Also, on the overhead gantries that house the electronic toll collection system are small beacons that flash a light when a solo driver passes and successfully pays the toll (Nookala, 2006). With this type of enforcement technology the successful operations of an HOT lane may be ensured.

2.4.2 San Diego, California

Interstate 15 is a major freeway in San Diego County, which connects the “bedroom communities” to the north with the major employment centers to the south. I-15 is a very busy connector to downtown San Diego as well as to the airport. As early as 1988 a serious congestion problem was noticed along the route and officials decided a reversible HOV lane should be built to help alleviate some of the congestion. The HOV facility was built as a separate roadway in the median along an 8 mile stretch of I-15. Later, it was observed that the facility was operating at significantly under capacity and some modifications to the system would have to be made in order for the lanes to provide an adequate level of demand management. In 1998, following a two year pilot project, the facility was converted to an HOT lane with a full electronic toll collection system. (Supernak, 2005)

The FasTrak system was implemented in 1998, which allowed motorists to pay a trip fee per use. The facility remained free of charge for carpools and other vehicles were required to purchase transponders and open accounts in order to be charged for their trips. The FasTrak system was one of the first dynamic pricing schemes in North America; as the system would re-evaluate the traffic on the facility and adjust the fee. It was mandated by the state that the facility maintain a level of service (LOS) C at all times, any time the traffic conditions threatened a level lower than C the computers would compute a different fee to limit the number of users. (Supernak, 2005)

Due primarily to the more efficient use of the HOV facility the FasTrak system was found to provide congestion relief on the general purpose lanes as well as an adequate level of service on the HOT lanes. The cost of delay reduction alone was found to outweigh all of the costs of building, maintaining and operating the facility. All benefit/cost analysis proved that the benefits outweighed the costs of the project. (Supernak, 2005)

2.4.3 Orange County, California

State Route 91 (SR91) in Orange County California is considered to be the primary link between Orange County to the west and the major urban centers further inland in the east. The freeway carries over 250,000 vehicles per day, on average, and congestion plagues the corridor at every peak period. Currently, Orange County has a strong job market and limited affordable housing. If the current trend continues this would cause a serious imbalance between housing and employment resulting in serious congestion problems. (TRB, 2005)

In 1989, the California State Assembly authorized the construction of public-private toll road partnerships. On SR91, this meant that express lanes were built in the median (TRB, 2005). The express lanes were tolled and had a variable pricing scheme. However, the toll rate was not determined dynamically instead it would vary according to a predefined schedule determined by the operators (www.91expresslanes.com). In 2003, the Orange County Transportation Authority (OCTA) bought the SR91 express lanes and made some slight modifications. Carpools with 3 or more people (HOV 3+) were allowed to use the lanes free of charge, except at “super peak” periods (Monday through Friday, 4 to 6 pm, Eastbound). During these times, the Carpools paid only half of what other vehicles pay. (TRB, 2005)

Currently the toll is changed dynamically, depending on the magnitude of the congestion on the road. With the new policy, electronic toll collection and pricing structure it was found that 40% more HOV 3+ carpools were formed. The average revenue per trip fell from \$2.70 to \$2.40 partly because there were fewer cars on the road. (TRB, 2005)

2.4.4 Houston, Texas

Many major cities across North America have turned to HOV lanes as a means of reducing congestion, some even so far as to convert all lanes of a highway to HOV, as in Washington DC on I-66 (www.commuterpage.com). In most cases the HOV facilities are never fully utilized, so planners and engineers have to look for other methods for congestion reduction. In Houston, Texas on the Katy freeway the congestion problem forced officials to open a reversible HOV2+ lane. Over time, the traffic volume on the HOV facility increased to the point where volumes increased to the point of capacity. The

city engineers were forced to change the entry requirements on the lane to HOV3+ in 1998, after which the volume returned to free flow conditions but excess capacity was observed. The underutilization problem prompted officials to convert the facility to an HOT lane where HOV3+ vehicles were allowed to use the facility free of charge and HOV2+ vehicle had to pay a congestion toll to use the facility. (Burris et al. 2003)

This HOT project was called Quickride, and it was the first value pricing project of its kind in Texas. At the time, there were only two other HOT lanes and five value pricing projects across the continent. Currently, there is much debate regarding whether single occupant vehicles (SOV) should be permitted to pay for use of the Quickride lane. Since permitting SOV drivers on the Quickride lane may result in reversion back to severe congestion on the lane, many people are opposed to the idea; however others argue that this may not be the case. The value pricing project in Houston has been shown to be very popular with the public; due to the flexibility of being able to choose their mode of transportation on a day to day basis. (Regional Congestion Pricing Workshop, 1999)

2.5 ITS Technology Used in HOT Facilities

Congestion charging is not a new concept; the theory behind congestion charging has been known for decades. However, the implementation of such a system had to wait for innovations in technology capable of accommodating such a system. ITS technologies are becoming more and more cost effective and are capable of supporting a congestion pricing scheme. There are many formal definitions of intelligent transportation systems, most of these seem to focus on the interaction between the technology and the various components of the transportation system: the vehicles, the infrastructure, the users and

the communication system. According to ITS America: “Intelligent Transportation Systems, or ITS, encompass a broad range of wireless and wire-line communications-based information, control and electronics technologies. When integrated into the transportation system infrastructure, and in vehicles themselves, these technologies help monitor and manage traffic flow, reduce congestion, provide alternate routes to travelers, enhance productivity, and save lives, time and money.” (ITS America, www.itsa.org)

ITS technology can facilitate the implementation of an HOT lane with tolls determined according to a congestion pricing algorithm by:

- Allowing tolls to be collected electronically, and at high speeds;
- Allowing for the price of the current congestion toll to be disseminated to motorists; and
- Facilitating data collection for use by the congestion pricing algorithm.

The following sections will address how ITS technologies can be utilized to implement a successful HOT lane with tolls determined by a congestion pricing algorithm.

2.5.1 Electronic Toll Collection

To facilitate seamless operations on an HOT lane, some method of collecting tolls without forcing vehicles to stop must be devised. Electronic toll collection allows for tolls to be collected from travellers, without their vehicles even having to slow down. There are several different technologies used in electronic toll collection including: Dedicated Short Range Communication (DSRC), Global Positioning Systems (GPS), and Automatic Number Plate Recognition (ANPR). The focus here will be on DSRC systems.

In a DSRC system, vehicles are generally equipped with a tag; this tag may be in the form of a sticker that is placed on the windshield of the vehicle or an electronic transponder. Each tag is linked to an account that the user must open; money is transferred to the account at the user's discretion. The tags operate similarly to a debit card, as the account is debited the full amount of the toll, each time the traveller enters the tolled facility. Tag readers are placed at access points to tolled facilities. When a vehicle equipped with a tag passes a tag reader, at an access point, the reader reads the coded data, and charges the associated account (ATLANTIC, 2004). Most commonly tag readers are placed on overhead gantries as shown in Figure 2.4. In this case, as the vehicle enters the access point it trips an underground sensor which activates the tag reader.

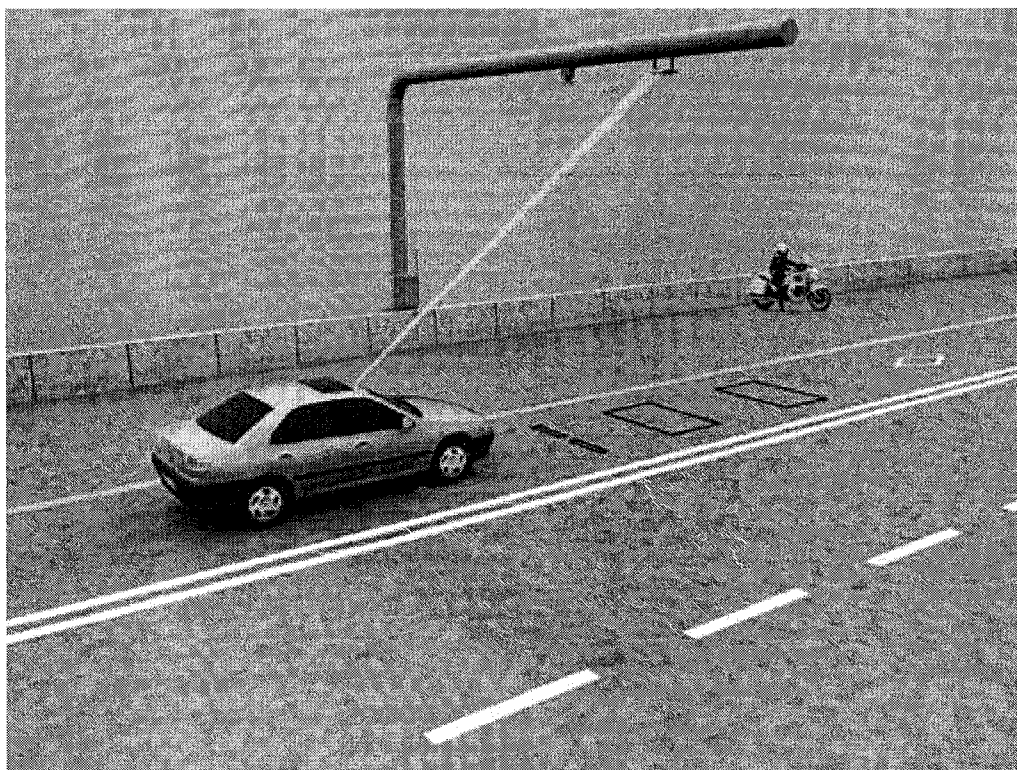


Figure 2.4 Overhead mounted Dedicated Short Range Communication (DSRC) system for electronic toll collection (Image courtesy of www.wsdot.wa.gov)

The term DSRC describes the process of direct communication between the vehicle tag and the reader. Radio frequency identification (RFID) systems are microwave based communications, and are the most common means of DSRC in North America (ATLANTIC, 2004). There are two forms of RFID communications:

- Active RFID, which employs microwave frequencies for communications with the vehicle; this systems requires that the tag have an active power source; and
- Passive RFID, in which the transmitters sends a continuous signal that is intercepted by the tag and reflected to the receiver.

Also there are three different types of tags that may be placed the vehicle (ATLANTIC, 2004):

- Read Only, where the information is fixed;
- Read/Write, where the information on the tag may be updated; and
- Smart Tags, which may communicate identifying information about the vehicle, customer and account balance.

For use in an HOT lane application, an active RFID system with either read/write or smart tags would be required.

2.5.2 Information Dissemination

For the successful operations of an HOT facility, a means of communicating important information is necessary. Dynamic Message Signs (DMS) provide the most fundamental method for disseminating traffic related information, from the roadside. DMS are generally utilized to alert drivers of upcoming congestion, closures, incidents and most

recently alerts for missing people. In the HOT lane case the DMS must provide real time information regarding the current toll.

DMS use words, numbers and symbols to convey the desired information to passing motorists in real time. DMS are large signs that are most commonly static, but may be moveable, and can be modified in real time to show the most current information. There are three types of DMS (Teng, 2006):

- Light Reflecting Displays: are signs built to general highway road sign standards and utilize mechanical devices to change the messages displayed on the sign;
- Electromagnetic Reflective Disk Matrix: consist of a grid of disks that form these signs, each disk represents 1 pixel of a typical 5 by 7 array of pixels reserved for each character. Each disk has 2 sides: one reflective (yellow or white) and the other matte black. A character forms by switching the appropriate subset of pixels to display their reflective side.
- Light Emitting Displays: the messages of light emitting display DMS are created by lighting pixels or characters against a black background. Message change times are virtually instantaneous compared to mechanical counterparts & the reduction of moving parts means less maintenance.



Figure 2.5 DMS at access point to HOT lane in Minneapolis – St. Paul (Image Courtesy of MnDOT)

Currently light emitting displays are most commonly used, and provide the best means of disseminating toll information to motorists. Figure 2.5 illustrates a DMS sign in the Minneapolis – St. Paul region. It is used to alert drivers of the current toll rate on the HOT lane, prior to an access point. The biggest challenge faced in Minneapolis was the dynamic toll that had to be displayed for two distinct sections of HOT lane (Nookala, 2006).

2.5.3 Data Collection and Surveillance

The congestion tolling algorithm requires real time information to be able to compute the appropriate tolling level. Real time data may be collected a number of different ways, although most commonly sensors and cameras are utilized. Generally, major cities already have some traffic detection and surveillance technology implemented as a part of the freeway management system. In this case the detection and surveillance system

would potentially only need to be modified slightly to meet the needs of the HOT facility. In other cities that do not have freeway management systems, detection and surveillance technology could not only be used for the HOT facility but also to monitor the performance of the entire freeway.

There are two different types of traffic detectors in use: embedded detectors and non-intrusive detectors. Embedded detectors are available in two types: inductive loop and magnetometer detectors. Whereas non-intrusive detectors are available in four different types: microwave, ultrasonic, acoustic and video image processing detectors. (Teng, 2006)

Inductive loop detectors are composed of a wire loop with one or more turns that are embedded in the ground. Current is passed through the loop creating an electric field, and when a vehicle passes over the detector the field is reduced, this is interpreted as a vehicle by the computer. Magnetometers consist of multiple embedded sensors that measure the density of the earth's magnetic flux lines. When a vehicle passes over the magnetometer the density of flux lines is increased and interpreted as a vehicle by the computer. (Teng, 2006)

Microwave detectors are mounted above the surface of the pavement, often on overhead gantries. They consist of radar sensors that direct a beam of microwave energy on the desired detection area. Vehicles are detected when microwave energy is reflected off the surface of the vehicle. Ultrasonic detectors operate in the same way as microwave detectors except they measure reflected sound waves. Acoustic detectors use two microphones one mounted above the other. Data is collected by measuring the delay

between the sound reaching the lower microphone and the upper microphone. Video image processing (VIP) detectors automatically analyze scenes of interest from closed circuit television (CCTV) cameras. VIP systems may operate in trip line mode, which works the same way inductive loop detectors do. VIP systems may also operate in tracking mode, which track the vehicles for a specified length of roadway and collect applicable data. (Teng, 2006)

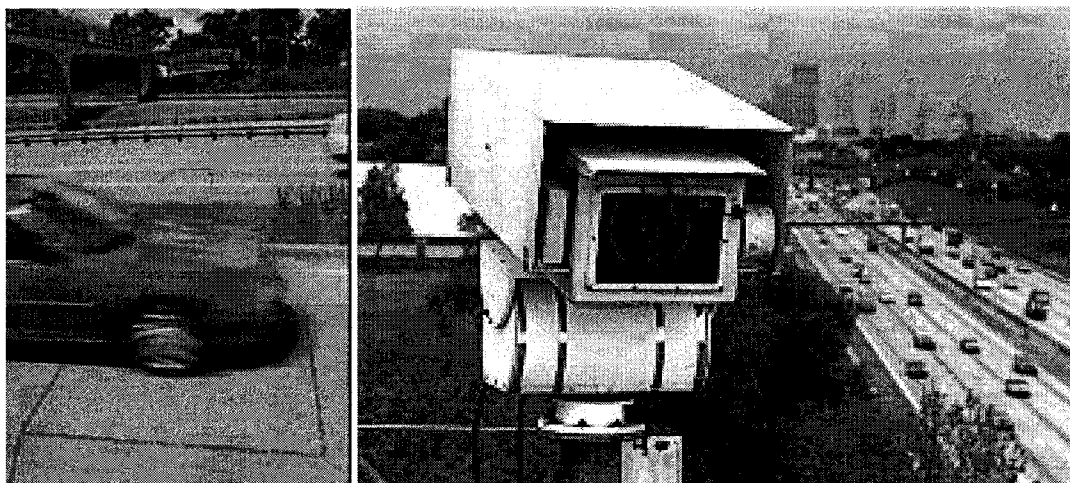


Figure 2.6 Embedded Inductive Loop Detector (Left) and Closed Circuit Television Camera (Right)
(Images Courtesy of MnDOT)

Embedded detectors and trip line VIP detectors may be used to collect the following data: speed, occupancy, presence and vehicle counts. Microwave and ultrasonic detectors can collect vehicle speeds, vehicle counts, and in special cases, presence and classification. Acoustic detectors can be used to collect volume, occupancy, presence and classification information. Tracking VIP detectors can return link information. (Teng, 2006)

The most cost effective choice for an HOT is the embedded detectors, since they collect all of the desired information and are less costly than the non-intrusive detectors. However, CCTV cameras should still be installed for surveillance and safety reasons.

2.6 HOT Lane Regulations and Design Considerations

When designing and implementing an HOT lane it is important to keep in mind that there are some rules and regulations to help the facilities operate efficiently. This study involves converting an existing HOV lane to an HOT lane so there are additional regulations that come into effect (Note: at the time of writing this report the HOV lanes in Ottawa were yet to be opened to the public). There are many regulations that affect the design and operation of an HOT lane. Since this study is primarily concerned with the planning of an HOT lane, only certain regulations will be discussed here, primarily those that will affect the HOT facility at the planning stage.

HOT lanes can be classified as a type of managed lane which include HOV, HOT, transit vehicle only as well as other types of special use lanes. It is important to define the criteria for access to the HOT lane. For this study, vehicles with multiple occupants (i.e. two or more people in the vehicle) will be permitted to use the HOT lane free of charge any time of the day. While, only single occupant vehicles will have to pay the toll to enter the facility. Solo motorists who wish to use the facility will have to buy a transponder and open an account. The transponder is important because it will communicate with the HOT infrastructure and through the transponder the toll amount will be deducted from the user's account. This technique was successfully demonstrated on the HOT facility in Minneapolis/St. Paul (Nookala, 2006).

It is important to keep traffic from the general purpose lanes from interfering with traffic in the HOT lanes in order to ensure that optimal conditions are be experienced by the HOV motorists and the paying solo motorists. There are many different measures that can

be used to delineate the HOT lane and keep it separated from the general purpose lanes. These include: painted stripe buffers, concrete barriers (jersey barriers), plastic pylons and retractable pylons or moveable barriers. The most common form of special lane delineation is the painted stripe buffers and the concrete barriers; however moveable barriers and pylons are being used in various locations in the United States. Painted stripe buffer zones are the least costly alternative while moveable barriers are the most expensive, consequently moveable barriers offer the greatest amount of flexibility and safety (Hlavacek et al. 2006). One can argue that the more expensive delineation alternatives provide more safety while the least expensive alternatives provide less safety. However, an HOT lane was built and is currently operating in Minneapolis/St. Paul, MN which uses the painted stripe buffer to separate tolled lanes from free lanes. The facility in Minneapolis/St. Paul is operating safely and efficiently (Nookala, 2006).

In this study, where an existing HOV lane is to be converted to an HOT lane: the HOV infrastructure already exists. It would be logical to use the painted stripe buffers and merging zones for the HOT lane facility seeing as it was shown to be safe and effective in Minneapolis/St. Paul. Of course the HOV infrastructure alone cannot accommodate the demands of an HOT facility, so modifications will have to be made. For example, dedicated short range communication systems will have to be installed on overhead gantries to facilitate the automated collection of tolls from solo drivers. Transponders will also have to be sold to the driving public to allow for the paid usage of HOT lanes when driving alone.

2.7 Microscopic Traffic Simulation Models

There are many different microscopic traffic simulation models available for a variety of purposes. The most common microsimulation models are: VISSIM, Paramics and Integration among others. These models move traffic through a network by adjusting each vehicle's position, speed and acceleration among other characteristics. The behaviour of drivers in a microsimulation model is governed by behavioural characteristics such as lane change behaviour and car following behaviour. As opposed to macroscopic models where traffic characteristics are expressed as more general characteristics such as average speed, volume and density, microscopic models express aggregate results based on the behaviour of each vehicle in the traffic stream. Hence, for a microscopic traffic simulation model to be successful a large amount of data is required, including: network geometry, traffic flows on each link, driver behaviour characteristics, signal timings, etc. The majority of traffic microsimulation models utilize random numbers generated from a random seed that determine, among others, vehicle release times from boundaries, vehicle type, vehicle's route and the vehicle's desired speed. Therefore, each simulation run utilizes a different random number seed thus each simulation run will yield different results. Therefore, to obtain the required data, multiple simulation runs must be conducted.

VISSIM was chosen as the microsimulation model for this study due to its ability to incorporate ITS technology, dynamic traffic assignment (or dynamic routing) and its ease of use. VISSIM is a "microscopic, time step and behavioural based simulation model developed to model urban traffic and public transit operations." (PTV, 2007) The model is capable of analyzing traffic and transit operations under various constraints.

VISSIM is capable of modelling HOT lanes in a variety of ways, due to its variety of features. The three ways in which HOT lanes can be modelled in VISSIM are using: static routes, dynamic routes with a choice model and dynamic traffic assignment with a choice model. The static route method involves building the network, defining the vehicle classes including driver behaviour, placing the static routes and then running the model. Using the dynamic routes method involves placing traffic detectors along the network to monitor the performance of the vehicles, defining a toll price model, estimating a choice model by using survey results or a logit model and finally placing the dynamic routes. Using the dynamic traffic assignment method involves defining vehicle class origin-destination matrices and running the model to convergence. (Dale, 2007) The decision as to which of the three methods are most appropriate is based on the available data, the purpose of analysis and the schedule.

2.8 Previous Research

High occupancy toll lanes have been in existence for over 10 years and have been studied for even longer. Despite the ongoing interest and research into HOT lane implementation, operations and construction there remain many areas that have yet to be investigated. Many of the existing HOT lanes have already been discussed in Section 2.5, so they will not be discussed again, here. The following outlines some of the past and ongoing research being conducted on the subject of HOT lanes.

Much research on the subject of HOT lanes is devoted to implementation. HOT lanes have existed for many years but there are no set standards or guidelines for engineers, planners and project managers regarding how to implement, operate and maintain such

facilities. A study by Ungemah et al. (2006) outlines the procedure for converting an HOV lane to an HOT lane from a project manager's perspective. This study discusses the conditions required for a successful HOV to HOT conversion and follows with a description of the conversion process. Other studies have taken the form of feasibility studies that look at specific locations and describe the process of converting HOV lanes to HOT lanes. The Texas Department of Transportation (TxDOT) sponsored a study that was based on determining measures of effectiveness for HOV to HOT lane conversions that could be used for projects around the state. The study identified many factors that could be used to evaluate HOV to HOT lane conversions and defined each of them, weighted them and finally analyzed which were most important. The study then analyzed software used for HOV to HOT lane conversions and applied the factors and software to a case study in Houston TX (Eisele et al. 2006). Another study looked at Atlanta Georgia, where currently no HOT lanes exist and discussed the possibilities for implementing an HOT lane in the metropolitan area (Meyer et al. 2006).

Other research on the topic of HOT lanes focuses on assessing usage and predicting possible single occupant vehicle demand on HOT lane facilities. This type of research examines an existing HOT lane and tries to infer conclusions based on how drivers behave or utilizes simulation or modelling techniques to assess a hypothetical or proposed HOT facility. Discrete choice models are commonly utilized, in the transportation industry, to predict how certain drivers will behave given a certain set of circumstances. Therefore it is not unreasonable to utilize discrete choice models for HOT lane analysis. To formulate a discrete choice model, household surveys are often used. Stated preference surveys are commonly used for proposed facilities and revealed

preference surveys for existing facilities. Public opinion is often an important factor when deciding whether or not to build a new transportation facility and how to operate it, so some studies consider public opinion. It was found that willingness to pay for usage of a tolled facility is significantly related to several observable factors of the traveling population including: income, age, trip purpose, time of day, trip distance and amount of time saved (Zmud et al. 2006). Other studies, examining the sensitivity of drivers to the toll they will potentially pay, show that the greater number of access points the less benefit there is to having an HOT lane. Also, the more sensitive a model was to the driver's generalized cost, the greater the percentage of people who elected to share a ride (Murray et al. 2001). Another study (Burris et al. 2006) utilized a stated preference survey along with traffic simulation techniques to determine potential single occupant vehicle demand on the Katy Freeway in Houston TX. Yet another study utilized revealed preference techniques and mathematical modeling to analyze the HOT facility in San Diego. This study found that variables such as household income, vehicle occupancy, trip purpose and age were all important factors that helped determine HOT lane use. While gender, trip length, trip frequency, household size and household type had little effect on HOT lane usage (Li, 2001).

There is also research regarding utilization of various simulation techniques to assess HOT facilities in terms of utilization and performance. Many researchers have designed equations and algorithms to better understand how HOT lanes operate and to predict usage and performance. A study conducted by Abdelghany et al. (2000) concentrated on the effects of dynamic traffic assignment methodologies in HOT lane evaluations. The DYNASMART model was constructed using dynamic traffic assignment and

microsimulation techniques to analyze: where HOT lanes should be placed, should a new lane be added for the facility or should an existing lane be converted to HOT, what prices single occupant drivers should be charged while on the facility, what the resulting level of service is and how much traffic will shift to the HOT lane. Other research has used various mathematical models to predict: demand on the HOT lane as well as on the general purpose lanes, time of day choice, lane choice and mode choice. The simulation utilized an iterative algorithm combining the models to assess the performance of the facility and the effects of the HOT lane on the remainder of the transportation network (McDonald et al. 2001).

As of the writing of this thesis, there is very little published research that pertains to the development of tolling algorithms for high occupancy toll lanes. There is currently one published research paper that pertains to the subject of tolling algorithm development; this is the study conducted by Zhang et al. (2008). In this study, the procedure for developing a feedback based dynamic tolling algorithm is described. Beginning with the motivation for developing such an algorithm the authors then explain the use of feedback control theory and discrete choice modelling for the purpose of tolling algorithm development. A complementary study by some of the same authors, Zhang et al. (2008a), explains the procedure for developing a module that can control the HOT lane operations remotely. The module was developed to be used with VISSIM, a traffic microsimulation software package. The module was developed in the Microsoft Visual Basic programming language and was incorporated into the VISSIM model through the COM interface (Zhang et al. 2008a). Both of the studies concerned the proposed HOT lane in

the Seattle, WA area. These studies provided an excellent starting point to assist with the algorithm development in this study.

2.9 Summary

A literature review was conducted to establish the current state of knowledge on the subject of HOT lanes as well as to determine whether research exists on development of a dynamic tolling algorithm that is self-calibrating. HOT lanes are growing in popularity as they are the logical choice for conversion when experiencing inefficiency on an HOV facility. Using congestion pricing can limit the number of motorists that enter a tolled facility and because of this it should be considered for HOT lane implementation. There are many HOT lanes in North America, some which operate very efficiently and collect revenue for maintenance of the facility itself. It was shown that it is possible to use the VISSIM microsimulation model to accurately model HOT facilities.

The literature review revealed that there is currently no research focused on the development of a dynamic, feedback based and self calibrating tolling algorithm. However, there has been considerable research conducted on the topic of HOT lanes in North America. The research deals with various aspects of the HOT facilities such as proper techniques for conversion from HOV to HOT lanes, and assessment using simulation techniques. Also, much research is devoted to studying public perception of HOT lanes and people's willingness to pay for tolled facilities.

Chapter 3

Research Description

3.1 Introduction

At the core of this research is the combined use of traffic microsimulation techniques, feedback control theory and data generated from a stated preference survey. The survey will be analyzed using statistical software to develop a logit model. The logit model will then be used, in combination with feedback control, to develop a tolling algorithm. The algorithm will then be tested by using a traffic microsimulation program. The traffic simulation will be done using VISSIM, which is capable of incorporating various ITS technologies into traffic models. The traffic model data will be collected and analyzed to determine if the dynamic, feedback based and self-calibrating tolling algorithm increases the efficiency.

This chapter will describe the methodology of this study, the scope of the study and a description of the various tools that will be required in successfully completing this study.

3.2 Methodology

The process for this study can be split into various stages and environments. The stages include: preliminary data preparation and base year model coding then development, administration and collection of data from the stated preference survey followed by the development of the logit model that will describe motorist's driving behaviour. Following that, the logit model will be combined with feedback control theory and a self-calibration mechanism to develop the tolling algorithm. The design year network will then be coded and the resulting simulation data will be used to evaluate the effectiveness of the tolling

algorithm. With the data collected from the design year model, the final stage includes analysis of the data and the evaluation of the tolling algorithm.

The various environments utilized in this study include the VISSIM environment, the online environment and the SPSS environment. Each of the three environments has its own purpose and its own contribution to the study. The following is a discussion of the various stages of the research including the environments corresponding to each stage. Figure 3.1 outlines the research methodology in flow chart form; where the various environments and each step throughout the process are outlined.

The initial stage of the study involved preparing the base year network. This stage was conducted within the VISSIM environment. VISSIM is a traffic microsimulator that is capable analyzing traffic under various conditions. Data preparation was an important aspect of this stage. Roadway geometric data as well as vehicle compositions, occupancy counts and traffic volumes were collected. The data was then coded into the traffic microsimulation software. Following the calibration and validation of the model, preliminary runs could be made.

The second step of the study involved preparing a stated preference (SP) survey. This stage was completed in an online environment. To begin this stage various questions for the SP survey questionnaire including demographic and trip information, were developed. Using the data collected from the preliminary runs conducted in stage one, the SP scenarios (discussed later in this document) were developed. Following testing of the survey, the questionnaire was administered to various groups of people by means of an online survey. All of the collected data was stored online until it was downloaded.

In the third stage, the data collected from the online survey questionnaire was analyzed in the SPSS environment. SPSS is a statistical software package that facilitates the statistical analysis of data and enables the user to create a variety of statistical models. A logit model was created from the collected SP data, to help model the behaviour of motorists in the presence of a tolled facility.

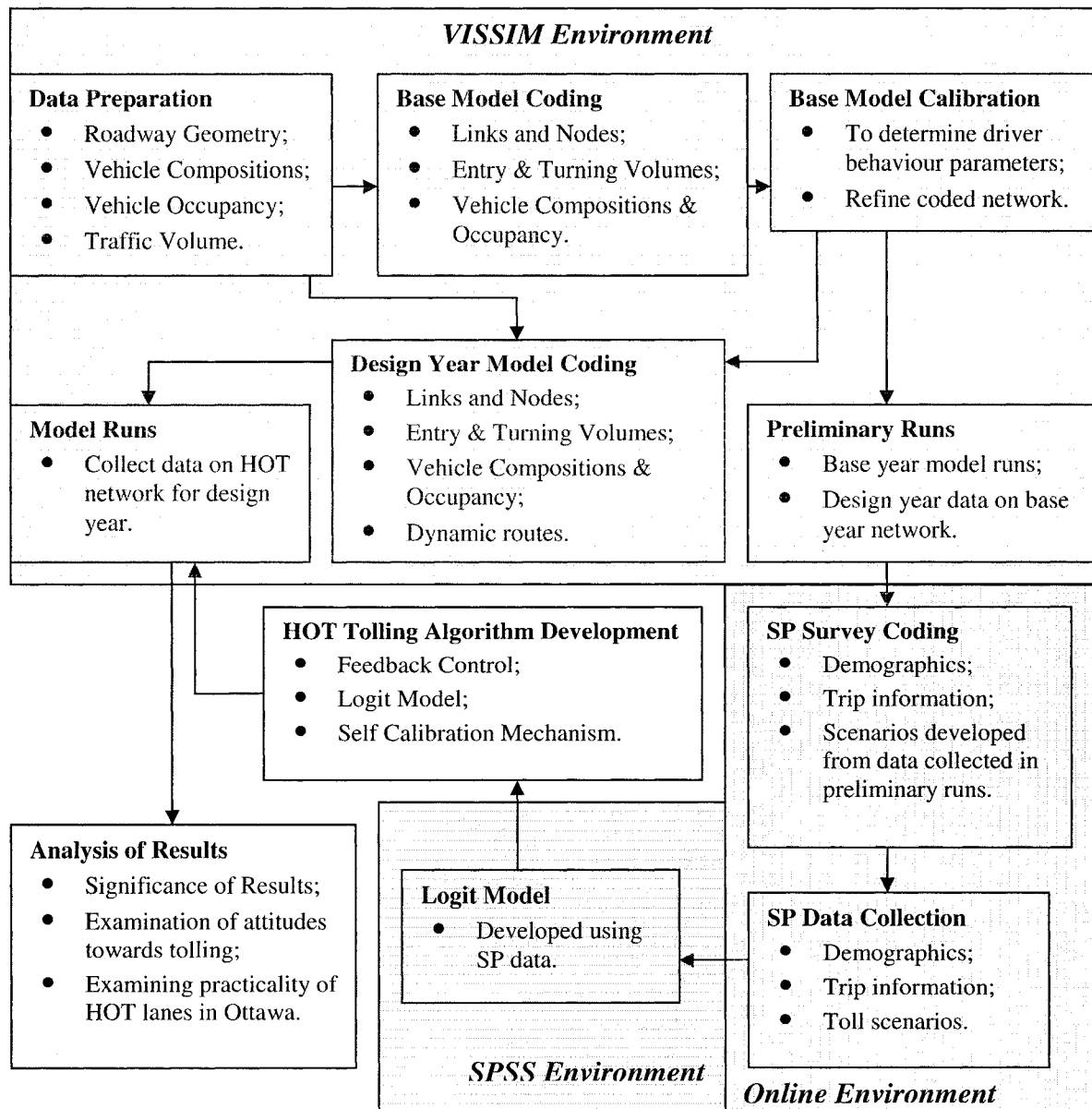


Figure 3.1 Research Methodology Flow Chart

In the fourth stage no environment was used since the tolling algorithm was developed using mathematical and control principles. The tolling algorithm was based on feedback control theory, the logit model and a self calibration mechanism. The tolling algorithm that was developed was such that it could operate dynamically, it was feedback based and had the capability of re-calibrating itself according to data previously collected.

The fifth stage of the study required that much of the previously collected data be compiled to form the design year model. Using the developed tolling algorithm the HOT lane operations were controlled by keeping track of the results and calculations in a spreadsheet. The design year roadway geometrics, vehicle compositions and occupancies and traffic volumes were coded in the VISSIM environment. After some preliminary testing and adjustments to the model the final simulation runs could be made.

The final step of the study involved collecting the final dataset from the simulation outputs in VISSIM and analyzing them to determine if the tolling algorithm added some benefits to the system. The significance of the results was also determined using statistical methods. This stage was completed in no particular environment as only simple statistical analysis was used. By using the final collected data from the microsimulation runs the effectiveness of the tolling algorithm could be determined.

3.3 Scope of the Study

The case study area for this research stretches from slightly west of the Palladium Dr. interchange to slightly east of the Moodie Dr. interchange along Highway 417 in Ottawa's west end. In this study, the through lanes of Highway 417 as well as various on and off-ramps were analyzed. Arterial roads and the signalized intersections that are often

present around interchanges were not considered. Highway 417 (also known as the Queensway) is the only major urban highway that stretches east to west through the Ottawa area. As such it sees a large number of vehicles daily. The study area was chosen because the Ministry of Transportation of Ontario (MTO) along with local contractors are currently rehabilitating the section of highway. As a part of the rehabilitation process, the MTO has decided to implement high occupancy vehicle lanes along this stretch of the Queensway. Since this corridor is already scheduled to have HOV lanes implemented, it made it the perfect candidate for this study. Currently there are no other HOV lanes in the area that are located on highways.

The study area corridor is approximately 10 kilometres long and contains five interchanges. All of the interchanges are of the partial cloverleaf configuration except for the Palladium drive interchange which is missing the west bound direct on-ramp. The study area lies in the west end of Ottawa and serves the communities of: Stittsville, Carp, Kanata and Bells Corners as well as other rural communities in West Ottawa. Figure 3.2 illustrates the study area.

The base year scenario data was collected in 2000; other studies and cross referencing with the City of Ottawa's screenline showed that the data corresponds roughly to conditions experienced in June of 2000. The design year data corresponds to the year 2016. A study conducted by the consulting firm McCormick Rankin Corporation and the MTO projected traffic volumes to this date. For the base year scenario, one hour during the morning peak period and one hour during the afternoon peak period were investigated. The base model was used for a variety of purposes including: calibration,

validation and data collection for the stated preference survey, whereas, the design year scenario was only used to test the effectiveness of the tolling algorithm for the HOT lane. As a result, the design year scenario only considered the morning peak period in the year 2016 since the traffic conditions were found to be much worse in the AM peak.

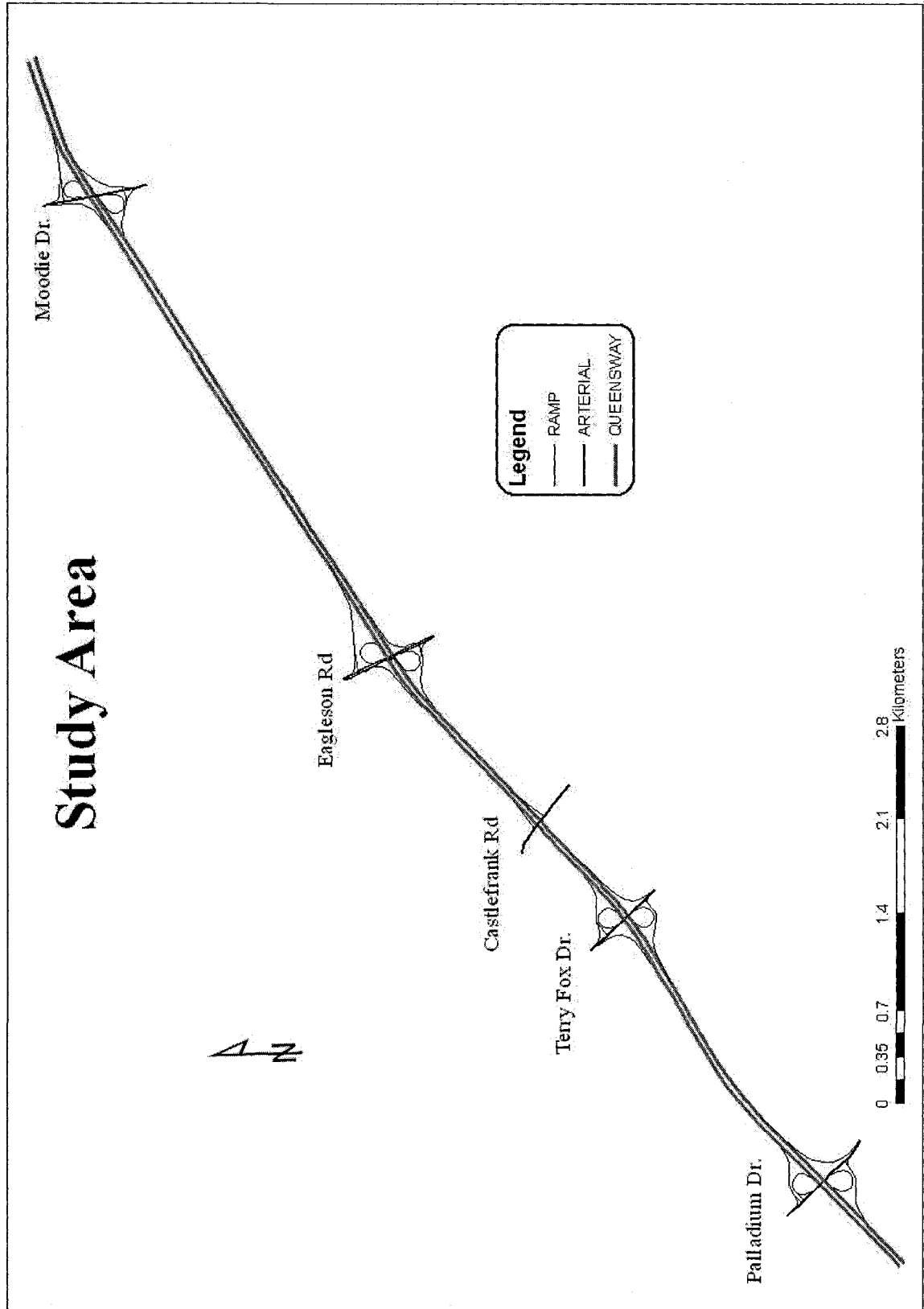


Figure 3.2 Highway 417 Study Area

3.4 Description of Tools

There are various tools that are required to successfully complete this thesis research. These include VISSIM, QueensOD and SPSS. Each serves its specific purpose and has its own set of strengths and weaknesses. The following discussion will introduce each of the tools required to complete this study and briefly describe their purpose in terms of the current research.

3.4.1 VISSIM

“VISSIM is a microscopic, time step and behaviour based simulation model developed to model urban traffic and public transit operations” (PTV, 2007). The model was originally developed in Germany; however it is popular in North America in addition to Europe. VISSIM is capable of analyzing transit and traffic operations under a variety of different constraints and configurations.

The traffic flow model in VISSIM is based on research by Weidemann and is a “discrete, stochastic, time step based, microscopic model with driver-vehicle-units as single entities. The model contains a psycho-physical car following model for longitudinal movement and a rule based algorithm for lateral movements” (PTV, 2007). The Wiedemann model is based on the presumption that a driver of a vehicle can be in only one of four possible driving modes, at a time. The driving modes are: free driving, approaching, following and braking. “For each mode, the acceleration is described as a result of speed, speed difference, distance and the individual characteristics of driver and vehicle. The driver switches from one mode to another as soon as he reaches a certain

threshold that can be expressed as a combination of speed difference and distance.” (PTV, 2007)

VISSIM is a very versatile and customizable traffic microsimulation model, which makes it an excellent model to use for this research. The research requires many complex elements to be combined to form an accurate representation of how motorists will behave in the presence of a tolled facility more specifically: an HOT lane. VisVAP is a complementary piece of software to VISSIM and it allows for many of the complex elements to be coded into the model. The COM interface is a platform that can use an external programming language to control certain elements of the simulation process within VISSIM. VisVAP and the COM interface both add to the versatility of VISSIM as a traffic microsimulator; however neither was used in this study.

3.4.2 QueensOD

“QueensOD ... is a model for estimating origin-destination traffic demands based on observed link traffic flows, observed link turning movement counts, link travel times and, potentially, additional information drivers’ route choices.” (Van Aerde & Associates, 2007) QueensOD was created as an origin-destination estimation model for the microsimulation software “Integration,” however QueensOD can be used as a stand alone piece of software.

Unlike other traffic simulation software packages, VISSIM does not have any means of developing synthetic origin-destination data from link flows. As a result, external software had to be utilized. QueensOD was used for just this purpose. The input files for QueensOD are in the same form of Integration files. Using Geographic Information

System's (GIS) mapping and analysis tools as well as manual input the QueensOD files were coded.

3.4.3 SPSS

SPSS is a statistical analysis and data management software package. Using SPSS one can perform complex statistical computations including analysis such as logit modelling (SPSS Help Menu, 2007). SPSS provides an easy to use graphical environment which facilitates quick completion of tasks.

SPSS will be used in this study to complete a single task: develop a binary logit model from the SP survey data. There are many advanced modelling and regression modelling options in the SPSS environment. A binary logit model is required and there are multiple ways that SPSS can compute such a model. Using the advanced regression models: "logistic regression" or "multinomial logistic regression" a binary logistic regression model can be developed to help predict drivers' decision making, based on data collected from the SP survey.

3.5 Summary

This study is focused on creating a dynamic, feedback based tolling algorithm for an HOT lane that is self-calibrating. There are various steps in completing such a task including initial data preparation, development of the preliminary or base year model, followed by development of the stated preference survey, after collecting data from the SP survey a logit model is developed to model driver decision making. Using the logit model combined with elements of feedback control theory, a tolling algorithm can then be created. The design year traffic simulation model gives this study a platform for

evaluating the strengths and weaknesses of the tolling algorithm. The entire process will be done in three environments: the VISSIM environment, an online environment and in the SPSS environment. VISSIM is a traffic microsimulator that allows the operations of various transportation facilities to be evaluated. SPSS is a statistical analysis and data management software package that is helpful in developing various models and algorithms.

The case study area for this research is Highway 417 (The Queensway) in the west end of the City of Ottawa. The stretch of the Queensway from Palladium Dr in the west to Moodie Dr in the east will be analyzed. In the study there are five interchanges and the design year will be 2016. Two traffic models will be developed: the base year model and the design year model. The base year model will simulate conditions on the Queensway as of early summer in the year 2000, this model will help gather preliminary data and calibrate the design year model. The design year model will simulate forecast conditions in the year 2016 and will be used to test and validate the tolling algorithm.

Chapter 4

Data Preparation and Model Coding

4.1 Introduction

VISSIM is a “microscopic, time step and behavior based simulation model developed to model urban traffic and public transit operations” (PTV 2007). This simulator can analyze traffic and transit operations under a variety of constraints and conditions, making it an effective tool for planning and operational analysis of traffic and transit. VISSIM, like any other traffic microsimulation model, requires a large amount of data including highway geometry, traffic volume, vehicle compositions and traffic controls. Other data such as routes and scheduling are required to analyze transit operations. This type of data can be collected from a variety of sources including: provincial and municipal governments, various consultants’ studies, transit operators as well as a variety of scientific publications.

Microsimulation models differ greatly in how collected data is coded into the software. Many traffic simulators utilize various text files that contain link, volume and traffic data. Other traffic models, such as VISSIM, utilize a graphical user interface to input some of the data. This chapter will discuss the data collected for this study as well as how it was coded to create a working model used for research applications.

4.2 Data Preparation

Data was collected from different sources and agencies. The primary sources of information used in this study were obtained from: the Ministry of Transportation of

Ontario (MTO), the City of Ottawa and the National Capital Commission (NCC). The following section describes the data that was obtained and used for this study.

4.2.1 Highway Geometric Data

Highway geometry data is used to code the highway links, interchanges, intersections and various other features of the network. The data was obtained from the MTO's "Highway 417 Preliminary Design Report: From Highway 7 to Highway 416" (MTO 2003). The data obtained from the MTO applied to the area between Highway 416 and Highway 7, some of this data did not apply to this study since the study area for this project stretches from the Moodie Drive interchange to the Palladium Drive interchange. The most prominent geometric features of the study are: five horizontal curves for both the east-bound lanes and the west-bound lanes, fourteen vertical curves in both the east-bound and west-bound directions and four 3.66 meter wide divided lanes (two in each direction). There are four interchanges that will play a role in the study including those at: Palladium Dr., Terry Fox Dr., Eagleson Rd. and Moodie Rd. All of the interchanges have partial cloverleaf configurations with one exit ramp, one inner loop on-ramp and one direct on-ramp. The only exception is the Palladium Dr. interchange which is missing the direct on-ramp in the west-bound direction. All of the horizontal and vertical curves are described in Appendix A.

In addition to the geometric data obtained from the MTO a detailed aerial photograph (digital orthophoto) of the study area was obtained from the City of Ottawa (2005). Such aerial photographs are very useful in coding transportation networks, since VISSIM has

the capability to import background photos as well as GIS and CAD files. Using the background, the network can then be traced into the simulator.

4.2.2 Balanced Volume Data

Volume data is important for determining the number of vehicles entering and exiting the network as well as how many vehicles turn at various intersections and interchanges. Balanced volume data is also used in the calibration and validation process (see Chapter 5) where simulated volumes are compared to the field collected volume. For these purposes, the balanced volumes for the AM and PM peak periods in the year 2000 were used. This data was obtained from the MTO and was the result of a study conducted by a local consultant. The AM and PM peak period data for the year 2016 was also obtained and was used for the modeling of the HOT lane; this will be discussed in greater detail later in this report. The balanced peak hour volumes were used because they provide detailed entry/exit volumes for each of the ramps and mainline sections. The volume data is said to be adjusted for seasonal variations, however, a study conducted by Fukutomi (2004) showed that these volumes were in fact most similar to those experienced in early summer of 2000. The balanced volumes for the year 2000 are provided in Table 4.1.

While the year 2000 data was used for the calibration and validation it was not used for the majority of the study. When modeling the HOT lane the year 2016 data had to be used. The 2016 balanced volumes are based on a forecast conducted by consultants: McCormick Rankin Corporation for the MTO. The balanced volumes for the year 2016 are provided in Table 4.2.

Table 4.1 Balanced Volumes for the Study Area of Highway 417 from the Year 2000

Link	AM Peak Hour Volume EB	AM Peak Hour Volume WB	PM Peak Hour Volume EB	PM Peak Hour Volume WB
Mainline				
West End	2720	940	1430	2380
Palladium to Terry Fox	2670	990	1410	2440
Terry Fox to Eagleson	3260	1410	1960	2860
Eagleson to Moodie	3840	3570	3490	3810
East End	4080	5260	4990	4520
Ramps				
Palladium OFF	120	80	80	140
Palladium ON I	20	30	20	80
Palladium ON D	50	n/a	40	n/a
Terry Fox OFF	210	570	180	840
Terry Fox ON I	200	70	240	170
Terry Fox ON D	600	80	490	250
Eagleson OFF	710	2260	180	1350
Eagleson ON I	740	20	1080	60
Eagleson ON D	550	80	630	340
Moodie OFF	310	1850	190	1190
Moodie ON I	220	80	1280	190
Moodie ON D	330	70	410	270

* Where: D refers to a direct ramp and I refers to an inner loop ramp

Table 4.2 Balanced Volumes for the Study Area of Highway 417 from the Year 2016

Link	AM Peak Hour Volume EB	AM Peak Hour Volume WB	PM Peak Hour Volume EB	PM Peak Hour Volume WB
Mainline				
West End	4130	1740	2770	4120
Palladium to Terry Fox	4740	3160	4160	5020
Terry Fox to Castlefrank	6010	4570	5370	6160
Castlefrank to Eagleson	6910	5180	6220	7170
Eagleson to Moodie	8930	9210	8920	9250
East End	8560	11410	10600	9480
Ramps				
Palladium OFF	300	1530	310	1370
Palladium ON I	400	110	1090	470
Palladium ON D	520	n/a	610	n/a
Terry Fox OFF	490	1860	740	2040
Terry Fox ON I	630	160	880	280
Terry Fox ON D	1230	290	1070	620
Castlefrank OFF	n/a	610	n/a	1010
Castlefrank ON	900	n/a	850	n/a
Eagleson OFF	1010	4390	670	3140
Eagleson ON I	1830	180	2490	150
Eagleson ON D	1200	180	880	910
Moodie OFF	1070	2760	630	1380
Moodie ON I	290	340	1710	510
Moodie ON D	410	210	600	620

4.2.3 Vehicle Compositions

Vehicle composition information is used to determine the types of vehicles that enter the network, and their proportions. Vehicle compositions are used throughout the simulation process, from calibration to the final product; so they are very important. Vehicle occupancy counts are also important, not as much for the calibration and validation process but for the HOT lane modelling. Vehicle compositions and occupancy counts for Highway 417 were available from the City of Ottawa in the form of a screenline count at Eagleson Road. The following table lists the most important information from the City of Ottawa regarding vehicle compositions and occupancy counts.

Table 4.3 Highway 417 Vehicle Compositions and Occupancy Counts from Eagleson Screenline (2000)

Vehicle Type	Eastbound				Westbound			
	AM Peak Hour		PM Peak Hour		AM Peak Hour		PM Peak Hour	
	No.	%	No.	%	No.	%	No.	%
Cars/Light Trucks/Taxis	3710	95.1	3300	94.3	3400	94.4	3750	95.0
<i>1 person</i>	3250	87.6	2620	79.4	2860	84.1	2850	76.0
<i>2 person</i>	430	11.6	630	19.1	480	14.1	800	21.3
<i>3+ person</i>	30	0.8	50	1.5	60	1.8	100	2.7
Trucks/Buses/Bikes/Other	190	4.9	200	5.7	200	5.6	200	5.0
Total	3900		3500		3600		3950	

To utilize the data presented in Table 4.3, a few assumptions had to be made:

1. The vehicle compositions and occupancy counts observed on the Eagleson screenline will be the same as those at every entry point to the network;
2. Transit vehicles travel on separate routes (transitway) and therefore do not interact with regular traffic;
3. Vehicles referred to as cars, taxis and light trucks will be categorized as passenger vehicles;

4. Vehicles referred to as trucks and other will be categorized as heavy trucks; and
5. Passenger vehicles with two or more passengers will be categorized as high occupancy vehicles.

Unlike many other traffic microsimulation models, VISSIM has few limitations on the number of different vehicle types that can be defined in a model. However, for simplicity of the model, only passenger vehicles, heavy trucks, and high occupancy vehicles were assumed to be traveling on Highway 417 through the study area.

4.3 Model Coding

Once the data was collected and checked for accuracy, the network was coded in VISSIM. The following section describes how the network was coded including highway link coding, coding of vehicle input OD tables as well as some of the problems encountered in the network coding phase and how they were overcome. A sample of a VISSIM input file can be found in Appendix B.

4.3.1 Highway Link Coding

Using the data provided by the MTO, pertaining to the geometry of the highway, and the digital aerial photographs provided by the City of Ottawa, the links were coded into VISSIM. As noted earlier VISSIM is a microsimulation package that allows for the import of digital images, CAD drawing or GIS shapefiles to use as a background. With the background in place the links were traced into the software. Unfortunately VISSIM does not allow for accurate coding of vertical curves, so the curves were modeled as changing grades. During the link coding data such as number of lanes and lane width was input along with the grade of each section.

The entire interchanges were not coded into the model since the interest in this study pertains to the drivers' behaviour on the mainline links with presence of an HOT facility and not in the drivers' behaviour on the interchanges. The desired speed on the mainline links was set to approximately 120 km/h; however this speed is much too high for entry/exit ramps. Using reduced speed areas, the speed on the ramps was adjusted. The inner loops on ramps were set to 60 km/h and the direct on-ramps were set to 80 km/h. The speed on the off-ramps remained the same as those on the mainline links because it was assumed that the drivers will only slow down when they are significantly close to any traffic control devices such as traffic lights downstream of the highway.

4.3.2 Vehicle Inputs

Some microsimulators have a built in means of computing origin-destination matrices. Unfortunately VISSIM is not one of these, so another piece of software had to be used. QueensOD is a model for estimating origin destination traffic demands based on observed link traffic volumes, intersection turning movements, link travel times and other information (Van Aerde, 2007). The QueensOD software requires three input files: the node descriptor, the link descriptor and the observed link traffic flow file. Both the node and link descriptor files were coded with the assistance of GIS software. The GIS was used to determine x y coordinates of the nodes and lengths of the links. Other data such as: node type, observed link flows, link capacity, free flow travel time on the link, travel time when loaded with observed traffic and saturation flow rate were input manually into their appropriate files. Once the finished input files were fed through QueensOD they had to be modified slightly so that their format met that expected by VISSIM.

The proportions of vehicles were coded into VISSIM by inputting values to the traffic compositions section of the software. Here all of the different vehicle proportions are adjusted, as well as the desired speed distributions are assigned. The desired speed is input as a predetermined speed distribution, however if one is so inclined the desired speed distributions can be customized. Passenger cars and HOVs were assigned desired speed distributions with maximum and minimum of 205 km/h and 80 km/h respectively and heavy trucks were assigned a desired speed distribution with maximum and minimum of 120 km/h and 85 km/h respectively. The proportions of each vehicle type were coded according to Table 4.3, above.

4.3.3 Troubleshooting

There were many elements in the model that required an iterative process to code. Most of these elements are discussed in the following chapter. However, a major obstacle in the coding of the network was how to get vehicles to merge onto the highway properly. After the initial runs it was noticed that traffic was becoming extremely congested at on ramp merge lanes with high volumes. Initially the solution was to use VISSIM's built-in "routing decision" functions. This did not give satisfactory results. After much research and discussion with experts, it was decided that the "priority rules" function would be used. The default priority rules did not result in satisfactory conditions, so they were slightly modified. The priority rule was set as to stop vehicles on the right lane of the mainline sections when a vehicle reaching the end of the merging lane was traveling at a speed under 10 km/h. This resulted in vehicles along the mainline stopping close to the end of the merging lane and allowing merging vehicles to enter the mainline. This may

not be the optimum solution however it did result in realistic merging behaviour and allowed for successful calibration (see Chapter 5).

4.4 Summary

Various types of data had to be collected in preparation for coding of the network. This data included: highway geometry, balanced traffic volumes, traffic compositions and vehicle occupancy counts. Highway geometric data, balanced traffic volumes, traffic compositions and vehicle occupancy counts were obtained from a document prepared for the MTO. To successfully code the network, a digital orthophoto was obtained from the City of Ottawa, using this aerial photograph all of the links were coded into the model. Characteristics of the traffic stream were also input to the model where appropriate. VISSIM has no built-in means of converting vehicle flows to origin-destination matrices, so QueensOD was used. QueensOD is a piece of software that, given various inputs, will output origin-destination matrices. Finally the merging lanes were coded using VISSIM's priority rules which made for realistic driving and merging behaviour.

Chapter 5:

Model Calibration

5.1 Introduction

The use of microsimulation models is becoming more and more important in the field of traffic engineering and is widely used for traffic impact studies. Since their humble beginnings, traffic microsimulators have grown into very user-friendly, customizable and ubiquitous pieces of software. To adequately harness the power of the microsimulator the model must be calibrated. Traffic model calibration can be defined as “the process by which the individual components of the simulation model are adjusted or tuned so that the model will accurately represent field measured or observed traffic conditions” (Milam et al. 2001). There is a multitude of model parameters that could be potentially adjusted in the calibration process. Generally, only a few parameters are selected and optimized so as to minimize the differential between modelled conditions and field measurements.

Following the calibration process, the model is carried to the validation process which is defined as the process where “... the accuracy of the model is tested by comparing traffic flow data generated by the model with that collected in the field” (Milam et al. 2001). During the validation step, a set of data that was not used in the calibration step is input to the microsimulator and modelled. Then, the difference in variables collected by the model is compared to field measurements. This chapter will discuss the methodology and tools used for the calibration and validation of the microsimulation model in VISSIM. Following that, the calibration process used for this study will be presented and discussed. Finally, the validation process will be discussed and the methodology used to validate the model will be illustrated.

5.2 Calibration Data

There were two sets of data used for the calibration process: balanced volume data and travel time data. The balanced volume data was obtained from the MTO in the form of the “Highway 417 Preliminary Design Report: From Highway 7 to Highway 416.” The travel time data was also obtained from the MTO through another report (Fukutomi, 2004). Unfortunately, the volume data corresponds to the year 2000 while the travel time data corresponds to the year 2001. The reason that both sets of data were accepted in the calibration process is that no set of data with both travel time and volume for the same year was available.

The volume data consists of balanced traffic volumes for the entire section of Highway 417 between Highway 7 and Highway 416, as well as volume data for the surrounding arterials and intersections. A detailed explanation of the volume data is available in the previous chapter so little detail will be given here. Instead the focus will be on the travel time data which has yet to be discussed.

As mentioned previously, the travel time data was provided by the MTO, and the only travel times available were for the year 2001 as opposed to 2000. Also, the AM peak period travel times were only available in the east bound direction and PM peak period travel times were only available for the west bound direction. The measurements were taken on weekdays during peak periods from the 11th to the 25th of June, 2001. The travel times were measured by means of a floating car survey conducted by a consultant. The travel times were recorded for five sections along the study area, only four of the sections provided by the MTO were required for this study.

Some runs were reported to yield unrealistic results, so those runs were excluded from the study. The average travel times were calculated based on 21 runs for the AM peak period and 14 runs for the PM peak period. The main possible reason for the errors encountered was due to reading or recording errors. The MTO data was accepted for two reasons: (1) the same data was used for calibration in another study (Fukutomi, 2004), and (2) the data was closely examined and found to be reasonable. The travel times and section distances reported by the MTO are given in Table 5.1.

Table 5.1 Travel times and section distances provided by the MTO

(a) AM Peak Period (EB)

Section	Distance (m)	Travel Time (s)
Palladium to Terry Fox	2450	90.7
Terry Fox to Eagleson	2630	191.7
Egleson to CNR	2670	183.7
CNR to Moodie	1350	56.9

(b) PM peak Period (WB)

Section	Distance (m)	Travel Time (s)
Moodie to CNR	1350	97.6
CNR to Eagleson	2670	111.3
Egleson to Terry Fox	2630	104.0
Terry Fox to Palladium	2450	89.5

There was another issue with the travel time data. It was noticed that the distances for the sections analyzed by the MTO were slightly different from those reproduced by VISSIM. However, since the error between sections was less than ten percent, in all cases, the values were accepted and used. A summary of the various section distances and the percent error values are given in Table 5.2.

Table 5.2 Comparison of section distances provided by the MTO with those computed in VISSIM

AM Peak Period (EB)			
Section	MTO Distance (m)	VISSIM Distance (m)	% Error
Palladium to Terry Fox	2450	2674.8	9.18%
Terry Fox to Eagleson	2630	2738.6	4.13%
Egleson to CNR	2670	2898.4	8.55%
CNR to Moodie	1350	1410.0	4.44%

PM peak Period (WB)			
Section	MTO Distance (m)	VISSIM Distance (m)	% Error
Moodie to CNR	1350	1461.5	8.26%
CNR to Ealeson	2670	2822.6	5.72%
Egleson to Terry Fox	2630	2846.8	8.24%
Terry Fox to Palladium	2450	2642.2	7.84%

5.3 Required Number of Simulation Runs

The traffic flow model in VISSIM is a discrete, stochastic, time step based microscopic model (PTV, 2007) that utilizes a random number seed to determine a variety of different aspects of the simulation. The specific random number seed affects the timing of the vehicle release, destination and route of each vehicle and the vehicle attributes among other things. Since the different random number seeds will yield different results; the simulation must be run multiple times until a satisfactory mean value of the specific measured variable is determined. The required number of runs to achieve a satisfactory mean value for a variable can be computed using Equation 5.1 (Fukutomi, 2004).

$$N = \left(t_{\frac{\alpha}{2}, n-1} \frac{s}{err} \right)^2$$

Equation 5.1

Where:

- N is the number of required simulation runs;
- $t_{\frac{\alpha}{2}, n-1}$ is the t-statistic value corresponding to $\alpha / 2$ and $n - 1$;

- α is the value whereby $100(1 - \alpha)\%$ corresponds to the confidence interval;
- n is the number of preliminary runs;
- s is the standard deviation of the preliminary runs; and
- err is the acceptable error for the simulation output.

Preliminary runs were made to obtain values of mean and standard deviation for specific simulation output variables. Then Equation 5.1 was applied, and the required number of runs was rounded up to the nearest five runs, so as to remain on the safe side. Following that, more simulations were run and checked with the equation again. The process was repeated until convergence was reached.

During the calibration process in this study, the variables in equation 5.1 were set as follows:

- α was set to a value of 5% (which corresponds to a confidence interval of 95%);
and
- err was set to 5% of the mean value for the preliminary runs, except where:
 - The mean volume was greater than 1000 vehicles/h, in this case the err variable was set to 50 vehicles/h; and
 - The mean travel time was greater than 200 seconds, in this case the err variable was set to 10 seconds.

5.4 Calibration Targets

Calibration of a microsimulation model is often a time consuming task, hence target values should be determined so as to recognize when the model is sufficiently calibrated.

According to Dowling et al. (2002) "...there is a limit to the amount of time and effort anyone can put into eliminating error in the [microsimulation] model." There comes a point in the process where great effort yields minimal returns in accuracy and precision improvement. To determine stopping criteria for the calibration in this study: the calibration criteria developed by the Wisconsin Department of Transportation were used, see Table 5.3. These criteria were based upon guidelines developed in the United Kingdom (Dowling et al. 2002).

Table 5.3 Slightly Modified Freeway Model Calibration Criteria from Wisconsin DOT

Criteria and Measures	Acceptability Targets
Hourly Flows, Model vs. Observed	
Individual Link Flows	
<i>Within 15%, for 700 veh/h < Flow < 2700 veh/h</i>	<i>> 85% of Cases</i>
<i>Within 100 veh/h, for Flow < 700 veh/h</i>	<i>> 85% of Cases</i>
<i>Within 400 veh/h, for Flow > 2700 veh/h</i>	<i>> 85% of Cases</i>
Total Link Flows	
<i>Within 10%</i>	<i>All Accepting Links</i>
GEH Statistic – Individual Link Flows	
<i>GEH < 5</i>	<i>> 85% of Cases</i>
GEH Statistic – Total Link Flows	
<i>GEH < 4</i>	<i>All Accepting Links</i>
Travel Times, Model vs. Observed	
Journey Times Network	
<i>Within 15% (or one minute)</i>	<i>> 85% of Cases</i>

The GEH statistic, referenced in Table 5.3, is computed by using Equation 5.2, as follows:

$$GEH = \sqrt{\frac{(V - C)^2}{(V - C)/2}}$$
Equation 5.2

Where:

- GEH is the GEH statistic;
- V is the model estimated directional hourly volume at a specific location; and
- C is the directional hourly count at the specific location.

5.5 Goodness of Fit

To determine which of the VISSIM parameters results in the optimum conditions, that is to say, the conditions where the simulation output most closely matches the field measurements, some goodness of fit measure must be used. There are many goodness-of-fit measures including: root mean square error (RMSE), mean square error (MSE), mean error (ME), root mean square percent error (RMSPE) and mean percent error (MPE) (Dowling et al. 2002 and Toledo et al. 2004). MSE, RMSE and RMSPE indicate the overall fit of the model while ME and MPE indicate the existence of systematic over or under prediction in the simulated results (Toledo et al. 2004). The measure chosen for the calibration process in this study was: the root mean squared error (RMSE), and was computed by using Equation 5.3, as follows:

$$RMSE = \sqrt{\frac{1}{R} \sum_r (M_{lpr} - F_l)^2}$$
Equation 5.3

Where:

- RMSE is the root mean square error term;

- $M_{ltp,r}$ is the model estimate of flow rate at location “l” at time “t” using parameter “p” for repetition “r”;
- F_l is the field measurement of flow rate at location “l”; and
- R is the number of repetitive model simulation runs with fixed parameter values and differing random number seeds.

Many researchers utilize RMSPE and MPE in the calibration of their models in order to avoid the unintended weighting effects when combining different measures of performance. The effect of RMSPE and MPE is to place greater importance on larger percent errors rather than on larger numerical errors (Dowling et al. 2002). In the calibration process of this study, it was more desirable to place greater weight on large numerical discrepancies between measured and simulated values. Even though two measures of performance were used in this study (volume and travel time), the RMSE was still considered to be the optimum goodness-of-fit measure for the calibration process.

5.6 Search Algorithm for Calibration

Traffic microsimulation models are generally complex and it is not usually possible to utilize traditional calculus techniques to formulate an equation to find the optimum solution. Therefore, it is necessary to use a search algorithm that involves multiple runs of the simulation model, plotting output results as points, and finally searching between these points. The problem in calibration is non-linear and a least-squares optimization problem, since the simulation results are non-linear and squared error is minimized (Dowling et al. 2002). There are many search algorithms available to researchers

including: Newton's method, secant method, quadratic approximation method and the golden section method. For this study, the golden section method was chosen because it is recommended by researchers (Dowling et al. 2002) and it was used in a similar calibration process yielding good results (Fukutomi, 2004). What follows is a brief description of the golden section method slightly modified from Hillier et al. 1995.

Step 1

The maximum and minimum acceptable values for the parameters to be optimized are chosen. The larger the chosen range, the longer it will take to find optimum values, however, the smaller the range the more likely that the actual solution lies outside of the range.

Step 2

The square error is computed for the maximum and minimum values chosen in step 1. These values are plotted.

Step 3

The two interior parameter values are identified. This step is where the "golden section" method gets its name, because the golden ratio is used to narrow the search boundaries. Utilizing the ratio 0.382 reduces the search interval at an optimal rate (Press et al 1988). Using the golden ratio (0.382) is the most efficient way to narrow the search boundaries. The two interior points are determined by using Equations 5.4 and 5.5 (Dowling et al. 2002).

$$x_1 = \min + 0.382 \cdot (\max - \min) \quad \text{Equation 5.4}$$

$$x_2 = \max - 0.382 \cdot (\max - \min) \quad \text{Equation 5.5}$$

Where:

- x_1 is the lower interior point value for the mean delay to be tested;
- x_2 is the upper interior point value for the mean delay to be tested;
- min is the lower end of the search range from the previous iteration; and
- max is the upper end of the search range from the previous iteration.

Step 4

The squared error is computed for the two interior parameter values (x_1 and x_2). These values are also plotted along with those determined in Step 2.

Step 5

The three parameter values that appear to bracket the optimum solution are identified. The interior parameter that produces the lowest squared error is identified (x_1 or x_2). Then the parameter values immediately to the left and right of the chosen value are taken as the new min and max values. This step is used to narrow the search range.

Step 6

Repeat Steps 3 through 5 until the uncertainty in the location of the optimal value is at a satisfactory level.

5.7 Review of Animation Outputs

A review of the animation output by a traffic microsimulation model allows the researcher to physically see the vehicle behaviour that is being modelled. This is an important stage in the calibration process because it can be determined whether the vehicles are moving through the network in a realistic fashion. Also, locations of bottlenecks and other problem areas can be identified. VISSIM, unlike other traffic microsimulators, allows the user to review the animation while the simulation is running.

Provided in VISSIM is the option to colour code the vehicles according to their speed at each specific time step throughout the simulation. This feature is useful in locating problem areas and ensuring bottlenecks occur where they do in the field. Realistic driver behaviour should also be checked at areas such as merging lanes and steep up-grades. A screen shot of a VISSIM animation is provided in Figure 5.1, below.

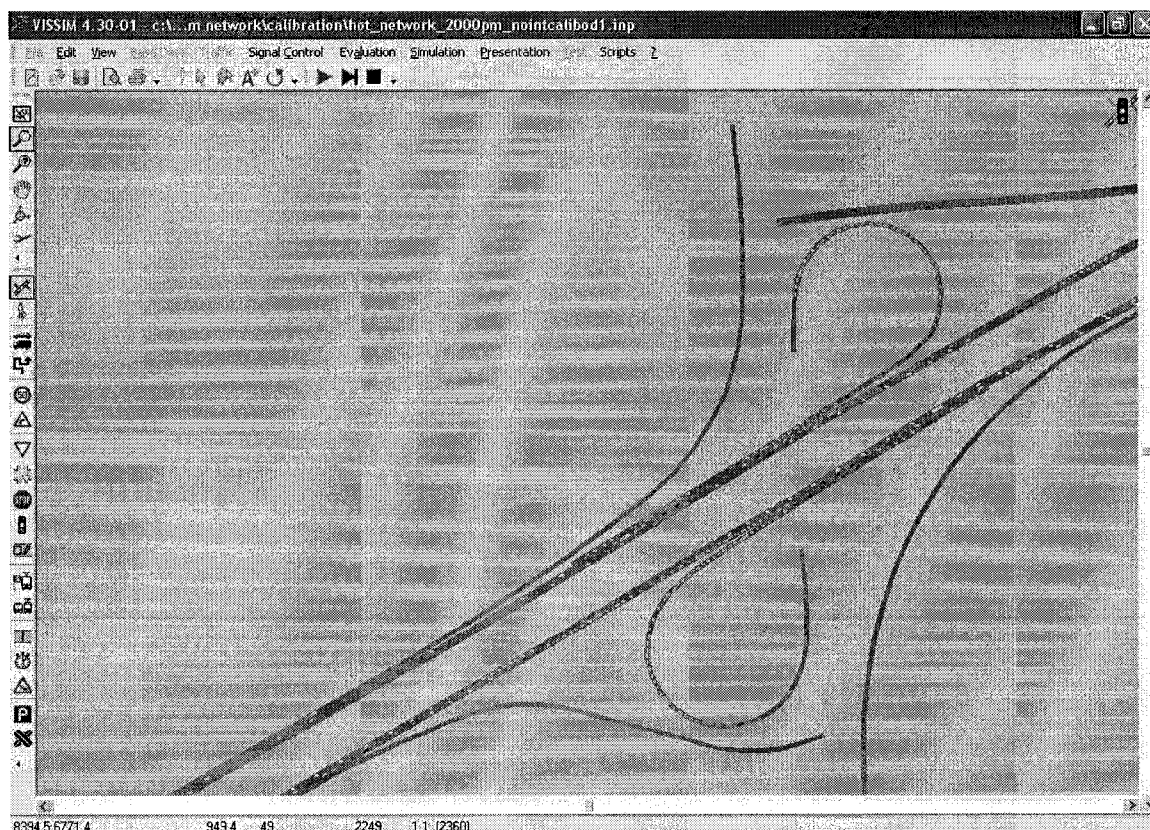


Figure 5.1 Screen shot of VISSIM simulation run

5.8 VISSIM Calibration

The calibration process used in any traffic microsimulator can potentially involve hundreds of model parameters whose effects will be highly correlated with those of the other parameters. This problem can lead the analyst to "...get trapped in a never ending circular process fixing one problem only to find a new one pops up somewhere else" (Dowling et al. 2002). Therefore, it is important to decide which parameters the analyst is

comfortable with changing and which ones he or she is not comfortable with changing. Once the parameters to be calibrated are selected, the calibration process can proceed. The following sections will describe the process followed to calibrate the traffic microsimulation for this study.

5.8.1 Calibration Parameters and Car Following Logic

The traffic flow model in VISSIM is a "...discrete, stochastic, time step based, microscopic model with driver-vehicle-units as single entities" (PTV 2007). The car following model is based on the continued work of Weidemann (Wiedemann 1974 and Wiedemann 1991). The basic principle of the Wiedemann model is based on the assumption that a driver can be in one of the following four modes at a given time (PTV 2007):

- **Free Driving:** In this mode the driver is seeking to reach and maintain his or her desired speed;
- **Approaching:** In this mode the driver is applying a deceleration so that the speed of his or her vehicle matches that of the slower preceding vehicle, while keeping in mind the desired safety distance;
- **Following:** In this mode the driver is following the preceding vehicle without any significant acceleration or deceleration; and,
- **Braking:** In this mode the driver applies a significant deceleration when the safety distance between his or her vehicle and the preceding vehicle is encroached upon.

VISSIM offers two of Wiedemann's car following logic models to choose from: his 74 model and his 99 model. The Wiedemann 74 model is said to be satisfactory for arterials, collectors and local streets while the Wiedemann 99 model is best suited for freeways (PTV 2007). Therefore, the Wiedemann 99 car following logic model was the only model used for this study.

There are ten parameters associated with the Wiedemann 99 car following model: CC0 to CC9. The main factors to influence freeway capacity and therefore the simulation results are CC0 and CC1 (Fukutomi 2004). The following is a brief description of the two parameters CC0 and CC1, for an explanation of the remainder of the parameters please see the VISSIM 4.30 User's Guide (PTV, 2007).

- **CC0**: is the standstill distance (in meters) which defines the desired distance between stopped cars, it has no variation (PTV 2007); and
- **CC1**: is the headway time (in seconds), the higher the value the more cautious a driver is (PTV 2007).

When the two variables are combined they form the basis for the safe following distance. The safe following distance can be computed by using Equation 5.6, below.

$$dx_safe = CC0 + CC1 * v \quad \text{Equation 5.6}$$

Where:

- dx_safe is the desired safe following distance;
- CC0 and CC1 are the standstill distance and the headway time respectively; and
- v is the speed of the vehicle.

5.8.2 Calibration of VISSIM Model

The model used for this study was calibrated according to principles and guidelines outlined in this chapter. The process involved conducting initial simulation runs and making adjustments then calibrating the CC0 and CC1 variables using the golden section method. The process used in calibration of the simulation for this study is described below.

Using the coded network and the default parameters, initial runs were completed to analyze the basic driving behaviour. The first problem that came to the attention of the author was that vehicles would bottleneck upstream of certain off-ramps. There is a variable that corresponds to connector links in the VISSIM model; this variable specifies the upstream point on a link where a vehicle approaching an intersection or exit ramp has to begin making lane change manoeuvres in order to be in the proper lane. The default value of the lane change distance in VISSIM is 200 meters, and some researchers feel that this value is too low and should be raised (Gomes et al. 2004). The lane change distance was therefore changed to values ranging from 500 to 1000 meters, depending on the severity of the blockage upstream of exit ramps. The second issue that was raised was that of vehicles entering the freeway from the direct and inner loop on-ramps. Vehicles would reach the end of a merging lane then stop because they could not find an appropriate gap into which to merge. To mitigate this problem priority rules were used at the ends of on-ramp merging lanes to force vehicles on the mainline to yield to merging vehicles when their speeds were below a specified level. To complement the use of the priority rules in the model, the lane change parameters of the driving behaviour were also modified. The parameters that were modified included maximum deceleration, accepted

deceleration, safety distance reduction factor and maximum deceleration for cooperative braking. The result of these modifications was that vehicles were more aggressive in their lane change behaviour. After reviewing the animations once again, it was decided that the vehicles were behaving in a realistic manner, especially at the on and off-ramps.

The range (min and max) chosen for the golden section approach to calibration of the CC1 variable was 0.50 and 3.00. For the initial run the value of CC0 was left at 1.50. Applying the golden section method yielded the distribution found in Figure 5.2. It was found that CC1 values of 1.32 and 1.46 yielded satisfactory results for travel time and CC1 values of 0.50, 0.87 and 1.09 yielded satisfactory results for volume. Hence, there was no overlapping range of acceptable results for the initial conditions input into the model. The value of 1.32 for the variable CC1 was determined to be the optimum in a study conducted by Fukutomi (2004), so it was used to check if various CC0 values would yield better results. Checking both CC0 equal to 1.00 and 2.00 was fruitless; the values of RMSE and percent error as well as GEH were all higher than that of the initial run with CC0 set to 1.50, when it came to volume. For the travel time error, the difference in the runs with CC0 equal to 1.50 and the other two runs was found to be minimal. So, CC0 was again set to 1.50, and the animation was closely examined. At this point the author came to the conclusion that simply adjusting the driver behaviour parameters, CC0 and CC1, would not suffice. To meet the calibration targets for volume the CC1 variable would have to be increased, which would result in higher capacity which in turn would increase the volume. While, to meet the calibration targets for travel time the CC1 parameter would have to be lowered, since a reduction in capacity would yield better results. It was determined that, due to the lane change variables being

modified after the initial runs, the vehicles were driving more aggressively than they should be. Thus, the lane change parameters were changed back to their defaults and the simulations were run again. Using the lane change defaults yielded better results. The RMSE for travel time as well as for volume were in both cases lower than those of the initial calibration runs. However, the error values as well as the GEH values placed this set of runs just outside of the acceptable targets established in Section 5.4. So once again the simulation output had to be analyzed.

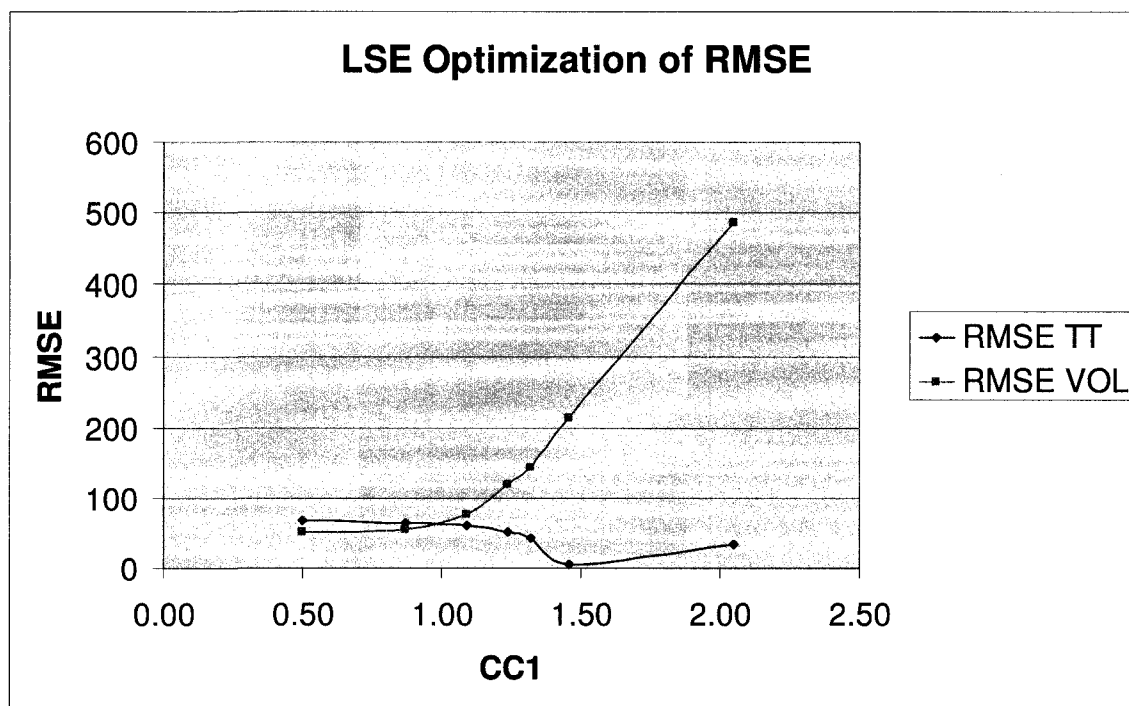


Figure 5.2 CC1 variable vs. RMSE (CC0 = 1.50)

It was noticed that for the case of exit ramps with high volumes there were unusual bottlenecks upstream. Upon closer examination it was determined that this can be attributed to large lane change distances attributed to these connector links. Reducing the lane change distance from 1000 meters to 500 meters or from 500 meters to 375 meters, was found to yield successful results. The final values of the calibration parameters CC0

and CC1 were 1.50 and 1.32 respectively. The lane change parameters in the driver behaviour section were set to their default values and the lane change distance specific to each of the connector links corresponding to exit ramps were modified to values within the range of 375 meters to 500 meters. This helped alleviate the congested conditions occurring just upstream of some of the exit ramps, and therefore helped increase the capacity of the freeway. A detailed table containing the final results of the calibration process is displayed in Appendix F.

The calibration targets were not satisfied for every case. On the Terry Fox interchange, the direct on-ramp in the east-bound direction failed to satisfy the targets. The percent error was at 22.47% and the GEH was slightly above 5.0. Also, the calibration targets were not satisfied for the Eagleson Road off-ramp in the east-bound direction, in this case the GEH value was satisfactory but the percent error was calculated at 19.53%. However, despite the two cases that failed the volume calibration targets, the calibration values were accepted because they were reasonably close to actual values, and only missed the calibration targets by 4.5 to 7.5 percent. Finally, the travel time on the section between Terry Fox Road and Eagleson Road had failed the percent error target but was accepted due to the fact that it was within one minute of the field recorded travel time. Hence, the calibration process was successful and the parameter values determined were carried over to the validation procedure.

5.8.3 Animation Check

After the calibration process was completed the animation was checked again to search for inconsistencies as well as unrealistic behaviour. Since the animation was observed

throughout the calibration process and many problems found in the animations were fixed, the focus of the animation review was on merging and diverging vehicles. It was found that the driver behaviour was realistic in both merging and diverging. Overall, the bottlenecks were occurring in logical areas, vehicles did not stop in the middle of the highway because they could not merge and speeds seemed reasonable. Therefore, the calibration process was accepted and was carried over to the validation process.

5.9 Validation

Using the same network as in the calibration procedure, the model was validated. The input data corresponding to the PM peak period was fed into VISSIM and output data was collected. It was found that the PM peak period data was overall within calibration targets of the field collected numbers. However, there were three simulated volume measurements that fell outside of the established calibration targets and the overall GEH value was rather high. Generally, this would be cause to rethink the process and search for other possible parameters to satisfy the calibration targets. However, the PM peak period data as well as the animation outputs were reviewed prior to any parameter changes. It was found that high volumes at the Moodie Road inner loop on-ramp as well as at the mainline sections up and downstream were very high. As a result there would be unavoidable errors in the validation. It was decided that disregarding the volume count along the mainline section at the east-bound east end section would be the best course of action. This was done because high errors on this particular link were unavoidable and because this link would have little influence in the future HOT simulations since it would be widened and the HOT lane itself will not reach it.

The only way to keep the original parameters determined in the calibration phase was to adjust the lane change properties. However, adjusting the lane change properties would make the drivers more aggressive and therefore result in different driving behaviour than in the calibration phase. So, to mitigate this problem the lane change parameters were only adjusted on the merging lanes so as to increase capacity at the interchanges while keeping the capacity constant on the mainline sections. This resulted in very close matches for both the travel time data and the volume data. A detailed table containing the final results of the validation process is displayed in Appendix G.

Again the animation was checked to ensure that vehicles are behaving in a realistic manner. It was noticed that there was severe congestion that continued to occur on the links between Eagleson Road and Moodie Road, while no significant congestion occurred anywhere else. The vehicles were merging onto the highway realistically; however there was congestion on the Moodie Road inner loop on ramp in the east bound direction, as discussed previously, which added to the problems of the mainline links. Since this particular problem should not significantly affect the later simulations the lane change parameters from the validation stage will be carried to the remaining stages of this study.

5.10 Summary

After the network and its attributes were coded into VISSIM the system had to be calibrated. Out of the ten parameters available in VISSIM's car following model (Wiedemann 99) it was decided that only two variables would be modified CC0 and CC1. The system was calibrated by using the golden section method, which involves constantly lowering the search range in an attempt to minimize the root mean square

error. After checking that the simulated output was acceptable according to previously established calibration targets, the system was accepted. The CC0 and CC1 values chosen were 1.50 and 1.32 respectively. However, other modifications throughout the calibration process were also required including adjustments to lane change parameters and lane change distances. The system was carried over to the validation process where the lane change parameters had to be modified slightly, to match the results obtained in the calibration phase.

Chapter 6

Modelling Transportation Decision Making

6.1 Introduction

Drivers make various decisions at every moment that they are behind the wheel of a vehicle. These decisions will affect their route, speed and in some cases safety. It is important to have some understanding of how motorists will behave in certain situations (i.e. what decisions they will make) in order to properly design certain facilities. Tolled facilities are no different; in fact the design of a tolled facility, such as an HOT lane, will rely heavily on accurately determining how drivers make choices. The number of vehicles that choose to use an HOT facility affects its performance, safety and longevity. Therefore, it is important to accurately determine how many people will choose to use the lane. To model transportation decision making, stated preference methods and discrete choice modelling are often employed. Stated preference methods are a means of polling people about how they think they would behave in a certain defined hypothetical situation. Discrete choice models take data collected using stated preference surveys and convert them to mathematical models that can output probabilities, proportion or odds of a certain event occurring.

This chapter will provide an overview of the theory behind stated preference survey methods, designs, and uses along with theory regarding the use of discrete choice models to interpret stated preference data. The methodology for creating the survey that was used for this study will also be presented. Finally, the analysis of the collected data and the final decision models will be presented and discussed in terms of adequacy and how they will be utilized in the remainder of this study.

6.2 Stated Preference Methods

To begin studying the impacts of an HOT lane on a transportation network, first it must be known how people will react to a tolled lane on the freeway, and at what prices solo travellers will switch from the general purpose lanes to the HOT lane. There are many techniques that may accomplish this including: diversion curves, usage of data from another city, and making assumptions about people's value of time. The most accurate method for choice modelling is the use of a logit model based on a stated preference (SP) survey that is administered to the people who will potentially use the facility. However, many economist and engineers are sceptical about relying on what people say they will do, as compared with observing what they will actually do. Surveys that rely on actual data are referred to as revealed preference (RP) surveys (Louviere et al. 2000). In this case actual data does not exist since the HOT lane is only hypothetical. So, for the case where the facility does not yet exist an SP survey will have to suffice.

Stated preference (or stated choice) techniques refer to a variety of approaches that are used to analyze how certain people make specific choices. All of the stated preference techniques utilize a set of statements that are realistic yet hypothetical and determine which factors most influence the decision making process. The most common set of SP techniques are referred to as "conjoint analysis" where experiments are designed in a way that different hypothetical situations are presented and respondents are asked to acknowledge how they would behave under the specified circumstances (Pearmain et al 1991).

There are a variety of different uses for a stated preference survey including: the evaluation of priorities among different policy elements and the establishment of accurate forecasts of behaviour in response to alternative scenarios (Pearmain et al 1991). In this study, the focus is on the latter of the two presented uses for stated preference techniques.

As mentioned earlier, there are many researchers that have issues with SP techniques and prefer the use of revealed preference techniques. The reason for this bias is that it is more reliable to trust what people actually do rather than what they say they will do. However, there are a variety of problems associated with revealed preference techniques including (Pearmain et al. 1991):

- Observations of actual behaviour may not vary enough for the satisfactory construction of a statistical model. There can also be correlations between variables prohibiting the analysis of the effects of different factors.
- Observed behaviour may not reflect the factors that are of interest in a particular study.
- Of course, when a policy or facility is completely new there exist no observable actual data that can be used to create statistical models or forecasts.

The advantages of stated preference surveys largely relate to the shortcomings of revealed preference surveys, in that the researcher can control choices offered and if designed properly eliminate correlations among variables. The researcher can also control the effects that will be analyzed in the statistical model or forecast model.

6.2.1 Experimental Design

When beginning the experimental design of an SP survey, consideration must be given to the scope of the choices in the scenario matrix as well as to the various other questions that will appear in the survey. The type of model to be constructed from the collected data is also an important consideration in the process. Generally there are seven steps that should be followed to result in a successful stated preference survey and an effective statistical model (Kocur et al. 1982); they are:

1. Identification of the scope of travel choices and issues to be considered.
2. Preparation of initial versions of the scenarios and drafts of the questionnaire.
3. Conducting a focus group meeting, consisting of members of the population to be polled, in order to determine factors that affect travel choices most and to suggest improvements to the draft survey.
4. Evaluation of the results of the focus group.
5. Redrafting of the questionnaire and scenarios.
6. Pre-testing the survey by administering it to a small portion of the sample population.
7. Final evaluation and final changes prior to mass distribution.

In the case of “quick-response” surveys, the procedure can be simplified by omitting Steps 2, 3 and 4. In the development of this type of survey, the experience and judgment of the analyst plays a more significant role.

In an SP survey, respondents are presented with a series of attributes and are asked to make a hypothetical choice based on the specific levels of each attribute. A factorial

design SP survey utilizes all of the levels of each of the attributes in the choice survey. Consider a choice matrix composed of 3 attributes, each attribute have 2 levels, that means there are $2 \times 2 \times 2 (= 2^3)$ or 8 possible combinations of the three attributes. For this to be a factorial design experiment, all eight combinations must be used in the choice matrix (Louviere, 2000). For example, if an analyst is trying to establish whether people will use a new train system as opposed to the existing bus system based on three levels: walking distance to station, changes to the existing fare and air conditioning; for the experiment to be fully factorial the scenario matrix must have all possible scenarios as shown in the table below.

Table 6.1 Example of Full Factorial Design of an SP Experiment

Scenario	If the walking distance to the station was:	and the fare was:	and there was:	Would you use the train?
1	less than 5 minutes	unchanged	no air conditioning	Yes <input type="checkbox"/> No <input type="checkbox"/>
2	less than 5 minutes	unchanged	air conditioning	Yes <input type="checkbox"/> No <input type="checkbox"/>
3	less than 5 minutes	\$1 higher	no air conditioning	Yes <input type="checkbox"/> No <input type="checkbox"/>
4	less than 5 minutes	\$1 higher	air conditioning	Yes <input type="checkbox"/> No <input type="checkbox"/>
5	more than 5 minutes	unchanged	no air conditioning	Yes <input type="checkbox"/> No <input type="checkbox"/>
6	more than 5 minutes	unchanged	air conditioning	Yes <input type="checkbox"/> No <input type="checkbox"/>
7	more than 5 minutes	\$1 higher	no air conditioning	Yes <input type="checkbox"/> No <input type="checkbox"/>
8	more than 5 minutes	\$1 higher	air conditioning	Yes <input type="checkbox"/> No <input type="checkbox"/>

A factorial design can only, practically, be used for small experiments, that is to say small choice matrices. Generally the most practical approach to experimental design is the use of the fractional factorial design. Fractional factorial design involves coming up with the entire set of possible combinations, then splitting them up into multiple different choice matrices. Then using each of those matrices to develop multiple different questionnaires, each possible combination of trade offs would then be covered. This method allows the use of all possible combinations of attribute levels without burdening the respondent with

an excessively long survey (Louviere, 2000). Experts have also developed tables that provide fractional factorial SP survey experimental designs that are completely orthogonal i.e. there are no correlations between any of the variables in the survey. These tables provide a survey that contains only a fraction of the full factorial scenarios (see Kocur et al. 1982). To utilize these fractional experimental designs, some assumptions must be made most importantly that some (or all) higher order interactions between the variables are negligible. If some of the lower order interaction terms are also assumed to be negligible the experiment can be further broken down into less and less required scenarios. However, these types of assumptions should only be made if the analyst is sure that the interaction terms can be ignored (i.e. assumed to be negligible). (Kocur et al. 1982)

6.3 SP Survey Design and Administration

A properly designed and administered survey will have a great affect on the reliability and accuracy of the statistical model derived from it. It is important to consider all aspects of the questionnaire including the scenario matrix, the demographic/socio-economic questions and the experimental design itself. It is also crucial to consider the type of mathematical model that is to be constructed from the collected data as that will dictate many elements of the design of the survey.

In this study, the purpose of the stated preference survey is to develop a discrete choice model that can be used, in combination with feedback control principles, for the purpose of a dynamic, feedback based and self-calibrating tolling algorithm for an HOT lane. Also, from the socio-economic data, an explanatory model can be created to study the

affects of certain demographics and various trip characteristics on the usage of an HOT facility in the Ottawa area.

In this section, the development of the stated preference survey will be discussed. The procedure for creating a usable SP survey will be presented along with a variety of considerations important to the successful completion of the survey. How the survey was tested and administered will also be discussed. Finally, the methods for collecting and cleaning the data from the survey in preparation for the statistical model will also be discussed.

6.3.1 Survey Design

The process for designing a proper stated preference survey was outlined in section 6.2.1. The procedure for this study was slightly modified to accommodate the specific nature of this survey as well as the financial constraints. Initially a draft of the survey was constructed including various socio-economic and trip questions. The initial draft was based on preliminary research on the subject, keeping in mind the scope of the study and the desired outcome. A focus group meeting was not conducted for this survey; instead research was conducted to determine which factors would be necessary to construct a discrete choice logit model. Also, an employee of the City of Ottawa Dr. Mohammad Tayyaran, whose expertise is with stated preference surveys, was contacted for assistance with the experimental design. Next, detailed data regarding travel times along the proposed corridor was necessary, so as to make the experiment as realistic as possible. Using the preliminary VISSIM traffic simulation model, this data was collected. Once the final draft of the survey was complete, a group of people from the sample population

were sent the survey so that additional feedback could be collected. After the final modifications, the survey was released to the public.

For the SP scenario matrix, it was decided that only three variables would be used. The other questions that were also considered important were separated from the scenario matrix and incorporated into the trip questions or the socio-economic questions. The three variables used for this experiment were: Toll on the HOT Lane, Travel time on the HOT Lane and Travel time on the General Purpose Lane. Each variable was assigned five different levels. The following discussion outlines how each of the levels was determined and how they were used.

For the toll variable it was decided that five levels were required and that they should be a minimum of one dollar apart, so that there was a noticeable difference between toll rates. From a study conducted in Minneapolis/St. Paul, Minnesota, it was found that the HOT lane operates with a minimum toll of \$0.25 and a maximum toll of \$8.00 (Nookala et al. 2006). The minimum toll used for this study was \$1.00, since it was assumed that the \$0.25 toll in Minneapolis was only used during off peak periods and the study pertains mostly to peak periods. The maximum toll used in the study was \$6.00. The reason that the maximum toll from the Minneapolis case was not utilized is that the region of Minneapolis/St Paul is more than three times larger (in terms of population) and therefore has far greater traffic problems than the Ottawa-Gatineau region.

Table 6.2 Various levels for the Toll variable

Level	Value
1	\$1.00
2	\$2.00
3	\$3.00
4	\$4.00
5	\$6.00

The preliminary microsimulation runs yielded data regarding the worst case scenarios for travel times along the corridor. It was found that traffic congestion was much more severe during the AM peak period in the east-bound direction. Therefore, the majority of the levels in the SP scenarios correspond to the AM east-bound simulation runs. However, since the HOT Lanes are assumed to be operational in both directions; the PM west-bound data was also incorporated into the experiment. Simulation runs were conducted, applying the year 2016 data on the year 2000 network. This yielded realistic yet extremely severe travel time data that was used to construct the “travel time on the general purpose lanes” levels. Table 6.3 presents the levels for the “travel time on the general purpose lanes” variable.

Table 6.3 Various levels for the “Travel time on the General Purpose Lanes” Variable.

Level	Value	Explanation
1	10 minutes	$u + 2s$ for PM west bound case.
2	25 minutes	$u - 2s$ for AM east bound case.
3	26 minutes	$u + s$ for AM east bound case.
4	27 minutes	u for AM east bound case.
5	29 minutes	$u + 2s$ for AM east bound case.

** Where: u is the mean and s is the standard deviation.*

The levels for the HOT lane travel time variable were determined by assuming that drivers would only opt to use the facility if there was a relatively high travel speed and therefore a high level of service. It was assumed, by the author, that the minimum speed on the HOT lane should be 70 km/h and the maximum speed was capped at 120 km/h.

The length of the HOT facility was rounded up to 10 km for the purpose of the survey, to simplify the calculations. Using the assumed travel speeds and the assumed length of the facility the travel times were determined. Table 6.4 lists the levels for the “Travel time on the HOT Lane” variable.

Table 6.4 Various levels for the “Travel time on the HOT Lane” Variable.

Level	Value	Explanation
1	5 minutes	For 120 km/h average speed.
2	6 minutes	For 100 km/h average speed.
3	7 minutes	For 85 km/h average speed.
4	8 minutes	For 75 km/h average speed.
5	9 minutes	For 70 km/h average speed. (Rounded up)

As noted earlier, there are three variables each with five levels in the stated preference scenario matrix; this results in $5 \times 5 \times 5$ (5^3) possible combinations of levels. As discussed earlier, there are two possibilities for the design of a stated preference survey: the full factorial and the fractional factorial designs. A full factorial design would entail 125 scenarios to be presented to the sample population. It would be unrealistic to expect that people would be willing to take the time to respond to each of the 125 scenarios. The other option is a fractional factorial design, which was utilized. There are two ways that a fractional factorial design can be implemented: either splitting the 125 scenarios into multiple surveys and administering each to an equal number of respondents or to make some assumptions regarding the higher order interaction terms and using a fractional factorial design that is pre-designed. It was assumed that all higher order interactions in the survey are negligible (i.e. only main effects and two way interaction terms were considered in the model); this allowed for the use of a pre-designed experiment to be used. Hahn & Shapiro (1966) provide a number of pre-designed experiments that are orthogonal (there are no correlations between the main effects and the two-factor

interaction terms in the experiment) and that significantly reduce the number of required scenarios to be presented to the potential respondents. The fractional factorial design that was used included 25 scenarios and can be found in the sample of the survey in Appendix H.

The stated preference scenarios are of course the most crucial aspect of the survey; however other data must also be collected including demographics and trip information. For the appropriate data to be collected, a proper questionnaire must be designed. There are two types of questions that may be asked in a survey: open-ended and closed-ended questions. Open-ended questions require the respondent to give their own answers, whereas closed-ended questions require the respondent to choose from a list of possible answers (Babbie, 2008). When asking respondents to report their age, for example; the open-ended approach would be to simply ask for the respondent's age. The closed-ended approach would be to give the respondent a list of age groups and ask them to select the age group that they belong to.

For a successful SP survey on willingness to pay for an HOT lane facility, many different types of data must be gathered from the sample population. The most important information is that gathered from the trade-off matrix similar to the sample matrix shown in Table 6.1. However, other information is also necessary including demographic information such as: age, sex, income bracket and aggregate location of residence. Trip data must also be collected including: purpose of last trip, length of last trip and time of the last trip. (Zmud, 2006)

6.3.2 Testing the Survey

Once the final draft of the survey was designed and coded in the online environment, it had to be tested by a small portion of the sample population. The testing of the survey was done informally and the purpose of the testing was to acquire information regarding the ease of reading and understanding the survey. The final draft was sent to thirty people and fourteen useable responses were received. The recipients of the draft survey were primarily friends and acquaintances of the author.

The information that was gathered during the testing phase of the stated preference survey was considered and many minor modifications were made to the questions. The types of suggestions that were given the highest weight were those that pertained to the wording of questions, since it was important that everyone understood what was asked in each survey question. Once the survey was brought up to a satisfactory level, it could then be administered to the entire sample population.

6.3.3 Administering the Survey

The survey was administered to the sample population using the services of “Free-Online-Surveys.com” (<http://freeonlinesurveys.com>) which is a websites that allows users to create, host and collect data from their surveys all on the company’s server. Standard types of survey questions are available to users; however, customization of questions is not possible. As a result, the stated preference scenario matrix had to be presented in a slightly different way than originally planned. The three variables were presented in the form: Toll / Travel time on HOT lane / Travel time on general purpose lane, as opposed to the originally indented format (see Table 6.1). As a result of the modified format, more

explanation was required for the respondents to understand what was being asked of them.

The survey was administered in a variety of different establishments including: the City of Ottawa PWS Department, Carleton University's Department of Civil and Environmental Engineering and Elections Canada (Ottawa Office). The contacted personnel were directors, department managers or administrative assistants in their respective companies. The surveys were distributed by personnel at each of these establishments so that the respondents remained anonymous.

6.3.4 Data Collection

The raw data from the survey was collected automatically by the free-online-surveys.com server. The data was downloaded in a *.csv file format which is compatible with any spreadsheet software such as Microsoft Excel. Before the data could be used in a statistical software package, such as SPSS, it had to be cleaned and re-formatted. The data was collected over period of a month from February 12th to March 12th 2008. In this period, 236 total responses were collected, 190 of these responses were complete and useable. It was decided to remove any of the responses that were incomplete from the raw data. To re-format the raw data, each individual response in the stated preference scenario matrix had to be changed into an individual data point. Thus, for each scenario response, the demographic and trip question responses were copied to form a new data point. This resulted in 4,750 total data points in the refined data, from 190 complete responses to the survey.

6.4 Discrete Choice Models

The term regression was coined by Francis Galton in a paper that explored children's heights with respect to that of their parents. He found that although tall parents tend to have tall children and short parents tend to have short children, the average height of each generation tended to move or "regress" towards the mean (Galton, 1886). The contemporary interpretation of the term regression is slightly different than the original:

"Regression analysis is concerned with the study of the dependence of one variable, the *dependent* variable, on one or more other variables, the *explanatory* variables, with a view to estimating and/or predicting the (population) mean or average value of the former in terms of the known or fixed (in repeated sampling) values of the latter."

(Gujarati, 2003)

There are various forms of regression models each serves a specific purpose and is applicable in certain situations. Linear regression models are used when there is (or there is assumed to be) a linear relationship between the dependent and the explanatory variables. Traditional regression models require that the dependent variable be quantitative while the explanatory variables can be either qualitative or quantitative (Gujarati, 2003). In the case of a discrete choice problem, where the dependent variable is qualitative, traditional multiple regression techniques cannot be utilized.

Discrete choice problems are ones where a decision maker is faced with a choice of alternatives that are mutually exclusive, collectively exhaustive and where the number of alternatives is finite (Train, 1986). Discrete choice models are based on the theory of utility maximization, whereby a function which represents a user's, or decision maker's,

utility is maximized. The utility function is composed of commodity characteristics; users of a transportation network will try to maximize their utility function to acquire the greatest benefit. From the user's perspective, the choice is deterministic; however, from the analyst's perspective, the choice is probabilistic, if only because the analyst is not able to observe all relevant factors that may affect the choice. Thus, the choice probability of alternative i ; P_{im} , is equal to the probability that the utility of alternative i ; U_{im} , is greater than that of any of the other alternatives (Ben-Akiva et al. 1985, Train 1986). This can all be expressed in the following equation:

$$P_{im} = \Pr [U_{im} > U_{jm}, \forall j \in C_m, i \neq j] \quad \text{Equation 6.1}$$

Where C_m is the set of all feasible and possible alternatives faced by user m . The utility function is composed of two different parts as shown in the following equation (Louviere, 2000):

$$U_{im} = V_{im} + \varepsilon_{im} \quad \text{Equation 6.2}$$

Where U represents the utility function, V is known as the representative utility function and ε is the random component of the utility function. The coefficients of the representative utility function are said to be characteristic of the entire population and do not vary; only the independent variables will vary. The random component of the utility function represents the unobservable individual idiosyncrasies and tastes (Louviere, 2000).

To develop a logit model it is required that one assumption be made about the random component of the utility function. That assumption is that all of the disturbance terms, ε , follow the Gumbel (or double exponential) distribution (Tayyaran 2000).

6.4.1 Binary Choice Logit Model

The logit model is an optimal method for the regression analysis of binary dependent variables. In the case of this study, since the dependent variable is whether one will use the HOT lane or not, the binary choice logit model is a satisfactory means of analysis. Probabilities are bounded by upper and lower limits i.e. one and zero. By converting probabilities (p) to odds (O), using Equation 6.3, the upper limit is removed (Allison, 1991):

$$O = \frac{p}{1-p} = \frac{\text{probability of event}}{\text{probability of no event}} \quad \text{Equation 6.3}$$

If the natural logarithm of the odds is then taken, the lower bound is also removed. Setting the result equal to a linear function of k explanatory variables and $i = 1, 2, 3 \dots, n$ individuals, the logit model is formed. Equation 6.4 shows the equation for the binary choice logit model (Allison, 1991):

$$\ln \left[\frac{p_i}{1-p_i} \right] = \alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_k x_{ik} \quad \text{Equation 6.4}$$

Where p_i is the probability of some dependent variable $y_i = 1$, \ln refers to the natural logarithm, and the right hand side of the equation is known as the utility function (previously discussed) (Allison 1991). With the logit model expressed in the form of a linear function, standard regression techniques can be used to formulate the model.

For analysis purposes, the Logit function is represented in terms of $\ln(\text{Odds})$; however, it is more commonly expressed in terms of probabilities. The binary choice logit model can be expressed as shown in Equation 6.5:

$$P_i = \frac{e^{U_i}}{e^{U_i} + 1} \quad \text{Equation 6.5}$$

The binary choice logit model can easily be extended to the multinomial logit model, where there are more than two possible outcomes as shown in equation 6.6:

$$P_i = \frac{e^{U_i}}{\sum_{j=1}^J e^{U_j}} \quad \text{Equation 6.6}$$

Where J represents the full choice set faced by the user or decision maker.

6.4.2 Properties of the Logit Model

The Logit model has many desirable properties that result in its being used widely. One of the properties that give the logit model an advantage over other similar models is its ease of use. The model only requires a few simple calculations and can be applied to complex choice problems. Also, it can be shown that the probability of choosing a specific alternative depends on all the other available alternatives. So, the alternative with highest utility (as perceived by the user or decision maker) is generally chosen as the best. In addition to the properties already described, there are two major properties of the logit model that are important and require some further exploration, these are: the independence from irrelevant alternatives property and the elasticity of the variables in the model.

The logit model has many properties that can be viewed as favourable by the analyst, however, some properties exhibited by the logit model can be perceived as unfavourable. The independence from irrelevant alternatives (IIA) property states that the ratio of the choice probabilities for any two possible alternatives does not depend on the any of the

other alternatives (Train, 1986). Consequently, the odds ratio for choosing one alternative over another only depends on the observable characteristics of the two alternatives in question. Consider the ratio of choice probabilities for two alternatives, i and k in a multinomial logit model:

$$\frac{P_i}{P_k} = \frac{e^{U_i} / \sum e^{U_j}}{e^{U_k} / \sum e^{U_j}} = \frac{e^{U_i}}{e^{U_k}} = e^{U_i - U_k} \quad \text{Equation 6.7}$$

While this property can provide an accurate reflection of reality in some cases, it is clearly inappropriate in others (see the red bus/blue bus example in Train (1986)). In cases where, as a result of the IIA property, the model does reflect reality there are some benefits. As a result of the IIA property "...it is possible to estimate model parameters consistently on a subset of alternatives for each sampled decision maker." (Train, 1986)

Another useful property of the logit model is that it is possible, and fairly easy, to derive equations for direct and cross-elasticities. A direct point elasticity equation calculates the percentage change in probability of choosing a specific alternative, i , with respect to a marginal change in one of the given attributes, x_{ink} , holding all others constant (Ortuzar et al 2001). The direct point elasticity function can be expressed in the form shown in Equation 6.8.

$$E_{x_{ink}}^{P_n(i)} = [1 - P_n(i)] x_{ink} \beta_k \quad \text{Equation 6.8}$$

The cross-point elasticity equation calculates the percentage change in the probability of choosing a specific alternative, i , with respect to a marginal change in the value of the k^{th}

attribute of another alternative, j (Ortuzar et al. 2001). The expression for the cross point elasticity of a logit function can be expressed as follows.

$$E_{x_{jnk}}^{P_n(i)} = -P_n(j)x_{jnk}\beta_k \quad \text{Equation 6.9}$$

It should be noted that all of the cross elasticities of an alternative i , with respect to attribute x_{jnk} of alternative j are equal and independent from alternative i . This result can be attributed to the IIA property.

6.4.3 Estimation Methods

There are multiple methods used for estimation of the parameters in a logit model, the two most common methods are: the least squares (LS) method and the maximum likelihood (ML) method. Both of these methods are described below.

In the least squares method, for a binary choice model, each of the two choices is converted to log(odds) format and the parameters are estimated using the generalized least squares techniques, similar to linear models. The binary logit model can be expressed, in the context of least-squared estimation, as follows:

$$\log\left[\frac{P_n(i)}{P_n(j)}\right] = \beta x_n \quad \text{Equation 6.10}$$

This of course is the same form as the binary logit model discussed in section 6.4.1. The problem with this method is that the probability $P_n(i)$ is never observed; instead y_{in} , an indicator variable that takes the values of either zero or one, is observed. Berkson (1953) devised a procedure whereby this problem can be mitigated. He proposed that the sample be divided into homogeneous subgroups and the share of each group be used for choosing

each alternative as an estimate of the choice probabilities. (For more details please see Ben-Akiva et al. 1985)

The maximum likelihood method is most commonly utilized to estimate the parameters of a logit model. “ML is based on the idea that although a sample could originate from several populations, a particular sample has a higher probability of being drawn from a certain population than others.” (Ortuzar et al. 2001) This results in the ML procedure estimating the set of parameters which will generate the observed sample most often.

The procedure for estimating the set of parameters in the ML method involves maximizing the likelihood function with respect to the parameters, β_k . More specifically, the log likelihood function is expressed in terms of $P_n(i)$, $P_n(j)$ and the parameters β_k then the function is differentiated with respect to β_k and set to zero (Ben-Akiva et al. 1985). By solving for the parameters in an iterative fashion, the ML procedure is completed. For a binary logit model, the ML procedure generally converges quickly and to some unique maximum. The estimates are generally consistent as well as asymptotically efficient and normal (Wuensch, 2006). Therefore, the maximum likelihood estimation method is the most commonly utilized parameter estimation method for logit models. The software package that was used for the statistical analysis in this study, SPSS, utilizes MLE (Maximum Likelihood Estimation) method to determine the parameters of the binary logit model.

6.4.4 Goodness of Fit

There are many different goodness of fit measures that can be applied to logit models including: the likelihood ratio test, the rho-squared index, the pseudo R-squared test, the

asymptotic t-test and the Hosmer and Lemeshow goodness of fit test. While all of the presented goodness of fit tests apply to logistic regression, only a few are well enough suited for interpreting the results of a binary choice logit model. In this section, the following goodness of fit tests will be discussed: the likelihood ratio test, the pseudo R-squared test and the Hosmer and Lemeshow goodness of fit test.

The likelihood ratio test utilizes the log likelihood function evaluated at the mean of the utility parameters as a criterion for assessing the overall goodness of fit of a discrete choice model, when the maximum likelihood estimation procedure is used to determine the parameters. To test the significance of a logit model with large sample size, the likelihood ratio test is often used by testing the null hypothesis that the probability of an individual n choosing alternative i , $P_n(i)$, is independent of the value of the parameters in the logit function. If the null hypothesis is retained it can be inferred that the parameter values, β , are in fact zero (Louviere et al. 2000).

In the SPSS framework, the likelihood ratio test is expressed as the product of the logarithm of the likelihood function and -2 or “-2 log likelihood.” The two simplest ways to interpret this value are first to look at the chi-squared value that is given; this value indicated how much the “-2 log likelihood” variable has been reduced from the model with only the intercept, by adding the variables (Wuensch, 2006). It has been shown by Wilks (1962) that the “-2 log likelihood distribution” is equivalent to the chi-squared distribution. The second way to interpret this variable is rather simplistic: the lower the “-2 log likelihood” value the better the model predicts the decisions (Wuensch, 2006).

The coefficient of determination, commonly referred to as R^2 , has been widely used in classical regression analysis. The value of R-squared represents the proportion of the variance that is explained by the regression model, this makes it a useful value in measuring the success of predicting the dependent variable from the independent variable(s). There are, however, models where the concept of residual variance is not easily defined, such as logit models (Nagelkerke, 1991). Cox and Snell (1989) defined a coefficient of determination that utilizes maximum likelihood as a criterion of fit. The expression for the Cox & Snell R-squared is:

$$R_{C\&S}^2 = 1 - \left[\frac{L(0)}{L(\beta)} \right]^{2/n} \quad \text{Equation 6.11}$$

Where $L(0)$ and $L(\beta)$ represent the likelihood of the null model (intercept only) and the fitted model, respectively, and n represents the sample size. This estimate of R-squared has many desirable properties including: that it is consistent with maximum likelihood as an estimation method, it is asymptotically independent of the sample size, and it is dimensionless. However, for this pseudo R-squared value to be consistent with the R-squared value known in classical regression, it has to have the capacity to reach the value of 1, which it cannot (Nagelkerke, 1991). As a means of correcting this problem, Nagelkerke (1991) proposed that the Cox and Snell R-squared value be divided by the maximum that it can possibly reach. Thus the Nagelkerke R-squared can be expressed as follows.

$$R_{NAG}^2 = \frac{R_{C\&S}^2}{\max(R_{C\&S}^2)} = \frac{1 - \left[\frac{L(0)}{L(\beta)} \right]^{2/n}}{1 - L(0)^{2/n}} \quad \text{Equation 6.12}$$

While the other two goodness of fit measures presented here, namely, the likelihood ratio test and the pseudo R-squared test can apply to multinomial as well as the binary logit model, the Hosmer and Lemeshow test is only valid when analyzing binary choice logit models. Hosmer and Lemeshow (1989) proposed a statistic that is distributed as chi-square when there is no replication within any of the subpopulations. The procedure involves sorting the observations in increasing order of their estimated probabilities. The observations are then divided into G groups. The Hosmer and Lemeshow statistic is then obtained by calculating the Pearson chi-squared statistic from the 2xG table of observed and expected frequencies, for the G groups (Shah et al. 2003). The statistic can be expressed as follows.

$$\chi^2_{H\&L} = \sum_{g=1}^G \frac{(O_g - N_g \bar{\pi}_g)^2}{N_g \bar{\pi}_g (1 - \bar{\pi}_g)} \quad \text{Equation 6.13}$$

Where N_g is the total frequency of subjects in the g^{th} group, O_g is the total frequency of the event outcomes in the g^{th} group and $\bar{\pi}_g$ is the average estimated probability of an event outcome for the g^{th} group. The distribution of the Hosmer and Lemeshow statistic is approximated by the chi-squared distribution with 2xG degrees of freedom (Shah et al. 2003). The simplest way to interpret this statistic is to consider that a large value of $\chi^2_{H\&L}$ indicates a lack of fit in the model.

6.5 Formulation of Binary Choice Logit Model

Once the data from the SP survey was collected, it was used to develop a binary choice logit model, that was in turn used to model the decision making process of the drivers in the presence of an HOT lane. In addition to the functional model that was used for the

development of the algorithm, an explanatory model was also constructed. The explanatory model was used to examine the different socio-economic effects that influence people's decisions regarding whether or not they will use a tolled facility. The results of the explanatory model were also used to compare the results obtained in this study with that of similar studies that were conducted, on the topic of willingness to pay for HOT facilities. To conduct the statistical analysis, a software package was required. SPSS was chosen due to its statistical calculation and data management capabilities as well as its ease of use.

The following discussion describes the process of developing a binary choice logit model from stated preference survey data. The process involves preparing the data, running the statistical software package to develop the model, and interpreting the results.

6.5.1 Data Preparation

In preparing the data for analysis, there are many measures that must first be taken. Initially, it was decided that any responses with missing entries would not be analyzed so, they were removed (See Section 6.3.4). The data also had to be re-formatted so that each response in the SP scenario matrix corresponded to an individual entry in the spreadsheet. This was required primarily because otherwise the software would not treat each response as a separate entry. It was also required to modify the groupings for some questions in the survey, as to reduce the number of categories in the variables and facilitate analysis.

All of the variables in the survey, including demographics and trip information, were categorical. Even the levels of the variables in the SP scenario matrix were coded as categorical (although in the analysis they were treated as continuous). It is important to

note here that, the separation between the levels of a categorical variable is not necessarily known. As a result, the categorical variables cannot simply be coded as they are collected. It is necessary to create multiple “dummy” variables from one categorical variable, in this way the model will be as accurate as possible. A dummy variable is coded by isolating each level of a specific categorical variable, except for one (isolating each level and using all of them in a model would result in redundancy). For example, consider the variable “trippeak” which asked respondents to indicate whether their last trip on the highway was during the AM peak period, the PM peak period or during the weekend or off-peak period. To convert this variable to a dummy, the variables “AMpeak” and “PMpeak” were created from their corresponding levels. The “AMpeak” variable was assigned a value of 1 (true) when a respondent indicated that he/she used the highway during the AM peak period and a value of 0 (false) if another level was chosen. The “PMpeak” variable was coded in the same way. All of the categorical variables were coded in this way except the variables that were contained in the SP scenario matrix.

As discussed earlier in this chapter, the higher order interaction terms were assumed to be negligible, i.e. all interaction terms with three or more variables were assumed to have little or no significance. However, the two variable interactions had to be checked for significance in the model. In this case, the interaction terms were only built from the variables in the SP scenario matrix. Since there were three variables in the scenario matrix, namely, toll for entering the HOT lane (toll), travel time on general purpose lanes (ttgpl) and travel time on the HOT lane (tthot), three interaction terms were constructed. These were: “toll*ttgpl,” “toll*tthot” and “ttgpl*tthot.” The interactions of the demographic and trip information variables would generally also be checked. However,

since each of the variables was coded as a dummy, it would require an unreasonable amount of interaction terms and it would also be very difficult to interpret the results. As a result, only the interactions among the SP scenario matrix variables were tested in the model.

6.5.2 SPSS

SPSS (Statistical Package for Social Sciences) is a statistical analysis and data management system that utilizes a graphical user interface to facilitate analysis (SPSS Inc, 2007). This particular software package was chosen because it is capable of managing, re-formatting and creating data. SPSS is also a powerful tool for complex statistical analysis such as binary logistic regression. In this section, the aspects of SPSS that are important to this study will be discussed, including data management, binary logistic regression and maximum likelihood estimation method for constructing the logit model.

In SPSS, it is possible to import data from a variety of sources and a variety of formats with ease. The data collected from the SP survey was in a form that was compatible with Microsoft Excel, as a result the data was easily imported from Excel after the initial cleaning and removing of missing values was completed. Using commands such as compute new variable and recode variable, all of the required dummy variables and interaction terms were created. It is also possible to define each variable in terms of their type of measure (continuous, categorical, etc.). All of the variables were coded as categorical “dummy” variables, except for the three variables that composed the SP section of the survey which were coded as continuous.

In SPSS there are multiple techniques for analyzing a dichotomous dependent variable in terms of the predictor (or independent) variables. Generally, discriminant analysis is used when all independent variables are continuous, logit analysis is employed when all predictors are categorical and logistic regression analysis is used when the independent variables are a mix of continuous and categorical variables (Wuensch, 2006). For the case of this particular study, there is a mix of both categorical and continuous predictor variables, so logistic regression analysis was the obvious choice. However, within the logistic regression model option there are two ways that a binary choice model can be formulated, these are; logistic regression and multinomial logistic regression. Each procedure has options that are not available in the other. Logistic regression formulates the predictions, residuals, influence statistics and goodness of fit tests using data at the individual level, regardless of how the data was entered. Multinomial logistic regression analysis, on the other hand, internally aggregates cases to form subpopulations with identical covariate patterns and formulates the predictions, residuals and goodness of fit tests based on the subpopulations. The subpopulation approach is much stronger in cases where the independent variables are either all categorical or where the continuous variables take on only a limited number of values (SPSS Inc, 2007). Unfortunately, as a result of the subpopulation approach, the multinomial logistic regression option treats the continuous variables with limited values as categorical variables, while the logistic regression function treats the variables as continuous. While the multinomial logistic regression function does result in a slightly more accurate model, it is also much more difficult to interpret and to later use in another software package. As a result, the logistic

regression option was chosen for analysis of the SP data and formulation of the binary choice logit model.

It was also mentioned earlier in the chapter that SPSS utilizes the MLE (Maximum Likelihood Estimation) procedure to determine the parameters in the logit functions. The following discussion regards the MLE algorithms used to determine the parameters in the desired logistic regression function.

In SPSS, the maximum likelihood estimates of the parameters, β , must satisfy the following equation (SPSS Inc. 2007):

$$\sum_{i=1}^n w_i (y_i - \hat{\pi}_i) x_{ij} = 0, \text{ for the } j^{\text{th}} \text{ parameter} \quad \text{Equation 6.14}$$

Where, w_i is the weight for the i^{th} case, y_i is the observed value of the i^{th} case of the dichotomous dependent variable, $\hat{\pi}_i$ is the probability of y_i occurring and x_{ij} is the observed value of the i^{th} case of the j^{th} parameter as well as where $x_{i0} = 1$, for $i = 1, 2, 3 \dots, n$.

It should be noted that SPSS utilizes a Newton - Raphson type algorithm to obtain the maximum likelihood estimations. The convergence of the algorithm is based on the following (SPSS Inc. 2007):

- Absolute difference for the parameter estimates between the iterations;
- Percent difference in the log likelihood function between successive iterations; and
- The maximum number of iterations specified.

Also, during the iterations, if the term $\hat{\pi}_i(1 - \hat{\pi}_i)$ becomes smaller than 10^{-8} for all cases, the log likelihood function comes very close to zero. In this situation, the iterations will also be stopped and all predicted values will be assigned either 1 or 0 (SPSS Inc. 2007).

6.5.3 Formulation of Logit Model

As mentioned earlier in this thesis, there were two different discrete choice models made for this study: the first was a functional model which was used in the design year traffic simulation to model driver's decision making process and the second was an explanatory model that included various socio-economic as well as trip information data. The following is a discussion of how the two models were formulated as well as a presentation of the logit functions.

Both models were formulated in SPSS using the binary logistic regression model option. The first model that was investigated was the functional model. In this model, only the options that applied to the stated preference portion of the survey were included, i.e. toll, travel time on the general purpose lane and the travel time on the HOT lane. The dependent variable was, of course, whether or not the respondent opted to use the HOT facility over the general purpose lanes. It was important to check if any of the second order interaction terms were significant, all of the higher order interaction terms were assumed to be insignificant as a result of the experimental design. It was found that all of the two-way interaction terms were insignificant (the hypothesis that these terms differ from zero was rejected) so, they were omitted from the model. The variables in the functional model can be found in Table 6.5, below:

Table 6.5 Functional logit model

Variable	B	SE	p	Notes
toll	-0.631	0.026	0.000	Toll on HOT Lanes
tthot	-0.086	0.026	0.001	Travel time on HOT lane
ttgpl	0.126	0.008	0.000	Travel time on General Purpose Lane
Constant	-1.550	0.246	0.000	Equation Constant
-2 Log Likelihood = 4673.283				$R^2_{C\&S} = 0.209$ $R^2_{NAG} = 0.297$
Hosmer and Lemeshow test				
Chi-Squared			p	
19.686			0.003	

In the explanatory model, many of the socio-economic and trip information variables were added to the existing functional model. It was found that the only variable that was completely insignificant was the geographic location of the respondent's residence and how frequently the respondent contributes to a carpool. All of the other variables were significant; however, many had to be re-coded and re-grouped for them to show any significance in the model. The variables that were added in the explanatory model were: age, gender, average annual household income, number of weekly trips on Highway 417, one way distance of last trip, trip purpose and time of day of last trip. The explanatory model is expressed in Table 6.6, below:

Table 6.6 Explanatory Logit Model

Variable	B	SE	p	Notes
toll	-0.667	0.027	0.000	Toll on HOT Lanes
tthot	-0.089	0.027	0.001	Travel time on HOT lane
ttgpl	0.133	0.008	0.000	Travel time on General Purpose Lane
gender	-0.436	0.080	0.000	Gender of respondent
age16to24	1.288	0.147	0.000	True if age between 16 and 24
age25to34	0.769	0.148	0.000	True if age between 25 and 34
age35to54	0.464	0.145	0.001	True if age between 35 and 54
hhinc34und	-0.541	0.099	0.000	True if annual household income less than \$34K
numtrip4to7	0.294	0.084	0.000	True if number of weekly trips between 4 and 7
triplen30over	-0.413	0.133	0.002	True if length of last trip was 30km or more
purpbusi	0.586	0.110	0.000	Purpose of last trip was business related
purprecr	0.340	0.083	0.000	Purpose of last trip was recreation
PMpeak	-0.205	0.090	0.023	Last trip was made during the PM peak period
Constant	-2.265	0.293	0.000	Equation Constant
-2 Log Likelihood = 4445.760			R²_{C&S} = 0.246	
			R²_{NAG} = 0.350	
Hosmer and Lemeshow Test				
Chi-squared			p	
16.936			0.031	

In the following section, the significance of these two presented models will be discussed. Also, the parameter coefficients will be interpreted and the entire model will be compared to similar models already constructed in other cities for other HOT lanes.

6.5.4 Discussion and Interpretation of Results

In Tables 6.5 and 6.6, the functional and explanatory models were presented. All of the variables that were found to be insignificant were removed. The minimum significance for a variable to remain in the model was 95%, and it can be seen that in the two models all of the β variables has less than a 2.3% probability of being equal to zero. However,

just because the variables are significant does not necessarily mean that the models are completely accurate.

The Hosmer and Lemeshow test is used to determine whether the difference between the observed and the expected events is simultaneously zero. Larger values of the Chi-squared statistic (and small values of p) indicate a poorly fitted model. The -2 log likelihood statistic indicates how well the model predicts the outcomes. The statistic can be compared to the intercept only model to determine if the addition of the variables results in a better model. As a result of the Hosmer and Lemeshow test it can be seen that there is considerable lack of fit in both models. However, the explanatory model is better fitted than the functional model. The -2 log likelihood statistic indicates that while both models do in fact predict the outcomes better than the intercept only model, both models are not as accurate as they potentially could be. Again, the explanatory model is better at predicting the outcomes than the functional model.

The pseudo R-squared statistics can be interpreted in the same way the coefficient of determination is interpreted in OLS (Ordinary Least Squares) multiple regression models. It can be seen that both models poorly explain the variance in each of the two cases, and again, the explanatory model is better than the functional model in explaining the variance.

The poor fit of the two models is expected for models constructed from stated preference data, because it would be impossible to test all of the factors that affect different types of decision making. The low R-squared values are expected in this type of model for these reasons. However, the outcomes of the Hosmer and Lemeshow test as well as the -2 log

likelihood test were not expected. These results indicate that, in order to make an accurate model, more variables would have to be tested. Due to lack of time and resources, this is impossible, so the functional model, determined here, will be carried over to the remaining stages of this study.

The variables that were found to influence whether or not a motorist chooses to utilize the HOT facility were: the displayed toll, the travel times on the general purpose and HOT lanes, gender age, average annual household income, trip frequency, trip length, trip purpose and time of day the trip was made. According to a study conducted on the HOT in Minneapolis/St. Paul (Zmud et al. 2006), these results are expected. In Minneapolis, it was found that all but gender and trip frequency affect a motorist's choice to utilize the HOT lanes. However, in a study regarding the HOT lanes in San Diego (Li, 2001) it was found that trip purpose, vehicle occupancy and age were significant while gender and trip length were found to have little or no effect on the choice to utilize the HOT lane. After reviewing the results of the model in this study and comparing them to those of Zmud et al. (2006) and Li (2001), it can be seen that there are some universal characteristics or properties that will determine HOT lane usage while the remainder will reflect local tendencies and preferences.

The explanatory model indicates that there are various local tendencies and preferences in the city of Ottawa that will affect a driver's choice to use an HOT facility. It was found that men are 0.627 times less likely to utilize the HOT lane than women, controlling for other variables. People aged 16 to 24 are 3.625 times more likely to use the HOT lanes than people aged 55 or older, while those aged 25 to 34 and 35 to 54 are 2.157 and 1.590

times more likely to use the HOT than those aged 55 or older, respectively. This indicates a trend that younger people are more likely to use a tolled facility than their older counterparts, perhaps younger people value time savings over money. It was also found that motorists with a household income less than \$34,000 are 0.582 times less likely to utilize the HOT lanes than people who earn \$35,000 or more. People who make between 4 and 7 trips per week are 1.342 times more likely to use the HOT than those who make more than 7 or less than 4 trips per week. People on a longer trip (30km or more) are 0.662 times less likely to use the HOT lanes than motorists making relatively shorter trips. Motorists on work or business related trips were found to be 1.797 times more likely to use the HOT lanes than those on out of town or commuter trips. People on recreational trips were found to be 1.406 times more likely to use the HOT than those on out of town or commuter trips. This was an unexpected result, seeing as it was assumed that people would be more willing to wait in traffic if their trip purpose was recreational; this can indicate that many people living in the City of Ottawa value their off-time enough to pay for a shorter travel time. Finally, it was found that motorists driving during the PM peak period were 0.815 times less likely to use the HOT facility than those traveling during the AM peak period or during off peak times.

6.6 Summary

A stated preference survey was designed and administered to various people throughout the Ottawa area. The survey was designed according to discrete choice principles. The SP scenario matrix was designed as a fractional factorial type, the remainder of the questions regarded socio-economics and trip information. Administration of the survey was conducted utilizing an online source, where the survey was hosted and the data was

collected. From the survey data, two binary choice logit models were developed; one was a functional model to be later used to determine a tolling algorithm for an HOT lane and the other, an explanatory model, was used to investigate local tendencies and preferences. The logit models were created by using the binary logistic regression function in the statistical software package, SPSS. The models were found to be fitted poorly; however, this is the general tendency of models based on SP methods. The variables that were found to be significant were found to be similar to those found in a willingness to pay for tolled facilities study conducted in Minnesota.

Chapter 7

Algorithm Development

7.1 Introduction

An HOT facility as a part of an urban transportation network must operate in a manner that helps the overall performance of the network. As such, the toll, which controls the access to the facility, must somehow be managed in order for an efficient and manageable system to thrive. Feedback control theory is the basic mechanism by which systems, such as these, maintain or attempt to achieve their equilibrium. By incorporating elements of control theory, discrete choice modeling, and various other statistical tools, an algorithm can be created that will not only manage the demand on the facility but also ensure that it runs smoothly and efficiently. It is important to note that traffic patterns are known to change over time, due to various issues such as mass lay-offs or the construction of a new housing development. Also, as the earth's population grows there will be more demand for technologies that can help mitigate urban traffic congestion, such as HOT facilities. As such, it may be important for the control logic in the tolling algorithm itself to automatically adjust and calibrate itself for the algorithm to compensate for changing traffic patterns as well as for different locations and local preferences.

In this chapter, the theory of modern control systems will be introduced and briefly discussed. The methodology for developing a tolling algorithm for an HOT lane will also be presented. The self-calibration aspects of the tolling algorithm will also be presented and discussed. Finally, the methodology for the preparation of the tolling algorithm for traffic simulation modeling trials will be presented.

7.2 Control Systems Theory

Automated control theory has been around for thousands of years from the Greeks in approximately 270 B.C. building water clocks, to the steam engine developed in the 17th century, to modern day computerized control algorithms (Lewis 1992). Modern control systems follow a time domain technique where a state-space model of the system to be controlled is required. The most general, linear version of a modern control system can be described by a first order differential equation as follows:

$$\begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) + Du(t) \end{aligned} \qquad \text{Equation 7.1}$$

Where $x(t)$ is a vector describing the system states (or internal variables), $u(t)$ is a vector of control inputs and $y(t)$ is a vector containing the measured outputs. A , B , C and D are matrices whose terms describe the system's interconnections (Lewis 1992). The control system in equation 7.1 describes a continuous time system, in the case of a tolling algorithm for an HOT lane, this would not suffice. Primarily due to the potentially overwhelming computing power required as well as the potential over-sensitivity to the slightest changes to the system, a continuous time representation of the control logic would not produce wanted results. Therefore, for its potential use as the governing control logic in an HOT lane tolling algorithm, the equation has to be modified to describe a discrete time system. Equation 7.2 illustrates a discrete time invariant system:

$$\begin{aligned} x(t+1) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) + Du(t) \end{aligned} \qquad \text{Equation 7.2}$$

In this situation the system is controlled based on time steps rather than a continuous time cycle. In certain situations, some of the system interconnection matrices (A, B, C and D) will have to be set to zero depending on the circumstances and system characteristics.

Feedback control theory is an expansion of the classic control systems theory. It utilizes an iterative process that collects output data from the system and utilizes this data to compute the outputs in the subsequent iteration. Simple modern control systems use open loops; feedback control systems use a closed loop which is much more efficient when dealing with an iterative process (Lewis 1992). As a result, feedback control theory along with a discrete choice model will form the basis of the tolling algorithm for this study.

7.3 Tolling Algorithm

Previous research and experience show that HOT lanes can help to control rising demand along urban transportation infrastructure. Practically, any tolled facility acts as a gate that can limit the amount of vehicles entering a certain corridor, with changing toll rates. To achieve a truly optimal system performance, these tolls have to be controlled in a way that not only helps to control access to the facility but also keeps the traffic flowing at a satisfactory rate.

Addressing the entire problem of urban mobility from a macroscopic level begins with a choice: whether to physically commute or telecommute. Modal choice is the precursor for route choice, here the motorist can either choose to utilize public transportation, participate in a carpool or drive his/her private vehicle (the author acknowledges that there are multiple other modes of transportation such as walking or bicycling, however for the sake of this illustration only the three mentioned modes will be considered). In the

route choice stage, the traveler will be most sensitive to tolled or HOT facilities because he/she will have to physically confront them by choosing to either pay a toll for relatively good travel conditions, save the cost of the toll and drive in slightly degraded conditions or move to a parallel route. A tolled facility in an urban area with a significant traffic congestion problem can impact traveler's decision making at all levels and therefore has a global effect on the transportation network. Please see Figure 7.1 for an illustration of the commuting problem in an urban area.

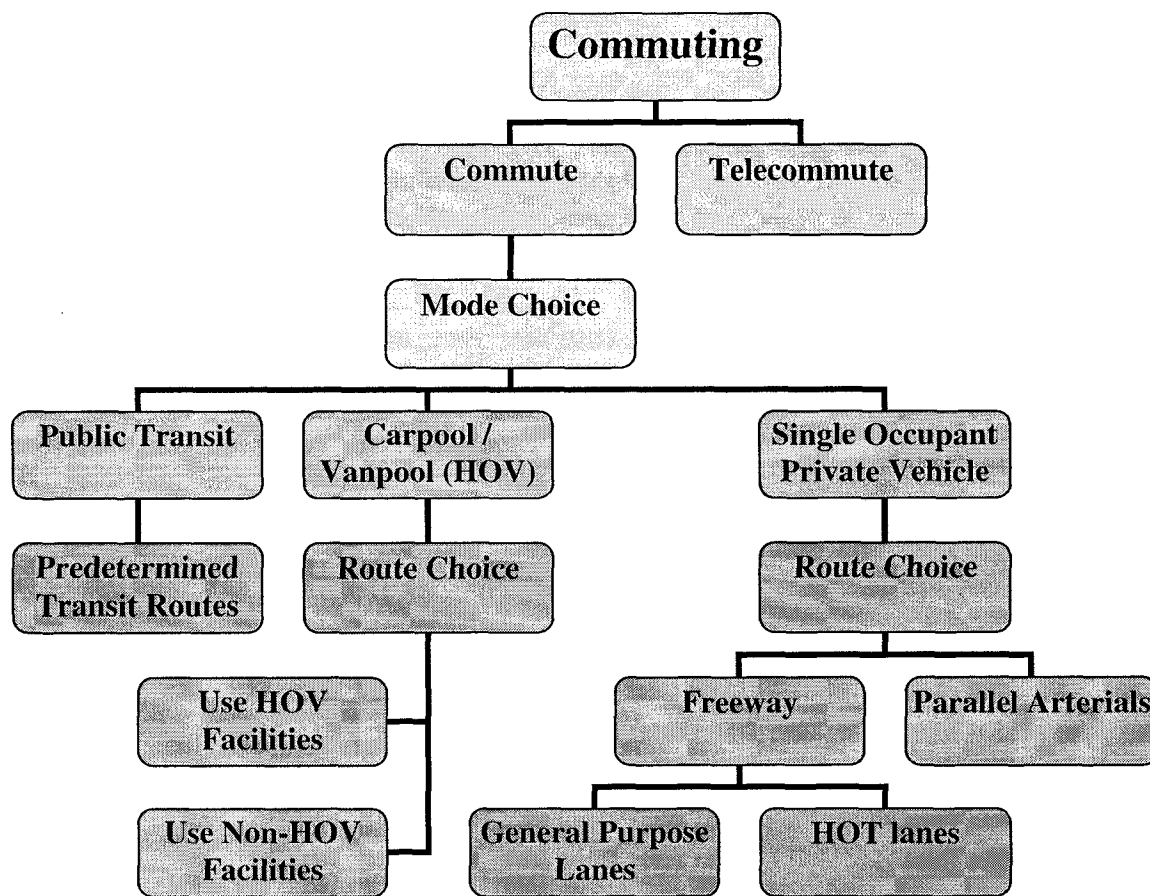


Figure 7.1 Hierarchical depiction of the Commuting problem in an urban area with an HOT facility

Considering the problem at a microscopic level the tolling mechanism on an HOT lane is used to manipulate the usage of the particular facility. The tolling mechanism will govern

how many vehicles use both the HOT and the general purpose lanes. In Figure 7.2, the process for HOT operations is depicted. A tolling algorithm for an HOT lane uses traffic data collected from various detectors to determine the optimum proportion of users or predict the proportion of users. The determined proportion of HOT lane users will determine the toll rate and as a result the route choice for each individual driver. As long as the algorithm is calibrated properly it should result in desirable performance of the HOT lanes.

There are many issues associated with designing a proper tolling algorithm for an HOT lane; mainly over or under-sensitivity. An overly sensitive tolling algorithm will react quickly but will also result in wild fluctuations of speed or volume along the lanes while an under-sensitive algorithm may respond too slowly to changing conditions. Both the over and the under-sensitive algorithms will achieve the desired results; however, an optimized system will allow for smooth transitions between tolling levels, resulting in a much more efficient system. Using control theory combined with discrete choice modelling, a dynamic tolling algorithm will be constructed. The goal is for the algorithm is to accommodate various traffic levels in a quick and stable manner resulting in smooth and efficient operations. The system should behave in a way that improves potential traffic demand by allowing single occupant vehicles to use the excess capacity of the HOT facility with out degrading the travel conditions for the HOVs. The following discussion outlines the process for constructing the tolling algorithm for this study.

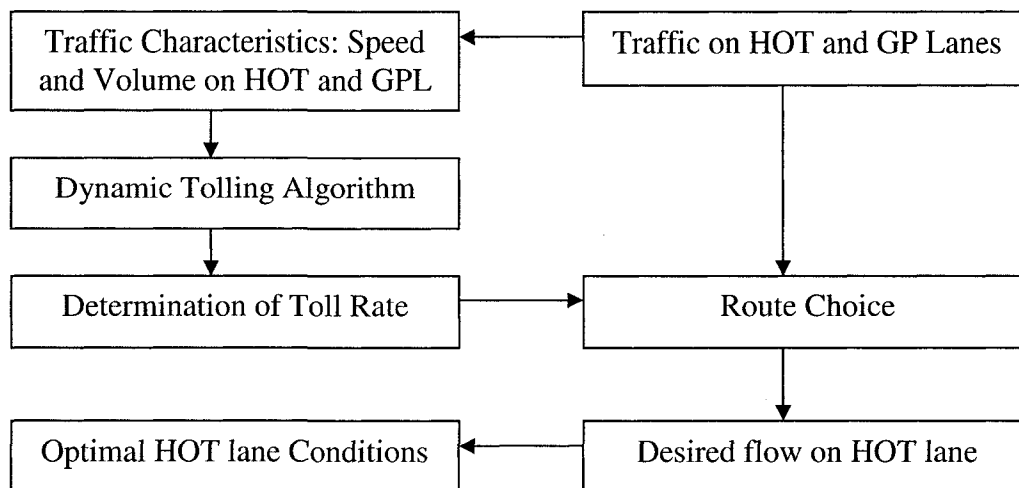


Figure 7.2 Flow chart depicting optimum HOT lane operations

7.3.1 Tolling Algorithm Scheme

A tolling algorithm for an HOT facility is only beneficial if there are some clear benefits to the transportation network, or at the very least, to the applicable corridor. As such, the algorithm must be optimized so that satisfactory conditions are achieved. It is important to note here that there is a complex non-linear relationship between the toll rate and the proportion of upstream traffic flow that enters the HOT facility. As a result, simplified tolling algorithms may not be flexible enough to satisfactorily control the traffic assignment. Conversely, a complex algorithm will be able to handle traffic allocations in a satisfactory manner but may be difficult to implement, or result in excessive computing power or cost. (Zhang et al. 2008)

To address the above mentioned problems, it was decided to follow and expand upon the work of Zhang et al. 2006, and use a second order control scheme for the development of a portion of the tolling algorithm in this study. Feedback control theory will provide a means for computing the flow ratio based on current conditions while the logit model developed in chapter 6 will be used to back calculate the ideal toll rate. Since, there is no

way to calibrate the feedback control aspect of the algorithm to local conditions without exceeding reasonable cost or time limits, the algorithm will also have a self-calibration aspect that will ensure that the prediction of the proportion of vehicles entering the HOT facility in the next time step is reasonable.

7.3.2 Using Logit to Model HOT lanes Usage

In chapter 6, the development of a logit model for the purpose of determining HOT lane usage was discussed. The model was a function of the current toll rate as well as the current travel times along both the HOT and the general purpose lanes. The coefficients as well as the goodness of fit measures of the functional logit model are displayed in Table 6.5. The logit model would traditionally be expressed as follows:

$$P_{HOT} = \frac{e^{-1.550-0.631 \cdot TOLL-0.086 \cdot TTHOT+0.126 \cdot TTGPL}}{1 + e^{-1.550-0.631 \cdot TOLL-0.086 \cdot TTHOT+0.126 \cdot TTGPL}} \quad \text{Equation 7.3}$$

Where P_{HOT} is the proportion of motorists that choose to utilize the HOT lanes based on external variables such as toll and travel time along the HOT lane and general purpose lane, $TOLL$ is the toll charged to motorists who opt to use the HOT facility, $TTHOT$ is travel time along the HOT lane and $TTGPL$ is the travel time along the general purpose lanes. This form of the logit model will, however, not suffice since the purpose of the logit model is to back calculate the toll that should be applied to HOT lane users. By rearranging the parameters in the equation, it can be brought to a more useful form, as shown below:

$$TOLL(t+1) = \frac{\ln\left(\frac{P_{HOT}(t+1)}{P_{HOT}(t+1)+1}\right) + 0.086 \cdot TTHOT(t) - 0.126 \cdot TTGPL(t) + 1.550}{-0.631}$$

Equation 7.4

To use the logit model in the algorithm, some assumptions must be made including; that the toll for the time step $t+1$ can be calculated using the travel time values from time step t as well as the predicted value of P_{HOT} for time step $t+1$. This assumption was made and therefore the logit model was accepted to be part of the tolling algorithm.

It is worth noting here that a logit model can be created by defining utility functions for the general purpose and the HOT lanes as the inverse of the total cost associated with traveling on that particular route. This method for logit model development was utilized in Zhang et al. (2008) with satisfactory results. However, it is the author's opinion that developing a logit model based on a stated preference survey of potential motorist's opinions with regard to tolled facilities yields better results because the model is better calibrated for the local conditions and preferences.

7.3.3 Feedback Control Mechanism

Feedback control is a simple means to control various entities and is widely utilized in the fields of mathematics and engineering. A feedback control mechanism will be used in this study to help develop a feedback-based, piecewise linear function that will calculate the proportion of vehicles that will use the HOT lanes in the following time step based on the speed on both the HOT and general purpose lanes in the current time step. The work of Zhang et al. (2008) was followed to help develop this aspect of the tolling algorithm; however, due to some apparent shortcomings certain aspects had to be modified.

Speed is generally the major indicator of performance or measure of effectiveness (MOE) on HOT facilities. This can be seen in the Washington State Route 167 pilot project where one of the limiting factors for determining the performance on the facility is that the speed remains above 45 mph (72.4km/h) (WSDOT 2008). Therefore, the tolling algorithm should incorporate the speed or travel time along the HOT lanes as one of its major factors. There are, however, cases where collecting physical speed data may not be feasible. The dynamic tolling algorithm for the MnPASS project on Interstate 394 in Minneapolis-St. Paul, Minnesota collects density data as a proxy for speed. By detecting platoons, the algorithm knows to adjust the toll upward or downward based on how the algorithm is coded (Nookala 2006). Despite the observed effectiveness of the Minneapolis HOT lanes, speed should be used as the principal MOE and therefore should be incorporated into the tolling algorithm directly and not by proxies such as density or headway. The utilization of collected speed data in a tolling algorithm should yield more accurate predictions of HOT lane usage and as a result lead to better HOT operations.

Zhang et al. (2008) state that the algorithm should be divided into three manipulation zones based on the travel speed along the HOT lanes. There must be three separate functions that would describe the operations of the facility in each of the zones. For this study, there will also be three manipulation zones and they will be initially partitioned according to their robustness. The first zone covered HOT lane speeds greater than 90 km/h. In this zone, there is ample capacity on the HOT lane and therefore the toll rate can be reduced to allow additional SOVs to enter. The second zone applied when the average speed on the HOT lane is between 90 and 70 km/h. Within this zone the operations of the HOT facility are approaching the critical state and therefore the toll should be

maintained. The third zone was defined for HOT lane speeds below the critical speed of 70 km/h; here the toll should be raised rapidly to ensure that some of the capacity can be freed to ensure smooth operations. By incorporating the three above mentioned operational zones into a feedback control mechanism, a function that predicts the proportion of SOV users that will enter the HOT facility in the next time step can be formulated as follows:

$$P_{HOT}(t+1) = P_{HOT}(t) + \Delta P_{HOT}(t) = P_{HOT}(t) + \begin{cases} b_1 + k_1(V_{HOT}(t) - V_{GPL}(t)) & \text{for: } V_{HOT}(t) > 90kph \\ sign \cdot [b_2 + k_2(V_{HOT}(t) - V_{GPL}(t))] & \text{for: } 90 \geq V_{HOT}(t) > 70kph \\ k_3(V_{HOT}(t) - 45) & \text{for: } V_{HOT}(t) \leq 70kph \end{cases}$$

Equation 7.5

Where $P_{HOT}(t+1)$ and $P_{HOT}(t)$ are the flow ratios for the HOT lane usage at time intervals $t+1$ and t , respectively; $\Delta P_{HOT}(t)$ is the feedback increment; b_n and k_n are the parameters that indicate the control intensities of the feedback quantities; $V_{HOT}(t)$ and $V_{GPL}(t)$ are the average traffic speeds along the HOT lane and the general purpose lanes, respectively; and $sign$ is a variable that defines the rise or fall of $P_{HOT}(t)$ based on the following function:

$$sign = \begin{cases} +1, & \text{for: } P_{HOT}(t-1) > P_{HOT}(t) \\ 0, & \text{for: } P_{HOT}(t-1) = P_{HOT}(t) \\ -1, & \text{for: } P_{HOT}(t-1) < P_{HOT}(t) \end{cases} \quad \text{Equation 7.6}$$

The function presented as equation 7.5 is a feedback-based, piecewise linear function with a feedback variable as the speed differential between the HOT and the general purpose lanes. The function will receive average speed data from vehicle detectors and compute the predicted flow ratio for the following time step. Then, by using the logit

model defined in section 7.3.2, the appropriate toll that should be applied to the motorists will be computed. This process will be repeated every five minutes.

Calibration of such a feedback control mechanism can be difficult due to the complexity. The details of estimating the parameters for the feedback control mechanism of this algorithm will be discussed in Section 7.5. It is important to note that even when the parameters are determined, they remain just an estimate. As a result, constant re-calibration of particular parameters may be necessary to obtain reliable results. The following section examines how this algorithm can be built upon by adding an element of self-calibration to produce more accurate results and therefore smoother and more efficient HOT lane operations.

7.4 Self-Calibration Mechanism

A dynamic and feedback based tolling algorithm was defined in the previous section. This algorithm should provide the single occupant drivers who choose to pay the toll as well as multiple occupancy vehicles with a relatively un-congested travel route along the HOT lanes. By selling off excess capacity on the HOT lanes, the average speed along the general purpose lanes should also improve. As defined previously, there are two major elements of the tolling algorithm: the feedback mechanism that predicts the proportion of HOT lane users in the following time step based on the travel conditions in the current time step, and the logit model which is used to back calculate the value of the toll based on the predicted proportion of HOT lane users as well as the travel times along both the HOT and the general purpose lanes. The logit model was calibrated to local conditions by means of a stated preference survey that polled a sample of the area residents asking them

to express their opinions regarding a hypothetical tolled facility. The feedback mechanism was only calibrated by considering the three manipulation zones. The parameters b_n and k_n in Equation 7.5 were calibrated based on the traffic speed variation and trial and error according to Zhang et al (2008). For this study, the parameters had to be slightly modified to accommodate the fact that this analysis is conducted in metric units and that the City of Ottawa is a much smaller city than, for example, Seattle, San Diego, Minneapolis, Houston or Dallas (cities that either currently have HOT facilities or a planning to implement an HOT facility). Please see Section 7.5 for a more detailed discussion regarding how the parameters in the feedback control mechanism equation were determined.

The only element in the tolling algorithm that is not accurately calibrated to local conditions is the variable $\Delta P_{HOT}(t)$ in the feedback control equation. Therefore, it will be the variable used in the self-calibration mechanism of the algorithm. After serious consideration, the author decided on two possible ways of calibrating $\Delta P_{HOT}(t)$. The first alternative involved determining the error between the predicted P_{HOT} and the actual P_{HOT} then determining one multiplicative factor that would be applied to $\Delta P_{HOT}(t)$ in subsequent time steps. The second self-calibration alternative involved recalculating each of the b_n and k_n values using simple linear regression in each self-calibration time step. The first alternative was simple and easy to apply but it did not take the robustness of each of the manipulation zones into account. The second alternative was slightly more computationally complicated; however, it did account for the differences in each of the manipulation zones in the feedback control equation. As a result, the second alternative

was pursued to re-adjust the feedback control equation's parameters in each self-calibration time step.

The self-calibration mechanism in the tolling algorithm will have to collect certain pieces of data in order for it to fulfill its intended purpose. These include the actual proportion of HOT lane users in the previous time step ($P_{HOT-ACT}(t-1)$), the actual proportion of HOT lane users in the current time step ($P_{HOT-ACT}(t)$) as well as the speeds along both the HOT lane ($V_{HOT}(t-1)$) and the general purpose lanes ($V_{GPL}(t-1)$), and the "sign" where applicable. Two variables will be computed for each time step, these are the actual difference in the proportion of HOT lane users between time steps t-1 and t as well as the speed differential. The equations defining these variables are shown below:

$$\Delta P_{HOT}(t)_{ACTUAL} = P_{HOT-ACT}(t) - P_{HOT-ACT}(t-1) \quad \text{Equation 7.7}$$

$$\Delta V_{HOT-GPL} = V_{HOT}(t) - V_{GPL}(t) \quad \text{Equation 7.8}$$

The variables b_n and k_n will be recomputed for each manipulation zone using OLS linear regression. This can be expressed as follows:

$$k_n^* = \frac{\sum \Delta V_{HOT-GPL} \Delta P_{HOT}(t)_{ACTUAL} - \frac{(\sum \Delta V_{HOT-GPL}) \cdot (\sum \Delta P_{HOT}(t)_{ACTUAL})}{N_n}}{\sum (\Delta V_{HOT-GPL})^2 - \frac{(\sum \Delta V_{HOT-GPL})^2}{N_n}} \quad \text{Equation 7.9}$$

$$b_n^* = \Delta \bar{P}_{HOT}(t)_{ACTUAL} - k_n^* \cdot \Delta \bar{V}_{HOT-GPL} \quad \text{Equation 7.10}$$

Where k_n^* and b_n^* are the recomputed control intensity parameters, $\Delta P_{HOT}(t)_{ACTUAL}$ and $\Delta V_{HOT-GPL}$ were defined in Equations 7.7 and 7.8 respectively, and N_n is the number of data points that correspond to the appropriate manipulation zone. This recalibration

procedure may not apply to all of the three manipulation zones. In the case where there are too few data points that apply to a certain manipulation zone, the recalibration step will be skipped for that manipulation zone only. Following multiple runs, when a reasonable amount of data is collected for the deficient manipulation zone, the recalibration procedure will then be applied.

Following the re-calibration of parameters, the algorithm should more accurately predict the number of vehicles that will be shifting to the HOT lanes. This should result in more realistic predictions by the algorithm and therefore smoother and more efficient HOT lane operations.

7.5 Preparation for Modeling

Before the algorithm can be tested by applying it in a microsimulation environment, certain operational features and parameter values must first be established. To simplify operations of the HOT facility, it was decided to charge a toll that had a value that was a multiple of \$0.25 also, the toll was always rounded up to the closest quarter. The minimum toll that was charged was \$0.25 and the maximum toll was \$6.00. For example, if the algorithm calculated that the applied toll should be \$0.11, the displayed toll would have been \$0.25 or if the calculated toll was \$1.01, the charged toll would have been \$1.25 and if the calculated toll exceeded \$6.00, the displayed and charged toll would have only been \$6.00. This provision is made to simplify the process of charging the toll. Also, the tolling algorithm itself will re-compute the toll that should be applied to users every 5 minutes, while the self calibration mechanism will only take effect every 4 hours. There are many other provisions that have to be made prior to the modeling process,

since many of these do not directly apply to the tolling algorithm itself, they will be discussed in Chapter 8.

The parameters in the logit model were determined as a result of calibration of the model by means of data collected from a stated preference survey and binary logistic regression modeling. The parameters in the feedback control function could not be so easily calibrated. As a result, the values determined by Zhang et al. (2008) were used as a starting point. The following discussion pertains to how the parameters in the feedback control equation were developed.

In their paper, Zhang et al. (2008) calibrated the feedback control mechanism based on the specific “traffic speed variation range” as well as “efforts of trial and error.” As a result, the parameters were assigned the following values: $b_1 = 0.075$, $k_1 = 0.005$, $b_2 = 0.024$, $k_2 = 0.0012$ and $k_3 = 0.03$. They justified their efforts by showing that the above presented values resulted in reasonable results. To utilize these values in this study, they had to be modified in order to accommodate that the analysis is conducted in metric units and that the population of Ottawa is much smaller than that of Seattle, WA (where the Zhang et al. (2008), study was conducted). The k_n values were modified by multiplying each by the ratio of km/h to mph, the value of this factor was 0.6214. The b_n values were modified by multiplying each by the ratio of the population of the City of Ottawa by the population of Seattle, WA, the value of this factor was 0.5. Since the population of Seattle, WA is roughly twice the size of the City of Ottawa, an approximate value of 0.5 was used to adjust the b_n parameters. As a result, the following control intensities for feedback elements were used in the initial stages of this study: $b_1 = 0.038$, $k_1 = 0.003$, b_2

$=0.012$, $k_2 = 0.0007$ and $k_3 = 0.018$. The reasonableness of these values can be shown by the following calculations:

$$V_{HOT} = 100 \text{ km/h}; V_{GPL} = 90 \text{ km/h}; \Delta P_{HOT} = 0.038 + 0.003 \cdot (100 - 90) = +6.80\%$$

$$V_{HOT} = 100 \text{ km/h}; V_{GPL} = 60 \text{ km/h}; \Delta P_{HOT} = 0.038 + 0.003 \cdot (100 - 60) = +15.80\%$$

$$V_{HOT} = 90 \text{ km/h}; V_{GPL} = 80 \text{ km/h}; \Delta P_{HOT} = 0.012 + 0.0007 \cdot (90 - 80) = \pm 1.90\% \quad \text{Equation 7.11}$$

$$V_{HOT} = 90 \text{ km/h}; V_{GPL} = 50 \text{ km/h}; \Delta P_{HOT} = 0.012 + 0.0007 \cdot (90 - 50) = \pm 4.00\%$$

$$V_{HOT} = 65 \text{ km/h}; V_{GPL} = (N/A) \text{ km/h}; \Delta P_{HOT} = 0.018 \cdot (65 - 70) = -9.00\%$$

$$V_{HOT} = 55 \text{ km/h}; V_{GPL} = (N/A) \text{ km/h}; \Delta P_{HOT} = 0.018 \cdot (55 - 70) = -27.00\%$$

It can be seen that when the average speed on the HOT lanes exceeds 90 km/h, the proportion of HOT lane users will increase in the following time step according to the speed differential between HOT and general purpose lanes. When the average speed on the HOT lanes approaches the critical level, the proportion of HOT lane users in the following time step will either rise or fall based on the value of “sign” but at a slower rate. When the speed on the HOT drops below the critical level, the feedback control mechanism will always decrease the number of HOT lane users added based on how far below the critical level the HOT lane speed is.

It is the opinion of the author that while parameters determined through definition of manipulation zones and the efforts of trial and error, and validated by only showing that results are reasonable is a satisfactory starting point. However, these values should be calibrated when actual data becomes available. This will be the purpose of the self calibration mechanism incorporated into the tolling algorithm.

7.6 Summary

In this chapter, the process for developing a tolling algorithm was demonstrated. Figure 7.3 illustrates the various aspects of the tolling algorithm including the feedback control mechanism, the toll computation based on a logit model and the self-calibration mechanism based on OLS linear regression.

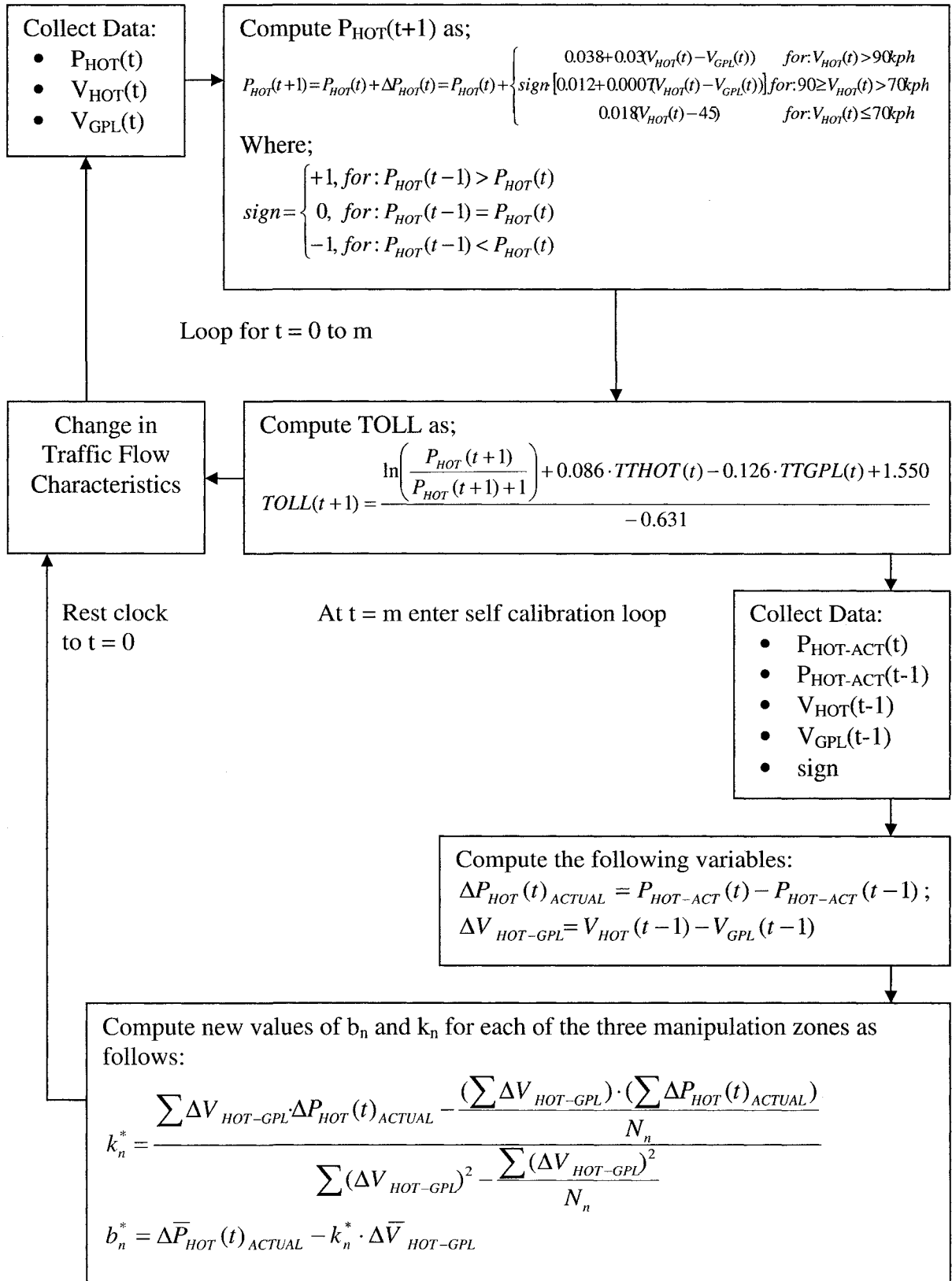


Figure 7.3 A schematic of the tolling algorithm for HOT lane operations

Chapter 8

Simulation of HOT Lane Operations: Evaluation of the Tolling Algorithm

8.1 Introduction

A dynamic and feedback based tolling algorithm was developed for the Ottawa region based on principles of feedback control and discrete choice modeling. Since there were elements within the algorithm that could not be calibrated to local conditions at the onset; a self-calibration mechanism was added to complement the tolling algorithm. The self-calibration mechanism was formulated to collect the appropriate data and then recalculate the control intensity parameters in the feedback control function based on OLS linear regression.

It is important to demonstrate that such an algorithm will in fact provide benefits to users of the applicable corridor. Physical testing is extremely costly and modern computer microsimulation has become easily accessible and does not require extensive coding (in most cases) and is not computationally excessive. As a result, traffic microsimulation will be used to validate the tolling algorithm for a hypothetical high occupancy toll lane in the Ottawa region.

This chapter provides a discussion of the validation process for an HOT lane tolling algorithm. The microsimulation software chosen for this task was VISSIM, the following discussion deals with preparation of the VISSIM network for simulation, various methods for simulating HOT lane operations employed elsewhere, as well as other aspects of the algorithm validation process that are required.

8.2 Simulation Methods

The concepts of congestion pricing and HOT lanes are not new, as noted earlier the problems with these concepts regards the fact that there was no adequate technology to facilitate building such facilities. Currently the available technology is at a level where implementing a variable (or congestion) pricing scheme is feasible, be it on an HOT lane, a cordon or area wide system. The feasibility of implementing such systems gives rise to new problems such as, how to simulate these facilities. Many of the newer microsimulation packages, such as VISSIM or Paramics, are capable of incorporating various types of intelligent technologies and ITS into the simulation itself. The microsimulation platform provides a cost effective means of measuring the effectiveness of certain technologies, facilities and systems. In this study, VISSIM will be used to model HOT lane operations.

According to PTV America, there are three ways that one can model the operations on an HOT lane: using static routes, using dynamic routes with a choice model and using dynamic traffic assignment with a choice model. The method used will ultimately depend on a number of factors including scheduling, budget, the available data as well as the purpose of the analysis (Dale, 2007). For a detailed description of the possible methods for simulating HOT lane operations, please see Section 2.6.

The aforementioned techniques for simulating HOT lane operations are good for modeling static operations or dynamic operations one step at a time. There are also innovations in modeling dynamic operations of HOT facilities such as the use of dynamic tolling algorithms. PTV America developed an HOT lane module for VISSIM that, as of

writing this report, is not yet available to the public. The module utilizes user input measures of effectiveness to designate the proper toll to the system and uses the NEMA controller to adjust the toll rate based on the conditions experienced in the simulation (Dale, 2007). In another study by Zhang et al. (2008a), a module was developed specifically for modeling a dynamic and feedback based tolling algorithm on an HOT lane. This module was developed using the COM interface, which allows for external programs, such as Microsoft Visual Basic, to execute certain functions in VISSIM. The module employs user specified traffic detectors in the simulation model to collect data, the data is then sent to the Visual Basic module and the proper calculations are done and the optimal toll rate is determined. Using the COM interface, the system can then be updated with the new toll rate. A logit model is then used in the module to determine the number of vehicles that will use the HOT lane and the number that will stay on the general purpose lanes (Zhang et al. 2008a). As with the PTV America module, this application is also not available to the public.

In this study, it was important not to rely on a user specified route choice model to determine the number of HOT and general purpose lane users. As a result, the above mentioned simulation techniques could not be applied. By using a non-user specified route choice model, the simulation could model unknown conditions and traffic patterns. In this case, the self-calibration mechanism could be shown to be either effective or ineffective. To fulfill this need, the dynamic traffic assignment mechanism, within VISSIM, was calibrated so that realistic results could be achieved and the simulations were run using solely the dynamic assignment's built in route choice mechanism. This will be discussed in further detail in Section 8.3.2.

8.3 Control and Simulation Process

To test the tolling algorithm developed in Chapter 7, the proper network was coded and calibrated then the simulations were run, keeping track of the algorithm's performance in a Microsoft Excel spreadsheet. The design year network, 2016, was used for the algorithm testing procedure although some features had to be adjusted to successfully simulate the HOT facility. VISSIM's built in route choice mechanism was used to divert solo drivers from the general purpose lanes to the HOT lane. Also, various dampers were tested to examine their effects on the tolling algorithm and the traffic stream. The simulations were run statically (i.e. one 5 minute interval at a time) while the algorithm was run in a spreadsheet. This section explains the process for coding the design year network as well as how the route choice mechanism was used for HOT lane algorithm testing purposes. The process of applying various dampers to the algorithm is discussed in this section, in addition to a discussion of how the microsimulation of the HOT facility was completed and how the data was collected.

8.3.1 Coding the HOT Network

The study area was an approximately 10 km long section of Highway 417 in Ottawa, ON, between the Palladium Drive interchange and the Moodie Drive interchange. The physical geometry of the study area was discussed in Section 4.2.1 and will not be repeated here. There were, however, a few differences between the base year network (2000) and the design year network (2016). As of approximately 2003, a new interchange was added at Castlefrank Road, with one direct on-ramp in the east-bound direction and one off-ramp in the west-bound direction. Also, in 2007, work had begun to convert the section of Highway 417 between Highway 7 and Highway 416 from a four lane highway

to a six lane highway with two additional HOV lanes between Palladium Drive and Moodie Drive. Both the Castlefrank Road interchange and the additional lanes were incorporated into the design year simulation network.

The 2016 network was coded in the same way that the base year network was coded; using aerial photographs and information provided by the Ministry of Transportation of Ontario (MTO, 2003) (Please see section 4.3). The HOT lane was coded as three separate sections: two entrance/egress areas at both ends of the network and two intermediate merging/diverging areas. The layout of the HOT facility, as it was coded into the VISSIM model, can be seen in figure 8.1.

The HOT lanes were coded into the network as separate links only connected to the general purpose links at the merging areas. The distance between the HOT lanes and the general purpose lanes was kept minimal, so there would be only a miniscule difference in travel distance between the two. This was done to simulate the painted stripe buffers that vehicles are forbidden to cross under penalty of a traffic citation. This technique could also be used to simulate concrete barriers on HOV or HOT lanes.

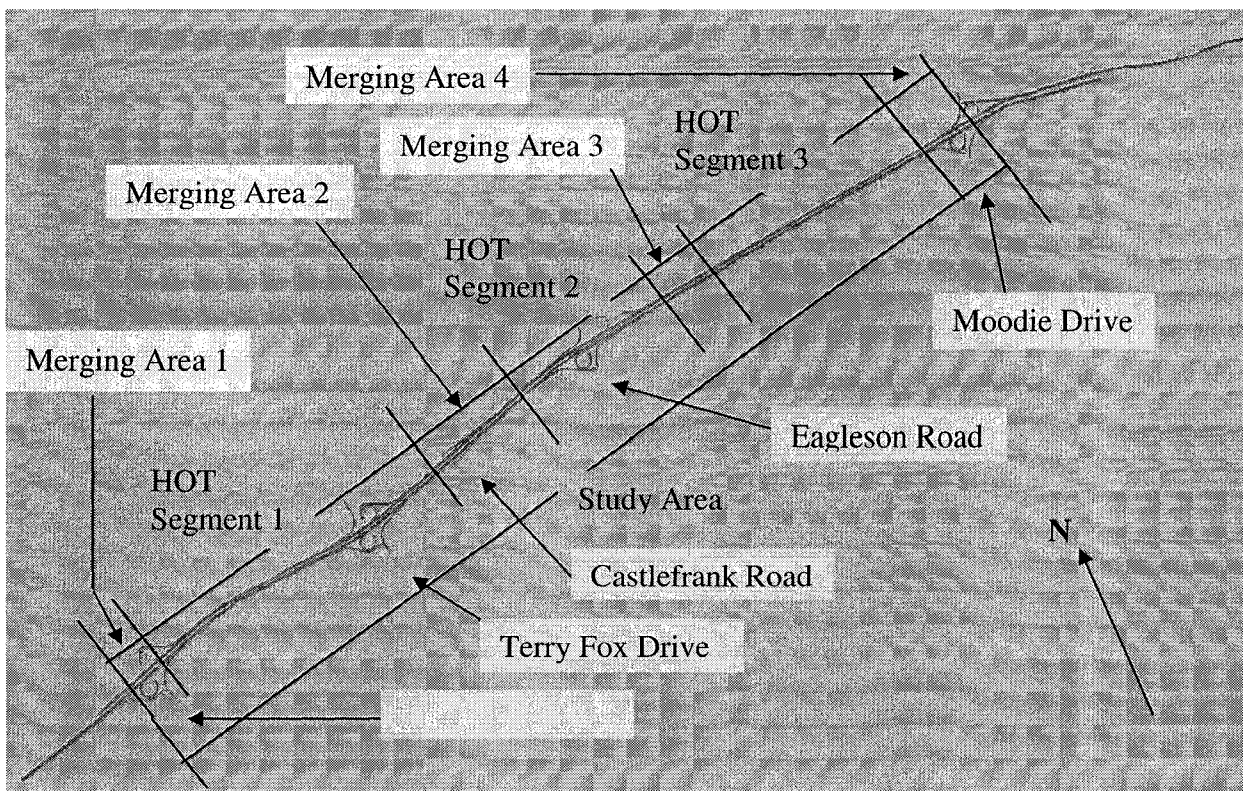


Figure 8.1 Depiction of the HOT facility on highway 417 in Ottawa, ON

According to the MTO's preliminary design report for the Highway 417 reconstruction (MTO, 2003) and Mr. David Lindensmith, a senior project engineer with the MTO, the HOV lanes will begin at 0.4 km west of Palladium Drive and end at the Moodie Drive structure in the east-bound direction and begin 1.9 km west of the Moodie Drive structure and end at the Palladium Drive structure in the west-bound direction. There will be two intermediate merging areas for vehicles to enter/exit the facility: one between the Terry Fox Drive and Eagleson Road Interchanges and the other between the Eagleson Road and Moodie Drive Interchanges. When coding the system for HOT lane operations, some minor adjustments were made to the entrance/egress areas. Merging area 1 in the east-bound direction started at the Palladium Drive structure and merging area 4 in the west-bound direction began at the Moodie Drive structure. Very little was specified in the MTO's report regarding the length of HOV/HOT merging areas, so additional

information was required. HOV lane design guidelines were found, care of the CaDOT (2003) and recommendations regarding the merging areas were used to design the HOT network for this study. A diagram illustrating the recommended practices for designing HOV ingress/egress points is shown in Figure 8.2.

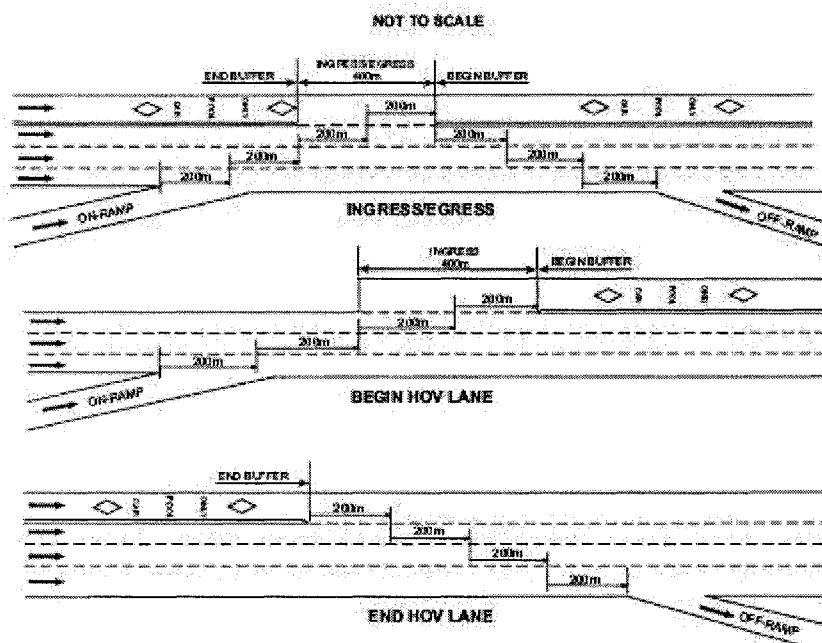


Figure 8.2 Weaving distances for buffer separated HOV facilities (Image Courtesy of CaDOT, 2003)

Using the CaDOT (2003) guidelines, the weaving areas on the HOT facility were designed to be a minimum of 400m long and a minimum of 200m multiplied by the number of lanes away from the closest on or off-ramp. The only exception was merging area 2, where the weaving area length was increased to approximately 1000m to accommodate traffic entering the highway from the Castlefrank Road Interchange in the eastbound direction.

The base year network was calibrated earlier in the study; the calibration procedure was explained in Chapter 5 and will not be repeated here except to say that the driver

behaviour parameters and merging/diverging lane characteristics were carried over from the base year network to the design year network.

The 2016 forecast volumes outlined in Chapter 4 were used in the design year network. However, it was found that using 100% of the 2016 forecast volumes did not create enough traffic congestion for an HOT lane to be warranted. It was decided to use a four hour peak period for the final simulation runs and the volume of traffic on the network varied from 80% to 180% of the 2016 forecast volumes discussed earlier. The assumed distribution of the design year traffic volume according to the percentage of the forecast 2016 traffic volume is shown in Figure 8.3.

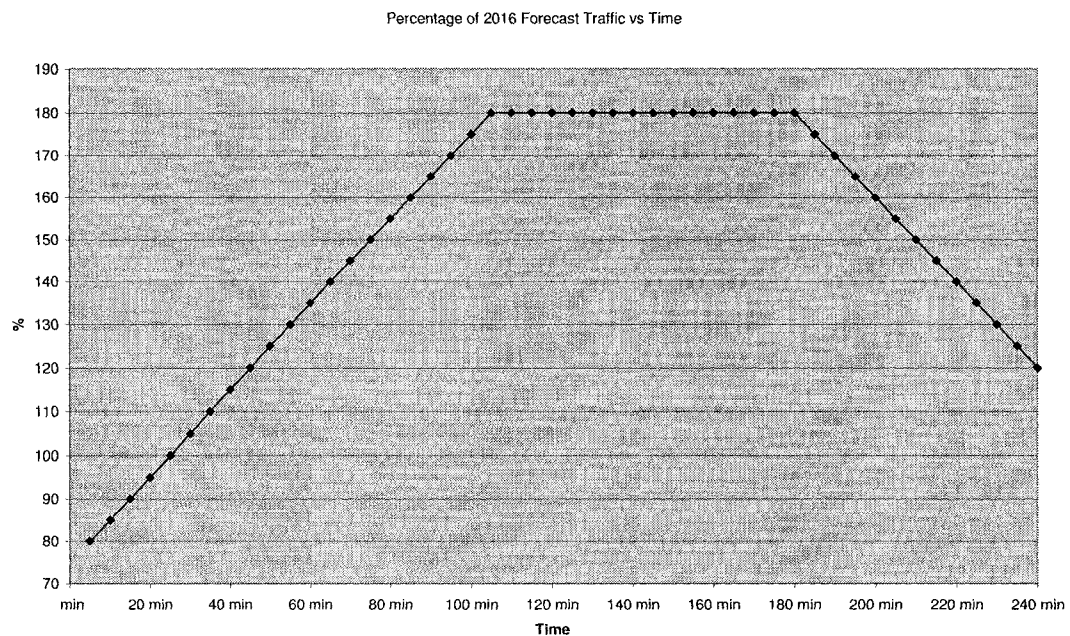


Figure 8.3 The assumed distribution of the design year traffic volume according to the percentage of the forecast 2016 traffic volume

Traffic detectors were modeled in the simulation as data collection points. Data collection points were strategically placed upstream of each merging zone on the general purpose lanes and downstream of each merging zone on the HOT lane. This configuration

allowed for the proper data to be collected at the most important sections on the network, and facilitated the use of the algorithm to control the traffic entering the HOT lane.

8.3.2 Dynamic Assignment

It was decided to use the dynamic assignment feature in VISSIM to control how vehicles will interact with the HOT lane facility. This decision was reached as dynamic assignment techniques allow for more flexibility than the use of static routes or even dynamic routes. It was important to find a method for simulating HOT operations without having to specify an external route choice function. Dynamic assignment allowed the author to simulate conditions that were unknown, to study whether the self-calibration mechanism would in fact create an improvement in the network. The following is a discussion of how standard dynamic assignment conventions and parameters were adjusted to obtain realistic results for a network with an HOT lane.

In VISSIM, the link and connector properties can be easily modified. Many properties can be adjusted by the user including lane width, grade, lane closures and cost to drivers. The first step in preparing for simulations was to close certain links and connectors to certain vehicle types. All of the links in the merging areas were closed to heavy goods vehicles (HGV) and left open to cars and HOVs. The downstream connectors that link the merging areas with rest of the HOT facility were also closed to HGVs, this feature tells prohibited vehicles that they cannot enter and subsequent links downstream of the closed connector. When testing the facility as an HOV lane, the links in the merging areas and the connectors leading to the HOT lane were also closed to single occupancy cars.

The properties of all the various vehicle types can also be modified in VISSIM. The parameters that can be modified include: length, width, vehicle model, emission data, maximum and desired acceleration and deceleration, parking lot selection and sensitivity to cost. In dynamic assignment applications, the route chosen by a vehicle is determined based on the general cost of each route (PTV, 2007). In VISSIM, the general cost of a route is calculated as follows:

$$general_cost = \alpha \cdot travel_time + \beta \cdot travel_distance + \gamma \cdot financial_cost + \sum supplement2$$

Equation 8.1

Where α , β and γ are parameters defined by the user that correspond to the sensitivity of the particular vehicle type to travel time, travel distance and financial cost, respectively. Supplement2 is an additional cost value that is added to the general cost equation by VISSIM.

The parameters in the dynamic assignment mechanism within VISSIM can be adjusted to facilitate the simulation of HOT facilities in the following way. First, the sensitivity to financial cost must be calibrated in order to produce realistic results. This was done by running the simulation with various values of γ while keeping the link cost on the HOT lanes constant and the α parameter at its default value. The values of γ that were tested were: 10, 50, 100, 200 and 350 and the link cost that was used was \$1.00 for the entire 10km long HOT lane. It was found that at lower sensitivities (10 and 50) too many cars would opt to use the HOT lane while at higher sensitivities (200 and 350) not enough cars chose to drive on the HOT lane. As a result, the γ value selected for the “cars” vehicle

class was 100. A summary of all the parameters used by the dynamic assignment mechanism in VISSIM are shown in table 8.1.

Table 8.1 Dynamic assignment parameters used in the simulation of the HOT facility

Vehicle Type	α	β	γ	HOT links and connectors
Cars	1	0	100	Open
HOV	1	0	0	Open
HGV	1	0	0	Closed

By configuring the links and connectors as well as the dynamic assignment parameters as described in Table 8.1, the operation of the HOT lane produced realistic results. This method was chosen because the route choice mechanism was not user specified. This was important to the study, seeing as the algorithm including the self-calibration mechanism was required to operate independently of any route choice model in order to be tested properly. This method was also found to be easier to use than specifying an external route choice mechanism and applying through the COM interface.

8.3.3 External Damping Mechanism

A damper is a device or mechanism used to restrain or to a certain degree suppress some external process. For the case of the tolling algorithm on an HOT lane, a damper was applied to ensure that the changes in the toll rate did not rise or fall too abruptly. It was also important that the changes in the traffic characteristics did not result in major fluctuations in toll value and traffic speed. Although, it was inevitable that fluctuations would occur, the role of the damper was to ensure that the fluctuations were not extreme.

To help visualize the role of the damper in HOT lane tolling algorithms, consider changing the average speed on an HOT lane from 35 mph to 45 mph, as shown in Figure 8.4. An under-damped tolling algorithm may elicit unfavourable results in the form of

major fluctuations due to its oversensitivity; an under-damped system will react to changes rapidly. An over-damped tolling algorithm can generate unfavourable results in the form of response delays; as a result, over-damping results in fewer fluctuations. The aim should be to achieve a tolling algorithm that is critically damped because it will control traffic stably and it will not result in delayed reactions to traffic conditions. (Zhang et al. 2008)

The goal in this part of the study was to find a method to dampen the reaction of the tolling algorithm by some external means and test it to determine if there is a benefit to applying such a mechanism.

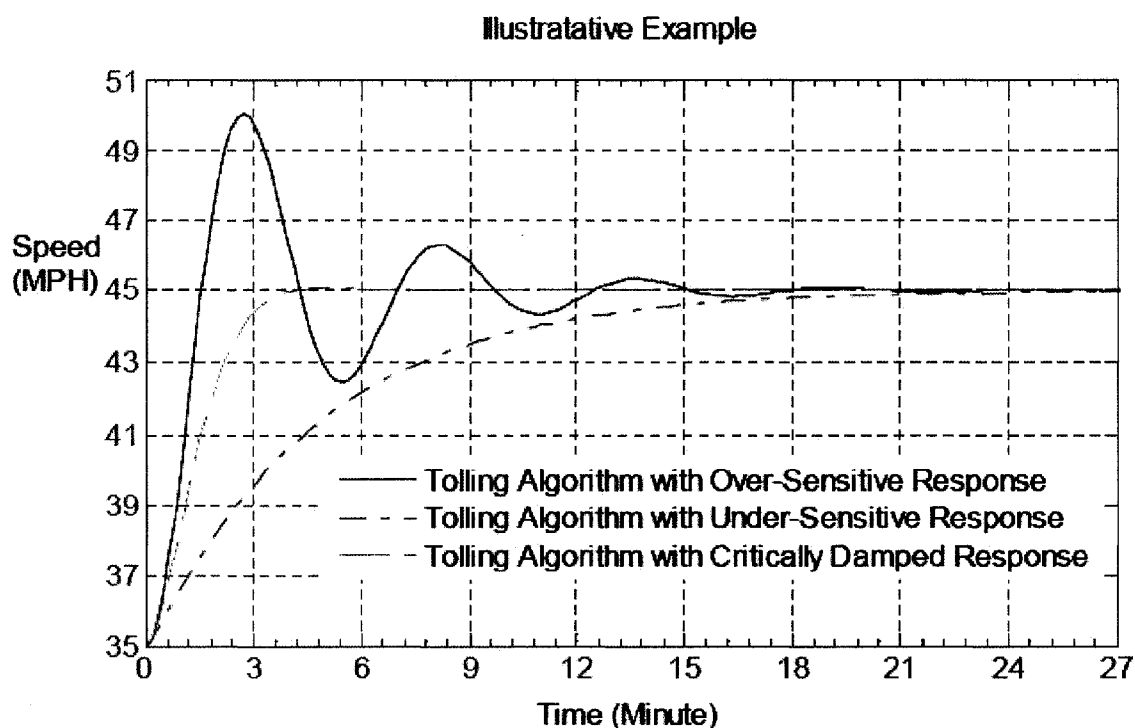


Figure 8.4 An illustrative example of speed responses under various damping responses (Image Courtesy of: Zhang et al. 2008)

The external damper that was tested here was motivated by the capacity restraint traffic assignment method developed by the FHWA. The method involves using free flow times

to determine minimum time paths and assigning the traffic in the all or nothing method, then calculating the travel times along the arcs as a function of free flow travel time, volume and the practical capacity. The new minimum time paths are then calculated by adding 75% of the previous travel time to 25% of the new travel time. This process is repeated with the new travel times about four times and then the volumes are averaged to determine the traffic on each arc (Morlok, 1978).

The damper that was applied to the tolling algorithm in this study took the following form:

$$TOLL(t) = A \cdot TOLL(t-1)_{Calculated} + B \cdot TOLL(t)_{Calculated} \quad \text{Equation 8.2}$$

Where, $A + B = 1$

The following combinations of A/B were used in the test scenarios: 0/1, 0.10/0.90, 0.25/0.75, 0.40/0.60, 0.50/0.50 and 0.75/0.25. The different scenarios were compared in terms of HOT lane speed, general purpose lane speed, combined speed and toll. It was found that the scenario where A/B was 0.75/0.25 did not produce any benefits and the scenario where A/B was 0.40/0.60 showed no difference from the scenario where A/B was 0.50/0.50; as a result, both cases were removed from the evaluation. Figures 8.5, 8.6 and 8.7 illustrate the results of the performance evaluation of the various damping scenarios.

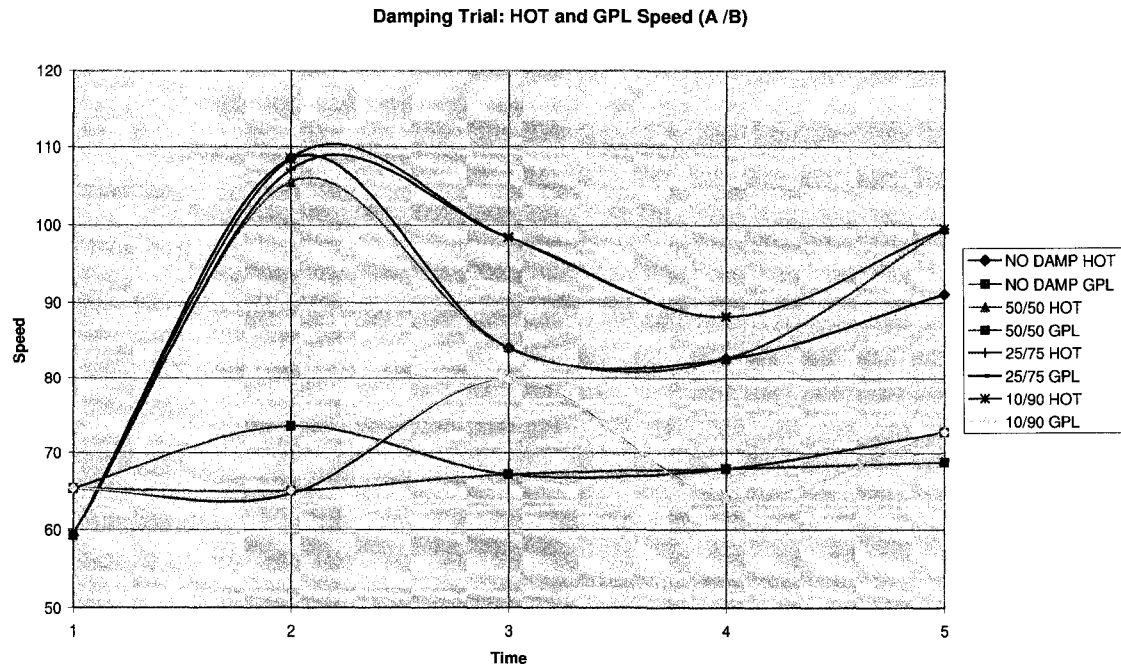


Figure 8.5 Average HOT and General Purpose lanes speeds under various damping scenarios

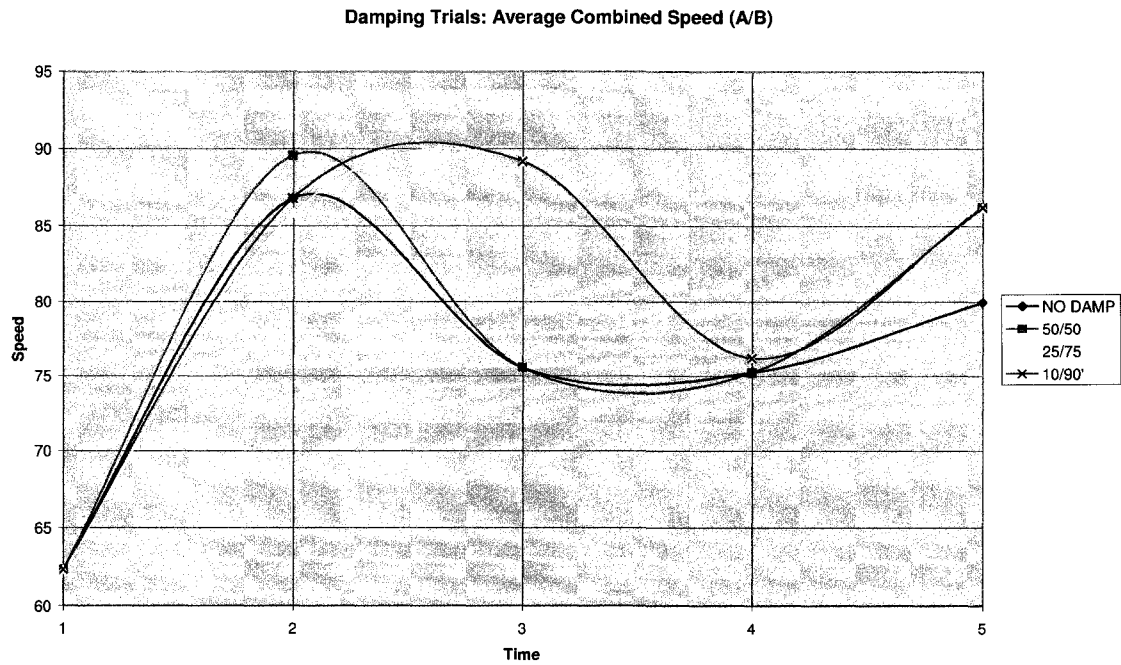


Figure 8.6 Average Combined speed under various damping scenarios

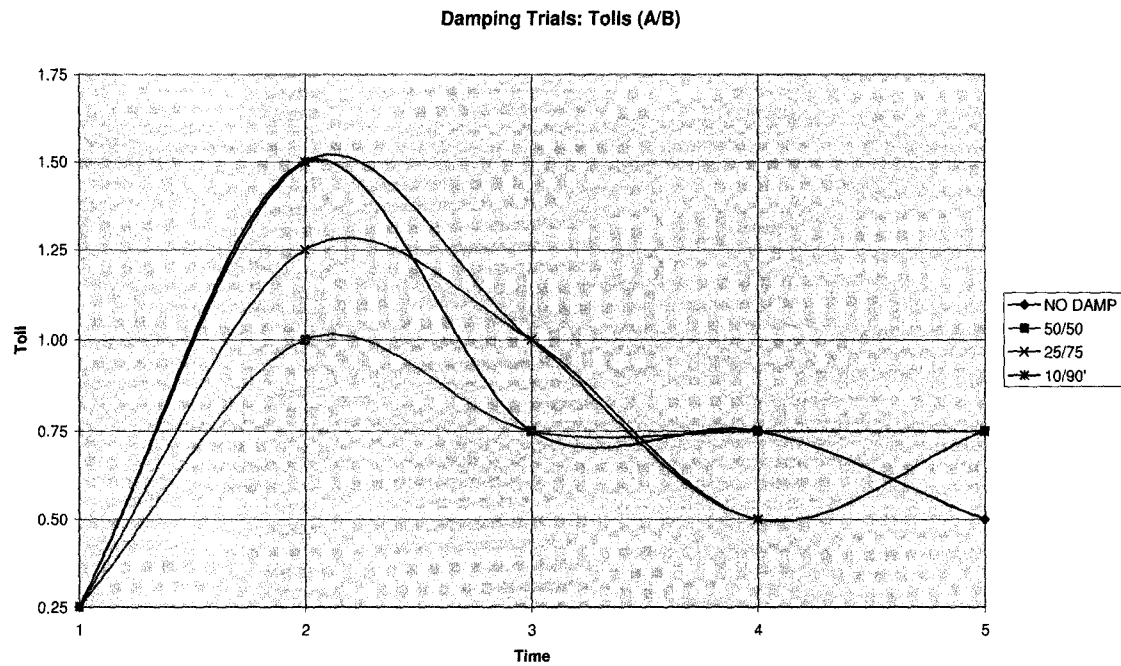


Figure 8.7 Toll changes under various damping scenarios

To evaluate the various damping scenarios, simulations were run in VISSIM and each scenario was conducted in five time steps. The initial time step was set up in a way that very unfavourable results would be experienced and in the remaining four time steps the algorithm combined with the damper would bring the performance of the system to a satisfactory level. It was found that the cases where A/B was 0.50/0.50 and 0.25/0.75 were the best in terms of smooth and stable transitions between speed levels. However, the A/B = 0.25/0.75 scenario offered the most overall benefits in terms of speeds on the HOT and general purpose lanes as well as the combined speed. The A/B = 0.50/0.50 scenario did offer the smoothest transitions; however, it was decided that the other benefits, such as improved speeds, that the A/B = 0.25/0.75 scenario offered outweigh the smooth transitions. As a result, a damper was used for subsequent simulation runs and the values of A and B were 0.25 and 0.75, respectively.

8.3.4 Running the Simulations

The simulation process was done statically i.e. each time step was simulated separately. Due to time and financial restraints a dynamic simulation was not conducted. Also, the modules that help to simulate HOT lane operations are not yet available to the public. As a result, in order to simulate the HOT lane operations dynamically, an HOT lane simulation module would have to be created. Since this study was not focused on the development of a VISSIM module for HOT lane operations, the static time slice simulation approach was taken.

Each five minute interval was simulated using VISSIM; the network was given ample time to populate (25 simulation minutes), before the appropriate data was collected and used in the tolling algorithm. The algorithm was run from a Microsoft Excel spreadsheet that was designed to take the appropriate input data from the traffic simulation and then compute the value of the toll that should be charged in the following time step. The toll value was then input into the VISSIM model and the simulation was run again. This process was repeated 48 times, to simulated four hours of peak period traffic. The percentage of the 2016 volumes was also increased or decreased in each time step according to Figure 8.3.

Once all of the data for a four hour peak period was collected (speeds on HOT and general purpose lanes and proportions of HOT lane users) it was used to re-calibrate the parameters in the feedback control mechanism of the tolling algorithm. The appropriate data was used to recalculate the parameters using linear regression. The new parameters were then incorporated into the following four hour simulated peak period and the

process was done again using the re-calibrated values. For subsequent runs of the self-calibration procedure the appropriate data from all the previous simulation runs was pooled to re-calibrate the feedback control parameters.

8.4 Operational Issues

Prior to commencement of the simulation process, there were many operational issues that were identified. Throughout the initial simulation runs, many of the issues were resolved; however, certain other issues could not be resolved or incorporated into the model for various reasons. The following discussion deals with some of these operational issues.

One issue that was identified early on in the simulation process was ensuring that drivers pay the price that they see posted on the variable message signs and not pay the toll for the following time step. This type of problem may occur if there is considerable congestion upstream of a merging area for the HOT lane. In this case, a particular motorist may see that the toll posted is of value \$X but because of the congestion, by the time this motorist reaches the merging area and the toll collection gantry, the value of the toll could have already increased to \$Y. This could potentially be an issue for the agency in charge of operating the HOT lane.

There are a few solutions to the problem some of these are simple and some more complicated. One solution is to simply place signs at each merging area that the toll posted can change at any moment and drivers should be aware that the toll they observed on the DMS upstream of the HOT lane entrance may not be the toll they will pay to use the facility. Another possible solution is to use larger DMS that are legible from farther

away but are placed adjacent to the toll collection gantry. This way, even if the toll is changed as a particular motorist is about to enter the facility he/she will be aware of the changed toll rate. The final solution is to increase the toll change time interval dynamically by adding an interval modification mechanism to the tolling algorithm. Consider the illustration in Figure 8.8, where vehicle v1 observed the DMS where the current toll rate, \$X, is displayed from a distance $d1$. Assume that the tolling algorithm interval is reaching the end of the regular five minute interval, and by the time v1 reaches the toll collection gantry, the toll rate will be changed. The traffic detectors determine the average travel speed of the traffic stream, V_t . The distance from the point where the current toll rate on the DMS is visible to the toll collection gantry is known and the value is: $d1 + d2$. The mechanism would then compute the time it should take vehicle v1 to drive to the toll collection gantry as: $t1 = (d1 + d2)/V_t$. The toll on the DMS will then be changed to that of the next interval, \$Y, while the toll collection gantry will continue to collect the toll computed for the current time step, \$X, for a time of $t1$ beginning at the end of the current five minute interval.

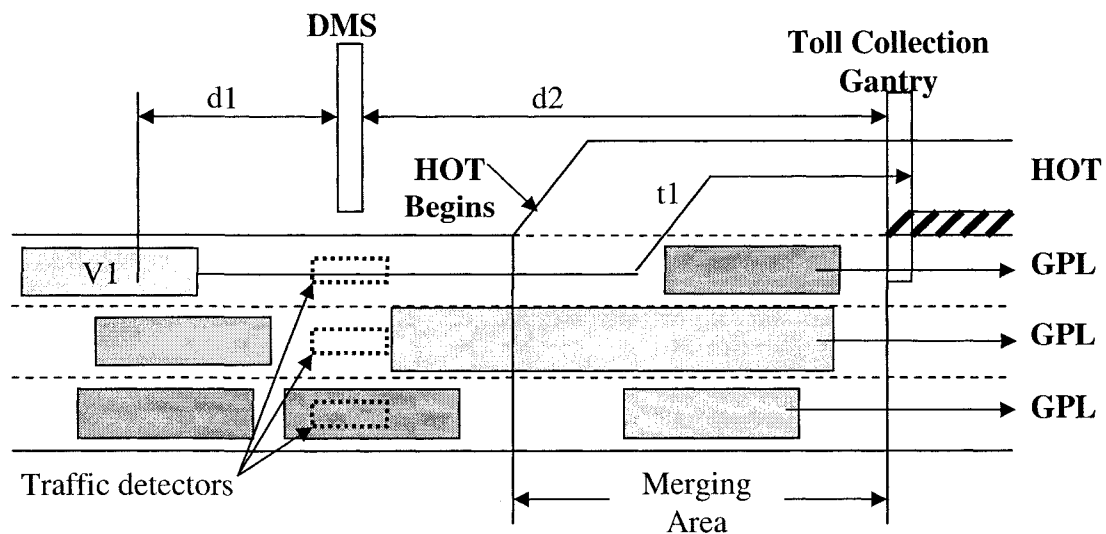


Figure 8.8 Illustration of an HOT Lane merging area and placement of DMS

Ideally, the time interval modification mechanism would be incorporated into the tolling algorithm; however this method is complicated and could potentially add to the cost of the system. In the simulations, it was assumed that a DMS was placed adjacent to the toll collection gantries so that as drivers enter the HOT facility they can see the toll that they are being charged. This method simplified the simulation process considerably and it was decided that this technique would be adequate for the study area. In other areas, the simplified techniques may not be satisfactory; in which case, it is recommended that a time interval modification mechanism be considered. In addition, this technique could only be tested under dynamic HOT lane simulations which were not used in this study.

Another operational issue that was identified early in the process of developing a tolling algorithm was the problem associated with merging areas, especially those located on the left hand side of a highway. In the simulations, this did not pose much of a problem; however, during regular operations of an HOT lane, this may cause unsafe conditions. Since drivers are moving into and out of the left lane, the speed along the left general purpose lane may vary considerably. It is recommended to ensure that proper signage is erected so that drivers are aware of merging areas. In this way, drivers will know to slow down slightly to allow for safe operations of the facility.

8.5 Summary

A dynamic, feedback-based and self-calibrating tolling algorithm was developed to help control the operation of high occupancy toll lanes. The algorithm was validated using the microsimulation software VISSIM. HOT lanes can be simulated in VISSIM a variety of ways. Static simulations required each algorithm time step to be simulated separately

while dynamic simulation involves complex modules to be built onto the existing VISSIM platform. The time-slice static method was used to validate the tolling algorithm in this study because of time and financial constraints. Despite its simplicity, the static simulation was used to successfully simulate HOT lane operations under the control of a dynamic tolling algorithm. VISSIM's built in route choice mechanism, dynamic assignment, was used to determine how many vehicles would use the HOT lane. This method was chosen over traditional external route choice models because it was important that there was no correlation between the route choice model and the logit model in the tolling algorithm and also because the results of VISSIM's route choice were unknown and therefore the self-calibration mechanism could be better tested. An external damper was used to ensure that the tolls changed smoothly and the algorithm responded rapidly. The results of the simulations are presented in the following chapter.

Chapter 9

Effectiveness of the Tolling Algorithm

9.1 Introduction

Managed lanes are currently operational in many North American cities and are controlled by various mechanisms. For example a static toll schedule is in effect on the State Route 91 express lanes in Orange County, California (www.91expresslanes.com) and a dynamic tolling structure is used on Minneapolis' MnPASS Lanes (Nookala, 2006). However, at this point in time there is no toll structure that is based on a dynamic, feedback-based and self-calibrating tolling algorithm. As a result, such an algorithm was developed in this study based on principles of microsimulation, discrete choice modeling, feedback control theory and OLS linear regression.

The process for development of the algorithm was described in Chapter 7 and the methodology and theory of simulating HOT lane operations for the purpose of evaluating a tolling algorithm was discussed in Chapter 8. In this chapter, the results of the evaluation are presented and discussed. The tolling algorithm was evaluated based on many criteria but primarily on the average speeds experienced on the HOT and general purpose lanes and the toll rates charged to the motorists.

9.2 Simulation

The process used to simulate the HOT lanes was explained in the previous chapter, including how the experiment was set up and how VISSIM was calibrated. The experiment consisted of three, four hour (simulated time) simulations of AM peak period traffic in the east-bound direction. In the first simulation, the control intensity parameters

(b_n and k_n) were set to the values described in Section 7.5. In the second simulation, the parameters were re-calibrated using the data collected in the first simulation run. The third and final simulation was conducted with control intensity parameters re-calibrated based on the data collected in the first two simulations.

In the following sections, the issues encountered while running the simulations will be discussed. The initial simulation runs refer to the simulations done prior to beginning the evaluation process of the tolling algorithm while the final simulation runs refer to the simulations used to evaluate the tolling algorithm.

The initial simulation runs were conducted to test if the simulated HOT facility could be controlled by the algorithm as discussed in Section 8.3.4. Also, the entire network was observed under various traffic volume intensities to determine if the vehicles were behaving realistically. It was found that the algorithm could successfully control the operations even though the simulations were run statically and the algorithm was run in a Microsoft Excel spreadsheet. It was noticed that there was considerable congestion on and around the merging areas for the HOT lane, this was expected.

The final simulations were run to collect the final data for the analysis of the dynamic assignment parameters which were assigned values, as discussed in Section 8.4.2. The full four hour (simulated time) run was conducted three times, after each run the values of the control intensity parameters were re-calibrated according to the self calibration mechanism. The following section describes the results obtained from the final simulation runs.

9.3 Effectiveness of the Tolling Algorithm

The tolling algorithm was tested against various measures of effectiveness (MOE) to determine whether it did provide some benefit to the traveling public. The MOEs used to determine if the tolling algorithm used on the HOT lane provided benefits were: speed on the HOT lane, speed on the general purpose lanes, combined weighted speed on all lanes, toll rate and traffic volume along critical sections of the HOT corridor. The speed and volume data was collected at three locations deemed to be critical from observation of the congestion patterns that build up in the network during initial simulation runs. Those locations were: merging area 1 (at the Palladium Drive interchange), merging area 2 (at the Castlefrank Road interchange) and merging area 3 (east of the Eagleson Road interchange). Merging area 4 was not used because the level of congestion in that area never reached severe conditions i.e. the travel conditions at the Moodie Drive interchange were always above average. The toll rate used as an MOE was determined through the tolling algorithm.

As mentioned previously, three separate simulation runs were conducted. Each run simulated a four hour AM peak period condition in the east-bound direction. The originally determined control intensity parameters (k_n and b_n) were used for the first simulation only, in the remaining two simulation runs, the parameters were re-computed using the self calibration mechanism. The following discussion examines each of the three simulation runs in terms of their measures of effectiveness.

The first simulation run was conducted using the original control intensity parameters determined in Chapter 7. Those values were: $b_1 = 0.038$, $k_1 = 0.003$, $b_2 = 0.012$, $k_2 =$

0.0007 and $b_3 = 0.018$. Figure 9.1 illustrates the changes in average speed on the HOT lane as well as the general purpose lanes. Figure 9.2 shows the changes to toll rate throughout the first simulation run. Figure 9.3 depicts the combined weighted average speed along all lanes in the HOT corridor. These three figures were compared to the corresponding figures for the second and third simulation runs to determine if the self-calibrating mechanism provided some benefits to the system.

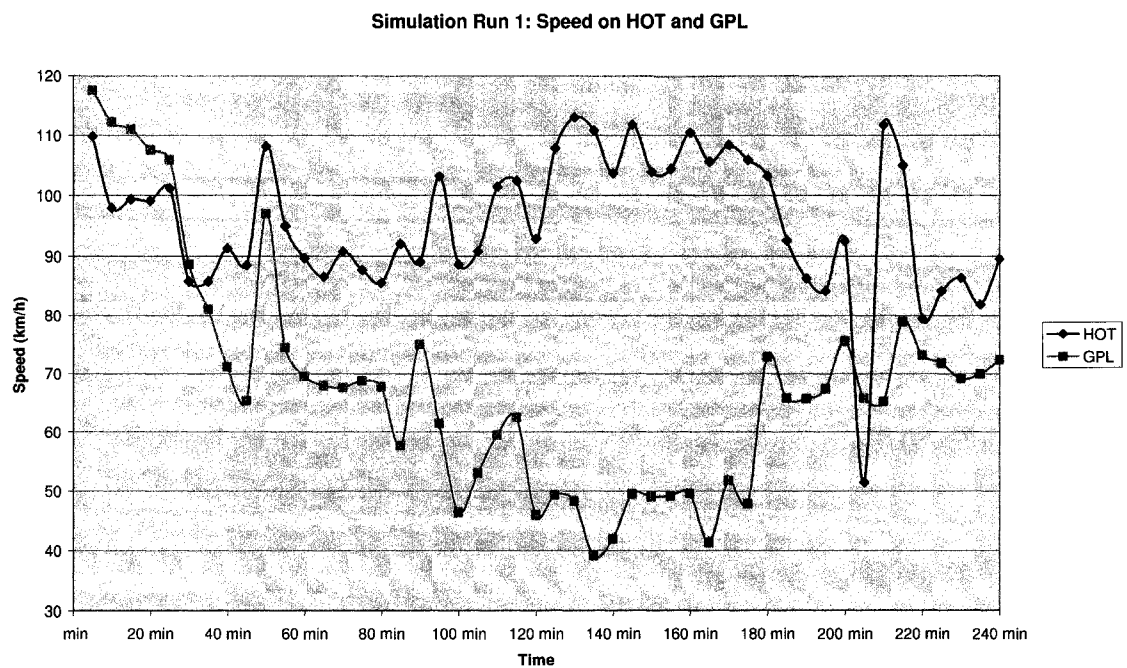


Figure 9.1 Average speed values on the HOT and the general purpose lanes during the first simulation run

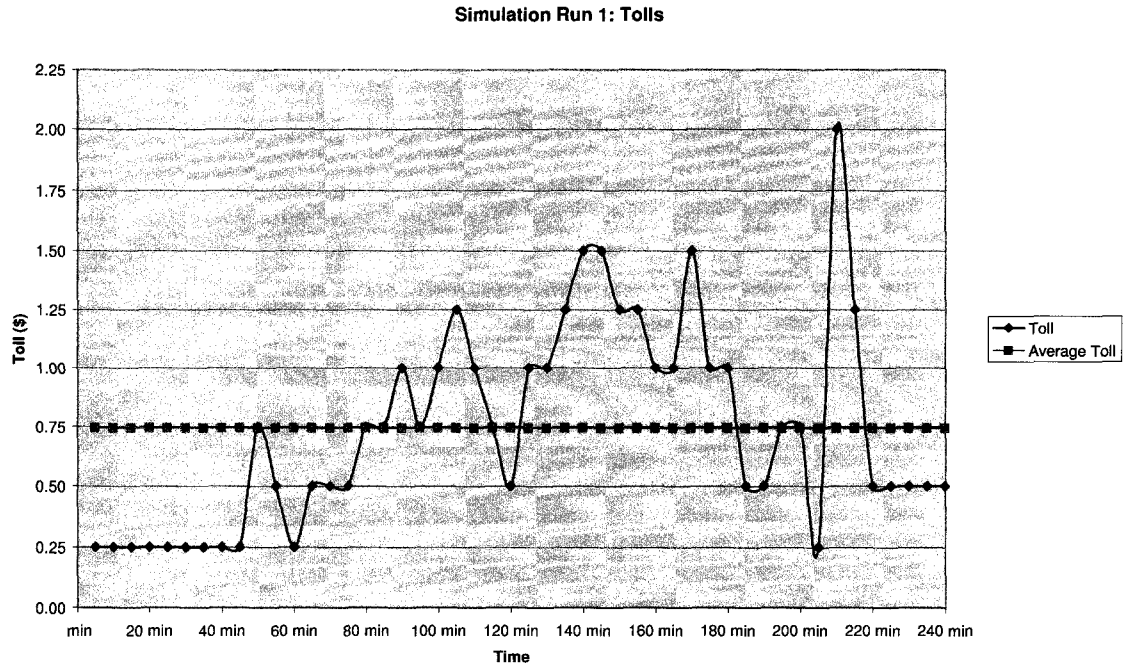


Figure 9.2 Changes in toll value during the first simulation run

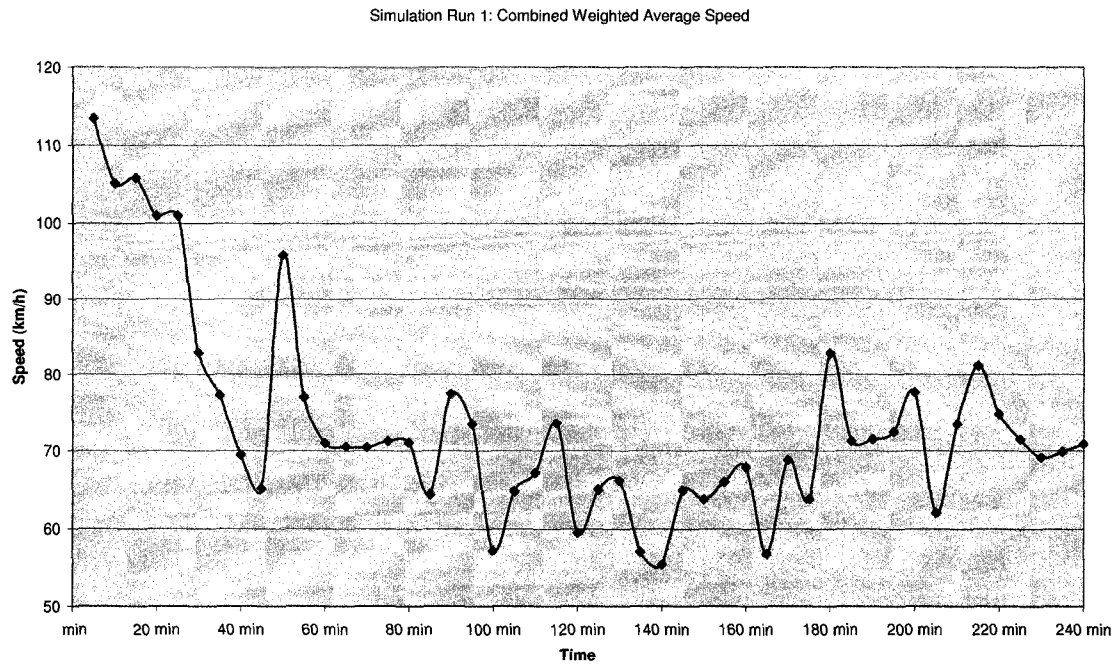


Figure 9.3 Combined weighted average speed along all lanes during the first simulation run

It was found that the speed on the HOT lane was lower than that on the general purpose lanes during the first 30 minutes; however, the average speed on both sets of lanes

remained above the critical level (70 km/h). This is the result of low traffic volumes i.e. 80% to 110% of the 2016 forecast traffic volumes. Despite the application of the damper, the speeds on the HOT lane varied quite unstably especially between the 200 minute and 220 minute marks. The toll rate was relatively stable averaging \$0.74 while keeping the speed on the HOT lane above the critical level except for one instance in the 200th minute when the average speed on the HOT lane dropped to 51.4 km/h. The combined weighted average speed, however, dropped below the critical level many times, primarily between the 80th and 180th minutes, this can be seen in Figure 9.3. The results show that the first simulation run yielded positive results, however there remains room for improvement.

In the second simulation run, the control intensity parameters were re-calibrated using the self calibration mechanism. The values of the control parameters used were as follows: $b_1 = 0.0025$, $k_1 = 0.0000004$, $b_2 = -0.023$, $k_2 = 0.0000004$ and $b_3 = 0.018$. The b_3 parameter remained unchanged from the first simulation because there was not enough data collected to allow for an estimate of the parameter. Figure 9.4 illustrates the changes in average speed on the HOT lane as well as the general purpose lanes. Figure 9.5 shows the changes to toll rate throughout the second simulation run. Figure 9.6 depicts the combined weighted average speed along all lanes in the HOT lane corridor. Again, after completing all three of the simulation runs, these figures were compared the corresponding figures for the other two simulation runs to determine if the self-calibration mechanism is warranted.

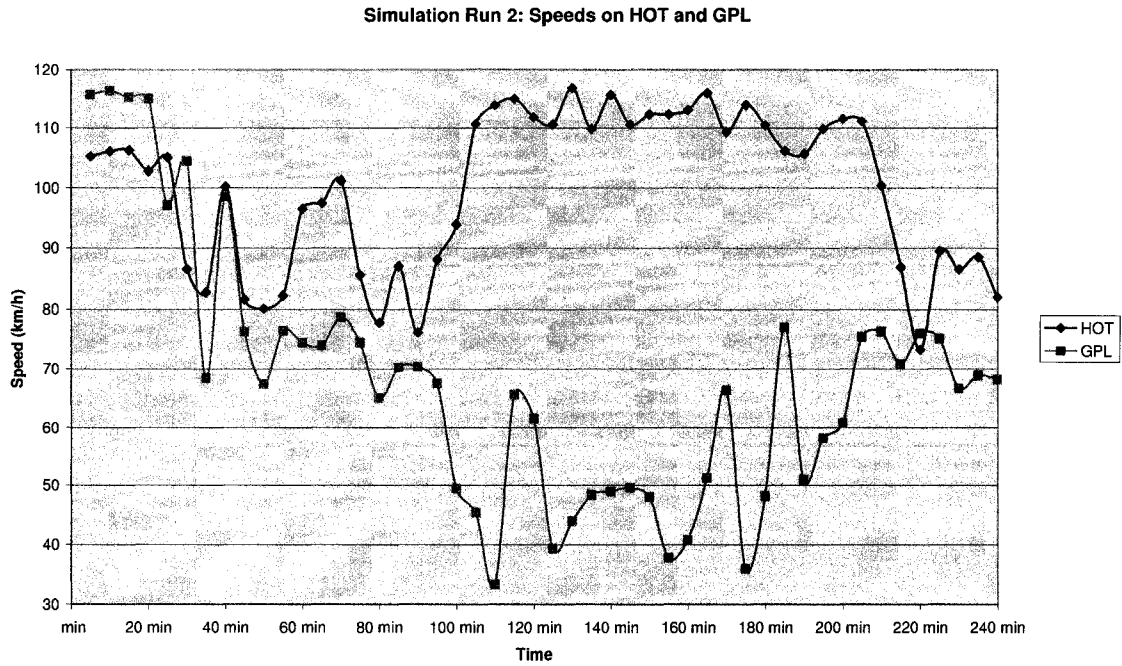


Figure 9.4 Average speed values on the HOT and the general purpose lanes during the second simulation run

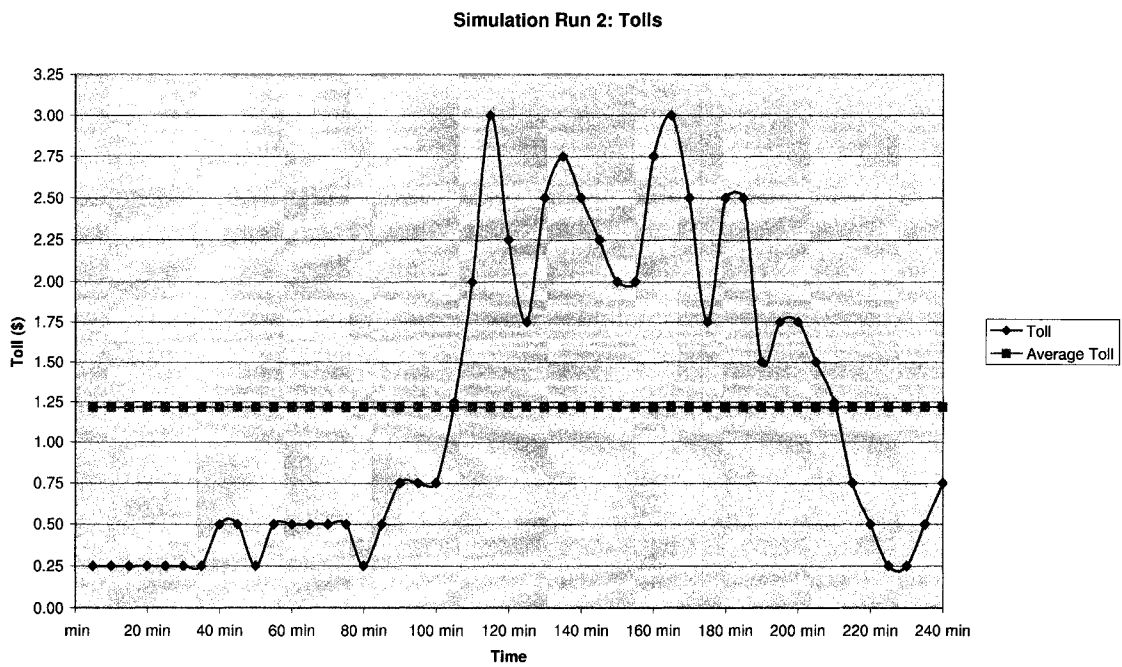


Figure 9.5 Changes in toll value during the second simulation run

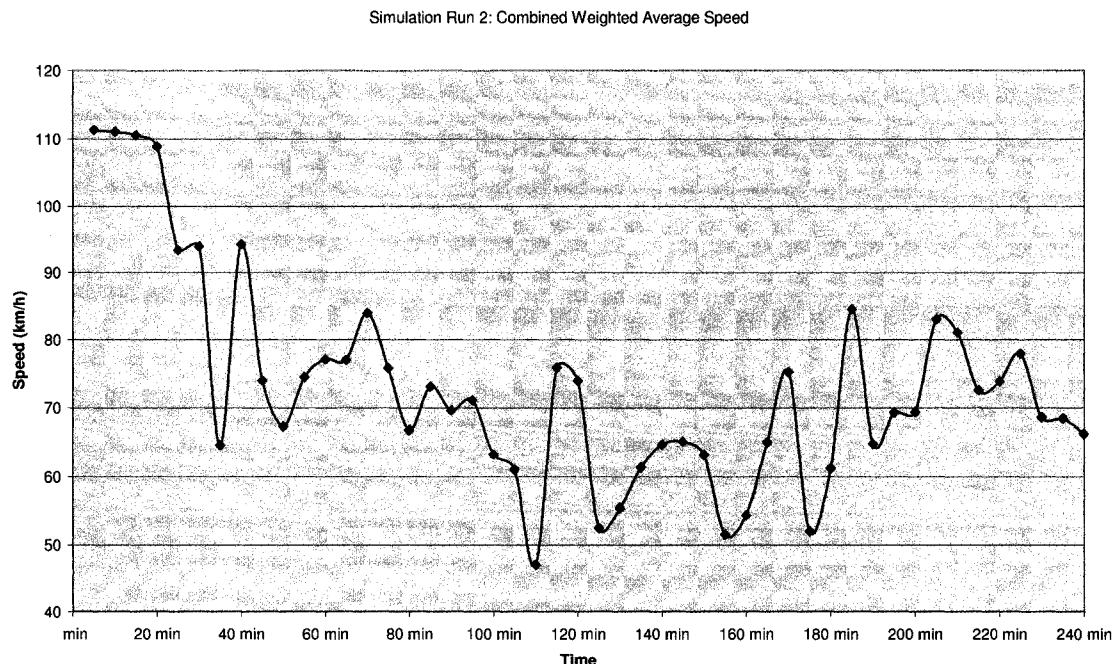


Figure 9.6 Combined weighted average speed along all lanes during the second simulation run

As in the first simulation run, the average travel speed was found to be lower on the HOT lanes than on the general purpose lanes during the first few time intervals. Again this problem most likely resulted because the percentage of the 2016 data used in those time intervals was too low to induce any significant traffic congestion. In the second simulation run, it was found that the speeds on the HOT lane did not vary as unstably as experienced in the first simulation run; however, the variation in the average speed on the general purpose lanes was quite unstable especially when the traffic volumes were the their highest levels. The average travel speed along the HOT lane never dipped below the critical speed value, this is a significant improvement over the previous run. The combined weighted average speed did remain below the critical level when the traffic congestion was most severe. The toll was found to change quite smoothly except at the points where the traffic volume was at the 180% of the 2016 forecast volume level. The average toll value also increase compared to the first simulation run to \$1.22. This

simulation run shows improvements compared to the first simulation run; however, there remains room for improvement especially in terms of stable variation of the average speeds.

The third simulation run required that the control intensity parameters be re-calibrated once again, this time using data from both the previous simulation runs. The values of the control parameters used were as follows: $b_1 = 0.0041$, $k_1 = -0.00007$, $b_2 = -0.027$, $k_2 = -0.0003$ and $b_3 = 0.018$. Again, the b_3 parameter remained unchanged from the first and second simulations because there was not enough data collected to allow for an accurate estimate of the parameter. Figure 9.7 illustrates the changes in average speed on the HOT lane as well as the general purpose lanes. Figure 9.8 shows the changes to toll rate throughout the third simulation run. Figure 9.9 depicts the combined weighted average speed along all lanes in the HOT lane corridor.

Simulation Run 3: Speeds on HOT and GPL

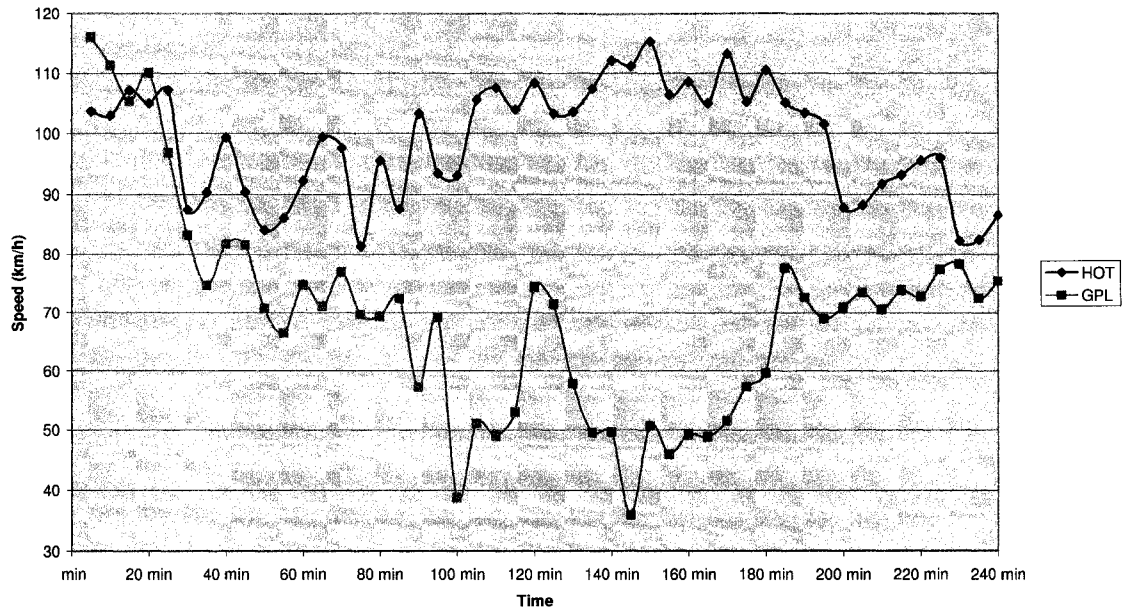


Figure 9.7 Average speed values on the HOT and the general purpose lanes during the third simulation run

Simulation Run 3: Tolls

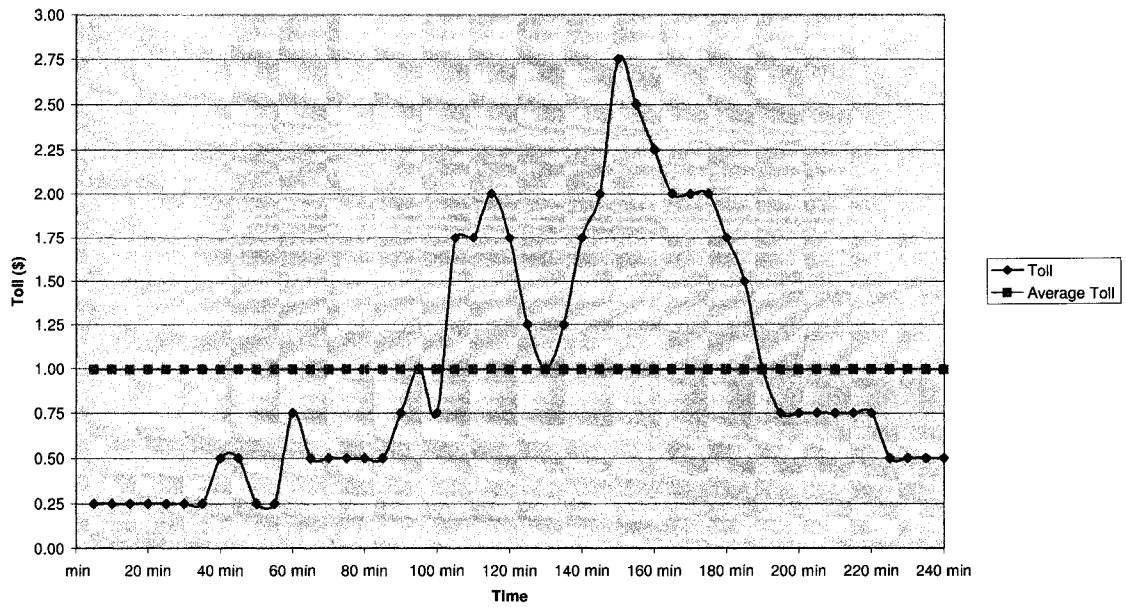


Figure 9.8 Changes in toll value during the third simulation run

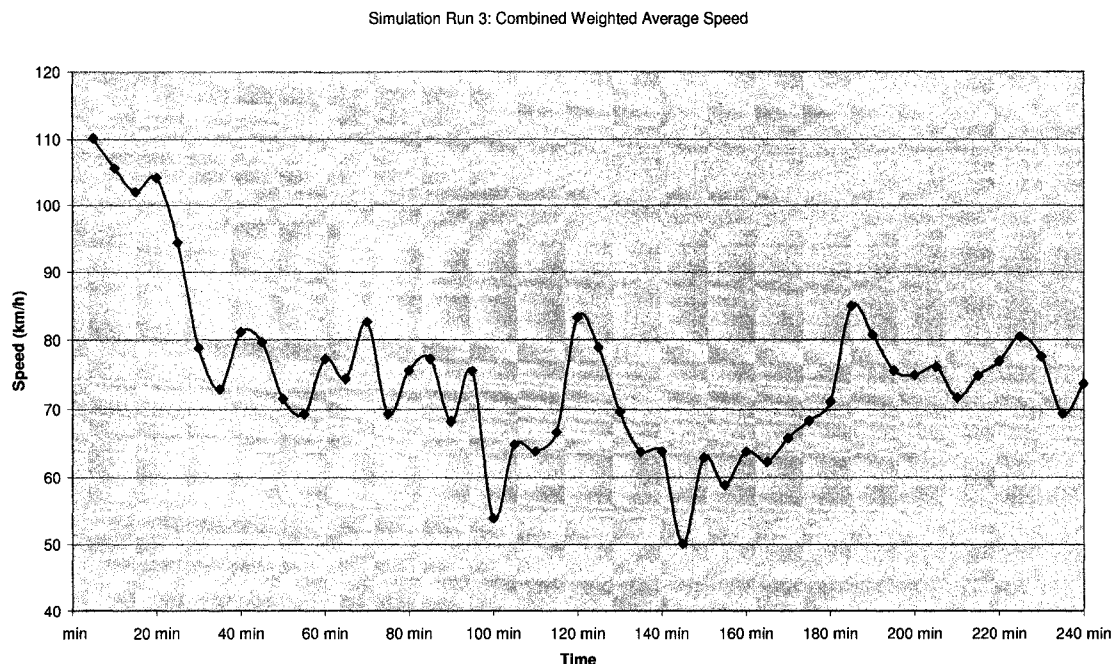


Figure 9.9 Combined weighted average speed along all lanes during the third simulation run

Once again, as a result of the low traffic volume, the average operating speed along the HOT lane was found to be lower than that on the general purpose lanes. It may be beneficial to the operating agency to close the HOT lane to solo motorists when volumes are low; however, this may result in a drop in total revenue. The speed along the HOT lane, in the third simulation run, was found to vary in a relatively stable manner as compared to the two previous simulation runs. Again, the variation of the average speed along the general purpose lanes varied stably except during the times when the traffic volume was at 180% of the 2016 forecast volume. The variation of the toll rate was found to be much more stable than that of the previous two simulation runs. The average value of the toll was found to be \$0.99; higher than that of the first simulation run but lower than that of the second. The average travel speed along the HOT lane never dropped below the critical level, in fact, it never dropped below 80 km/h. The combined average speed showed signs of unstable variation, however it was not severe. The average

combined operating speed only dropped below the critical speed a few times mostly between the 100th and 180th minutes. The final simulation run showed much improvement over the previous two simulation runs. The fluctuations in speed and toll rate will continue to occur as a result of the changing traffic conditions, however changing the parameters in the damping mechanism could cause a degradation of the travel conditions, primarily to the HOT lane travelers.

The comparisons done in this section were primarily based on comparisons between the 9 figures. The discussion in the following two sections is based on actual data and difference of means statistical analysis.

9.3.1 Dynamic, Feedback Based Tolling Algorithm

The development of a dynamic and feedback based tolling algorithm was initially shown by Zhang et al. (2008). This study can, in part, validate that thesis and show that a dynamic and feedback based tolling algorithm can provide benefits to motorists traveling on a facility with an HOT lane. The tolling algorithm in this study was different from that used by Zhang et al. (2008), in that it used a logit model that was calibrated to local conditions based on an SP survey to compute the value of the toll, it also incorporated an external damper to mitigate severe speed fluctuations and finally a self-calibration mechanism was incorporated into the tolling algorithm.

It was found that the tolling algorithm worked very well, providing many benefits over an HOV only facility. For the purpose of comparison, an additional simulation run was conducted where an HOV only system was used instead of an HOT system. This was accomplished by closing the entire HOT lane to HGVs as well as single occupant cars

while keeping the facility open to HOVs. The results of all the simulation runs are summarized in Table 9.1.

Table 9.1 Summary of the results of all three simulation runs under HOT conditions and one simulation run under HOV only conditions

Simulation Run	HOV	#1	#2	#3
Average Toll	N/A	\$0.74	\$1.22	\$0.99
Average HOT Speed (km/h)	127.11	95.74	99.90	98.88
Average GPL Speed (km/h)	65.24	68.00	67.97	69.49
Average Combined Weighted Speed (km/h)	70.07	73.52	73.34	74.95
Volume Palladium GPL (veh/h)	3258	3530	3510	3641
Volume Castlefrank GPL (veh/h)	4024	4166	4183	4191
Volume Eagleson GPL (veh/h)	5602	5156	5179	5208
Volume Palladium HOT (veh/h)	163	1192	1108	1217
Volume Castlefrank HOT (veh/h)	232	1770	1595	1754
Volume Eagleson HOT (veh/h)	258	1831	1617	1774
Total Revenue	N/A	\$3,900.33	\$4,892.25	\$4,755.67
P_{HOT} Error (Predicted to Actual Values)	N/A	-29.30%	-1.45%	-0.28%

The average HOT lane speeds were found to be lower for HOT operations than in the HOV operations. The average speed on the general purpose lanes was found to be only slightly lower on the simulation under HOV only conditions compared to HOT conditions. The average combined weighted speed was found to be slightly higher under the HOT operating conditions. Despite the fact that the operating speed on the HOT lane is slower under HOT conditions, it remains close to free flow conditions. It was found that the major benefits of converting an HOV lane to an HOT were the added revenue and the increased efficiency of the facility. With the exception of the general purpose lane section at the Eagleson Road merging area, the system was found to carry a higher volume of travellers, under HOT conditions as compared to HOV conditions. This result indicates that while the overall HOT lane speeds may be higher during HOV only operations, the throughput is actually much higher during HOT operations. The following

section examines the benefits of adding a self-calibration mechanism to a dynamic and feedback based tolling algorithm for high occupancy toll lanes.

9.3.2 Self Calibration Mechanism

The self calibration mechanism was added to the tolling algorithm to examine whether there could be benefits to continuously re-calibrating the algorithm to better match the actual conditions experienced rather than idealized conditions that may never become a reality. The self-calibration mechanism collected speed and HOT lane usage data to re-compute the control intensity parameters using linear regression. Three separate simulation runs were conducted; each simulated the conditions of the AM peak period in the east-bound direction with volumes of 80% to 180% of the 2016 forecast volumes. The results of the three simulation runs are shown in Table 9.1. These values were compared with each other using small sample difference of means analysis to determine if there was a significant drop or rise in the specific parameter. The analysis used a 95% confidence interval to determine whether the differences were significant. The results of the small sample difference of means analysis are shown in Figure 9.2.

Table 9.2 Results of the difference of means analysis conducted to compare the results of the three HOT lane operations simulation runs (+ and – signs refer to a respective rise or fall in the value)

Difference Between	Runs #1 and #2	Runs #2 and #3	Runs #1 and #3
Average Toll	+ Significant	- Significant	+ Significant
Average HOT Speed (km/h)	+ Significant	Not Significant	+ Significant
Average GPL Speed (km/h)	Not Significant	Not Significant	Not Significant
Average Combined Speed (km/h)	Not Significant	Not Significant	Not Significant
Volume Palladium GPL (veh/h)	Not Significant	+ Significant	Not Significant
Volume Castlefrank GPL (veh/h)	Not Significant	Not Significant	Not Significant
Volume Eagleson GPL (veh/h)	Not Significant	Not Significant	Not Significant
Volume Palladium HOT (veh/h)	- Significant	+ Significant	Not Significant
Volume Castlefrank HOT (veh/h)	- Significant	+ Significant	Not Significant
Volume Eagleson HOT (veh/h)	- Significant	+ Significant	Not Significant

The results indicate that there was a significant rise in toll value and average HOT lane speed between simulation runs 1 and 2, while there was a significant drop in the volume on the HOT lane. The average toll rate was found to have a significant drop between simulation runs 2 and 3, while showing a significant rise in HOT lane volumes. The difference in volumes between runs 1 and 3 was found to be insignificant while a significant rise in toll and average HOT lane speed was noticed. These results indicate that as more data is collected, the most important benefit (speed) may drop slightly; the overall benefits are higher than those of the original estimates of the control intensity parameters. Thus, after the first re-calibration the average speed on the HOT lane and the average toll rate is likely to rise while the subsequent re-calibrations will tend towards lower total benefits as compared to the previous runs but at the same time higher overall benefits than the initial simulation run, this was expected. A similar result was observed when analyzing the system in terms of the total revenue, after the first re-calibration, the revenue rose sharply but the next re-calibration resulted in slightly lower revenue as compared to the second run but still higher than that of the initial run. The error between the actual proportions of HOT lane users and the predicted HOT lane users was found to decrease significantly after each re-calibration. In the following section, the significance of the above explained results is discussed.

9.4 Discussion of Results and Possible Issues

The basic tolling algorithm tested in this study was influenced by the work of Zhang et al. (2008); however, this thesis went beyond their work. Comparing the results of the HOV only simulation to the three HOT simulations, it was found that while the HOV operations offered the highest speed on the managed lane, the efficiency was much better

when the system operated under HOT conditions. The throughput was overall much better when the system operated under HOT conditions and in the third HOT simulation run it was found that there was actually a significant rise in the general purpose lane speed. This shows that when the traffic conditions reach a certain point where severe congestion is experienced and an HOV lane seems to be underutilized, an HOT lane is a viable alternative.

The self-calibration mechanism was shown to adjust the base tolling algorithm in a way that provided additional benefits to the base tolling algorithm. By re-calibrating the control intensity parameters to better reflect the actual proportions of HOT lane users, the entire algorithm output more realistic toll rates because it was totally calibrated to local conditions. This was as opposed to the idealized and assumed initial control intensity parameters which produced reasonable results but did not increase the efficiency of the system.

The self-calibration mechanism was shown to be a good way of re-calibrating the tolling algorithm to adjust for local trends. However, the data collected from a specific period during the average day should only be used to re-calibrate the control intensity parameters for the same period on other days. Therefore, data collected during the normal operations of the HOT system under the tolling algorithm for an AM peak period in the east bound direction should only be used to re-compute the parameters for AM peak periods in the east-bound direction on other days. In this way, the algorithm will eventually calibrate itself to the point where the local conditions as well as the specific time of day traffic patterns will be accounted for in the algorithm itself.

The controlling agency will dictate the specific regulations and operating hours of the HOT facility. There are many possible operating schedules and regulations that can be implemented on the HOT facility. The tolling algorithm will have its greatest effect during the peak periods, so a different operating schedule may have to be implemented during off-peak times. The facility could, for example, operate under HOV only conditions, charging the minimum toll to solo motorists or be closed all together during off-peak times. In some cases allowing vehicles containing two people to use the facility free of charge may result in an over utilized facility. As a result, in some locations the HOT regulations may have to be modified to allow 3+ HOVs (vehicles containing 3 or more people) to use the facility free of charge, allow 2+ HOVs to pay the toll for access to the facility and deny solo motorists access to the facility altogether. These types of regulations and operating schedules will have to be determined by the operating agency and will primarily depend on the local attitudes of the travelers, traffic patterns during different times of the day, the level of traffic congestion and the desired profit the operating agency wishes to take.

In this section, the results of the algorithm testing along with potential operational issues were discussed. The following section discusses the possible issues that affect the implementation of an HOT facility in the Ottawa area.

9.5 HOT Lanes in the City of Ottawa

In this chapter it was shown that an HOT facility could potentially operate efficiently in the City of Ottawa. However, there were many assumptions made to bring the simulations to the point where benefits were observed. The traffic volume had to be

raised to 180% percent of the 2016 forecast levels. This indicates that the Ottawa area will not have a severe enough traffic problem to warrant an HOT facility until roughly 2030 (Assuming traffic increases in the same way it is forecast to increase between 2000 and 2016). This alone makes the implementation of an HOT facility in Ottawa unrealistic in the near future, as it would only start to increase the efficiency of the corridor more than 20 years from now.

The logit model, developed from the stated preference survey, showed that Ottawa motorists are very conservative when it comes to spending their money. The simulations did reflect this; the highest toll that was charged to motorists was \$3.00 which is half of the maximum rate for the facility. As a result, the tolling algorithm that was developed here would make a good starting point for the pricing structure on an Ottawa area HOT lane. It is, however, recommended that the algorithm determined here only be used as a preliminary pricing structure. The logit model should be re-calibrated after the facility has been operational for some time using revealed preference data. Using a revealed preference survey to re-calibrate the logit model would account for the local preferences of the motorists and the self calibration mechanism would help account for daily traffic patterns.

It would be very important to launch a marketing campaign that would help educate the local residents about the HOT facility, its regulations, operating schedules and other issues. Without properly educating the potential users, there will likely be very little public support for such a facility. If enough time and funds are allocated to educating the

potential drivers of the benefits of using such a facility, this type of project may be feasible in the Ottawa region.

9.6 Summary

The dynamic, feedback based and self-calibrating tolling algorithm was validated using microsimulation techniques. The results of the validation process were presented in this chapter. It was found that the self calibration mechanism did improve the efficiency of the system and all of the simulation trials showed benefits over an HOV only facility, primarily in terms of throughput. The damper that was applied to the tolling algorithm was found to help smooth out the speed profile slightly, i.e. less fluctuations between evaluation intervals, but it did not have as significant an effect as originally assumed. The initial values of the control intensity parameters were found to be an excellent starting point; however, the re-calibrated values offered (in most cases) increased benefits to the system. The initial revenue for an AM peak period was \$3900 and after the self calibration mechanism was applied this value rose to between \$4750 and \$4900 for an AM peak period. The error between the predicted and the actual proportions of HOT lane users was found to diminish significantly after each self-calibration. The agency responsible for the operations of any HOT facility will be forced to come up with its own regulations and operations schedule to suit its needs. It was shown that an HOT lane could be successfully used to mitigate congestion problems in the Ottawa area; however significant benefits will not be observed until the traffic volumes increase to 180% of the 2016 forecast levels.

Chapter 10

Conclusions and Recommendations

10.1 Conclusions

This thesis outlined the methodology for developing and testing a dynamic, feedback-based and self-calibrating tolling algorithm for a high occupancy toll lane. The study began by explaining the process for coding and calibrating an urban traffic network. It was then shown how the data collected from the initial simulation runs could be used to develop a stated preference survey and how the results of the SP survey could be used to create a logit model to simulate drivers' route choice decisions. The procedure for developing a tolling algorithm based on feedback control theory and the above mentioned logit model was also explained. The validation process, for the tolling algorithm, was then conducted using traffic microsimulation software.

There were two objectives in this study: (1) to expand the knowledge base on the subject of HOT lane pricing algorithm development and (2) to examine the effects of such an algorithm on a medium sized city such as Ottawa, ON, Canada. The first objective was satisfied by outlining the process for the development of a dynamic, feedback-based and self-calibrating tolling algorithm for HOT lanes using a variety of different tools. The second objective was satisfied seeing as the study area for this thesis was in the City of Ottawa and conclusions could be drawn from the results of the study regarding the use of an HOT lane in the Ottawa area. The first objective was the primary focus of this study and the second objective was less critical but nonetheless important to this study.

The major conclusions of this study are summarized below. They are separated into specific sections including: conclusions about the tolling algorithm itself, conclusions regarding the stated preference survey as well as the development of the route choice logit model, conclusions pertaining to the use of VISSIM in simulating HOT facilities and conclusions regarding the implementation of an HOT facility in the Ottawa area.

10.1.1 Conclusions Regarding the Tolling Algorithm

- A dynamic, feedback based and self calibrating tolling algorithm can be developed and shown to provide benefits to the entire traffic corridor;
- The originally assumed values for the control intensity parameters in the feedback control function of the tolling algorithm provided an excellent starting point for the algorithm, however it was found that the re-calibrated values resulted in more efficient operations;
- Applying a self-calibration mechanism to a tolling algorithm increases the efficiency of the algorithm by reducing the error between the actual and the predicted proportions of HOT lane users;
- During (simulated) operation of the self-calibration mechanism, it was found that the toll rate, the average speed and the throughput on the HOT lane increased, while the speed and throughput on the general purpose lanes did not change significantly;
- While an external damper applied to a tolling algorithm can add some benefits to the system, the primary benefit is the fact that the fluctuations in speed and toll value are reduced;

10.1.2 Conclusions Regarding SP Survey and Logit Model

- The results of a stated preference survey can be used to successfully calibrate a logit model that will be used for the purpose of predicting the proportions of HOT lane users;
- A properly designed, fractional factorial stated preference survey can eliminate any collinearity among the independent variables and allows for the interactions between all of the independent variables to be accounted for (unless they were initially assumed to be zero);
- A fully calibrated logit model, developed by using principles of binary logistic regression can successfully be used in a tolling algorithm to back calculate the appropriate toll that should be charged to users;

10.1.3 Conclusions Regarding Use of VISSIM to Simulate HOT Lanes

- Running VISSIM with its default parameters can yield severe discrepancies in volume counts and travel time measurements as compared to the actual (observed values). As a result VISSIM must be fully calibrated prior to beginning the simulation runs;
- Adjusting the model parameters CC0 and CC1 can dramatically improve the performance of the model and should be the primary parameters that are adjusted during the calibration of the model;
- When problems regarding the performance of the merging/diverging or weaving areas are encountered during the simulations, the CC0 and CC1 parameters often do not help improve the situation. Instead, VISSIM's priority rules can be applied in the

weaving areas and the parameters can be modified to produce realistic driving behaviour;

- VISSIM's built in dynamic assignment mechanism can be modified to model route choice behaviour of drivers on an HOT corridor. By increasing the sensitivity of certain vehicle types to financial costs while setting the financial cost sensitivity of other vehicles to zero and applying a cost to strategically located links and connectors the vehicles will behave realistically with respect to the use of the HOT lane;
- While dynamic methods such as modules developed specifically for the purpose of modelling HOT lanes are likely most effective, time-sliced static simulation methods can also be used to successfully simulate the operations of HOT lanes. The time-sliced static simulation method can also be successfully used to evaluate the performance of a complex tolling algorithm;

10.1.4 Conclusions Regarding Use of an HOT Facility in Ottawa, ON

- The City of Ottawa with its current population and traffic congestion state does not provide favourable conditions for the implementation of an HOT lane;
- The volume on Highway 417 which runs through the City of Ottawa must increase by 80% as compared to the forecast 2016 volumes before HOT lanes will provide any benefit to the travelling public;
- Generally, the people of Ottawa were found to be conservative with regard to financial expenditure. The tolling algorithm that was developed was found to account for this very well and as a result could potentially be used to control access to an HOT facility if one was ever opened in Ottawa.

10.2 Recommendations

Based on the complex nature of this study, further research may be required to obtain an even better understanding of the problem at hand. Throughout this research there have been many problems and issues encountered, in many cases suggestions for improvements were noted. This section outlines the recommendations for further research and suggestions for the mitigation of some of the problems encountered during the course of writing this thesis.

- The tolling algorithm developed in this thesis was influenced by the work done by Zhang et al. (2008). The validation process used for testing the effectiveness of the tolling algorithm involved the use of traffic microsimulation. As opposed to Zhang et al. (2008) and Zhang et al. (2008a), the simulation process used here was time-slice static, i.e. the simulations were conducted one evaluation interval at a time. Although the results were realistic, it is recommended that the algorithm is further tested under dynamic simulation; using a module developed using the VISSIM framework, the COM interface and some external programming language. Unfortunately, time and financial constraints did not allow for this type of testing to be conducted.
- The data obtained from the MTO provided good estimates of average volumes and travel times along Highway 417. However, many assumptions had to be made to facilitate the modelling of the HOT facility. More detailed data would have allowed for a more accurate evaluation of the HOT lanes. Traffic patterns throughout the AM and PM peak periods were not broken down so that the simulation process could account for them instead only average values were provided. It is recommended that

detailed traffic data be used for the analysis of HOT lanes where available. In this way, the local traffic patterns and tendencies can be studied.

- A time interval modification mechanism was discussed as part of this study, however it was not included in the algorithm due to the complexity of the mechanism and the financial and time constraints. It is recommended that future studies on this subject include such a mechanism as a part of the tolling algorithm to ensure that drivers pay the toll that they see displayed on the DMS.
- The stated preference survey was used to calibrate the logit model that in turn computed the toll value as a part of the tolling algorithm. The SP survey, however, was distributed to a completely random sample, consisting of persons who work for the City of Ottawa, Carleton University and Elections Canada as well as other residents of the Ottawa area. In future studies, it is recommended that the survey be administered more specifically to the primary users of the facility during peak periods. In this study, the survey should have been administered primarily to the residents of Kanata, Stittsville and West Nepean. This would have been a more accurate depiction of local attitudes toward tolled facilities. Again, due to financial restraints this could not be done for this study.
- The Ottawa area was chosen as the study area for this thesis for many different reasons. Primarily as a result of the MTO's plans to construct an HOV lane on Highway 417 between the Palladium Drive and the Moodie Drive interchanges. The results showed that while an HOT lane may in fact provide benefits to the travelling community, the traffic conditions that would warrant such a facility would not be realized until approximately the year 2030. As a result, the tolling algorithm that was

developed in this study should be tested for other, larger cities that may have more immediate traffic congestion problems.

- VISSIM is an excellent tool for evaluating the operations of various transportation systems and facilities. However, the software is lacking in certain respects. It was noticed many times throughout this study that weaving areas caused severe bottlenecks on the roadway. VISSIM does not provide any parameters that can be easily adjusted to help mitigate severely degenerated conditions on and around weaving areas. Such parameters would help to simplify the calibration process instead of having to add priority rules to prevent severe bottlenecks. Also, more modules should be included with or be available for purchase to accompany VISSIM, to simplify the simulation of various more complicated facilities such as HOT lanes.

References

- Abdelghany, A.F. & Abdelghany, K. & Mahmassani, H.S. & Murray, P.M., Dynamic Traffic Assignment in Design and Evaluation of High Occupancy Toll Lanes, Transportation Research Record, N.1733, 2000.
- Allison, P.D., Logistic Regression, Using the SAS System: Theory and Application, Wiley and Sons, 1991
- Babbie, Earl, The Basics of Social Research, Thomson Wadsworth, 2007
- Ben-Akivya, M. & Lerman, S.R., Discrete Choice Analysis: Theory and Application to Travel Demand, The MIT Press, Cambridge, Massachusetts, 1985
- Berkson, J., A Statistically Precise and Relatively Simple Method of Estimating the Bioassay with Quantal Response, Based on the Logit Function, J. Amer. Stat. Assn 48, pp. 565-599, 1953
- Burris, M. & Xu, L., Potential Single Occupancy Vehicle Demand for High Occupancy Vehicle Lanes: Results from Stated Preference Survey of Travellers in High Occupancy Toll Corridors, Transportation Research Record, N.1960, 2006.
- Burris, M.W. & Hannay, R.L., Equity Analysis of the Houston Quickride Project, Transportation Research Board, TRB 82nd Annual Meeting, 2003
- California Department of Transportation (CaDOT), High Occupancy Vehicle Guidelines, 2003 Edition, URL: http://www.dot.ca.gov/hq/traffops/systemops/hov/files/hov_guidelines/TOC.pdf
[Last Accessed: July 22, 2008]
- Cramer, J.S., The Origins and development of the logit model, Univeristy of Amsterdam and Tinbergen Institute, August 2003, URL:

www.cambridge.org/resources/0521815886/1208_default.pdf [Last Accessed: April 21, 2008]

- Dale, J., VISSIM – Modeling HOT Lanes, Freeway Simulation Subcommittee AAHB20(2), Presented at the 86th Annual TRB Conference, 2007, URL: http://www.trb-freewayops.org/sim_model/AnnualMeeting2007/HOT_Lanes_VISSIM.pdf [Last Accessed: July 20, 2008].
- Dowling, R. & Holland, J., California Department of Transportation: Guidelines for Applying Traffic Microsimulation Modelling Software, Dowling Associates Inc, Oakland California, 2002;
- Eisele, W.L. & Burris, M.W. & Wilner, H.T. & Bolin, M.J., Analytical Tool for Evaluating Adaptation of a High Occupancy Vehicle Lane to a High Occupancy Toll Lane, Transportation Research Record, N.1960, 2006.
- Federal Highway Administration (FHWA), Congestion Pricing, a Primer, Publication Number: FHWA-HOP-07-074, 2006;
- Federal Highway Administration (FHWA), Freeway Management Program, URL: <http://www.ops.fhwa.dot.gov/freewaymgmt/> [Last Accessed: November 28, 2007];
- Fukutomi, A., Simulation Approach to the Study of Driving Behaviour, Fuel Consumption and Emissions, MASc Thesis Dissertation, Carleton University, Ottawa, Ontario, 2004;
- Galton, Francis, Family Likeness in Stature, Proceedings of Royal Society, London, vol 40, pp 42-72, 1886

- Gomes, G. & May, A. & Horowitz, R., A Microsimulation Model of a Congested Freeway Using VISSIM, Paper Presented At: 83rd TRB Annual Meeting, January 11-15, 2004, Washington D.C.;
- Gryz, Thomas & Armstrong, Jennifer, & Khan, Ata, Role of Simulation in Assessing Intelligent Technology for Sustainable Mobility: Example of Toll Route and Toll Lanes, Presented at the CSCE Annual General Meeting and Conference, Yellowknife, NT, Canada, 2007;
- Gujarati, Damodar N., Basic Econometrics; Fourth Edition, McGraw-Hill Companies, Inc. New York, NY, 2003
- Hahn, G.J & Shapiro, S.S., A Catalog of and Computer Program for the Design of and Analysis of Orthogonal Symmetric and Asymmetric Fractional Factorial Experiments, Report 66-C165, General Electric Research and Development Center, Schenectady, New York, May 1966
- Hanna, H.N. & Khan, A.M. & Shallal, L.A., Simulation of a Binary Choice Logit Model for the Ottawa-Hull Area, RTAC Forum, Vol 3, No 2, pp 59 – 65, 1981
- Hillier, F.S. & Lieberman, G.J., Introduction to Operation Research, 6th Edition, McGraw-Hill, New York NY, 1995;
- Hlavacek, I. & Vitek, M. & Machemehl, R.B., Best Practices: Separation Devices between Toll Lanes and Free Lanes, Center for Transportation Research, University of Texas at Austin, Austin TX, 2006.
- Homburger, W.S. & Keefer, L.E. & MacGarth, W.R., Transportation and Traffic Engineering Handbook: Second Edition, ITE, Prentice-Hall Inc, Engelwood Cliffs NJ, 1982

- Kindleysides, Sharon, Congestion Charging – A Beginners Guide, Paper Presented at the ITS World Congress, London, UK, 2006.
- Kocur, G. & Adler, T. & Hyman, W. & Aunet, B., Guide to Forecasting Travel Demand With Direct Utility Assessment, Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH, 1982
- Kriger, D. & Miller, C. & Baker, M. & Joubert, F., The Cost of Urban Congestion in Canada: A Model-Based Approach, Transportation Research Board, TRB 86th Annual Meeting, 2007;
- Lemeshow, S. & Hosmer, D.W. Jr, A Review of Goodness of Fit Statistics for Use in the Development of Logistic Regression Models, American Journal of Epidemiology, Vol 115, No 1, pp 92 – 106, 1982
- Lerman, S.R. & Louviere, J.J., Using Functional Measurement to Identify the Form of Utility Functions in Travel Demand Models, TRB, Transportation Research Record, No 673, pp 78 – 86, 1978.
- Lewis, Frank L., Applied Optimal Control & Estimation: Digital Design & Implementation, Texas Instruments, Prentice Hall, Englewood Cliffs NJ, 1992
- Li, Jianlang, Explaining High-Occupancy-Toll Lane Use, Transportation Research Part D6, pp 61 -74, Elsevier Science Ltd, 2001
- Louviere, J. L. & Hensher, D. A. & Swait, J. D., Stated Choice Methods: Analysis and Application, Cambridge University Press, 2000
- Mallinckrodt, A.J., HOV Lane Effectiveness, AJM Engineering, April 2003, URL: <http://home.comcast.net/~e.davis21/NAST/Mallinckrodt.pdf> (Last Accessed: June 25, 2007).

- McDonald, N. & Noland, R.B., Simulated Travel Impacts of High-Occupancy Vehicle Lane Conversion Alternatives, Transportation Research Record, N.1765, 2001.
- Meyer, M.D. & Saben, L. & Shephard, W. & Drake, D.E., Feasibility Assessment of Metropolitan High Occupancy Toll Lane Network in Atlanta, Georgia, Transportation Research Record, N.1959, 2006.
- Milam, R.T. & Choa, F., Recommended Guidelines for the Calibration and Validation of Traffic Simulation Models, Paper Presented At: The 8th TRB Conference on the Application of Transportation Planning Methods, 22-26 April, 2001, Corpus Christi, Texas;
- Ministry of Transportation of Ontario (MTO), High Occupancy Vehicle (HOV) Lanes, URL: <http://www.mto.gov.on.ca/english/traveller/hov/index.html#whatis> (Last Accessed June 19, 2007).
- Minnesota Department of Transportation (MnDOT), Official Website, URL: www.dot.state.mn.us/tmc/tmctools.html [Last Accessed: November 28, 2007]
- Morlok, E.K., Introduction to Transportation Engineering and Planning, McGraw-Hill, New York, NY, pp.520-523, 1978.
- Murray, P. & Mahmassani, H.S. & Abdelghany, A. & Handy, S., Defining Special Use Lanes: Case Studies and Guidelines, FHWA/TX-00/0-1832-1, Centre for Transportation Research, 2000.
- Murray, P.M. & Mahmassani, H.S. & Abdelghany, K.F., Methodology for Assessing High Occupancy Toll Lane Usage and Network Performance, Transportation Research Record, N.1765, 2001.

- Mustafa, Muhammad & Abdulhai, Baher, Discussion Paper: Electronic Road User Charging Systems and Smart Cards, Atlantic Project, Work Group 2.3, March 2004.
- Nagelkerke, N.J.D., A Note on a General Definition of the Coefficient of Determination, *Biometrika*, Vol 78, No 3, pp 691-692, September 1991
- Nookala, Marthand, Halvorson, Randy, Buckeye, Kenneth, Doan, John, High Occupancy Toll Lanes Innovations: I394 MNPASS, Paper presented at the ITS World Congress, London, UK, 2006.
- Orange County Transportation Authority, 91 Express Lanes, URL: <http://www.91expresslanes.com/> [Last Accessed: November 28, 2007]
- Ortuzar, J.D. & Willumsen, L.G., Modelling Transport, Third Edition, John Wiley & Sons Ltd., Chichester, UK, 2001
- Pearmain, D. & Swanson, J. & Kroes, E. & Bradley, M., Stated Preference Techniques: A Guide to Practice, Second Edition, Steer Davies Gleave and Hague Consulting Group, 1991
- Press, W.H. & Flannery, B.P. & Teukolsky, S.A. & Vetterling, W.T., Numerical Recipes in C, Cambridge University Press 1988
- PTV, VISSIM 4.30 User's Guide, PTV AG, Karlsruhe, Germany, 2007;
- Safirova, E. & Houde, S. & Coleman, C. & Harrington, W. & Lipman, A., A Small Cordon in the Hand is Worth Two in the Bush: Long-Term Consequences of Road Pricing, Transportation Research Board, TRB 86th Annual Meeting, 2007.
- Scholz, D. & Koy-Oberthur, R., Tollchecker: System Design for High Performance Toll Enforcement, How Next Generation Enforcement Can Support All Tolling Schemes, Paper Presented at the ITS World Congress, London, UK, 2006.

- Shah, B.V. & Barnwell, B.G., Hosmer-Lemeshow goodness of fit test for Survey data, Annual Meeting of the American Statistical Association, Joint Statistical Meeting – Section on Survey Research Methods, San Francisco, CA, August 2003
- SPSS Inc., SPSS v16.0 Online Help, SPSS Inc., 2007
- Supernak, J, HOT Lanes on Interstate 15 in San Diego: Technology, Impacts and Equity Issues, Presented at: PIARC Seminar on Road Pricing with emphasis on Financing, Regulation and Equity, Cancun, Mexico, 2005.
- Tayyaran, Mohammad R., Impacts of Telecommuting, and Related Aspects of Intelligent Transportation Systems on Residential Location Choice: A Combined Revealed and Stated Preference Approach, PhD Thesis Dissertation, Department of Civil and Environmental Engineering, Carleton University, Ottawa, Ontario, 2000
- Teng, Harry, Fundamentals of ITS and Traffic Management; Tools of ATMS, CITE (Consortium of ITS Training and Education), University of Maryland, 2006.
- Toledo, T. & Koutsopoulos H.N., Statistical Validation of Traffic Simulation Models, Paper Presented At: 83rd TRB Annual Meeting, January 11-15, 2004, Washington D.C.;
- Train, Kenneth, Qualitative Choice Analysis: Theory, Econometrics and an Application to Automobile Demand, The MIT Press, Cambridge, Massachusetts, 1986
- Transport Canada, The Cost of Urban Congestion in Canada, March 22, 2006
- Transportation Research Board (TRB), Conference Proceedings 34: International Perspective on Road Pricing, Key Biscayne, Florida, 2005

- Ungemah, D. & Swisher, M., So You Want to Make a High Occupancy Toll Lane? – Project Manager’s Guide for Conversion from High-Occupancy Vehicle Lane to High Occupancy Toll Lane, Transportation Research Record, N.1960, 2006.
- Van Aerde & Associates, QueensOD Rel. 2.10 – User’s Guide: Estimating Origin – Destination Traffic Demands from Link Flow Counts, M. Van Aerde & Associates, Ltd., Kingston, ON, 2007.
- Various Authors, Regional Congestion Pricing Workshop: Summary of Proceedings, New York City, NY, 1999.
- Washington State Department of Transportation (WSDOT), SR 167 – HOT Lanes Pilot Project, URL: <http://www.wsdot.wa.gov/projects/sr167/hotlanes> [Last Accessed: July 12, 2008]
- Wiedemann, R., Modeling of RTI-Elements on Multi-Lane Roads, Advanced Telematics in Road Transport, Edited by: The Commission of the European Community, DG XIII, Brussels, 1991
- Wiedemann, R., Simulation des Straßenverkehrsflusses, Schriftenreihe des Instituts für Verkehrswesen der Universität Karlsruhe, Heft 8, 1974
- Wilks, S.S., Mathematical Statistics, Wiley, New York, NY, 1962
- Wisconsin Department of Transportation, Freeway System Operational Assessment, Technical Report I-33, Paramics Calibration and Validation Guidelines, Draft, June 2002;
- Wolff, C. & Vilain, P., Congestion Pricing as a Traffic Management Tool: Evaluating the Impacts at New York City’s Interstate Crossings, Transportation Research Board, TRB 86th Annual Meeting, 2007

- Wunesch, Karl L., Binary Logistic Regression with SPSS[®], East Carolina University, Department of Psychology, 2006 URL: <http://core.ecu.edu/psyc/wuenschk/MV/MultReg/Logistic-SPSS.doc> [Last Accessed: April 14, 2008]
- Zhang, G. & Wang, Y. & Wei, H. & Yi, P., A Feedback –Based Dynamic Tolling Algorithm for High Occupancy Toll (HOT) Lane Operations, Paper Presented at the 87th Annual TRB Conference, 2008.
- Zhang, G. & Yan, S. & Wang, Y., Simulation-based Investigation on High Occupancy Toll (HOT) Lane Operations for Washington State Route 167, Paper Presented at the 87th Annual TRB Conference, 2008a.
- Zmud, J & Bradley, M & Douma, F & Simek, C, Panel Survey Evaluation of Attitudes and Willingness to Pay for Tolled Facilities, Paper Presented at the 85th Annual TRB Conference, 2006.

Appendix A

Geometric Data

There are two chainage equations within the study area. The first is at the boundary between the former Huntley and March Townships, just west of the Huntmar Road Underpass:

EBL: Sta 31+159.243 Twp. Huntley = 10+000.000 Twp. March

WBL: Sta 31+107.177 Twp. Huntley = 10+000.000 Twp. March

The second is at the boundary between the former March and Nepean Townships, just east of the Eagleson Road Underpass:

EBL: Sta 14+432.211 Twp. March = 10+004.357 Twp. Nepean

WBL: Sta 14+447.123 Twp. March = 10+010.589 Twp. Nepean

The study area extends from approximately station 29+800 Twp. Huntley to station 16+960 Twp. Nepean (MTO 2003).

Existing Horizontal Alignment Circular Curves (MTO 2003)

Number	TWP.	From Station	To Station	Radius	A (spiral)
Eastbound Lanes					
HC-1	March	10+000.000	10+594.644	2354.255	None
HC-3	March	11+495.838	12+034.688	2408.249	None
HC-5	March	13+969.795	14+398.061	2371.657	None
HC-7	Nepean	14+275.412	14+555.212	873.188	230.715
HC-9	Nepean	15+206.683	15+659.599	1500.000	325.000
Westbound Lanes					
HC-2	March	10+000.000	10+605.107	2395.678	None
HC-4	March	11+506.306	12+035.878	2366.796	None
HC-6	March	13.970.986	14+406.738	2413.109	None
HC-8	Nepean	14+313.286	14+578.621	873.188	230.715
HC-10	Nepean	15+234.825	15+726.570	2000.000	365.000

Existing Vertical Alignment (MTO 2003)

Number	TWP.	VPI Station	G1	G2	Type	K Value	Length
Eastbound Lanes							
VC-7	Huntley	30+787.360	-0.450	-0.570	Crest	762	91.440
VC-8	March	10+289.560	-0.570	-0.890	Crest	339	108.509
VC-10	March	10+929.640	-0.890	0.878	Sag	339	598.627
VC-13	March	11+981.200	0.878	-0.704	Crest	339	535.838
VC-15	March	12+407.920	-0.704	-1.769	Crest	274	291.998
VC-16	March	12+865.120	-1.769	0.305	Sag	190	395.021
VC-19	March	13+946.855	0.305	-0.901	Crest	274	331.013
VC-20	March	14+432.000	1.200	-0.600	Sag	60	108.000
VC-22	Nepean	11+657.118	-1.800	2.400	Crest	122	512.064
VC-24	Nepean	12+259.799	2.400	1.000	Sag	69	96.317
VC-26	Nepean	12+659.300	1.000	3.000	Crest	85	169.469
VC-29	Nepean	13+414.503	3.000	0.600	Sag	122	292.608
VC-30	Nepean	14+415.219	0.600	-0.280	Sag	191	167.640
VC-32	Nepean	15+205.511	-0.280	0.280	Crest	274	153.619
Westbound Lanes							
VC-6	Huntley	30+756.880	-0.380	-0.620	Crest	762	182.880
VC-9	March	10+304.800	-0.620	-0.735	Crest	763	87.782
VC-11	March	10+943.966	-0.735	0.784	Sag	339	514.502
VC-12	March	11+920.240	0.784	-0.302	Crest	488	529.742
VC-14	March	12+334.769	-0.302	-1.455	Crest	190	219.456
VC-17	March	12+971.800	-1.455	0.521	Sag	191	376.733
VC-18	March	13+855.720	0.521	-0.933	Crest	339	492.557
VC-21	March	14+447.000	1.200	-0.600	Sag	60	108.000
VC-23	Nepean	11+657.118	-1.800	2.400	Crest	122	512.064
VC-25	Nepean	12+295.735	2.400	1.000	Sag	69	96.317
VC-27	Nepean	12+659.300	1.000	3.000	Crest	85	169.469
VC-28	Nepean	13+393.563	3.000	0.600	Sag	191	457.200
VC-31	Nepean	14+474.079	0.600	-0.280	Sag	274	241.402
VC-33	Nepean	15+263.511	-0.280	0.280	Crest	274	153.619

Appendix B

VISSIM Input Files

Note: adding all of the VISSIM input files for each simulation run conducted throughout this study would require thousands of pages. Instead only one set of VISSIM inputs is included, this sets represents the design year network.

TITLE "2016 HOT Final Trials: Toll \$0.50, Intensity 120%"

-- VISSIM 4.30-01

RANDOM_SEED 468
 SIMULATION_DURATION 1800.0
 SIMULATION_STARTTIME "00:00:00"
 SIMULATION_SPEED MAX 10.0
 TIME_STEP 5
 UNIT DISTANCE 1 0
 UNIT DISTANCE 2 0
 UNIT SPEED 0
 UNIT ACCELERATION 0
 QUEUE SPEED UNDER 5.0 OVER 10.0 DX UNDER 20.0 LENGTH MAX 500.0
 FROM 0 UNTIL 99999 AGGREGATION_INTERVAL 99999

-- Multi-Run: --

MULTIRUN
 RANDOM_SEED 101
 RANDOM_SEED_INCREMENT 1
 NUMBER_RUNS 16
 DTA_INCREMENT 0.0
 EVAL_DIRECTORY "#data#HOV network"

-- Dynamic Assignment: --

DTA
 TRIP_CHAIN_FILE 0 ""
 MATRICES 1
 COMPOSITION 2 MATRIX_FILE "ebam2016.fma"
 COST_FILE "2016_network.bew" NODE YES
 PATH_FILE "2016_network.weg" NODE YES
 COST_INTERVAL 600
 MAX_PATHNUMBER -999
 STRATEGY 0
 ROUTE_GUIDANCE_OFFSET 999999 999999
 OFFSET 0 0
 KIRCHHOFF_EXPONENT 3.50
 VOLUME PERCENT 1.20
 PATHEVAL PERCENT -0.75
 DETOURS -2.50
 LOGIT 1.50000
 UNDER 0.00100
 CONVERGENCE
 PATHS
 EDGE
 MSA 0

-- Vehicle Types: --

```

-----
VEHICLE_TYPE 100
NAME          "Car"
CATEGORY      CAR
COLOR_DIST    1
LENGTH        4.760
WIDTH         1.500
MASS          1
POWER         1
LAYER         0
ALLOWEDLOAD   0
MODEL_YEAR    0
MILEAGE       0
LOAD          0.0
OCCUPANCY     0.0
KATTEMPERATURE 0
WATERTEMPERATURE 0
MAX_ACCELERATION 1
DESIRED_ACCELERATION 1
MAX_DECELERATION 1
DESIRED_DECELERATION 1
EQUIPMENT     NONE
DRIVER        UNIDENTIFIED
PASSENGERS    1.0
VEHICLE_MODEL_DIST 10
COST_COEFFICIENTS 1.000 0.000 100.000
FEE 0.000 0.000 0.000 0.000
ATTRACTION 0.000 0.000 0.000 0.000
DESTINATION 0.000 0.000 0.000 0.000
POSITION 0.000 0.000 0.000 0.000
PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
VEHICLE_TYPE 150
NAME          "HOV"
CATEGORY      CAR
COLOR_DIST    1
LENGTH        4.760
WIDTH         1.500
MASS          1
POWER         1
LAYER         0
ALLOWEDLOAD   0
MODEL_YEAR    0
MILEAGE       0
LOAD          0.0
OCCUPANCY     0.0
KATTEMPERATURE 0
WATERTEMPERATURE 0
MAX_ACCELERATION 1
DESIRED_ACCELERATION 1
MAX_DECELERATION 1
DESIRED_DECELERATION 1
EQUIPMENT     NONE
DRIVER        UNIDENTIFIED

```

PASSENGERS 1.0
 VEHICLE_MODEL_DIST 10
 ALIGHTING_TIME 0.00 BOARDING_TIME 0.00 ADDITION YES
 DELAY_TIME 0.00 CAPACITY 9999
 COST_COEFFICIENTS 1.000 0.000 0.000
 FEE 0.000 0.000 0.000 0.000
 ATTRACTION 0.000 0.000 0.000 0.000
 DESTINATION 0.000 0.000 0.000 0.000
 POSITION 0.000 0.000 0.000 0.000
 PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
 VEHICLE_TYPE 200
 NAME "HGV"
 CATEGORY HGV
 COLOR_DIST 1
 LENGTH 10.215
 WIDTH 2.500
 MASS 2
 POWER 2
 LAYER 0
 ALLOWEDLOAD 0
 MODEL_YEAR 0
 MILEAGE 0
 LOAD 1.0
 OCCUPANCY 0.0
 KATTEMPERATURE 0
 WATERTEMPERATURE 0
 MAX_ACCELERATION 2
 DESIRED_ACCELERATION 2
 MAX_DECELERATION 2
 DESIRED_DECELERATION 2
 EQUIPMENT NONE
 DRIVER UNIDENTIFIED
 PASSENGERS 1.0
 VEHICLE_MODEL_DIST 20
 COST_COEFFICIENTS 1.000 0.000 1.000
 FEE 0.000 0.000 0.000 0.000
 ATTRACTION 0.000 0.000 0.000 0.000
 DESTINATION 0.000 0.000 0.000 0.000
 POSITION 0.000 0.000 0.000 0.000
 PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
 VEHICLE_TYPE 300
 NAME "Bus"
 CATEGORY BUS
 COLOR_DIST 1
 LENGTH 11.541
 WIDTH 2.500
 MASS 3
 POWER 3
 LAYER 0
 ALLOWEDLOAD 0
 MODEL_YEAR 0
 MILEAGE 0
 LOAD 0.0
 OCCUPANCY 0.0
 KATTEMPERATURE 0
 WATERTEMPERATURE 0

MAX_ACCELERATION 3
 DESIRED_ACCELERATION 3
 MAX_DECELERATION 3
 DESIRED_DECELERATION 3
 EQUIPMENT NONE
 DRIVER UNIDENTIFIED
 PASSENGERS 1.0
 VEHICLE_MODEL_DIST 30
 ALIGHTING_TIME 0.00 BOARDING_TIME 0.00 ADDITION YES
 DELAY_TIME 0.00 CAPACITY 999
 COST_COEFFICIENTS 1.000 0.000 1.000
 FEE 0.000 0.000 0.000 0.000
 ATTRACTION 0.000 0.000 0.000 0.000
 DESTINATION 0.000 0.000 0.000 0.000
 POSITION 0.000 0.000 0.000 0.000
 PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
 VEHICLE_TYPE 400
 NAME "Tram"
 CATEGORY TRAM
 COLOR_DIST 1
 LENGTH 15.698
 WIDTH 2.500
 MASS 4
 POWER 4
 LAYER 0
 ALLOWEDLOAD 0
 MODEL_YEAR 0
 MILEAGE 0
 LOAD 0.0
 OCCUPANCY 0.0
 KATTEMPERATURE 0
 WATERTEMPERATURE 0
 MAX_ACCELERATION 4
 DESIRED_ACCELERATION 4
 MAX_DECELERATION 4
 DESIRED_DECELERATION 4
 EQUIPMENT NONE
 DRIVER UNIDENTIFIED
 PASSENGERS 1.0
 VEHICLE_MODEL_DIST 40
 ALIGHTING_TIME 0.00 BOARDING_TIME 0.00 ADDITION YES
 DELAY_TIME 0.00 CAPACITY 9999
 COST_COEFFICIENTS 1.000 0.000 1.000
 FEE 0.000 0.000 0.000 0.000
 ATTRACTION 0.000 0.000 0.000 0.000
 DESTINATION 0.000 0.000 0.000 0.000
 POSITION 0.000 0.000 0.000 0.000
 PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
 VEHICLE_TYPE 500
 NAME "Pedestrian"
 CATEGORY PEDESTRIAN
 COLOR_DIST 1
 LENGTH 0.342
 WIDTH 0.500
 MASS 5
 POWER 5

LAYER 0
 ALLOWEDLOAD 0
 MODEL_YEAR 0
 MILEAGE 0
 LOAD 0.0
 OCCUPANCY 0.0
 KATTEMPERATURE 0
 WATERTEMPERATURE 0
 MAX_ACCELERATION 5
 DESIRED_ACCELERATION 5
 MAX_DECELERATION 5
 DESIRED_DECELERATION 5
 EQUIPMENT NONE
 DRIVER UNIDENTIFIED
 PASSENGERS 1.0
 VEHICLE_MODEL_DIST 50
 COST_COEFFICIENTS 1.000 0.000 1.000
 FEE 0.000 0.000 0.000 0.000
 ATTRACTION 0.000 0.000 0.000 0.000
 DESTINATION 0.000 0.000 0.000 0.000
 POSITION 0.000 0.000 0.000 0.000
 PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
 VEHICLE_TYPE 600
 NAME "Bike"
 CATEGORY BICYCLE
 COLOR_DIST 1
 LENGTH 1.445
 WIDTH 0.500
 MASS 6
 POWER 6
 LAYER 0
 ALLOWEDLOAD 0
 MODEL_YEAR 0
 MILEAGE 0
 LOAD 0.0
 OCCUPANCY 0.0
 KATTEMPERATURE 0
 WATERTEMPERATURE 0
 MAX_ACCELERATION 6
 DESIRED_ACCELERATION 6
 MAX_DECELERATION 6
 DESIRED_DECELERATION 6
 EQUIPMENT NONE
 DRIVER UNIDENTIFIED
 PASSENGERS 1.0
 VEHICLE_MODEL_DIST 60
 COST_COEFFICIENTS 1.000 0.000 1.000
 FEE 0.000 0.000 0.000 0.000
 ATTRACTION 0.000 0.000 0.000 0.000
 DESTINATION 0.000 0.000 0.000 0.000
 POSITION 0.000 0.000 0.000 0.000
 PARKING_AVAILABILITY 0.000 0.000 0.000 0.000

-- Vehicle Classes: --

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VEHICLE_CLASS 10
  NAME      "Car"
  COLOR     NONE
  VEHICLE_TYPES 100
VEHICLE_CLASS 15
  NAME      "HOV"
  COLOR     NONE
  VEHICLE_TYPES 150
VEHICLE_CLASS 20
  NAME      "HGV"
  COLOR     NONE
  VEHICLE_TYPES 200
VEHICLE_CLASS 30
  NAME      "Bus"
  COLOR     NONE
  VEHICLE_TYPES 300
VEHICLE_CLASS 40
  NAME      "Tram"
  COLOR     NONE
  VEHICLE_TYPES 400
VEHICLE_CLASS 50
  NAME      "Pedestrian"
  COLOR     NONE
  VEHICLE_TYPES 500
VEHICLE_CLASS 60
  NAME      "Bike"
  COLOR     NONE
  VEHICLE_TYPES 600

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-- Driving Behavior: --

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DRIVING_BEHAVIOR 1 NAME "Urban (motorized)"
  LANE_CHANGE_BEHAVIOR FREE_LANESEL
    T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 0.00
    MIN_ACCELERATION OWN MIN -4.00 DISTANCE 200.00 MAX -1.00
    TRAILING_VEHICLE MIN -3.00 DISTANCE 200.00 MAX -0.50
  CAR_FOLLOW_MODEL WIEDEMANN99
    NUMB_PRECED 2 OBS_DISTANCE MIN 0.00 MAX 250.00
    AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
    CC0 1.50 CC1 1.32 CC2 4.00 CC3 -8.00 CC4 -0.35
    CC5 0.35 CC6 11.44 CC7 0.25 CC8 3.50 CC9 1.50
  LATERAL_BEHAVIOR MIDDLE
    OVERTAKE RIGHT VEHICLE_CLASSES
    OVERTAKE LEFT VEHICLE_CLASSES
    LAT_DISTANCE DEFAULT DY_STAND 1.00 DY_50KMH 1.00
  AMBER_BEHAVIOR CONT_CHECK
    AMBER_ALPHA 1.59000000 AMBER_BETA1 -0.26000000 AMBER_BETA2 0.27000000
DRIVING_BEHAVIOR 2 NAME "Right-side rule (motorized)"
  LANE_CHANGE_BEHAVIOR RIGHT_HAND_RULE
    T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 11.00
    MIN_ACCELERATION OWN MIN -4.00 DISTANCE 200.00 MAX -1.00
    TRAILING_VEHICLE MIN -3.00 DISTANCE 200.00 MAX -0.50
    COOPERATIVE -3.00 ABXFACTOR 0.60

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CAR_FOLLOW_MODEL WIEDEMANN99
 NUMB_PRECED 2 OBS_DISTANCE MIN 0.00 MAX 250.00
 AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
 CC0 1.50 CC1 0.90 CC2 4.00 CC3 -8.00 CC4 -0.35
 CC5 0.35 CC6 11.44 CC7 0.25 CC8 3.50 CC9 1.50
 LATERAL_BEHAVIOR MIDDLE
 OVERTAKE RIGHT VEHICLE_CLASSES
 OVERTAKE LEFT VEHICLE_CLASSES
 LAT_DISTANCE DEFAULT DY_STAND 1.00 DY_50KMH 1.00
 AMBER_BEHAVIOR CONT_CHECK
 AMBER_ALPHA 1.58858105 AMBER_BETA1 -0.26198070 AMBER_BETA2 0.26945295
 DRIVING_BEHAVIOR 3 NAME "Freeway (free lane selection)"
 LANE_CHANGE_BEHAVIOR FREE_LANESEL
 T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 0.00
 MIN_ACCELERATION OWN MIN -4.00 DISTANCE 100.00 MAX -1.00
 TRAILING_VEHICLE MIN -3.00 DISTANCE 100.00 MAX -1.00
 COOPERATIVE -3.00 ABXFACTOR 0.60
 CAR_FOLLOW_MODEL WIEDEMANN99
 NUMB_PRECED 2 OBS_DISTANCE MIN 0.00 MAX 250.00
 AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
 CC0 1.50 CC1 1.32 CC2 4.00 CC3 -8.00 CC4 -0.35
 CC5 0.35 CC6 11.44 CC7 0.25 CC8 3.50 CC9 1.50
 LATERAL_BEHAVIOR MIDDLE
 OVERTAKE RIGHT VEHICLE_CLASSES
 OVERTAKE LEFT VEHICLE_CLASSES
 LAT_DISTANCE DEFAULT DY_STAND 1.00 DY_50KMH 1.00
 AMBER_BEHAVIOR CONT_CHECK
 AMBER_ALPHA 1.59000000 AMBER_BETA1 -0.26000000 AMBER_BETA2 0.27000000
 DRIVING_BEHAVIOR 4 NAME "Footpath (no interaction)"
 LANE_CHANGE_BEHAVIOR FREE_LANESEL
 T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 11.00
 MIN_ACCELERATION OWN MIN -4.00 DISTANCE 100.00 MAX -1.00
 TRAILING_VEHICLE MIN -3.00 DISTANCE 100.00 MAX -1.00
 COOPERATIVE -3.00 ABXFACTOR 0.60
 CAR_FOLLOW_MODEL NO_INTERACTION
 NUMB_PRECED 2 OBS_DISTANCE MIN 0.00 MAX 250.00
 AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
 CC0 1.50 CC1 0.90 CC2 4.00 CC3 -8.00 CC4 -0.35
 CC5 0.35 CC6 11.44 CC7 0.25 CC8 3.50 CC9 1.50
 LATERAL_BEHAVIOR ANY
 OVERTAKE RIGHT VEHICLE_CLASSES
 OVERTAKE LEFT VEHICLE_CLASSES
 LAT_DISTANCE DEFAULT DY_STAND 1.00 DY_50KMH 1.00
 AMBER_BEHAVIOR CONT_CHECK
 AMBER_ALPHA 1.58858105 AMBER_BETA1 -0.26198070 AMBER_BETA2 0.26945295
 DRIVING_BEHAVIOR 5 NAME "Cycle-Track (free overtaking)"
 LANE_CHANGE_BEHAVIOR FREE_LANESEL
 T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 11.00
 MIN_ACCELERATION OWN MIN -4.00 DISTANCE 100.00 MAX -1.00
 TRAILING_VEHICLE MIN -3.00 DISTANCE 100.00 MAX -1.00
 COOPERATIVE -3.00 ABXFACTOR 0.60
 CAR_FOLLOW_MODEL WIEDEMANN99
 NUMB_PRECED 2 OBS_DISTANCE MIN 10.00 MAX 250.00 DIAMOND_SHAPE
 AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
 CC0 0.50 CC1 0.50 CC2 0.00 CC3 -8.00 CC4 -0.35
 CC5 0.35 CC6 11.44 CC7 0.25 CC8 3.50 CC9 1.50

LATERAL_BEHAVIOR RIGHT
 OVERTAKE RIGHT VEHICLE_CLASSES ALL
 OVERTAKE LEFT VEHICLE_CLASSES ALL
 LAT_DISTANCE DEFAULT DY_STAND 0.10 DY_50KMH 0.30
 AMBER_BEHAVIOR CONT_CHECK
 AMBER_ALPHA 1.58858105 AMBER_BETA1 -0.26198070 AMBER_BETA2 0.26945295

-- Link Types: --

LINKTYPE 1 NAME "Urban (motorized)" COLOR GRAY
 DEFAULT DRIVING_BEHAVIOR 1
 LINKTYPE 2 NAME "Right-side rule (motorized)" COLOR GRAY
 DEFAULT DRIVING_BEHAVIOR 2
 LINKTYPE 3 NAME "Freeway (free lane selection)" COLOR GRAY
 DEFAULT DRIVING_BEHAVIOR 3
 LINKTYPE 4 NAME "Footpath (no interaction)" COLOR GRAY
 DEFAULT DRIVING_BEHAVIOR 4
 LINKTYPE 5 NAME "Cycle-Track (free overtaking)" COLOR GRAY
 DEFAULT DRIVING_BEHAVIOR 5

-- Links: --

LINK 1 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 934.323 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT -0.00450
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM -1137.125 479.955
 TO -422.403 1081.729
 LINK 2 NAME "PALL ON" LABEL 0.00 0.00
 TYPE 3 LENGTH 225.193 LANES 1 LANE_WIDTH 3.60 GRADIENT 0.01000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM -405.066 1089.901
 OVER -366.750 1120.497 0.000 OVER -326.432 1151.665 0.000 OVER -297.266 1173.397 0.000
 OVER -264.668 1192.841 0.000 OVER -241.507 1202.277 0.000
 TO -216.916 1210.283
 LINK 3 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 524.813 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT -0.00450
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM -409.948 1095.705
 OVER -272.568 1220.016 0.000
 TO -22.354 1449.536
 LINK 4 NAME "PALL OFF I" LABEL 0.00 0.00
 TYPE 3 LENGTH 495.817 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.01000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 45.379 1387.277
 OVER 55.930 1367.436 0.000 OVER 62.368 1347.477 0.000 OVER 65.802 1324.727 0.000 OVER
 64.300 1300.132 0.000 OVER 55.500 1276.953 0.000
 OVER 41.980 1258.496 0.000 OVER 23.737 1243.441 0.000 OVER 2.061 1235.071 0.000 OVER -
 22.406 1232.496 0.000 OVER -48.160 1237.861 0.000
 OVER -68.977 1249.429 0.000 OVER -85.503 1265.740 0.000 OVER -97.521 1288.757 0.000 OVER -
 102.458 1314.061 0.000 OVER -100.526 1334.310 0.000
 OVER -94.517 1351.050 0.000 OVER -85.288 1368.724 0.000 OVER -66.187 1394.124 0.000
 TO -16.648 1444.463

LINK 5 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 409.482 LANES 5 LANE_WIDTH 3.60 3.60 3.60 3.60 3.60 GRADIENT -
 0.00540 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM -17.578 1453.266
 OVER 76.898 1542.066 0.000 OVER 139.270 1599.062 0.000
 TO 283.642 1730.636
 CLOSED
 LANE 5 VEHICLE_CLASSES 20
 LINK 6 NAME "PALL ON D" LABEL 0.00 0.00
 TYPE 3 LENGTH 344.288 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.00500 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 179.902 1591.761
 OVER 207.008 1627.610 0.000 OVER 247.812 1670.950 0.000
 TO 417.296 1840.621
 LINK 7 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 169.189 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT -0.00540
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 286.406 1733.152
 TO 411.994 1846.521
 LINK 8 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 394.171 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT -0.00900
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 423.458 1854.024
 OVER 489.032 1914.541 0.000 OVER 537.709 1958.329 0.000 OVER 586.823 1999.366 0.000 OVER
 645.323 2046.384 0.000
 TO 725.027 2107.454
 LINK 9 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 172.027 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.00540 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 281.687 1738.683
 OVER 317.755 1772.091 0.000 OVER 371.201 1820.261 0.000
 TO 409.222 1854.123
 LINK 10 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 400.460 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.00901 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 412.906 1857.377
 OVER 420.897 1864.338 0.000 OVER 481.111 1919.903 0.000 OVER 535.266 1968.617 0.000 OVER
 580.563 2006.432 0.000 OVER 605.320 2026.258 0.000
 OVER 640.414 2054.374 0.000 OVER 676.972 2082.957 0.000
 TO 719.069 2115.141
 LINK 11 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 681.115 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT -0.00900
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 728.580 2112.313
 OVER 747.117 2125.907 0.000 OVER 841.816 2187.086 0.000 OVER 922.865 2234.681 0.000 OVER
 1015.459 2285.667 0.000 OVER 1270.187 2421.489 0.000
 TO 1321.186 2446.982
 LINK 12 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 685.561 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.00901 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 720.874 2116.423
 OVER 740.882 2130.840 0.000 OVER 757.250 2141.485 0.000 OVER 800.755 2169.456 0.000 OVER
 819.048 2181.317 0.000 OVER 833.666 2190.784 0.000
 OVER 845.989 2198.283 0.000 OVER 875.518 2215.724 0.000 OVER 917.660 2240.426 0.000 OVER
 960.385 2263.933 0.000 OVER 1002.411 2287.117 0.000
 OVER 1053.066 2314.324 0.000 OVER 1111.764 2345.613 0.000 OVER 1263.420 2426.767 0.000

TO 1317.004 2453.953
 LINK 13 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 443.968 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT 0.00790
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 1326.407 2447.750
 OVER 1449.346 2511.639 0.000
 TO 1719.579 2653.958
 LINK 14 NAME "TERR OFF" LABEL 0.00 0.00
 TYPE 3 LENGTH 326.004 LANES 1 LANE_WIDTH 3.60 GRADIENT 0.01000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 1725.080 2650.798
 OVER 1767.022 2672.163 0.000 OVER 1817.291 2694.860 0.000 OVER 1854.667 2711.852 0.000
 OVER 1885.997 2722.703 0.000 OVER 1912.741 2730.039 0.000
 OVER 1939.945 2734.318 0.000 OVER 1970.205 2735.388 0.000 OVER 1999.089 2732.790 0.000
 TO 2033.481 2726.211
 LINK 15 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 502.185 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT 0.00792 COST
 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 1741.285 2667.591
 OVER 1839.602 2719.819 0.000 OVER 1963.343 2788.796 0.000 OVER 2075.651 2858.595 0.000
 TO 2171.758 2925.249
 LINK 16 NAME "TERR ON I" LABEL 0.00 0.00
 TYPE 3 LENGTH 457.727 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.01000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 2220.050 2842.183
 OVER 2227.804 2826.592 0.000 OVER 2229.797 2809.152 0.000 OVER 2230.129 2787.809 0.000
 OVER 2221.990 2762.895 0.000 OVER 2209.201 2745.189 0.000
 OVER 2192.425 2731.403 0.000 OVER 2167.013 2721.272 0.000 OVER 2138.113 2720.773 0.000
 OVER 2106.721 2734.227 0.000 OVER 2088.450 2752.074 0.000
 OVER 2076.160 2775.991 0.000 OVER 2073.668 2804.161 0.000 OVER 2078.319 2826.625 0.000
 OVER 2091.108 2848.276 0.000 OVER 2108.548 2864.553 0.000
 OVER 2157.723 2904.110 0.000
 TO 2177.521 2920.136
 LINK 17 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 378.618 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT 0.00050
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 2180.152 2929.276
 OVER 2265.073 2993.699 0.000 OVER 2344.922 3060.438 0.000 OVER 2405.305 3110.115 0.000
 TO 2472.441 3169.704
 LINK 18 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 190.294 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT -0.01760
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 2473.339 3172.679
 OVER 2549.326 3236.567 0.000
 TO 2617.649 3296.702
 LINK 19 NAME "TERR ON D" LABEL 0.00 0.00
 TYPE 3 LENGTH 547.340 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.01000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 2286.392 2874.594
 OVER 2289.748 2915.521 0.000 OVER 2301.185 2949.439 0.000 OVER 2320.670 2980.953 0.000
 OVER 2345.873 3010.138 0.000 OVER 2375.100 3042.553 0.000
 OVER 2401.362 3071.144 0.000 OVER 2440.967 3113.534 0.000 OVER 2479.301 3154.484 0.000
 TO 2622.706 3291.437
 LINK 20 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 327.853 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT -0.01760
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000

FROM 2621.239 3297.477
 OVER 2770.902 3427.253 0.000
 TO 2868.168 3513.143
 LINK 21 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 191.246 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT 0.00150 COST
 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 2871.589 3518.437
 TO 3017.929 3641.562
 LINK 22 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 403.012 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT 0.00150
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 3018.880 3644.697
 TO 3324.450 3907.462
 CLOSED
 LANE 4 VEHICLE_CLASSES 20
 LINK 23 NAME "CAST ON" LABEL 0.00 0.00
 TYPE 3 LENGTH 412.674 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.01000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 3039.667 3608.382
 OVER 3120.271 3694.716 0.000 OVER 3169.974 3747.664 0.000 OVER 3212.320 3789.585 0.000
 OVER 3260.878 3836.206 0.000 OVER 3293.904 3867.385 0.000
 TO 3330.717 3900.654
 LINK 24 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 299.148 LANES 5 LANE_WIDTH 3.60 3.60 3.60 3.60 3.60 GRADIENT
 0.00340 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 3328.187 3908.021
 TO 3555.572 4102.406
 CLOSED
 LANE 5 VEHICLE_CLASSES 20
 LINK 25 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 357.850 LANES 5 LANE_WIDTH 3.60 3.60 3.60 3.60 3.60 GRADIENT -
 0.00800 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 3559.638 4105.851
 TO 3831.355 4338.717
 CLOSED
 LANE 5 VEHICLE_CLASSES 20
 LINK 26 NAME "" LABEL 0.00 0.00
 TYPE 3 LENGTH 979.106 LANES 1 LANE_WIDTH 3.50 GRADIENT 0.00790 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 1322.404 2456.356
 OVER 1416.952 2505.790 0.000 OVER 1534.252 2567.156 0.000 OVER 1692.983 2651.119 0.000
 OVER 1848.984 2733.892 0.000 OVER 1962.477 2797.691 0.000
 OVER 2055.749 2855.199 0.000 OVER 2077.065 2869.097 0.000
 TO 2174.516 2936.771
 LINK 27 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 896.505 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.01760 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 2178.548 2939.899
 OVER 2257.039 2999.783 0.000 OVER 2343.552 3072.229 0.000 OVER 2435.383 3150.534 0.000
 OVER 2485.698 3194.419 0.000 OVER 2526.312 3227.812 0.000
 OVER 2604.830 3295.861 0.000 OVER 2725.918 3401.695 0.000
 TO 2861.489 3520.388
 LINK 28 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 176.434 LANES 1 LANE_WIDTH 3.60 GRADIENT 0.00150 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 2864.943 3523.173

TO 3000.049 3636.642
 LINK 30 NAME "EAGL OFF" LABEL 0.00 0.00
 TYPE 3 LENGTH 363.634 LANES 1 LANE_WIDTH 3.60 GRADIENT 0.00500 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 3839.499 4335.559
 OVER 3889.116 4378.023 0.000 OVER 3974.566 4443.649 0.000 OVER 4014.322 4468.291 0.000
 OVER 4045.600 4482.030 0.000 OVER 4076.586 4491.092 0.000
 OVER 4111.372 4496.354 0.000
 TO 4153.554 4496.103
 LINK 31 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 611.915 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT -0.00800
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 3836.631 4342.883
 OVER 3905.250 4402.020 0.000 OVER 3965.380 4453.702 0.000 OVER 4046.260 4520.106 0.000
 OVER 4134.632 4584.277 0.000 OVER 4223.004 4642.065 0.000
 TO 4326.970 4707.025
 LINK 32 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 615.464 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.00800 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 3829.904 4347.341
 OVER 3921.389 4426.590 0.000 OVER 3961.403 4460.168 0.000 OVER 3999.822 4491.946 0.000
 OVER 4039.233 4524.573 0.000 OVER 4076.337 4551.906 0.000
 OVER 4117.136 4581.402 0.000 OVER 4143.574 4599.388 0.000 OVER 4169.969 4616.512 0.000
 OVER 4230.308 4656.368 0.000
 TO 4322.934 4713.800
 LINK 33 NAME "EAGL ON I" LABEL 0.00 0.00
 TYPE 3 LENGTH 445.124 LANES 2 LANE_WIDTH 3.60 3.60 GRADIENT -0.01000 COST
 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 4364.002 4600.652
 OVER 4366.604 4577.950 0.000 OVER 4362.063 4548.882 0.000 OVER 4347.296 4524.057 0.000
 OVER 4325.467 4507.096 0.000 OVER 4296.361 4499.178 0.000
 OVER 4273.676 4500.462 0.000 OVER 4247.353 4512.233 0.000 OVER 4226.808 4531.066 0.000
 OVER 4215.465 4554.179 0.000 OVER 4212.469 4579.582 0.000
 OVER 4217.391 4605.220 0.000 OVER 4229.162 4626.408 0.000 OVER 4252.489 4647.766 0.000
 TO 4330.886 4698.601
 LINK 34 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 376.817 LANES 5 LANE_WIDTH 3.60 3.60 3.60 3.60 3.60 GRADIENT
 0.00720 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 4334.529 4707.527
 TO 4660.790 4896.060
 LINK 35 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 208.315 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT 0.00730
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 4663.112 4899.372
 TO 4842.541 5005.203
 LINK 36 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 593.363 LANES 1 LANE_WIDTH 3.60 GRADIENT 0.00000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 4326.623 4715.993
 OVER 4467.709 4797.840 0.000 OVER 4601.973 4875.742 0.000 OVER 4745.718 4959.427 0.000
 TO 4839.271 5014.771
 LINK 37 NAME "EAGL ON D" LABEL 0.00 0.00
 TYPE 3 LENGTH 567.380 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.01000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 4406.887 4657.678

OVER 4414.695 4687.844 0.000 OVER 4428.163 4711.662 0.000 OVER 4443.647 4731.336 0.000
 OVER 4466.054 4751.675 0.000 OVER 4507.588 4780.712 0.000
 OVER 4592.842 4836.546 0.000 OVER 4742.397 4931.016 0.000
 TO 4847.214 4997.416
 LINK 38 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 333.464 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT 0.01790
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 4862.981 5016.752
 TO 5149.579 5187.222
 LINK 39 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 451.538 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT 0.01790 COST
 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 5151.631 5190.476
 TO 5542.664 5416.262
 LINK 40 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 400.263 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT 0.01790
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 5544.434 5419.355
 TO 5889.976 5621.372
 CLOSED
 LANE 4 VEHICLE_CLASSES 20
 LINK 41 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 798.084 LANES 1 LANE_WIDTH 3.60 GRADIENT 0.01792 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 4846.119 5018.578
 OVER 4945.832 5077.126 0.000 OVER 5038.181 5132.152 0.000 OVER 5127.399 5185.003 0.000
 OVER 5205.748 5230.764 0.000 OVER 5312.302 5291.941 0.000
 OVER 5413.691 5350.588 0.000 OVER 5524.263 5414.216 0.000
 TO 5535.524 5420.618
 LINK 42 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 1081.214 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT -0.02809
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 5894.611 5621.936
 TO 6825.394 6172.087
 LINK 43 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 1079.070 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.02809 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 5892.792 5629.567
 OVER 5948.730 5662.940 0.000
 TO 6821.525 6178.972
 LINK 44 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 708.354 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT -0.03499
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 6829.045 6174.271
 TO 7442.158 6529.036
 LINK 45 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 707.619 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.03499 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 6825.515 6181.235
 TO 7437.928 6535.741
 LINK 46 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 230.314 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT -0.00600
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 7445.448 6528.813
 TO 7643.401 6646.538
 LINK 47 NAME "HOT" LABEL 0.00 0.00

TYPE 3 LENGTH 231.854 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.00600 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 7439.131 6536.442
 TO 7638.521 6654.764
 LINK 48 NAME "MOOD OFF" LABEL 0.00 0.00
 TYPE 3 LENGTH 273.389 LANES 1 LANE_WIDTH 3.60 GRADIENT 0.01000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 7650.666 6644.532
 OVER 7679.984 6660.664 0.000 OVER 7711.752 6676.284 0.000 OVER 7760.942 6698.454 0.000
 OVER 7799.201 6710.068 0.000 OVER 7831.482 6712.971 0.000
 OVER 7865.471 6710.580 0.000
 TO 7907.979 6698.828
 LINK 49 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 495.559 LANES 3 LANE_WIDTH 3.60 3.60 3.60 GRADIENT -0.00600
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 7645.375 6649.854
 TO 8072.377 6901.345
 LINK 50 NAME "HOT" LABEL 0.00 0.00
 TYPE 3 LENGTH 496.410 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.00600 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 7640.773 6656.101
 TO 8068.523 6908.000
 LINK 51 NAME "MOOD ON I" LABEL 0.00 0.00
 TYPE 3 LENGTH 448.994 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.01000 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 8090.090 6789.228
 OVER 8088.167 6758.853 0.000 OVER 8079.426 6730.357 0.000 OVER 8056.350 6704.265 0.000
 OVER 8028.029 6692.901 0.000 OVER 7999.708 6692.552 0.000
 OVER 7972.261 6704.789 0.000 OVER 7951.632 6727.341 0.000 OVER 7941.842 6752.192 0.000
 OVER 7944.639 6787.156 0.000 OVER 7965.093 6819.734 0.000
 OVER 8000.232 6847.478 0.000
 TO 8076.203 6894.681
 LINK 52 NAME "417" LABEL 0.00 0.00
 TYPE 1 LENGTH 250.731 LANES 5 LANE_WIDTH 3.60 3.60 3.60 3.60 3.60 GRADIENT -
 0.00600 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 8085.053 6909.125
 TO 8302.241 7034.406
 CLOSED
 LANE 5 VEHICLE_CLASSES 20
 LINK 53 NAME "417" LABEL 0.00 0.00
 TYPE 3 LENGTH 184.035 LANES 4 LANE_WIDTH 3.60 3.60 3.60 3.60 GRADIENT -0.00600
 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 8305.169 7038.021
 OVER 8369.080 7073.258 0.000 OVER 8418.500 7099.300 0.000
 TO 8469.303 7120.870
 CLOSED
 LANE 4 VEHICLE_CLASSES 20
 LINK 54 NAME "MOOD ON D" LABEL 0.00 0.00
 TYPE 3 LENGTH 419.783 LANES 1 LANE_WIDTH 3.60 GRADIENT -0.00600 COST 0.00000
 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 8170.755 6837.556
 OVER 8194.876 6886.834 0.000 OVER 8225.361 6933.412 0.000 OVER 8262.652 6977.436 0.000
 OVER 8316.518 7024.140 0.000 OVER 8373.047 7061.224 0.000
 OVER 8421.585 7089.755 0.000
 TO 8473.231 7112.300
 LINK 55 NAME "417" LABEL 0.00 0.00

TYPE 3 LENGTH 250.803 LANES 5 LANE_WIDTH 3.60 3.60 3.60 3.60 3.60 GRADIENT
 0.00270 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH 10.000
 FROM 8473.667 7120.625
 OVER 8559.487 7152.417 0.000
 TO 8712.799 7195.622

-- Connectors: --

CONNECTOR 10000 NAME "" LABEL 0.00 0.00
 FROM LINK 1 LANES 1 AT 931.100
 OVER -421.39048 1075.52234 0.00000 OVER -421.352 1075.555 0.000 OVER -400.638 1093.437
 0.000 OVER -400.599 1093.468 0.000
 TO LINK 2 LANES 1 AT 5.716 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 1000.000
 GRADIENT 0.00000 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION

CONNECTOR 10001 NAME "" LABEL 0.00 0.00
 FROM LINK 1 LANES 2 3 4 AT 930.625
 OVER -426.39117 1080.72414 0.00000 OVER -426.353 1080.756 0.000 OVER -406.617 1098.719
 0.000 OVER -406.579 1098.753 0.000
 TO LINK 3 LANES 1 2 3 AT 4.543 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00450 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION

CONNECTOR 10002 NAME "" LABEL 0.00 0.00
 FROM LINK 4 LANES 1 AT 493.673
 OVER -18.15159 1442.93513 0.00000 OVER -18.116 1442.971 0.000 OVER -8.611 1451.813 0.000
 OVER -8.575 1451.847 0.000
 TO LINK 5 LANES 1 AT 5.591 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT 0.00000 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION

CONNECTOR 10003 NAME "" LABEL 0.00 0.00
 FROM LINK 3 LANES 1 2 3 AT 520.646
 OVER -25.42455 1446.71940 0.00000 OVER -25.388 1446.753 0.000 OVER -13.643 1456.965 0.000
 OVER -13.607 1456.999 0.000
 TO LINK 5 LANES 2 3 4 AT 5.450 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00220 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION

CONNECTOR 10004 NAME "" LABEL 0.00 0.00
 FROM LINK 5 LANES 2 3 4 AT 405.836
 OVER 280.94696 1728.17986 0.00000 OVER 280.984 1728.214 0.000 OVER 294.485 1740.445 0.000
 OVER 294.522 1740.478 0.000
 TO LINK 7 LANES 1 2 3 AT 10.933 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT 0.00000 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION

CONNECTOR 10005 NAME "" LABEL 0.00 0.00
 FROM LINK 6 LANES 1 AT 341.670
 OVER 415.44625 1838.76934 0.00000 OVER 415.482 1838.805 0.000 OVER 430.459 1853.137 0.000
 OVER 430.496 1853.171 0.000
 TO LINK 8 LANES 1 AT 4.595 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000

GRADIENT -0.00700 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10006 NAME "" LABEL 0.00 0.00
 FROM LINK 7 LANES 1 2 3 AT 168.553
 OVER 411.52200 1846.09478 0.00000 OVER 411.559 1846.128 0.000 OVER 423.673 1856.672 0.000
 OVER 423.709 1856.705 0.000
 TO LINK 8 LANES 2 3 4 AT 2.003 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00720 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10007 NAME "" LABEL 0.00 0.00
 FROM LINK 5 LANES 5 AT 408.721
 OVER 278.22944 1735.44472 0.00000 OVER 278.267 1735.479 0.000 OVER 281.847 1738.831 0.000
 OVER 281.884 1738.865 0.000
 TO LINK 9 LANES 1 AT 0.268 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 800.000
 GRADIENT -0.00540 COST 0.00000 SURCHARGE 0.17000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION VEHICLE_CLASSES 20
 CLOSED
 LANE 1 VEHICLE_CLASSES 20
 CONNECTOR 10008 NAME "" LABEL 0.00 0.00
 FROM LINK 9 LANES 1 AT 171.904
 OVER 409.13011 1854.04116 0.00000 OVER 409.167 1854.074 0.000 OVER 414.739 1858.974 0.000
 OVER 414.777 1859.007 0.000
 TO LINK 10 LANES 1 AT 2.481 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00720 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10009 NAME "" LABEL 0.00 0.00
 FROM LINK 8 LANES 2 3 4 AT 388.966
 OVER 719.80005 2105.71669 0.00000 OVER 719.840 2105.747 0.000 OVER 733.054 2115.594 0.000
 OVER 733.094 2115.623 0.000
 TO LINK 11 LANES 1 2 3 AT 5.598 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00900 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10010 NAME "" LABEL 0.00 0.00
 FROM LINK 10 LANES 1 AT 398.350
 OVER 717.39245 2113.85924 0.00000 OVER 717.432 2113.890 0.000 OVER 720.188 2115.944 0.000
 OVER 722.371 2117.502 0.000 OVER 722.411 2117.531 0.000
 TO LINK 12 LANES 1 AT 1.895 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00900 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10011 NAME "" LABEL 0.00 0.00
 FROM LINK 11 LANES 1 2 3 AT 677.947
 OVER 1318.35244 2445.56499 0.00000 OVER 1318.397 2445.587 0.000 OVER 1324.433 2448.660
 0.000 OVER 1331.797 2452.580 0.000 OVER 1331.841 2452.603 0.000
 TO LINK 13 LANES 2 3 4 AT 7.060 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00050 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10012 NAME "" LABEL 0.00 0.00
 FROM LINK 13 LANES 1 AT 441.152
 OVER 1719.60380 2647.86775 0.00000 OVER 1719.648 2647.891 0.000 OVER 1728.126 2652.350
 0.000 OVER 1728.171 2652.373 0.000

TO LINK 14 LANES 1 AT 3.469 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 1000.000
 GRADIENT 0.00900 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10013 NAME "" LABEL 0.00 0.00
 FROM LINK 13 LANES 2 3 4 AT 441.996
 OVER 1716.99625 2654.63195 0.00000 OVER 1717.040 2654.655 0.000 OVER 1743.140 2668.576
 0.000 OVER 1743.184 2668.599 0.000
 TO LINK 15 LANES 1 2 3 AT 2.150 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 500.000
 GRADIENT 0.00790 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10014 NAME "" LABEL 0.00 0.00
 FROM LINK 16 LANES 1 AT 456.436
 OVER 2176.51685 2919.32372 0.00000 OVER 2176.556 2919.355 0.000 OVER 2186.063 2926.982
 0.000 OVER 2186.103 2927.012 0.000
 TO LINK 17 LANES 1 AT 3.369 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00470 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10015 NAME "" LABEL 0.00 0.00
 FROM LINK 15 LANES 1 2 3 AT 498.820
 OVER 2168.99297 2923.33145 0.00000 OVER 2169.034 2923.360 0.000 OVER 2174.239 2926.944
 0.000 OVER 2182.377 2933.223 0.000 OVER 2182.417 2933.253 0.000
 TO LINK 17 LANES 2 3 4 AT 4.210 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT 0.00420 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10016 NAME "" LABEL 0.00 0.00
 FROM LINK 17 LANES 2 3 4 AT 376.112
 OVER 2469.37286 3169.38752 0.00000 OVER 2469.410 3169.421 0.000 OVER 2477.583 3176.247
 0.000 OVER 2477.621 3176.279 0.000
 TO LINK 18 LANES 1 2 3 AT 5.594 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00850 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10017 NAME "" LABEL 0.00 0.00
 FROM LINK 19 LANES 1 AT 546.619
 OVER 2622.18534 3290.93908 0.00000 OVER 2622.221 3290.974 0.000 OVER 2626.102 3294.547
 0.000 OVER 2626.140 3294.579 0.000
 TO LINK 20 LANES 1 AT 1.804 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.01380 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10018 NAME "" LABEL 0.00 0.00
 FROM LINK 18 LANES 1 2 3 AT 189.115
 OVER 2616.76362 3295.92315 0.00000 OVER 2616.801 3295.956 0.000 OVER 2621.323 3299.933
 0.000 OVER 2621.361 3299.966 0.000
 TO LINK 20 LANES 2 3 4 AT 1.723 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.01760 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10019 NAME "" LABEL 0.00 0.00
 FROM LINK 20 LANES 2 3 4 AT 325.835
 OVER 2865.46371 3513.15633 0.00000 OVER 2865.501 3513.189 0.000 OVER 2867.569 3515.164
 0.000 OVER 2875.408 3521.650 0.000 OVER 2875.446 3521.682 0.000

TO LINK 21 LANES 1 2 3 AT 5.041 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00800 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10020 NAME "" LABEL 0.00 0.00
 FROM LINK 21 LANES 1 2 3 AT 187.742
 OVER 3015.24755 3639.30569 0.00000 OVER 3015.286 3639.338 0.000 OVER 3022.083 3645.077
 0.000 OVER 3022.121 3645.110 0.000
 TO LINK 22 LANES 1 2 3 AT 2.727 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT 0.00150 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10021 NAME "" LABEL 0.00 0.00
 FROM LINK 23 LANES 1 AT 409.705
 OVER 3328.51412 3898.66353 0.00000 OVER 3328.551 3898.697 0.000 OVER 3336.837 3905.944
 0.000 OVER 3336.875 3905.976 0.000
 TO LINK 24 LANES 1 AT 5.275 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00330 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10022 NAME "" LABEL 0.00 0.00
 FROM LINK 22 LANES 1 2 3 4 AT 400.941
 OVER 3322.87992 3906.11186 0.00000 OVER 3322.918 3906.145 0.000 OVER 3330.331 3912.222
 0.000 OVER 3330.369 3912.254 0.000
 TO LINK 24 LANES 2 3 4 5 AT 4.409 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT 0.00250 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CLOSED
 LANE 4 VEHICLE_CLASSES 20
 CONNECTOR 10023 NAME "" LABEL 0.00 0.00
 FROM LINK 24 LANES 1 2 3 4 5 AT 293.679
 OVER 3551.41504 4098.85233 0.00000 OVER 3551.453 4098.885 0.000 OVER 3566.081 4111.373
 0.000 OVER 3566.118 4111.404 0.000
 TO LINK 25 LANES 1 2 3 4 5 AT 8.534 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00230 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CLOSED
 LANE 5 VEHICLE_CLASSES 20
 CONNECTOR 10024 NAME "" LABEL 0.00 0.00
 FROM LINK 12 LANES 1 AT 684.148
 OVER 1315.74433 2453.31364 0.00000 OVER 1315.789 2453.336 0.000 OVER 1323.845 2457.109
 0.000 OVER 1323.889 2457.133 0.000
 TO LINK 26 LANES 1 AT 1.676 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00060 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10025 NAME "" LABEL 0.00 0.00
 FROM LINK 26 LANES 1 AT 978.563
 OVER 2174.07047 2936.46182 0.00000 OVER 2174.112 2936.490 0.000 OVER 2180.750 2941.579
 0.000 OVER 2180.790 2941.609 0.000
 TO LINK 27 LANES 1 AT 2.819 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00480 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION

CONNECTOR 10026 NAME "" LABEL 0.00 0.00
FROM LINK 27 LANES 1 AT 895.752
OVER 2860.92306 3519.89248 0.00000 OVER 2860.961 3519.925 0.000 OVER 2866.903 3524.819
0.000 OVER 2866.941 3524.852 0.000
TO LINK 28 LANES 1 AT 2.610 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
GRADIENT -0.00800 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10027 NAME "" LABEL 0.00 0.00
FROM LINK 28 LANES 1 AT 175.462
OVER 2999.30468 3636.01728 0.00000 OVER 2999.343 3636.049 0.000 OVER 3017.112 3650.298
0.000 OVER 3017.149 3650.331 0.000
TO LINK 22 LANES 4 AT 2.361 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
GRADIENT 0.00150 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10028 NAME "" LABEL 0.00 0.00
FROM LINK 25 LANES 5 AT 357.607
OVER 3826.48510 4344.02579 0.00000 OVER 3826.523 4344.058 0.000 OVER 3830.856 4348.166
0.000 OVER 3830.894 4348.199 0.000
TO LINK 32 LANES 1 AT 1.310 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 1000.000
GRADIENT -0.00800 COST 0.00000 SURCHARGE 0.17000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION VEHICLE_CLASSES 20
CLOSED
LANE 1 VEHICLE_CLASSES 20
CONNECTOR 10029 NAME "" LABEL 0.00 0.00
FROM LINK 25 LANES 1 AT 357.188
OVER 3835.53756 4332.81915 0.00000 OVER 3835.576 4332.852 0.000 OVER 3841.960 4337.665
0.000 OVER 3841.998 4337.698 0.000
TO LINK 30 LANES 1 AT 3.289 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 800.000
GRADIENT -0.00150 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10030 NAME "" LABEL 0.00 0.00
FROM LINK 25 LANES 2 3 4 AT 356.922
OVER 3830.65028 4338.11304 0.00000 OVER 3830.689 4338.146 0.000 OVER 3837.724 4343.825
0.000 OVER 3837.761 4343.857 0.000
TO LINK 31 LANES 1 2 3 AT 1.492 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 900.000
GRADIENT -0.00800 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10032 NAME "" LABEL 0.00 0.00
FROM LINK 33 LANES 1 2 AT 445.123
OVER 4330.88525 4698.60014 0.00000 OVER 4330.927 4698.627 0.000 OVER 4340.549 4704.768
0.000 OVER 4340.592 4704.793 0.000
TO LINK 34 LANES 1 2 AT 3.882 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
GRADIENT -0.00140 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10033 NAME "" LABEL 0.00 0.00
FROM LINK 31 LANES 1 2 3 AT 610.228
OVER 4325.53898 4706.13087 0.00000 OVER 4325.581 4706.157 0.000 OVER 4338.674 4714.080
0.000 OVER 4338.718 4714.105 0.000
TO LINK 34 LANES 3 4 5 AT 6.918 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000

GRADIENT -0.00040 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10034 NAME "" LABEL 0.00 0.00
 FROM LINK 34 LANES 2 3 4 5 AT 374.451
 OVER 4657.84070 4896.43493 0.00000 OVER 4657.884 4896.460 0.000 OVER 4667.489 4901.954
 0.000 OVER 4667.532 4901.979 0.000
 TO LINK 35 LANES 1 2 3 4 AT 5.132 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 400.000
 GRADIENT 0.00720 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10035 NAME "" LABEL 0.00 0.00
 FROM LINK 32 LANES 1 AT 614.817
 OVER 4322.38440 4713.45923 0.00000 OVER 4322.427 4713.486 0.000 OVER 4329.063 4717.409
 0.000 OVER 4329.107 4717.434 0.000
 TO LINK 36 LANES 1 AT 2.872 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00400 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10036 NAME "" LABEL 0.00 0.00
 FROM LINK 37 LANES 1 AT 566.277
 OVER 4846.28190 4996.82613 0.00000 OVER 4846.324 4996.853 0.000 OVER 4865.698 5012.085
 0.000 OVER 4865.741 5012.111 0.000
 TO LINK 38 LANES 1 AT 0.000 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT 0.00400 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10037 NAME "" LABEL 0.00 0.00
 FROM LINK 35 LANES 2 3 4 AT 208.314
 OVER 4841.62555 5006.75266 0.00000 OVER 4841.669 5006.778 0.000 OVER 4862.018 5018.274
 0.000 OVER 4862.061 5018.299 0.000
 TO LINK 38 LANES 2 3 4 AT 0.000 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 800.000
 GRADIENT 0.01260 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10038 NAME "" LABEL 0.00 0.00
 FROM LINK 38 LANES 2 3 4 AT 330.009
 OVER 5145.68905 5187.00259 0.00000 OVER 5145.732 5187.028 0.000 OVER 5167.194 5199.462
 0.000 OVER 5167.237 5199.487 0.000
 TO LINK 39 LANES 1 2 3 AT 18.021 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT 0.01790 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10039 NAME "" LABEL 0.00 0.00
 FROM LINK 39 LANES 1 2 3 AT 447.890
 OVER 5539.50495 5414.43781 0.00000 OVER 5539.548 5414.463 0.000 OVER 5548.479 5419.635
 0.000 OVER 5548.522 5419.660 0.000
 TO LINK 40 LANES 1 2 3 AT 3.683 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT 0.01790 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10040 NAME "" LABEL 0.00 0.00
 FROM LINK 36 LANES 1 AT 592.697
 OVER 4838.69734 5014.43206 0.00000 OVER 4838.740 5014.458 0.000 OVER 4848.090 5019.735
 0.000 OVER 4848.133 5019.761 0.000
 TO LINK 41 LANES 1 AT 2.336 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000

GRADIENT 0.00900 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10041 NAME "" LABEL 0.00 0.00
 FROM LINK 41 LANES 1 AT 797.279
 OVER 5534.82386 5420.22049 0.00000 OVER 5534.867 5420.245 0.000 OVER 5543.228 5424.905
 0.000 OVER 5543.271 5424.930 0.000
 TO LINK 40 LANES 4 AT 1.810 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT 0.01790 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10042 NAME "" LABEL 0.00 0.00
 FROM LINK 40 LANES 1 2 3 AT 398.627
 OVER 5889.47249 5618.99258 0.00000 OVER 5889.516 5619.018 0.000 OVER 5898.910 5624.477
 0.000 OVER 5898.952 5624.502 0.000
 TO LINK 42 LANES 1 2 3 AT 5.043 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 800.000
 GRADIENT -0.00510 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10043 NAME "" LABEL 0.00 0.00
 FROM LINK 40 LANES 4 AT 399.898
 OVER 5886.93581 5625.84974 0.00000 OVER 5886.979 5625.875 0.000 OVER 5894.486 5630.578
 0.000 OVER 5894.529 5630.603 0.000
 TO LINK 43 LANES 1 AT 2.023 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 1000.000
 GRADIENT -0.00510 COST 0.00000 SURCHARGE 0.17000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION VEHICLE_CLASSES 20
 CLOSED
 LANE 1 VEHICLE_CLASSES 20
 CONNECTOR 10044 NAME "" LABEL 0.00 0.00
 FROM LINK 42 LANES 1 2 3 AT 1080.397
 OVER 6824.69113 6171.67157 0.00000 OVER 6824.734 6171.697 0.000 OVER 6832.005 6175.984
 0.000 OVER 6832.048 6176.009 0.000
 TO LINK 44 LANES 1 2 3 AT 3.470 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.03159 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10045 NAME "" LABEL 0.00 0.00
 FROM LINK 43 LANES 1 AT 1078.628
 OVER 6821.14464 6178.74648 0.00000 OVER 6821.188 6178.772 0.000 OVER 6826.067 6181.555
 0.000 OVER 6826.110 6181.580 0.000
 TO LINK 45 LANES 1 AT 0.688 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.03159 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10046 NAME "" LABEL 0.00 0.00
 FROM LINK 44 LANES 1 2 3 AT 707.110
 OVER 7441.08057 6528.41300 0.00000 OVER 7441.124 6528.438 0.000 OVER 7447.748 6532.275
 0.000 OVER 7447.791 6532.300 0.000
 TO LINK 46 LANES 2 3 4 AT 3.796 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.02050 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10047 NAME "" LABEL 0.00 0.00
 FROM LINK 45 LANES 1 AT 707.137
 OVER 7437.51084 6535.50023 0.00000 OVER 7437.554 6535.525 0.000 OVER 7439.905 6536.901
 0.000 OVER 7439.948 6536.927 0.000

TO LINK 47 LANES 1 AT 0.950 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
GRADIENT -0.02050 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10048 NAME "" LABEL 0.00 0.00
FROM LINK 46 LANES 1 AT 230.044
OVER 7645.92910 6641.75870 0.00000 OVER 7645.972 6641.784 0.000 OVER 7651.256 6644.856
0.000 OVER 7651.299 6644.881 0.000
TO LINK 48 LANES 1 AT 0.723 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 1000.000
GRADIENT -0.00600 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10049 NAME "" LABEL 0.00 0.00
FROM LINK 46 LANES 2 3 4 AT 229.447
OVER 7641.73570 6647.64189 0.00000 OVER 7641.779 6647.668 0.000 OVER 7647.568 6651.146
0.000 OVER 7647.611 6651.171 0.000
TO LINK 49 LANES 1 2 3 AT 2.595 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 400.000
GRADIENT -0.00600 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10050 NAME "" LABEL 0.00 0.00
FROM LINK 47 LANES 1 AT 231.623
OVER 7638.32108 6654.64574 0.00000 OVER 7638.364 6654.671 0.000 OVER 7641.308 6656.416
0.000 OVER 7641.351 6656.441 0.000
TO LINK 50 LANES 1 AT 0.670 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
GRADIENT -0.00600 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10051 NAME "" LABEL 0.00 0.00
FROM LINK 51 LANES 1 AT 448.145
OVER 8075.48218 6894.23312 0.00000 OVER 8075.525 6894.260 0.000 OVER 8090.127 6903.740
0.000 OVER 8090.172 6903.766 0.000
TO LINK 52 LANES 1 AT 1.756 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
GRADIENT -0.00800 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10052 NAME "" LABEL 0.00 0.00
FROM LINK 50 LANES 1 AT 495.398
OVER 8067.65061 6907.48609 0.00000 OVER 8067.694 6907.511 0.000 OVER 8082.418 6915.917
0.000 OVER 8082.460 6915.941 0.000
TO LINK 52 LANES 5 AT 1.160 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
GRADIENT -0.00600 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10053 NAME "" LABEL 0.00 0.00
FROM LINK 49 LANES 1 2 3 AT 495.226
OVER 8072.09095 6901.17667 0.00000 OVER 8072.134 6901.202 0.000 OVER 8085.760 6909.533
0.000 OVER 8085.803 6909.558 0.000
TO LINK 52 LANES 2 3 4 AT 0.866 ALL
DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
GRADIENT -0.00600 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
SEGMENT LENGTH 10.000 ANIMATION
CONNECTOR 10054 NAME "" LABEL 0.00 0.00
FROM LINK 52 LANES 2 3 4 5 AT 249.531
OVER 8300.30228 7035.36568 0.00000 OVER 8300.345 7035.390 0.000 OVER 8307.055 7039.061
0.000 OVER 8307.099 7039.085 0.000

TO LINK 53 LANES 1 2 3 4 AT 2.204 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00600 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10055 NAME "" LABEL 0.00 0.00
 FROM LINK 54 LANES 1 AT 418.746
 OVER 8472.28128 7111.88537 0.00000 OVER 8472.327 7111.905 0.000 OVER 8479.671 7115.171
 0.000 OVER 8479.718 7115.189 0.000
 TO LINK 55 LANES 1 AT 3.798 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00160 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION
 CONNECTOR 10056 NAME "" LABEL 0.00 0.00
 FROM LINK 53 LANES 1 2 3 4 AT 182.963
 OVER 8468.31593 7120.45091 0.00000 OVER 8468.362 7120.470 0.000 OVER 8474.404 7122.818
 0.000 OVER 8474.450 7122.835 0.000
 TO LINK 55 LANES 2 3 4 5 AT 1.501 ALL
 DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
 GRADIENT -0.00160 COST 0.00000 SURCHARGE 0.00000 SURCHARGE 0.00000
 SEGMENT LENGTH 10.000 ANIMATION

-- Direction Decisions: --

-- Routing Decisions: --

-- Desired Speed Decisions: --

-- Reduced Speed Areas: --

REDUCED_SPEED_AREA 1

NAME "" LABEL 0.00 0.00
 POSITION LINK 4 LANE 1 AT 2.485 LENGTH 489.372
 VEHICLE_CLASS 10 DESIRED_SPEED 60 MAX_DECELERATION 2.000
 VEHICLE_CLASS 15 DESIRED_SPEED 60 MAX_DECELERATION 2.000
 VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
 TIME FROM 0.0 UNTIL 3600.0

REDUCED_SPEED_AREA 2

NAME "" LABEL 0.00 0.00
 POSITION LINK 6 LANE 1 AT 3.439 LENGTH 335.210
 VEHICLE_CLASS 10 DESIRED_SPEED 80 MAX_DECELERATION 2.000
 VEHICLE_CLASS 15 DESIRED_SPEED 80 MAX_DECELERATION 2.000
 VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
 TIME FROM 0.0 UNTIL 3600.0

REDUCED_SPEED_AREA 3

NAME "" LABEL 0.00 0.00
 POSITION LINK 19 LANE 1 AT 3.225 LENGTH 537.025

VEHICLE_CLASS 10 DESIRED_SPEED 80 MAX_DECELERATION 2.000
VEHICLE_CLASS 15 DESIRED_SPEED 80 MAX_DECELERATION 2.000
VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
TIME FROM 0.0 UNTIL 3600.0

REDUCED_SPEED_AREA 4
NAME "" LABEL 0.00 0.00
POSITION LINK 23 LANE 1 AT 2.853 LENGTH 404.594
VEHICLE_CLASS 10 DESIRED_SPEED 80 MAX_DECELERATION 2.000
VEHICLE_CLASS 15 DESIRED_SPEED 80 MAX_DECELERATION 2.000
VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
TIME FROM 0.0 UNTIL 3600.0

REDUCED_SPEED_AREA 5
NAME "" LABEL 0.00 0.00
POSITION LINK 37 LANE 1 AT 3.264 LENGTH 559.938
VEHICLE_CLASS 10 DESIRED_SPEED 80 MAX_DECELERATION 2.000
VEHICLE_CLASS 15 DESIRED_SPEED 80 MAX_DECELERATION 2.000
VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
TIME FROM 0.0 UNTIL 3600.0

REDUCED_SPEED_AREA 6
NAME "" LABEL 0.00 0.00
POSITION LINK 54 LANE 1 AT 2.977 LENGTH 411.467
VEHICLE_CLASS 10 DESIRED_SPEED 80 MAX_DECELERATION 2.000
VEHICLE_CLASS 15 DESIRED_SPEED 80 MAX_DECELERATION 2.000
VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
TIME FROM 0.0 UNTIL 3600.0

REDUCED_SPEED_AREA 7
NAME "" LABEL 0.00 0.00
POSITION LINK 51 LANE 1 AT 2.713 LENGTH 440.300
VEHICLE_CLASS 10 DESIRED_SPEED 60 MAX_DECELERATION 2.000
VEHICLE_CLASS 15 DESIRED_SPEED 60 MAX_DECELERATION 2.000
VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
TIME FROM 0.0 UNTIL 3600.0

REDUCED_SPEED_AREA 8
NAME "" LABEL 0.00 0.00
POSITION LINK 33 LANE 1 AT 1.825 LENGTH 439.747
VEHICLE_CLASS 10 DESIRED_SPEED 60 MAX_DECELERATION 2.000
VEHICLE_CLASS 15 DESIRED_SPEED 60 MAX_DECELERATION 2.000
VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
TIME FROM 0.0 UNTIL 3600.0

REDUCED_SPEED_AREA 9
NAME "" LABEL 0.00 0.00
POSITION LINK 16 LANE 1 AT 2.233 LENGTH 450.227
VEHICLE_CLASS 10 DESIRED_SPEED 60 MAX_DECELERATION 2.000
VEHICLE_CLASS 15 DESIRED_SPEED 60 MAX_DECELERATION 2.000
VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
TIME FROM 0.0 UNTIL 3600.0

REDUCED_SPEED_AREA 10
NAME "" LABEL 0.00 0.00
POSITION LINK 33 LANE 2 AT 2.499 LENGTH 438.052

VEHICLE_CLASS 10 DESIRED_SPEED 60 MAX_DECELERATION 2.000
 VEHICLE_CLASS 15 DESIRED_SPEED 60 MAX_DECELERATION 2.000
 VEHICLE_CLASS 20 DESIRED_SPEED 60 MAX_DECELERATION 2.000
 TIME FROM 0.0 UNTIL 3600.0

-- Inputs: --

-- Traffic Compositions: --

COMPOSITION 1 NAME "Default"
 KATTEMPERATURE 1
 WATERTEMPERATURE 2
 VEHICLE_TYPE 100 FRACTION 0.980 DESIRED_SPEED 50
 VEHICLE_TYPE 200 FRACTION 0.020 DESIRED_SPEED 50

COMPOSITION 2 NAME "2016COMP"
 VEHICLE_TYPE 100 FRACTION 0.833 DESIRED_SPEED 140
 VEHICLE_TYPE 150 FRACTION 0.118 DESIRED_SPEED 140
 VEHICLE_TYPE 200 FRACTION 0.049 DESIRED_SPEED 130

-- Distributions: --

DESIRED_SPEED 999 48.00 0.000 58.00 1.000
 DESIRED_SPEED 140 80.00 0.000 99.00 0.030 109.00 0.100 121.00 0.260 131.00 0.470 149.00 0.800
 165.00 0.930 185.00 0.990 205.00 1.000
 DESIRED_SPEED 130 80.00 0.000 98.00 0.030 110.00 0.100 130.00 0.680 135.00 0.720 143.00 0.910
 155.00 0.970 170.00 1.000
 DESIRED_SPEED 120 85.00 0.000 105.00 0.030 110.00 0.100 125.00 0.680 140.00 0.910 155.00
 1.000
 DESIRED_SPEED 100 88.00 0.000 95.00 0.030 100.00 0.100 110.00 0.700 120.00 0.910 130.00 1.000
 DESIRED_SPEED 90 85.00 0.000 90.00 0.050 100.00 0.800 110.00 0.950 120.00 1.000
 DESIRED_SPEED 85 84.00 0.000 88.00 1.000
 DESIRED_SPEED 80 75.00 0.000 80.00 0.050 90.00 0.800 100.00 0.950 110.00 1.000
 DESIRED_SPEED 70 68.00 0.000 78.00 1.000
 DESIRED_SPEED 60 58.00 0.000 68.00 1.000
 DESIRED_SPEED 50 48.00 0.000 58.00 1.000
 DESIRED_SPEED 40 40.00 0.000 45.00 1.000
 DESIRED_SPEED 30 30.00 0.000 35.00 1.000
 DESIRED_SPEED 25 25.00 0.000 30.00 1.000
 DESIRED_SPEED 20 20.00 0.000 25.00 1.000
 DESIRED_SPEED 15 15.00 0.000 20.00 1.000
 DESIRED_SPEED 12 12.00 0.000 15.00 1.000
 DESIRED_SPEED 5 4.00 0.000 6.00 1.000
 MODEL_YEARS 1 1990.00 0.000 2003.00 1.000
 MILEAGE 1 0.00 0.000 200000.00 1.000
 MASSES 6 40.00 0.000 130.00 1.000
 MASSES 5 30.00 0.000 120.00 1.000
 MASSES 4 23000.00 0.000 58000.00 1.000
 MASSES 3 4000.00 0.000 12000.00 1.000

MASSES 2 2800.00 0.000 40000.00 1.000
 MASSES 1 800.00 0.000 2000.00 1.000
 POWER 6 0.50 0.000 0.70 1.000
 POWER 5 0.50 0.000 0.70 1.000
 POWER 4 300.00 0.000 600.00 1.000
 POWER 3 150.00 0.000 300.00 1.000
 POWER 2 150.00 0.000 400.00 1.000
 POWER 1 55.00 0.000 160.00 1.000
 TEMPERATURE 2 0.00 0.000 100.00 1.000
 TEMPERATURE 1 0.00 0.000 400.00 1.000
 TIMES 1 MEAN 20.0 STANDARD_DEVIATION 2.0

-- Color Distributions: --

 COLOR_DIST 1 NAME "Default"
 FRACTION 1.000 COLOR 0 0 0
 FRACTION 1.000 COLOR 255 0 0
 FRACTION 1.000 COLOR 255 255 255
 FRACTION 1.000 COLOR 0 0 185
 FRACTION 1.000 COLOR 209 209 209
 FRACTION 0.500 COLOR 95 95 95
 FRACTION 0.250 COLOR 0 128 0
 FRACTION 0.250 COLOR 0 128 255
 FRACTION 0.100 COLOR 255 255 0
 FRACTION 0.100 COLOR 255 128 0

-- Vehicle Model Distributions: --

 VEHICLE_MODEL_DIST 60 NAME "Bike"
 FRACTION 0.100
 FILE "#3dmodels#vehicles\bike.v3d" LENGTH 1.445 AXLE FRONT 0.232 AXLE REAR 1.097
 SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 1.408

VEHICLE_MODEL_DIST 50 NAME "Pedestrian"
 FRACTION 0.100
 FILE "#3dmodels#vehicles\man.v3d" LENGTH 0.342 AXLE FRONT 0.016 AXLE REAR 0.054
 SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 0.342

VEHICLE_MODEL_DIST 40 NAME "Tram"
 FRACTION 0.100
 FILE "#3dmodels#vehicles\tram.v3d" LENGTH 15.698 AXLE FRONT 3.385 AXLE REAR 12.346
 SHAFT 1.224 CLUTCH FRONT 0.144 CLUTCH REAR 15.819

VEHICLE_MODEL_DIST 30 NAME "Bus"
 FRACTION 0.100
 FILE "#3dmodels#vehicles\bus.v3d" LENGTH 11.541 AXLE FRONT 2.567 AXLE REAR 8.446
 SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 11.262

VEHICLE_MODEL_DIST 20 NAME "HGV"
 FRACTION 0.100
 FILE "#3dmodels#vehicles\truck.v3d" LENGTH 10.215 AXLE FRONT 1.559 AXLE REAR 7.333
 SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 9.940

VEHICLE_MODEL_DIST 10 NAME "Car"

FRACTION 0.260

FILE "#3dmodels#vehicles\car1.v3d" LENGTH 4.110 AXLE FRONT 0.850 AXLE REAR 3.336
SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 4.026

FRACTION 0.180

FILE "#3dmodels#vehicles\car2.v3d" LENGTH 4.550 AXLE FRONT 0.808 AXLE REAR 3.494
SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 4.550

FRACTION 0.180

FILE "#3dmodels#vehicles\car3.v3d" LENGTH 4.610 AXLE FRONT 0.935 AXLE REAR 3.695
SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 4.600

FRACTION 0.180

FILE "#3dmodels#vehicles\car4.v3d" LENGTH 4.760 AXLE FRONT 0.910 AXLE REAR 3.695
SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 4.713

FRACTION 0.160

FILE "#3dmodels#vehicles\car5.v3d" LENGTH 4.400 AXLE FRONT 0.800 AXLE REAR 3.298
SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 4.400

FRACTION 0.020

FILE "#3dmodels#vehicles\car6.v3d" LENGTH 4.340 AXLE FRONT 0.873 AXLE REAR 3.212
SHAFT 0.000 CLUTCH FRONT 0.000 CLUTCH REAR 4.340

-- Functions: --

MAX_ACCELERATION 6 NAME "Bike" 0.0 250.0 0.0 7.0

BASE_POINT 0.000 3.500 1.960 3.500 10.000 3.200 1.493 3.500 20.000 2.786 1.300 3.500 30.000
2.468 1.152 3.500 40.000 2.200 1.027 3.500 50.000 1.964 0.917 3.273 60.000 1.751 0.817 2.918 70.000
1.554 0.725 2.590 80.000 1.372 0.640 2.286 90.000 1.200 0.560 2.000 100.000 1.038 0.484 1.730
110.000 0.969 0.452 1.614 120.000 0.899 0.420 1.499 130.000 0.830 0.387 1.384 140.000 0.761 0.355
1.268 150.000 0.692 0.323 1.153 160.000 0.623 0.291 1.038 170.000 0.553 0.258 0.922 180.000 0.484
0.226 0.807 190.000 0.415 0.194 0.692 200.000 0.346 0.161 0.577 210.000 0.277 0.129 0.461 220.000
0.208 0.097 0.346 230.000 0.138 0.065 0.231 240.000 0.069 0.032 0.115 250.000 0.000 0.000 0.000

MAX_ACCELERATION 5 NAME "Pedestrian" 0.0 250.0 0.0 7.0

BASE_POINT 0.000 3.000 3.000 3.000 10.000 3.000 3.000 3.000 20.000 0.000 0.000 0.000 30.000
0.000 0.000 0.000 40.000 0.000 0.000 0.000 50.000 0.000 0.000 0.000 60.000 0.000 0.000 0.000 70.000
0.000 0.000 0.000 80.000 0.000 0.000 0.000 90.000 0.000 0.000 0.000 100.000 0.000 0.000 0.000
110.000 0.000 0.000 0.000 120.000 0.000 0.000 0.000 130.000 0.000 0.000 0.000 140.000 0.000 0.000
0.000 150.000 0.000 0.000 0.000 160.000 0.000 0.000 0.000 170.000 0.000 0.000 0.000 180.000 0.000
0.000 0.000 190.000 0.000 0.000 0.000 200.000 0.000 0.000 0.000 210.000 0.000 0.000 0.000 220.000
0.000 0.000 0.000 230.000 0.000 0.000 0.000 240.000 0.000 0.000 0.000 250.000 0.000 0.000 0.000

MAX_ACCELERATION 4 NAME "Tram" 0.0 250.0 0.0 7.0

BASE_POINT 0.000 1.000 1.000 1.000 10.000 1.000 1.000 1.000 20.000 1.000 1.000 1.000 30.000
1.000 1.000 1.000 40.000 1.000 1.000 1.000 50.000 1.000 1.000 1.000 60.000 1.000 1.000 1.000 70.000
1.000 1.000 1.000 80.000 1.000 1.000 1.000 90.000 1.000 1.000 1.000 100.000 1.000 1.000 1.000
110.000 1.000 1.000 1.000 120.000 1.000 1.000 1.000 130.000 1.000 1.000 1.000 140.000 1.000 1.000
1.000 150.000 1.000 1.000 1.000 160.000 1.000 1.000 1.000 170.000 1.000 1.000 1.000 180.000 1.000
1.000 1.000 190.000 1.000 1.000 1.000 200.000 1.000 1.000 1.000 210.000 1.000 1.000 1.000 220.000
1.000 1.000 1.000 230.000 1.000 1.000 1.000 240.000 1.000 1.000 1.000 250.000 0.000 0.000 0.000

MAX_ACCELERATION 3 NAME "Bus" 0.0 250.0 0.0 7.0

BASE_POINT 0.000 1.240 1.042 1.488 10.000 1.240 1.042 1.488 20.000 1.240 1.042 1.488 30.000
1.240 1.042 1.488 40.000 1.100 0.924 1.320 50.000 1.000 0.840 1.200 60.000 0.900 0.756 1.080 70.000
0.800 0.672 0.960 80.000 0.600 0.504 0.720 90.000 0.400 0.336 0.480 100.000 0.000 0.000 0.000
110.000 0.000 0.000 0.000 120.000 0.000 0.000 0.000 130.000 0.000 0.000 0.000 140.000 0.000 0.000
0.000 150.000 0.000 0.000 0.000 160.000 0.000 0.000 0.000 170.000 0.000 0.000 0.000 180.000 0.000

0.000 0.000 190.000 0.000 0.000 0.000 200.000 0.000 0.000 0.000 210.000 0.000 0.000 0.000 220.000
 0.000 0.000 0.000 230.000 0.000 0.000 0.000 240.000 0.000 0.000 0.000 250.000 0.000 0.000 0.000
 MAX_ACCELERATION 2 NAME "HGV" 0.0 250.0 0.0 7.0
 BASE_POINT 0.000 7.300 2.500 9.300 10.000 6.900 2.400 9.300 20.000 3.100 1.120 5.200 30.000
 2.000 0.730 3.200 40.000 1.520 0.530 2.350 50.000 0.950 0.320 1.550 60.000 0.790 0.250 1.310 70.000
 0.640 0.190 1.100 80.000 0.520 0.150 0.900 90.000 0.410 0.110 0.750 100.000 0.350 0.080 0.650
 110.000 0.200 0.000 0.550 120.000 0.000 0.000 0.100 130.000 0.000 0.000 0.000 140.000 0.000 0.000
 0.000 150.000 0.000 0.000 0.000 160.000 0.000 0.000 0.000 170.000 0.000 0.000 0.000 180.000 0.000
 0.000 0.000 190.000 0.000 0.000 0.000 200.000 0.000 0.000 0.000 210.000 0.000 0.000 0.000 220.000
 0.000 0.000 0.000 230.000 0.000 0.000 0.000 240.000 0.000 0.000 0.000 250.000 0.000 0.000 0.000
 MAX_ACCELERATION 1 NAME "Car" 0.0 250.0 0.0 7.0
 BASE_POINT 0.000 3.500 1.960 3.500 10.000 3.200 1.493 3.500 20.000 2.786 1.300 3.500 30.000
 2.468 1.152 3.500 40.000 2.200 1.027 3.500 50.000 1.964 0.917 3.273 60.000 1.751 0.817 2.918 70.000
 1.554 0.725 2.590 80.000 1.372 0.640 2.286 90.000 1.200 0.560 2.000 100.000 1.038 0.484 1.730
 110.000 0.969 0.452 1.614 120.000 0.899 0.420 1.499 130.000 0.830 0.387 1.384 140.000 0.761 0.355
 1.268 150.000 0.692 0.323 1.153 160.000 0.623 0.291 1.038 170.000 0.553 0.258 0.922 180.000 0.484
 0.226 0.807 190.000 0.415 0.194 0.692 200.000 0.346 0.161 0.577 210.000 0.277 0.129 0.461 220.000
 0.208 0.097 0.346 230.000 0.138 0.065 0.231 240.000 0.069 0.032 0.115 250.000 0.000 0.000 0.000
 DESIRED_ACCELERATION 6 NAME "Bike" 0.0 250.0 0.0 7.0
 BASE_POINT 0.000 3.500 1.960 3.500 10.000 3.200 1.493 3.500 20.000 2.786 1.300 3.500 30.000
 2.468 1.152 3.500 40.000 2.200 1.027 3.500 50.000 1.964 0.917 3.273 60.000 1.751 0.817 2.918 70.000
 1.554 0.725 2.590 80.000 1.372 0.640 2.286 90.000 1.200 0.560 2.000 100.000 1.038 0.484 1.730
 110.000 0.969 0.452 1.614 120.000 0.899 0.420 1.499 130.000 0.830 0.387 1.384 140.000 0.761 0.355
 1.268 150.000 0.692 0.323 1.153 160.000 0.623 0.291 1.038 170.000 0.553 0.258 0.922 180.000 0.484
 0.226 0.807 190.000 0.415 0.194 0.692 200.000 0.346 0.161 0.577 210.000 0.277 0.129 0.461 220.000
 0.208 0.097 0.346 230.000 0.138 0.065 0.231 240.000 0.069 0.032 0.115 250.000 0.000 0.000 0.000
 DESIRED_ACCELERATION 5 NAME "Pedestrian" 0.0 250.0 0.0 7.0
 BASE_POINT 0.000 3.000 3.000 3.000 10.000 3.000 3.000 3.000 20.000 0.000 0.000 0.000 30.000
 0.000 0.000 0.000 40.000 0.000 0.000 0.000 50.000 0.000 0.000 0.000 60.000 0.000 0.000 0.000 70.000
 0.000 0.000 0.000 80.000 0.000 0.000 0.000 90.000 0.000 0.000 0.000 100.000 0.000 0.000 0.000
 110.000 0.000 0.000 0.000 120.000 0.000 0.000 0.000 130.000 0.000 0.000 0.000 140.000 0.000 0.000
 0.000 150.000 0.000 0.000 0.000 160.000 0.000 0.000 0.000 170.000 0.000 0.000 0.000 180.000 0.000
 0.000 0.000 190.000 0.000 0.000 0.000 200.000 0.000 0.000 0.000 210.000 0.000 0.000 0.000 220.000
 0.000 0.000 0.000 230.000 0.000 0.000 0.000 240.000 0.000 0.000 0.000 250.000 0.000 0.000 0.000
 DESIRED_ACCELERATION 4 NAME "Tram" 0.0 250.0 0.0 7.0
 BASE_POINT 0.000 1.000 1.000 1.000 10.000 1.000 1.000 1.000 20.000 1.000 1.000 1.000 30.000
 1.000 1.000 1.000 40.000 1.000 1.000 1.000 50.000 1.000 1.000 1.000 60.000 1.000 1.000 1.000 70.000
 1.000 1.000 1.000 80.000 1.000 1.000 1.000 90.000 1.000 1.000 1.000 100.000 1.000 1.000 1.000
 110.000 1.000 1.000 1.000 120.000 1.000 1.000 1.000 130.000 1.000 1.000 1.000 140.000 1.000 1.000
 1.000 150.000 1.000 1.000 1.000 160.000 1.000 1.000 1.000 170.000 1.000 1.000 1.000 180.000 1.000
 1.000 1.000 190.000 1.000 1.000 1.000 200.000 1.000 1.000 1.000 210.000 1.000 1.000 1.000 220.000
 1.000 1.000 1.000 230.000 1.000 1.000 1.000 240.000 1.000 1.000 1.000 250.000 0.000 0.000 0.000
 DESIRED_ACCELERATION 3 NAME "Bus" 0.0 250.0 0.0 7.0
 BASE_POINT 0.000 1.240 1.042 1.488 10.000 1.240 1.042 1.488 20.000 1.240 1.042 1.488 30.000
 1.240 1.042 1.488 40.000 1.100 0.924 1.320 50.000 1.000 0.840 1.200 60.000 0.900 0.756 1.080 70.000
 0.800 0.672 0.960 80.000 0.600 0.504 0.720 90.000 0.400 0.336 0.480 100.000 0.000 0.000 0.000
 110.000 0.000 0.000 0.000 120.000 0.000 0.000 0.000 130.000 0.000 0.000 0.000 140.000 0.000 0.000
 0.000 150.000 0.000 0.000 0.000 160.000 0.000 0.000 0.000 170.000 0.000 0.000 0.000 180.000 0.000
 0.000 0.000 190.000 0.000 0.000 0.000 200.000 0.000 0.000 0.000 210.000 0.000 0.000 0.000 220.000
 0.000 0.000 0.000 230.000 0.000 0.000 0.000 240.000 0.000 0.000 0.000 250.000 0.000 0.000 0.000
 DESIRED_ACCELERATION 2 NAME "HGV" 0.0 250.0 0.0 7.0
 BASE_POINT 0.000 2.500 2.500 2.500 10.000 2.500 2.400 2.500 20.000 2.500 1.120 2.500 30.000
 2.000 0.730 2.500 40.000 1.520 0.530 2.350 50.000 0.950 0.320 1.550 60.000 0.790 0.250 1.310 70.000
 0.640 0.190 1.100 80.000 0.520 0.150 0.900 90.000 0.410 0.110 0.750 100.000 0.350 0.080 0.650
 110.000 0.200 0.000 0.550 120.000 0.000 0.000 0.100 130.000 0.000 0.000 0.000 140.000 0.000 0.000
 0.000 150.000 0.000 0.000 0.000 160.000 0.000 0.000 0.000 170.000 0.000 0.000 0.000 180.000 0.000

0.000 0.000 190.000 0.000 0.000 0.000 200.000 0.000 0.000 0.000 210.000 0.000 0.000 0.000 220.000
 0.000 0.000 0.000 230.000 0.000 0.000 0.000 240.000 0.000 0.000 0.000 250.000 0.000 0.000 0.000
 DESIRED_ACCELERATION 1 NAME "Car" 0.0 250.0 0.0 7.0
 BASE_POINT 0.000 3.500 1.960 3.500 10.000 3.200 1.493 3.500 20.000 2.786 1.300 3.500 30.000
 2.468 1.152 3.500 40.000 2.200 1.027 3.500 50.000 1.964 0.917 3.273 60.000 1.751 0.817 2.918 70.000
 1.554 0.725 2.590 80.000 1.372 0.640 2.286 90.000 1.200 0.560 2.000 100.000 1.038 0.484 1.730
 110.000 0.969 0.452 1.614 120.000 0.899 0.420 1.499 130.000 0.830 0.387 1.384 140.000 0.761 0.355
 1.268 150.000 0.692 0.323 1.153 160.000 0.623 0.291 1.038 170.000 0.553 0.258 0.922 180.000 0.484
 0.226 0.807 190.000 0.415 0.194 0.692 200.000 0.346 0.161 0.577 210.000 0.277 0.129 0.461 220.000
 0.208 0.097 0.346 230.000 0.138 0.065 0.231 240.000 0.069 0.032 0.115 250.000 0.000 0.000 0.000
 MAX_DECELERATION 6 NAME "Bike" 0.0 250.0 -10.0 0.0
 BASE_POINT 0.000 -7.500 -8.500 -6.500 10.000 -7.400 -8.400 -6.400 20.000 -7.300 -8.300 -6.300
 30.000 -7.200 -8.200 -6.200 40.000 -7.100 -8.100 -6.100 50.000 -7.000 -8.000 -6.000 60.000 -6.900 -
 7.900 -5.900 70.000 -6.800 -7.800 -5.800 80.000 -6.700 -7.700 -5.700 90.000 -6.600 -7.600 -5.600
 100.000 -6.500 -7.500 -5.500 110.000 -6.400 -7.400 -5.400 120.000 -6.300 -7.300 -5.300 130.000 -6.200
 -7.200 -5.200 140.000 -6.100 -7.100 -5.100 150.000 -6.000 -7.000 -5.000 160.000 -5.900 -6.900 -4.900
 170.000 -5.800 -6.800 -4.800 180.000 -5.700 -6.700 -4.700 190.000 -5.600 -6.600 -4.600 200.000 -5.500
 -6.500 -4.500 210.000 -5.400 -6.400 -4.400 220.000 -5.300 -6.300 -4.300 230.000 -5.200 -6.200 -4.200
 240.000 -5.100 -6.100 -4.100
 MAX_DECELERATION 5 NAME "Pedestrian" 0.0 250.0 -10.0 0.0
 BASE_POINT 0.000 -9.000 -9.500 -8.500 10.000 -9.000 -9.500 -8.500 20.000 -9.000 -9.500 -8.500
 30.000 -9.000 -9.500 -8.500 40.000 -9.000 -9.500 -8.500 50.000 -9.000 -9.500 -8.500 60.000 -9.000 -
 9.500 -8.500 70.000 -9.000 -9.500 -8.500 80.000 -9.000 -9.500 -8.500 90.000 -9.000 -9.500 -8.500
 100.000 -9.000 -9.500 -8.500 110.000 -9.000 -9.500 -8.500 120.000 -9.000 -9.500 -8.500 130.000 -9.000
 -9.500 -8.500 140.000 -9.000 -9.500 -8.500 150.000 -9.000 -9.500 -8.500 160.000 -9.000 -9.500 -8.500
 170.000 -9.000 -9.500 -8.500 180.000 -9.000 -9.500 -8.500 190.000 -9.000 -9.500 -8.500 200.000 -9.000
 -9.500 -8.500 210.000 -9.000 -9.500 -8.500 220.000 -9.000 -9.500 -8.500 230.000 -9.000 -9.500 -8.500
 240.000 -9.000 -9.500 -8.500
 MAX_DECELERATION 4 NAME "Tram" 0.0 250.0 -10.0 0.0
 BASE_POINT 0.000 -5.000 -6.000 -4.000 10.000 -4.900 -5.900 -3.900 20.000 -4.800 -5.800 -3.800
 30.000 -4.700 -5.700 -3.700 40.000 -4.600 -5.600 -3.600 50.000 -4.500 -5.500 -3.500 60.000 -4.400 -
 5.400 -3.400 70.000 -4.300 -5.300 -3.300 80.000 -4.200 -5.200 -3.200 90.000 -4.100 -5.100 -3.100
 100.000 -4.000 -5.000 -3.000 110.000 -3.900 -4.900 -2.900 120.000 -3.800 -4.800 -2.800 130.000 -3.700
 -4.700 -2.700 140.000 -3.600 -4.600 -2.600 150.000 -3.500 -4.500 -2.500 160.000 -3.400 -4.400 -2.400
 170.000 -3.300 -4.300 -2.300 180.000 -3.200 -4.200 -2.200 190.000 -3.100 -4.100 -2.100 200.000 -3.000
 -4.000 -2.000 210.000 -2.900 -3.900 -1.900 220.000 -2.800 -3.800 -1.800 230.000 -2.700 -3.700 -1.700
 240.000 -2.600 -3.600 -1.600
 MAX_DECELERATION 3 NAME "Bus" 0.0 250.0 -10.0 0.0
 BASE_POINT 0.000 -7.500 -8.500 -6.500 10.000 -7.400 -8.400 -6.400 20.000 -7.300 -8.300 -6.300
 30.000 -7.200 -8.200 -6.200 40.000 -7.100 -8.100 -6.100 50.000 -7.000 -8.000 -6.000 60.000 -6.900 -
 7.900 -5.900 70.000 -6.800 -7.800 -5.800 80.000 -6.700 -7.700 -5.700 90.000 -6.600 -7.600 -5.600
 100.000 -6.500 -7.500 -5.500 110.000 -6.400 -7.400 -5.400 120.000 -6.300 -7.300 -5.300 130.000 -6.200
 -7.200 -5.200 140.000 -6.100 -7.100 -5.100 150.000 -6.000 -7.000 -5.000 160.000 -5.900 -6.900 -4.900
 170.000 -5.800 -6.800 -4.800 180.000 -5.700 -6.700 -4.700 190.000 -5.600 -6.600 -4.600 200.000 -5.500
 -6.500 -4.500 210.000 -5.400 -6.400 -4.400 220.000 -5.300 -6.300 -4.300 230.000 -5.200 -6.200 -4.200
 240.000 -5.100 -6.100 -4.100
 MAX_DECELERATION 2 NAME "HGV" 0.0 250.0 -10.0 0.0
 BASE_POINT 0.000 -5.500 -6.000 -5.000 10.000 -5.500 -6.000 -5.000 20.000 -5.500 -6.000 -5.000
 30.000 -5.500 -6.000 -5.000 40.000 -5.500 -6.000 -5.000 50.000 -5.500 -6.000 -5.000 60.000 -5.500 -
 6.000 -5.000 70.000 -5.500 -6.000 -5.000 80.000 -5.500 -6.000 -5.000 90.000 -5.500 -6.000 -5.000
 100.000 -5.500 -6.000 -5.000 110.000 -5.500 -6.000 -5.000 120.000 -5.500 -6.000 -5.000 130.000 -5.500
 -6.000 -5.000 140.000 -5.500 -6.000 -5.000 150.000 -5.500 -6.000 -5.000 160.000 -5.500 -6.000 -5.000
 170.000 -5.500 -6.000 -5.000 180.000 -5.500 -6.000 -5.000 190.000 -5.500 -6.000 -5.000 200.000 -5.500
 -6.000 -5.000 210.000 -5.500 -6.000 -5.000 220.000 -5.500 -6.000 -5.000 230.000 -5.500 -6.000 -5.000
 240.000 -5.500 -6.000 -5.000
 MAX_DECELERATION 1 NAME "Car" 0.0 250.0 -10.0 0.0

BASE_POINT 0.000 -7.500 -8.500 -6.500 10.000 -7.400 -8.400 -6.400 20.000 -7.300 -8.300 -6.300
 30.000 -7.200 -8.200 -6.200 40.000 -7.100 -8.100 -6.100 50.000 -7.000 -8.000 -6.000 60.000 -6.900 -
 7.900 -5.900 70.000 -6.800 -7.800 -5.800 80.000 -6.700 -7.700 -5.700 90.000 -6.600 -7.600 -5.600
 100.000 -6.500 -7.500 -5.500 110.000 -6.400 -7.400 -5.400 120.000 -6.300 -7.300 -5.300 130.000 -6.200
 -7.200 -5.200 140.000 -6.100 -7.100 -5.100 150.000 -6.000 -7.000 -5.000 160.000 -5.900 -6.900 -4.900
 170.000 -5.800 -6.800 -4.800 180.000 -5.700 -6.700 -4.700 190.000 -5.600 -6.600 -4.600 200.000 -5.500
 -6.500 -4.500 210.000 -5.400 -6.400 -4.400 220.000 -5.300 -6.300 -4.300 230.000 -5.200 -6.200 -4.200
 240.000 -5.100 -6.100 -4.100

DESIRED_DECELERATION 6 NAME "Bike" 0.0 250.0 -10.0 0.0

BASE_POINT 0.000 -2.750 -3.000 -2.550 10.000 -2.750 -3.000 -2.550 20.000 -2.750 -3.000 -2.550
 30.000 -2.750 -3.000 -2.550 40.000 -2.750 -3.000 -2.550 50.000 -2.750 -3.000 -2.550 60.000 -2.750 -
 3.000 -2.550 70.000 -2.750 -3.000 -2.550 80.000 -2.750 -3.000 -2.550 90.000 -2.750 -3.000 -2.550
 100.000 -2.750 -3.000 -2.550 110.000 -2.750 -3.000 -2.550 120.000 -2.750 -3.000 -2.550 130.000 -2.750
 -3.000 -2.550 140.000 -2.750 -3.000 -2.550 150.000 -2.750 -3.000 -2.550 160.000 -2.750 -3.000 -2.550
 170.000 -2.750 -3.000 -2.550 180.000 -2.750 -3.000 -2.550 190.000 -2.750 -3.000 -2.550 200.000 -2.750
 -3.000 -2.550 210.000 -2.750 -3.000 -2.550 220.000 -2.750 -3.000 -2.550 230.000 -2.750 -3.000 -2.550
 240.000 -2.750 -3.000 -2.550

DESIRED_DECELERATION 5 NAME "Pedestrian" 0.0 250.0 -10.0 0.0

BASE_POINT 0.000 -9.000 -9.500 -8.600 10.000 -9.000 -9.500 -8.600 20.000 -9.000 -9.500 -8.600
 30.000 -9.000 -9.500 -8.600 40.000 -9.000 -9.500 -8.600 50.000 -9.000 -9.500 -8.600 60.000 -9.000 -
 9.500 -8.600 70.000 -9.000 -9.500 -8.600 80.000 -9.000 -9.500 -8.600 90.000 -9.000 -9.500 -8.600
 100.000 -9.000 -9.500 -8.600 110.000 -9.000 -9.500 -8.600 120.000 -9.000 -9.500 -8.600 130.000 -9.000
 -9.500 -8.600 140.000 -9.000 -9.500 -8.600 150.000 -9.000 -9.500 -8.600 160.000 -9.000 -9.500 -8.600
 170.000 -9.000 -9.500 -8.600 180.000 -9.000 -9.500 -8.600 190.000 -9.000 -9.500 -8.600 200.000 -9.000
 -9.500 -8.600 210.000 -9.000 -9.500 -8.600 220.000 -9.000 -9.500 -8.600 230.000 -9.000 -9.500 -8.600
 240.000 -9.000 -9.500 -8.600

DESIRED_DECELERATION 4 NAME "Tram" 0.0 250.0 -10.0 0.0

BASE_POINT 0.000 -0.850 -1.000 -0.730 10.000 -0.850 -1.000 -0.730 20.000 -0.850 -1.000 -0.730
 30.000 -0.850 -1.000 -0.730 40.000 -0.850 -1.000 -0.730 50.000 -0.850 -1.000 -0.730 60.000 -0.850 -
 1.000 -0.730 70.000 -0.850 -1.000 -0.730 80.000 -0.850 -1.000 -0.730 90.000 -0.850 -1.000 -0.730
 100.000 -0.850 -1.000 -0.730 110.000 -0.850 -1.000 -0.730 120.000 -0.850 -1.000 -0.730 130.000 -0.850
 -1.000 -0.730 140.000 -0.850 -1.000 -0.730 150.000 -0.850 -1.000 -0.730 160.000 -0.850 -1.000 -0.730
 170.000 -0.850 -1.000 -0.730 180.000 -0.850 -1.000 -0.730 190.000 -0.850 -1.000 -0.730 200.000 -0.850
 -1.000 -0.730 210.000 -0.850 -1.000 -0.730 220.000 -0.850 -1.000 -0.730 230.000 -0.850 -1.000 -0.730
 240.000 -0.850 -1.000 -0.730

DESIRED_DECELERATION 3 NAME "Bus" 0.0 250.0 -10.0 0.0

BASE_POINT 0.000 -0.850 -1.000 -0.730 10.000 -0.850 -1.000 -0.730 20.000 -0.850 -1.000 -0.730
 30.000 -0.850 -1.000 -0.730 40.000 -0.850 -1.000 -0.730 50.000 -0.850 -1.000 -0.730 60.000 -0.850 -
 1.000 -0.730 70.000 -0.850 -1.000 -0.730 80.000 -0.850 -1.000 -0.730 90.000 -0.850 -1.000 -0.730
 100.000 -0.850 -1.000 -0.730 110.000 -0.850 -1.000 -0.730 120.000 -0.850 -1.000 -0.730 130.000 -0.850
 -1.000 -0.730 140.000 -0.850 -1.000 -0.730 150.000 -0.850 -1.000 -0.730 160.000 -0.850 -1.000 -0.730
 170.000 -0.850 -1.000 -0.730 180.000 -0.850 -1.000 -0.730 190.000 -0.850 -1.000 -0.730 200.000 -0.850
 -1.000 -0.730 210.000 -0.850 -1.000 -0.730 220.000 -0.850 -1.000 -0.730 230.000 -0.850 -1.000 -0.730
 240.000 -0.850 -1.000 -0.730

DESIRED_DECELERATION 2 NAME "HGV" 0.0 250.0 -10.0 0.0

BASE_POINT 0.000 -1.250 -1.500 -1.050 10.000 -1.250 -1.500 -1.050 20.000 -1.250 -1.500 -1.050
 30.000 -1.250 -1.500 -1.050 40.000 -1.250 -1.500 -1.050 50.000 -1.250 -1.500 -1.050 60.000 -1.250 -
 1.500 -1.050 70.000 -1.250 -1.500 -1.050 80.000 -1.250 -1.500 -1.050 90.000 -1.250 -1.500 -1.050
 100.000 -1.250 -1.500 -1.050 110.000 -1.250 -1.500 -1.050 120.000 -1.250 -1.500 -1.050 130.000 -1.250
 -1.500 -1.050 140.000 -1.250 -1.500 -1.050 150.000 -1.250 -1.500 -1.050 160.000 -1.250 -1.500 -1.050
 170.000 -1.250 -1.500 -1.050 180.000 -1.250 -1.500 -1.050 190.000 -1.250 -1.500 -1.050 200.000 -1.250
 -1.500 -1.050 210.000 -1.250 -1.500 -1.050 220.000 -1.250 -1.500 -1.050 230.000 -1.250 -1.500 -1.050
 240.000 -1.250 -1.500 -1.050

DESIRED_DECELERATION 1 NAME "Car" 0.0 250.0 -10.0 0.0

BASE_POINT 0.000 -2.750 -3.000 -2.550 10.000 -2.750 -3.000 -2.550 20.000 -2.750 -3.000 -2.550
 30.000 -2.750 -3.000 -2.550 40.000 -2.750 -3.000 -2.550 50.000 -2.750 -3.000 -2.550 60.000 -2.750 -

3.000 -2.550 70.000 -2.750 -3.000 -2.550 80.000 -2.750 -3.000 -2.550 90.000 -2.750 -3.000 -2.550
 100.000 -2.750 -3.000 -2.550 110.000 -2.750 -3.000 -2.550 120.000 -2.750 -3.000 -2.550 130.000 -2.750
 -3.000 -2.550 140.000 -2.750 -3.000 -2.550 150.000 -2.750 -3.000 -2.550 160.000 -2.750 -3.000 -2.550
 170.000 -2.750 -3.000 -2.550 180.000 -2.750 -3.000 -2.550 190.000 -2.750 -3.000 -2.550 200.000 -2.750
 -3.000 -2.550 210.000 -2.750 -3.000 -2.550 220.000 -2.750 -3.000 -2.550 230.000 -2.750 -3.000 -2.550
 240.000 -2.750 -3.000 -2.550

KATTEMPERATURE 1 NAME "" 0.0 1080.0 -10.0 400.2

BASE_POINT 0.000 -10.000 -10.000 -10.000 36.000 -4.500 -4.500 -4.500 72.000 1.000 1.000 1.000
 108.000 6.500 6.500 6.500 144.000 12.000 12.000 12.000 180.000 17.500 17.500 216.000 23.000
 23.000 23.000 252.000 50.000 50.000 50.000 288.000 53.000 53.000 53.000 324.000 56.000 56.000
 56.000 360.000 79.000 79.000 79.000 396.000 121.600 121.600 121.600 432.000 175.000 175.000
 175.000 468.000 233.000 233.000 233.000 504.000 291.000 291.000 291.000 540.000 342.400 342.400
 342.400 576.000 347.760 347.760 347.760 612.000 353.120 353.120 353.120 648.000 358.480 358.480
 358.480 684.000 363.840 363.840 363.840 720.000 369.200 369.200 369.200 756.000 374.560 374.560
 374.560 792.000 379.920 379.920 379.920 828.000 385.280 385.280 385.280 864.000 390.640 390.640
 390.640 900.000 396.000 396.000 396.000 925.200 400.200 400.200 400.200 1080.000 400.200 400.200
 400.200

WATERTEMPERATURE 1 NAME "" 0.0 1080.0 -10.0 91.0

BASE_POINT 0.000 -10.000 -10.000 -10.000 36.000 -5.600 -5.600 -5.600 72.000 -1.200 -1.200 -1.200
 108.000 3.200 3.200 3.200 144.000 7.600 7.600 7.600 180.000 12.000 12.000 12.000 216.000 16.400
 16.400 16.400 252.000 20.800 20.800 20.800 288.000 26.000 26.000 26.000 324.000 32.000 32.000
 32.000 360.000 39.500 39.500 39.500 396.000 47.000 47.000 47.000 432.000 53.000 53.000 53.000
 468.000 59.000 59.000 59.000 504.000 65.000 65.000 65.000 540.000 69.345 69.345 69.345 576.000
 73.708 73.708 73.708 612.000 78.071 78.071 78.071 648.000 82.434 82.434 82.434 684.000 86.797
 86.797 86.797 720.000 91.000 91.000 91.000 1080.000 91.000 91.000 91.000

-- Priority Rules: --

 PRIORITY_RULE ONLY_OWN_LINK NO

PRIORITY_RULE NUMBER 8 NAME "" LABEL 0.00 0.00

POSITION LINK 35 LANE 2 AT 185.453 VEHICLE_CLASSES ALL
 BY POSITION LINK 35 LANE 1 AT 201.220 VEHICLE_CLASSES ALL
 TIME_GAP 0.0 HEADWAY 10.0 VMAX 1.4 BEYONDREDSIGNAL

PRIORITY_RULE NUMBER 7 NAME "" LABEL 0.00 0.00

POSITION LINK 52 LANE 2 AT 214.668 VEHICLE_CLASSES ALL
 BY POSITION LINK 52 LANE 1 AT 240.194 VEHICLE_CLASSES ALL
 TIME_GAP 0.0 HEADWAY 10.0 VMAX 1.4

PRIORITY_RULE NUMBER 6 NAME "" LABEL 0.00 0.00

POSITION LINK 38 LANE 2 AT 295.041 VEHICLE_CLASSES ALL
 BY POSITION LINK 38 LANE 1 AT 321.969 VEHICLE_CLASSES ALL
 TIME_GAP 0.0 HEADWAY 10.0 VMAX 1.4

PRIORITY_RULE NUMBER 5 NAME "" LABEL 0.00 0.00

POSITION LINK 34 LANE 2 AT 344.297 VEHICLE_CLASSES ALL
 BY POSITION LINK 34 LANE 1 AT 368.445 VEHICLE_CLASSES ALL
 TIME_GAP 0.0 HEADWAY 10.0 VMAX 1.4 BEYONDREDSIGNAL

PRIORITY_RULE NUMBER 4 NAME "" LABEL 0.00 0.00

POSITION LINK 20 LANE 2 AT 297.293 VEHICLE_CLASSES ALL
 BY POSITION LINK 20 LANE 1 AT 320.288 VEHICLE_CLASSES ALL
 TIME_GAP 0.0 HEADWAY 10.0 VMAX 1.4

PRIORITY_RULE NUMBER 3 NAME "" LABEL 0.00 0.00

POSITION LINK 17 LANE 2 AT 346.778 VEHICLE_CLASSES ALL
 BY POSITION LINK 17 LANE 1 AT 368.245 VEHICLE_CLASSES ALL
 TIME_GAP 0.0 HEADWAY 10.0 VMAX 1.4

PRIORITY_RULE NUMBER 2 NAME "" LABEL 0.00 0.00
 POSITION LINK 8 LANE 2 AT 361.218 VEHICLE_CLASSES ALL
 BY POSITION LINK 8 LANE 1 AT 385.771 VEHICLE_CLASSES ALL
 TIME_GAP 0.0 HEADWAY 10.0 VMAX 1.4
 PRIORITY_RULE NUMBER 1 NAME "" LABEL 0.00 0.00
 POSITION LINK 5 LANE 2 AT 375.087 VEHICLE_CLASSES ALL
 BY POSITION LINK 5 LANE 1 AT 398.771 VEHICLE_CLASSES ALL
 TIME_GAP 0.0 HEADWAY 10.0 VMAX 1.4

-- Stop Signs: --

-- Conflict Areas: --

-- Signal Controllers (SC): --

-- Detectors: --

-- Public Transport: --

-- Travel Times: --

TRAVEL_TIME AGGREGATION_INTERVAL 99999 FROM 0 UNTIL 99999 RAW NO
 AGGREGATE YES

-- Delays: --

-- Data Collection: --

CROSS_SEC_MEASUREMENT FROM 0 UNTIL 1800 AGGREGATION_INTERVAL 300
 RAW NO AGGREGATE YES VISUM_ONLINE NO
 CONFIG_FILE "2016_network.qmk"

CROSS_SEC_MEASUREMENT 1 COLLECTION_POINT 1 2 3
 CROSS_SEC_MEASUREMENT 4 COLLECTION_POINT 4
 CROSS_SEC_MEASUREMENT 5 COLLECTION_POINT 5 6 7
 CROSS_SEC_MEASUREMENT 8 COLLECTION_POINT 8
 CROSS_SEC_MEASUREMENT 9 COLLECTION_POINT 9 10 11

CROSS_SEC_MEASUREMENT 12 COLLECTION_POINT 12
 CROSS_SEC_MEASUREMENT 13 COLLECTION_POINT 13 14 15 16 17

-- Queue Counters: --

-- Data Collection Points: --

COLLECTION_POINT 1 NAME "WEND" LABEL 0.00 0.00
 POSITION LINK 3 LANE 3 AT 294.922
 COLLECTION_POINT 2 NAME "WEND" LABEL 0.00 0.00
 POSITION LINK 3 LANE 2 AT 294.903
 COLLECTION_POINT 3 NAME "WEND" LABEL 0.00 0.00
 POSITION LINK 3 LANE 1 AT 294.889
 COLLECTION_POINT 4 NAME "HOT WEND" LABEL 0.00 0.00
 POSITION LINK 10 LANE 1 AT 286.257
 COLLECTION_POINT 5 NAME "PALL-CAST" LABEL 0.00 0.00
 POSITION LINK 21 LANE 3 AT 181.478
 COLLECTION_POINT 6 NAME "PALL-CAST" LABEL 0.00 0.00
 POSITION LINK 21 LANE 2 AT 181.493
 COLLECTION_POINT 7 NAME "PALL-CAST" LABEL 0.00 0.00
 POSITION LINK 21 LANE 1 AT 181.496
 COLLECTION_POINT 8 NAME "HOT PALL-EAGL" LABEL 0.00 0.00
 POSITION LINK 32 LANE 1 AT 534.356
 COLLECTION_POINT 9 NAME "EAGL-MOOD" LABEL 0.00 0.00
 POSITION LINK 39 LANE 3 AT 431.130
 COLLECTION_POINT 10 NAME "EAGL-MOOD" LABEL 0.00 0.00
 POSITION LINK 39 LANE 2 AT 431.112
 COLLECTION_POINT 11 NAME "EAGL-MOOD" LABEL 0.00 0.00
 POSITION LINK 39 LANE 1 AT 431.114
 COLLECTION_POINT 12 NAME "HOT EAGL-MOOD" LABEL 0.00 0.00
 POSITION LINK 43 LANE 1 AT 857.817
 COLLECTION_POINT 13 NAME "EEND" LABEL 0.00 0.00
 POSITION LINK 55 LANE 5 AT 109.737
 COLLECTION_POINT 14 NAME "EEND" LABEL 0.00 0.00
 POSITION LINK 55 LANE 4 AT 109.742
 COLLECTION_POINT 15 NAME "EEND" LABEL 0.00 0.00
 POSITION LINK 55 LANE 3 AT 109.698
 COLLECTION_POINT 16 NAME "EEND" LABEL 0.00 0.00
 POSITION LINK 55 LANE 2 AT 109.672
 COLLECTION_POINT 17 NAME "EEND" LABEL 0.00 0.00
 POSITION LINK 55 LANE 1 AT 109.686

-- Evaluations: --

EVALUATION DATABASE "" CONFIRM_OVERWRITE NO

EVALUATION TYPE CONVERGENCE EDGE LENGTH 20.000
 TIME FROM 0.0 UNTIL 999999.0

WINDOW TYPE VEHICLE_INFO CONFIG_FILE "2016_network.fzi"
WINDOW TYPE LDP SIGNAL_GROUP NUMBER DETECTOR NUMBER
SCJ
WINDOW TYPE SZP SIGNAL_GROUP NUMBER DETECTOR NUMBER
SCJ

-- Parking Lots: --

PARKING_LOT 1 NAME "" LABEL 0.00 0.00
ZONES 1 FRACTION 1.000
POSITION LINK 1 AT 32.781
LENGTH 82.699
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 2 NAME "" LABEL 0.00 0.00
ZONES 2 FRACTION 1.000
POSITION LINK 2 AT 178.807
LENGTH 26.025
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 3 NAME "" LABEL 0.00 0.00
ZONES 3 FRACTION 1.000
POSITION LINK 4 AT 9.964
LENGTH 27.928
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 4 NAME "" LABEL 0.00 0.00
ZONES 4 FRACTION 1.000
POSITION LINK 6 AT 14.522
LENGTH 36.688
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0

ATTRACTION 0.0
PARKING_LOT 5 NAME "" LABEL 0.00 0.00
ZONES 5 FRACTION 1.000
POSITION LINK 14 AT 244.397
LENGTH 52.476
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 6 NAME "" LABEL 0.00 0.00
ZONES 6 FRACTION 1.000
POSITION LINK 16 AT 12.100
LENGTH 33.919
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 7 NAME "" LABEL 0.00 0.00
ZONES 7 FRACTION 1.000
POSITION LINK 19 AT 16.957
LENGTH 35.021
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 8 NAME "" LABEL 0.00 0.00
ZONES 8 FRACTION 1.000
POSITION LINK 23 AT 18.085
LENGTH 40.577
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 9 NAME "" LABEL 0.00 0.00
ZONES 9 FRACTION 1.000
POSITION LINK 30 AT 280.604
LENGTH 64.727
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140

OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 10 NAME "" LABEL 0.00 0.00
ZONES 10 FRACTION 1.000
POSITION LINK 33 AT 15.161
LENGTH 44.697
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 11 NAME "" LABEL 0.00 0.00
ZONES 11 FRACTION 1.000
POSITION LINK 37 AT 17.190
LENGTH 38.232
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 12 NAME "" LABEL 0.00 0.00
ZONES 12 FRACTION 1.000
POSITION LINK 48 AT 197.054
LENGTH 52.836
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 13 NAME "" LABEL 0.00 0.00
ZONES 13 FRACTION 1.000
POSITION LINK 51 AT 19.431
LENGTH 43.057
CAPACITY 100
OCCUPANCY 0
DEFAULT DESIRED_SPEED 140
OPEN_HOURS FROM 0 UNTIL 99999
MAX_TIME 99999
FLAT_FEE 0.0
FEE_PER_HOUR 0.0
ATTRACTION 0.0
PARKING_LOT 14 NAME "" LABEL 0.00 0.00
ZONES 14 FRACTION 1.000
POSITION LINK 54 AT 19.605

LENGTH 47.224
 CAPACITY 100
 OCCUPANCY 0
 DEFAULT DESIRED_SPEED 140
 OPEN_HOURS FROM 0 UNTIL 99999
 MAX_TIME 99999
 FLAT_FEE 0.0
 FEE_PER_HOUR 0.0
 ATTRACTION 0.0
 PARKING_LOT 15 NAME "" LABEL 0.00 0.00
 ZONES 15 FRACTION 1.000
 POSITION LINK 55 AT 113.429
 LENGTH 115.825
 CAPACITY 100
 OCCUPANCY 0
 DEFAULT DESIRED_SPEED 140
 OPEN_HOURS FROM 0 UNTIL 99999
 MAX_TIME 99999
 FLAT_FEE 0.0
 FEE_PER_HOUR 0.0
 ATTRACTION 0.0

-- Nodes: --

NODE 1 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 -1167.189 492.827 -1136.032 459.484 -1113.075 477.522 -1145.871 509.225
 NODE 2 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 -212.935 1228.504 -207.275 1199.497 -220.717 1198.082 -226.377 1220.014
 NODE 3 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 26.392 1386.512 51.664 1402.500 60.948 1388.059 36.191 1376.712
 NODE 4 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 168.226 1594.828 187.825 1578.839 197.625 1593.280 175.447 1605.143
 NODE 5 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 2031.545 2702.672 2040.682 2741.712 2026.561 2746.696 2016.593 2711.809
 NODE 6 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 2209.469 2840.255 2228.598 2852.026 2232.522 2840.255 2213.884 2831.426
 NODE 7 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 2271.270 2871.646 2297.266 2868.703 2296.775 2880.474 2277.646 2883.417
 NODE 8 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 3026.660 3613.870 3047.557 3596.660 3054.318 3612.026 3037.723 3624.318
 NODE 9 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 4159.768 4513.784 4159.180 4486.179 4146.259 4486.179 4146.846 4510.260
 NODE 10 NAME "" LABEL 0.00 0.00
 EVALUATION NO
 NETWORK_AREA 4 4352.672 4605.566 4371.702 4607.945 4374.081 4595.100 4356.002 4591.769

NODE 11 NAME "" LABEL 0.00 0.00
EVALUATION NO
NETWORK_AREA 4 4395.966 4655.640 4412.141 4651.834 4418.802 4663.728 4398.820 4668.961
NODE 12 NAME "" LABEL 0.00 0.00
EVALUATION NO
NETWORK_AREA 4 7917.626 6708.878 7908.402 6683.976 7896.412 6691.354 7902.869 6711.645
NODE 13 NAME "" LABEL 0.00 0.00
EVALUATION NO
NETWORK_AREA 4 8078.442 6796.693 8101.310 6793.834 8096.308 6779.541 8080.228 6782.043
NODE 14 NAME "" LABEL 0.00 0.00
EVALUATION NO
NETWORK_AREA 4 8154.909 6839.554 8178.849 6827.405 8184.566 6841.698 8164.199 6850.631
NODE 15 NAME "" LABEL 0.00 0.00
EVALUATION NO
NETWORK_AREA 4 8691.607 7212.259 8706.614 7171.881 8730.912 7180.100 8715.905 7216.904

-- Edge Closure: --

-- TEAPAC: --

-- Emissions: --

EMISSION
LAYERS ""
AIR_DENSITY 1.202
TEMPERATURE 20.000

-- Static 3D Models: --

-- Pavement Markers: --

-- Keyframes: --

-- 3D Traffic Signal Object Defaults: --

V3D_SIG_DEFAULTS_INIT
DEF_ARM_ROTATION 90.000000

DEF_USE_LIGHT 0
DEF_STOP_BAR 0
DEF_SIG_ROTATION 90.000000
DEF_SIG_SPACING -1.200000
DEF_SIG_ARROWS_LIT 0

DEF_SIG_LOD 600.000000 250.000000 150.000000 100.000000

V3D_SIGNAL_MASTS

MAST_ID 0
MAST_STYLE 0

MAST_POS 0.000000 0.000000 0.000000
MAST_HEIGHT 5.000000
MAST_LENGTH 0.100000
MAST_RADIUS 10.000000
MAST_ROTATION 0.000000
SIG_SCALE_FAC 1.000000

V3D_SIGNAL_MASTS_END

V3D_SIGNAL_ARMS

ARM_ID 0
ARM_STYLE 0
ARM_VISIBILITY 1
ARM_POS 0.000000 0.000000 0.000000
ARM_LENGTH 5.000000
ARM_HEIGHT 4.800000
ARM_ROTATION 0.000000
SIG_SCALE_FAC 1.000000

V3D_SIGNAL_ARMS_END

V3D_SIGNAL_ARMS

ARM_ID 0
ARM_STYLE 7
ARM_VISIBILITY 1
ARM_POS 0.000000 0.000000 0.000000
ARM_LENGTH 3.000000
ARM_HEIGHT 3.000000
ARM_ROTATION 0.000000
SIG_SCALE_FAC 1.000000

V3D_SIGNAL_ARMS_END

V3D_SIGNAL_HEADS

SIG_ID 0
SIG_STYLE 0
SIG_VISIBILITY 1

SIG_TYPE 0
SIG_ORIENTATION 0
SIG_LAYOUT 11 0

SIG_LSA_LEFT -1
SIG_LSA_RIGHT -1
SIG_LSA_THRU -1
SIG_GRP_LEFT -1
SIG_GRP_RIGHT -1
SIG_GRP_THRU -1

SIG_POS 0.000000 0.000000 0.210000
SIG_HEIGHT 2.600000
SIG_ROTATION 0.000000
SIG_SCALE_FAC 0.550000

V3D_SIGNAL_HEADS_END

V3D_SIG_DEFAULTS_END

-- 3D Traffic Signal Data: --

-- Texture Lists: --

-- Compass: --

-- 3D Settings: --

Appendix C

Sample VISSIM Output File

Note: including all of the VISSIM output files would require hundreds of pages as a result only one sample output file is included.

Data Collection (Compiled Data)

File: c:\documents and settings\tomek\Desktop\design year network\redone des year network\2016_network.inp

Comment: 2016 HOT Final Trials: Toll \$0.50, Intensity 120%

Date: July 18, 2008 7:10:35 PM

Measurement 1: Data Collection Point(s) 1, 2, 3
 Measurement 4: Data Collection Point(s) 4
 Measurement 5: Data Collection Point(s) 5, 6, 7
 Measurement 8: Data Collection Point(s) 8
 Measurement 9: Data Collection Point(s) 9, 10, 11
 Measurement 12: Data Collection Point(s) 12
 Measurement 13: Data Collection Point(s) 13, 14, 15, 16, 17

Measur.: Data Collection Number
 from: Start time of the Aggregation interval
 to: End time of the Aggregation interval
 Number Veh: Number of Vehicles
 Speed: Speed [km/h]

Measur.;from;to;Number Veh;Number Veh;Number Veh;Speed

; ;;;;Mean
 ; ; ;Car;HOV;HGV;all veh. types
 1;0;300;196;30;10;125.3
 4;0;300;66;12;0;121.0
 5;0;300;283;33;18;109.0
 8;0;300;86;11;0;109.1
 9;0;300;225;31;18;107.5
 12;0;300;63;11;0;105.2
 13;0;300;274;44;17;122.0
 1;300;600;195;31;10;122.6
 4;300;600;85;20;0;109.6
 5;300;600;360;54;30;93.0
 8;300;600;152;22;0;97.9
 9;300;600;356;53;29;86.8
 12;300;600;136;16;0;93.1
 13;300;600;491;63;29;110.9
 1;600;900;217;28;16;122.3
 4;600;900;105;14;0;112.2
 5;600;900;385;59;23;87.1
 8;600;900;151;24;0;108.9
 9;600;900;354;49;31;62.5
 12;600;900;132;34;0;100.7
 13;600;900;586;100;38;93.7
 1;900;1200;181;30;12;122.7
 4;900;1200;76;13;0;115.3
 5;900;1200;387;55;24;77.3
 8;900;1200;137;22;0;72.9
 9;900;1200;378;48;22;63.8
 12;900;1200;149;29;0;104.2
 13;900;1200;575;88;33;99.5
 1;1200;1500;201;38;15;124.4
 4;1200;1500;91;17;0;106.1
 5;1200;1500;338;58;21;57.5
 8;1200;1500;127;17;0;48.1

9;1200;1500;347;51;30;62.1
12;1200;1500;146;19;0;95.6
13;1200;1500;606;92;32;100.1
1;1500;1800;206;31;10;122.9
4;1500;1800;92;19;0;106.3
5;1500;1800;305;40;20;31.4
8;1500;1800;121;33;0;65.8
9;1500;1800;342;57;31;71.9
12;1500;1800;135;26;0;87.6
13;1500;1800;554;72;35;108.5

Appendix D

QueensOD Sample Input Files

Note: all of the QueensOD input files are not presented here since that would require many pages. As a result, only a sample is shown.

EB AM 2016 Master File

22	1000	0.01
5	20	0.10
2	1	0.00

nodes.dat

links.dat

none

none

none

amflo.dat

none

none

none

am10.out

am11.out

am12.out

am13.out

am14.out

am15.out

am16.out

2016 Link coordination file

36	1.0	1.0	1.0	1.0	1.0								
1	1	2	0.648	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
2	2	3	0.220	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
3	3	5	0.371	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
4	3	4	0.448	120	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
5	6	5	0.442	60	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
6	5	7	0.572	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
7	7	9	0.339	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
8	8	9	0.892	80	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
9	9	10	0.777	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
10	10	11	0.293	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
11	11	13	0.477	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
12	11	12	0.557	120	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
13	14	13	0.380	60	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
14	13	15	0.465	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
15	15	17	0.192	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
16	16	17	0.618	80	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
17	17	18	0.306	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
18	18	20	0.360	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
19	19	20	0.303	80	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
20	20	21	0.805	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
21	21	23	0.559	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
22	21	22	0.415	120	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
23	24	23	0.458	60	2400	2	0	0	0	0	0	0	0
	0	0	0	0	0	0							
24	23	26	0.498	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
25	26	27	0.109	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
26	25	27	0.692	80	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
27	27	28	0.425	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
28	28	29	2.006	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
29	29	30	0.436	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
30	30	32	0.595	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							

31	30	31	0.398	120	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
32	33	32	0.508	60	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
33	32	34	0.335	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							
34	34	36	0.098	120	2400	3	0	0	0	0	0	0	0
	0	0	0	0	0	0							
35	35	36	0.598	80	2400	1	0	0	0	0	0	0	0
	0	0	0	0	0	0							
36	36	37	0.678	120	2400	4	0	0	0	0	0	0	0
	0	0	0	0	0	0							

Nodes 2016 configuration file

37	1.0	1.0			
1	425.5067011	5015.102148	3	0	0
2	425.9937358	5015.529593	4	0	0
3	426.1611121	5015.671757	4	0	0
4	426.5933655	5015.790054	2	0	0
5	426.4380831	5015.917947	4	0	0
6	426.5390868	5015.90695	3	0	0
7	426.8681404	5016.29574	4	0	0
8	426.7749094	5015.693193	3	0	0
9	427.1290733	5016.511468	4	0	0
10	427.8064971	5016.891074	4	0	0
11	428.0686101	5017.022054	4	0	0
12	428.6144553	5017.135257	2	0	0
13	428.4856706	5017.25423	4	0	0
14	428.5733187	5017.250812	3	0	0
15	428.8541416	5017.538033	4	0	0
16	428.6906806	5017.125724	3	0	0
17	429.0022461	5017.659786	4	0	0
18	429.2365385	5017.856738	4	0	0
19	429.3486187	5017.831571	3	0	0
20	429.5144292	5018.085762	4	0	0
21	430.1395397	5018.593747	4	0	0
22	430.5436151	5018.689946	2	0	0
23	430.595514	5018.916444	4	0	0
24	430.5912088	5018.821274	3	0	0
25	430.6646862	5018.697202	3	0	0
26	431.029809	5019.161016	4	0	0
27	431.1246168	5019.214409	4	0	0
28	431.4943643	5019.423779	4	0	0
29	433.2461082	5020.402032	4	0	0
30	433.6267794	5020.614709	4	0	0
31	434.023726	5020.649835	2	0	0
32	434.1418358	5020.912277	4	0	0
33	434.0880299	5020.778977	3	0	0
34	434.4398863	5021.065814	4	0	0
35	434.1325371	5020.650098	3	0	0
36	434.5345655	5021.092431	4	0	0
37	435.1883219	5021.270948	2	0	0

Appendix E

QueensOD Sample Output File

Note: Only one sample file for one specific run of the program is shown in this appendix.

Listing of seed, est and if available, actual ods

1. Final estimated and seed o-d matrix (vph)

orig	dest	LT	Seed	Estimate
1	4	1	581.0	730.20
1	12	1	581.0	754.08
1	22	1	581.0	618.56
1	31	1	581.0	469.16
1	37	1	581.0	894.75
6	12	1	581.0	168.17
6	22	1	581.0	219.82
6	31	1	581.0	192.98
6	37	1	581.0	512.95
8	12	1	581.0	100.21
8	22	1	581.0	177.64
8	31	1	581.0	159.86
8	37	1	581.0	516.10
14	22	1	581.0	155.29
14	31	1	581.0	141.63
14	37	1	581.0	577.70
16	22	1	581.0	187.05
16	31	1	581.0	155.83
16	37	1	581.0	753.86
19	22	1	581.0	109.89
19	31	1	581.0	112.08
19	37	1	581.0	768.82
24	31	1	581.0	139.05
24	37	1	581.0	1113.11
25	31	1	581.0	4.50
25	37	1	581.0	873.18
33	37	1	581.0	805.00
35	37	1	581.0	660.43

Appendix F

Calibration Results

F.1 Final Results of the Volume Calibration

(A) East Bound Mainline Sections								
Link	N required	N actual	Balanced Volume	Mean Volume	Standard Deviation	GEH	Percent Error	Square Error
East End	3	30	4080	3910.1	38.98	2.69	-4.17%	28877.3
Eagleson to Moodie	2	30	3840	3664.0	36.04	2.87	-4.58%	30976.0
Terry Fox to Eagleson	6	30	3260	3423.1	58.35	2.82	5.00%	26612.5
Palladium to Terry Fox	4	30	2670	2684.9	51.07	0.29	0.56%	223.0
West End	5	30	2720	2734.9	53.22	0.29	0.55%	223.0
(B) West Bound Mainline Sections								
Link	N required	N actual	Balanced Volume	Mean Volume	Standard Deviation	GEH	Percent Error	Square Error
West End	2	30	940	984.5	33.50	1.44	4.74%	1983.2
Moodie to Eagleson	19	30	3570	3502.6	106.48	1.13	-1.89%	4542.8
Eagleson to Terry Fox	5	30	1410	1445.1	55.61	0.93	2.49%	1229.7
Terry Fox to Palladium	3	30	990	1038.1	39.09	1.51	4.86%	2310.4
East End	23	30	5260	5213.2	117.58	0.65	-0.89%	2190.2
(C) East Bound Ramp Sections								
Link	N required	N actual	Balanced Volume	Mean Volume	Standard Deviation	GEH	Percent Error	Square Error
Palladium OFF	7	30	120	146.0	9.53	2.25	21.67%	676.0
Palladium ON I	74	80	20	25.0	5.39	1.05	25.00%	25.0
Palladium ON D	19	30	50	74.0	7.95	3.05	48.00%	576.0
Terry Fox OFF	6	30	210	243.2	14.00	2.21	15.81%	1102.2
Terry Fox ON I	9	30	200	260.2	19.25	3.97	30.10%	3624.0
Terry Fox ON D	2	30	600	734.8	28.27	5.22	22.47%	18171.0
Eagleson OFF	2	30	710	848.7	26.25	4.97	19.53%	19228.4
Eagleson ON I	2	30	740	722.7	24.34	0.64	-2.33%	298.1
Eagleson ON D	2	30	550	554.9	18.00	0.21	0.90%	24.3
Moodie OFF	6	30	330	336.7	20.04	0.37	2.04%	45.3
Moodie ON I	5	30	220	245.6	13.35	1.68	11.64%	655.4
Moodie ON D	4	30	310	337.0	15.98	1.50	8.71%	729.0
(D) West Bound Ramp Sections								
Link	N required	N actual	Balanced Volume	Mean Volume	Standard Deviation	GEH	Percent Error	Square Error
Moodie OFF	5	30	1850	1818.6	53.22	0.73	-1.70%	986.0
Moodie ON I	12	30	80	83.5	7.14	0.38	4.33%	12.0
Moodie ON D	16	30	70	74.1	7.28	0.49	5.90%	17.1
Eagleson OFF	8	30	2260	2172.3	69.51	1.86	-3.88%	7697.1
Eagleson ON I	61	70	20	21.8	4.28	0.40	9.14%	3.3
Eagleson ON D	14	30	80	82.1	7.45	0.24	2.67%	4.6
Terry Fox OFF	5	30	570	572.3	31.20	0.09	0.40%	5.1
Terry Fox ON I	23	30	70	75.1	8.89	0.60	7.33%	26.4
Terry Fox ON D	18	30	80	84.6	8.66	0.51	5.75%	21.2
Palladium OFF	21	30	80	87.4	9.90	0.81	9.25%	54.8
Palladium ON I	53	60	30	34.4	6.27	0.78	14.78%	19.7

Where: "I" refers to an inner loop type on ramp and "D" refers to a direct type on ramp.

Table F.2 Final Results of the Travel Time Calibration (East Bound, AM Peak Period Only)

Section	MTO Distance	Simulation Distance	N required	N actual	MTO Travel Time	Mean Travel Time	Standard Deviation	Percent Error	Square Error
Palladium to Terry Fox	2450	2674.8	0	30	90.7	90.7	1.16	0.03%	0.0
Terry Fox to Eagleson	2630	2738.6	25	30	191.7	148.4	18.06	22.58%	1872.9
Eagleson to CN	2670	2898.4	17	30	183.7	191.5	19.47	4.24%	60.6
CN to Moodie	1350	1410.0	1	30	56.9	51.2	1.28	-9.95%	32.1

Table F.3 Final Results of the Entire Calibration Process

	Overall GEH	Percent Error	RMSE
Volume	1.26	8.01%	68.1
Travel Time	N/A	-7.07%	22.2

Appendix G

Validation Results

Table G.1 Final Results of the Volume Validation

(A) East Bound Mainline Sections								
Link	N required	N actual	Balanced Volume	Volume	Standard Deviation	GEH	Percent Error	Square Error
West End	4	55	1430	1418.9	46.90	0.29	-0.78%	123.0
Eagleson to Moodie	7	55	3490	3094.1	66.28	6.90	-11.34%	156758.4
Terry Fox to Eagleson	5	55	1960	1961.5	53.17	0.03	0.08%	2.3
Palladium to Terry Fox	3	55	1410	1411.6	45.02	0.04	0.11%	2.4
East End	3	55	4990	4294.5	43.23	10.21	-13.94%	483707.6
(B) West Bound Mainline Sections								
Link	N required	N actual	Balanced Volume	Volume	Standard Deviation	GEH	Percent Error	Square Error
East End	11	55	4520	4510.9	84.49	0.14	-0.20%	83.3
Moodie to Eagleson	6	55	3810	3739.6	61.12	1.15	-1.85%	4951.0
Eagleson to Terry Fox	5	55	2860	2822.5	54.06	0.70	-1.31%	1405.6
Terry Fox to Palladium	4	55	2440	2399.3	48.87	0.83	-1.67%	1655.8
West End	4	55	2380	2335.9	47.83	0.91	-1.85%	1945.6
(C) East Bound Ramp Sections								
Link	N required	N actual	Balanced Volume	Volume	Standard Deviation	GEH	Percent Error	Square Error
Palladium OFF	23	55	80	91.5	10.94	1.24	14.41%	132.9
Palladium ON I	50	55	20	35.9	6.36	3.01	79.64%	253.7
Palladium ON D	32	55	40	48.9	6.95	1.34	22.27%	79.4
Terry Fox OFF	8	55	180	201.9	14.04	1.59	12.18%	480.8
Terry Fox ON I	7	55	240	249.5	16.12	0.61	3.97%	90.8
Terry Fox ON D	4	55	490	499.6	24.71	0.43	1.95%	91.5
Eagleson OFF	9	55	180	199.9	15.29	1.44	11.03%	394.2
Eagleson ON I	2	55	1080	1097.0	38.20	0.52	1.58%	289.6
Eagleson ON D	3	55	630	634.3	26.52	0.17	0.69%	18.7
Moodie OFF	19	55	190	166.8	18.00	1.73	-12.19%	536.6
Moodie ON I	2	55	1280	1295.0	39.82	0.42	1.17%	225.5
Moodie ON D	3	55	410	410.5	18.52	0.03	0.13%	0.3
(D) West Bound Ramp Sections								
Link	N required	N actual	Balanced Volume	Volume	Standard Deviation	GEH	Percent Error	Square Error
Moodie OFF	3	55	1190	1185.6	42.18	0.13	-0.37%	19.0
Moodie ON I	7	55	190	190.3	12.43	0.02	0.17%	0.1
Moodie ON D	5	55	270	263.7	14.43	0.39	-2.33%	39.6
Eagleson OFF	3	55	1350	1344.7	44.32	0.14	-0.39%	27.8
Eagleson ON I	24	55	60	60.8	7.41	0.10	1.27%	0.6
Eagleson ON D	6	55	340	341.1	21.32	0.06	0.32%	1.2
Terry Fox OFF	3	55	840	838.0	37.81	0.07	-0.23%	3.9
Terry Fox ON I	10	55	170	169.9	13.09	0.01	-0.04%	0.0
Terry Fox ON D	6	55	250	250.7	15.66	0.04	0.26%	0.4
Palladium OFF	14	55	140	139.6	13.08	0.03	-0.26%	0.1
Palladium ON I	20	55	80	79.0	8.88	0.11	-1.23%	1.0

where: "I" refers to an inner loop type on ramp and "D" refers to a direct type on ramp.

Table G.2 Final Results of the Travel Time Validation (West Bound, PM Peak Period Only)

Section	MTO Distance	Simulation Distance	N required	N actual	MTO Travel Time	Mean Travel Time	Standard Deviation	Percent Error	Square Error
Moodie to CN	1350	1461.5	30	30	97.6	79.6	10.62	-18.42%	323.0
CN to Ealeson	2670	2822.6	1	30	111.3	112.9	2.68	1.45%	2.6
Eagleson to Terry Fox	2630	2846.8	4	30	104	103.8	4.98	-0.15%	0.0
Terry Fox to Palladium	2450	2642.2	1	30	89.5	86.6	1.50	-3.22%	8.3

Table G.3 Final Results of the Entire Validation Process

	Overall GEH	Percent Error	RMSE
Volume	2.78	-3.07%	140.7
Travel Time	N/A	-5.08%	9.1

Appendix H
Stated Preference Survey

STATED PREFERENCE SURVEY ON WILLINGNESS TO PAY FOR TOLLED FACILITIES

SECTION 1: Introduction

Welcome, and thank you for agreeing to participate in this survey. This survey will attempt to gather information about people's willingness to pay for a hypothetical tolled facility in the City of Ottawa. The study area for this survey is the Queensway (Highway 417) between Palladium Drive and Highway 416. The following is an explanation of some of the concepts that this survey will include and how these concepts will be put into action.

A High Occupancy Toll (HOT) lane operates in a similar manner to a High Occupancy Vehicle (HOV) lane. Vehicles with multiple occupants (i.e. 2 persons or more) may utilize the lane free of charge. However, on the HOT lane solo travellers may also use the lane for some fee. So, carpools, vanpools and transit vehicles use the lane for free and solo travellers may choose to use the HOT lane for a small toll or to remain on the general purpose (free) lanes.

The toll charged to solo users of the HOT facility will be calculated based on the number of vehicles on the road at the time as well as their speed, so that the HOT lane offers a consistently high level of service. This concept is referred to as value pricing. The cost of using the HOT lane will be displayed on large electronically changeable message signs prior to the entrance of the facility. The tolls will be collected by means of an electronic toll collection device. The general layout of an access points is displayed in figure 1.

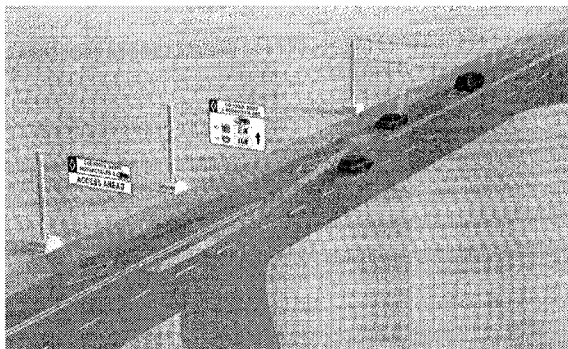


Figure 2: Depiction of Access Area on an HOT lane facility (Image courtesy of MnDOT's MnPASS Program).

Thank you again for agreeing to participate in this survey, I hope that the preceding information gives you some insight into the research we are conducting and helps you answer the questions in this survey.

SECTION 2: Demographics

In this section of this survey we would like to know a little bit about you so that we may study how certain people view tolled facilities. Please check the appropriate box (only one per question), and fill in the space provided if applicable.

1. What is your age?

- 16 – 24 years old;
- 25 – 34 years old;
- 35 – 54 years old;
- 55 – 64 years old;
- 65 – 74 years old;
- 75 years old or older.

2. What is your gender?

- Male;
- Female.

3. What is your total annual household income?

- \$12,000 and under;
- \$12,001 - \$19,000;
- \$19,001 - \$29,000;
- \$29,001 - \$34,000;
- \$34,001 - \$53,000;
- \$53,001 - \$74,000;
- \$74,001 - \$104,000;
- Over \$104,000.

4. In what part of the city of Ottawa do you currently reside?

- Central Ottawa (Inside the Greenbelt);
- Kanata;
- Barrhaven / South Gloucester;
- Orleans;
- West Rural City of Ottawa;
- East Rural City of Ottawa;
- South Rural City of Ottawa;
- Gatineau / Hull / Aylmer;
- Outside of the Ottawa area. Please Specify: _____

SECTION 3: Information about your last trip

The information collected in this section of the survey will be used to evaluate characteristics of the type of trips you make. It will also give the analyst a frame of reference for the information collected in section 4. Please check the appropriate box (only one per question), and fill in the space provided if applicable.

1. How many one way trips do you make on the Queensway (Highway 417) each week?
 - 3 or fewer;
 - 4 – 7;
 - 8 – 10;
 - 11 or more.

2. How often would you say that you participate in a carpool (i.e. drive in a vehicle with more than one occupant)?
 - Never;
 - Rarely;
 - Sometimes;
 - Often;
 - Always.

3. Consider the last trip you made on the Queensway, approximately how long was the last trip you made (one way)?
 - Under 10 km;
 - 10 – 30 km;
 - Over 30 km;

4. Consider the last trip you made on the Queensway, what was the purpose of that trip?
 - To/from Work;
 - Work Related/Business;
 - To/from Recreation/Shopping;
 - To/from Out of Town
 - Emergency (e.g. Hospital);
 - Other, Please Specify: _____

5. Consider the last trip you made on the Queensway, on what day of the week and time of day did you make that trip?

- Weekday Morning Peak Period (6 am to 10 am);
- Weekday Afternoon Peak Period (2 pm to 6 pm);
- Weekend or Off Peak Period.

Section 4: Opinions on tolling scenarios

Each of the following 25 scenarios is represented by three numbers. The first represents the toll on the HOT lane, the second represents the travel time on the HOT lane and the third represents the travel time on the general purpose (or free) lanes. So, each scenario is in the form:

\$(Toll on HOT lane) / (Travel time on HOT lane) min / (Travel time on free lanes) min

Assume there is a 10 km long section of highway in which the HOT lane facility has been implemented, and you are driving alone. For each of the following scenarios indicate whether you would have used the HOT facility on your last trip based on the following:

Scenario	Response
\$1.00 / 5 min / 10 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$1.00 / 6 min / 26 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$1.00 / 7 min / 29 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$1.00 / 8 min / 25 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$1.00 / 9 min / 27 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$2.00 / 5 min / 25 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$2.00 / 6 min / 27 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$2.00 / 7 min / 10 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$2.00 / 8 min / 26 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$2.00 / 9 min / 29 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$3.00 / 5 min / 26 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$3.00 / 6 min / 29 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$3.00 / 7 min / 25 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$3.00 / 8 min / 27 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$3.00 / 9 min / 10 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$4.00 / 5 min / 27 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$4.00 / 6 min / 10 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$4.00 / 7 min / 26 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$2.00 / 8 min / 29 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$4.00 / 9 min / 25 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$6.00 / 5 min / 29 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$6.00 / 6 min / 25 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$6.00 / 7 min / 27 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$6.00 / 8 min / 10 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.
\$6.00 / 9 min / 26 min	<input type="checkbox"/> Yes, <input type="checkbox"/> No.