Measuring Work Zone Throughput and User Delays

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

A larger amount of funding and attention are going toward highway infrastructure of Ontario for rehabilitation, maintenance and construction projects. These rehabilitation and maintenance activities on highways involve lane closures, which reduce the traffic throughput and cause delays for the road users. The impact of these activities is very important and has led to research into improvements of work zones in Ontario. To prevent the significant cost that these construction delays have on the general public, contractors are required to keep highway lanes open during the peak traffic hours and work at night. However, working at night may reduce the quality of the work by increasing cold joints and construction joints in the pavement, and may increase the amount of time needed to complete the work. Therefore, finding a balance between the times that the lanes can be closed and the times they should be kept open requires an accurate prediction of the construction work zone throughputs, which can increase the efficiency of the contractor work, save money and reduce the user delay costs.

Consequently, this study which has been funded by the Ministry of Transportation of Ontario (MTO) Highway Infrastructure Innovation Funding Program (HIIFP) involves measurement of highway construction work zones throughput of Southern Ontario, to determine the factors affecting the throughput. It has been carried out in partnership with researchers at the University of Toronto. For this study, a manual counting method for collecting throughput data has been employed. This involved data collection of variables such as heavy vehicles which had not been included in previous studies. This provides the visual confirmation of queuing and assists in evaluating the intensity of work activity at the work zones. New generic models for throughput have been developed in this research to better describe current state-of-the practice on Southern Ontario highways. Furthermore, a better functioning highway specific model was developed to calculate the throughput of the MTO Southern Ontario Highway network. In addition to development of these new models, this project involved further development and refinement to a spreadsheet based model SZUDA (Simplified work Zone User Delay Analysis) that uses normal hourly traffic flows to calculate the resulting queue for that entire hour and approximate user delay cost associated with road user delay.

Overall, the thesis describes a methodology for collection of data in work zones. This involved collection of data during 2009 and 2010 Ontario construction season. Furthermore, the data were then used to develop more reliable generic and highway specific models for the MTO. These models can

be used to determine when and how work zones should be established. Finally the refined SZUDA model and case studies demonstrate the impact of various work zone configurations on the travelling public.

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Chapter 1 Introduction

1.1 Introduction

Rehabilitation and maintenance projects on highways usually involve lane closures. These lane closures cause reductions in the traffic throughput and cause delays. Reduced traffic throughput can cause premature queuing in highway construction work zones and result in significant delays. Inevitably, delays occur in and around the construction work zone due to associated restrictions, and such disruptions and their associated traffic congestion can impact the economy, the environment and cost millions of dollars each year in lost productivity. They can also cause potential decreases in safety, and increased emissions from slowing or idling vehicles, or both. A certain amount of delay in work zones is typically assumed to be unavoidable and considered a cost of doing business when roadway improvements are in progress.

To prevent the significant cost that these construction delays have on the general public, contractors are required to keep highway lanes open during the peak traffic hours and work at night. Night-time construction is generally being used by many highway agencies to conduct highway maintenance and reconstruction projects. However, working at night can reduce the quality of the work because of lower temperature and potential increases in the amount of time needed to complete the work. The overall advantages and disadvantages of night work are not fully clear for most highway agencies, as the use of this strategy in their projects is a fairly new practice (Al-Kaisy, 2009). Moreover, limited analysis tools are currently available to help highway agencies in evaluating the suitability of night-time construction for highway projects. Yet, this evaluation is essential whenever night shifts are thought of as an alternative scheduling strategy to avoid serious disruptions to traffic during daytime.

Therefore, finding a balance between the time that the lanes can be closed and the times they should be kept open requires an accurate prediction of the construction work zone throughputs, which can increase the efficiency of the contractors work, save money and reduce the user delay costs.

The traffic accident analysis of work zones shows that more than 70% of the total accidents and more than 90% of the total injury and fatal accidents occur during traffic congestion. Every year more than 1000 people are killed in highway work zone related crashes in North America (Xing, 2010). Work zone safety is an issue that is of increasing importance in the United States. Over the last five years, there has been an average annual increase in fatalities related to work zones of approximately 10 percent, growing from 693 in 1997 to 1181 in 2002 (National Work Zone Safety Information Clearinghouse, 2004). National statistics with a breakdown by State are made available to the public through a website maintained as part of the National Work Zone Information Clearinghouse (Scriba, 2004). Transport

Canada indicated a total of 190 recorded accidents and 10,677 non-fatal injuries over the last five years (Bushman, 2004). The Washington state's highways are getting smarter by introducing high-tech overhead signs which will display variable speed limits, lane status and real-time traffic information, so drivers know what is happening ahead. This smarter highway technology will increase roadway efficiency and help drivers travel more safely (Philip, 2010).

In view of the above, the aim of this study is to gain a better understanding of the amount of traffic that can travel through a work zone and the site characteristics that affect flow. A number of Ministry of Transportation of Ontario (MTO) construction work zone sites have been visited to calculate the work zone throughput, so the value can be compared to the demand for a given section of road, allowing predictions for whether or not vehicles will experience delays due to the construction. This study is designed to develop a model predicting the traffic throughput values for highway work zones in Southern Ontario during queuing conditions.

1.2 Background

This research is funded under the Highway Infrastructure Innovation Funding Program (HIIFP) by the Ministry of Transportation of Ontario (MTO) to evaluate the possibility of refining the existing models and standards used by MTO for lane closures at various construction work zone in southern Ontario. It is a joint collaborative partnership with the University of Toronto and the University of Waterloo.

The research was conducted in two phases during the course of four construction season from 2007 to 2010. During the research completed in phase I of this study (2007/2008) a paradox was uncovered as many sites did not experience forced flow conditions which indicated that the construction work zone hours could be extended (Hicks, 2009). Forced flow also called breakdown flow, occurs either when vehicles arrive at a rate greater than the rate at which they are discharged or when the forecast demand (throughput) exceeds the computed capacity of a planned facility (HCM, 2000).

For this study, a manual counting method is employed to obtain the throughput data at different work zones. This provides the visual confirmation of queuing and assists in evaluating the intensity of work activity at the work zones causing delays. Delays due to the work zones are estimated by comparing the throughput at work zone site to the theoretical capacity per lane for different work zones. The difference between throughput and theoretical capacity per lane are treated as delays attributed to work zone. Therefore throughput is obtained by measuring flows during the forced flow conditions at different work zone sites.

Two types of models were examined, generic and highway specific models during phase I of this research. A brief explanation of each of these models is included below:

1.2.1 Generic Model

The result of this analysis is a mathematical model that includes a base capacity of 1666 vehicle per hour per lane (vphpl), with reductions for nights, weekends, the use of barrels instead of jersey barriers, and 2 or more lanes closed. In this regression model four of the site characteristics were found to be statistically significant in predicting the mean throughput. The equation produced through this analysis is shown below (Hicks, 2009).

Construction Lane Throughput= 1666

- 179 (If Night)
- 216 (If Using Barrels)
- 126 (If Weekend)
- 184 (If 2 or More Lanes Closed)

1.2.2 Highway Specific Models

The throughput predicted by the generic model was observed to be lower than for MTO values. This means that the closure durations must be reduced. However, on many of the sites visited during phase one of the study (2007/2008) construction season, there were no forced flow conditions. These two contradicting results present a paradox. Based on this paradox, during phase I, it was concluded that one throughput model for all work zones may not have been an optimal solution. Therefore, it was decided to develop highway specific models. Through this analysis, the highway identifier was found to be statistically significant in the regression analysis (Hicks, 2009).

Highway specific models were developed for Hwy 427, 400, 401 and QEW. A highway indicator as a variable in the mathematical model caused the characteristics included in the model to be reduced to two: day of the week and number of lanes closed.

Construction Lane Throughput= 1702

- **- 0 (If Hwy 427)**
- **- 137 (If Hwy 400/401)**
- **- 430 (If QEW)**
- **- 107 (If Weekend)**
- **- 373 (If 2 or More Lanes Closed)**

Many transportation agencies are trying to account for user delay costs in their decision making process. However, the difficulty is in evaluating the real economic value of user delay costs and absence of a standard quantification method. There are different models developed to quantify user delays and their related costs. However, most of these models require many different input variables including assumptions and are complex to use. For this reason the Simplified Work Zone User Delay Analysis (SZUDA) model was developed in phase I of the study period. SZUDA is a spreadsheet based model that requires normal hourly traffic flows and expected average work zone throughput to calculate the resulting queue for that entire hour (Hicks, 2009). Using the value for the forming queue the user delay costs can be calculated using the standard delay costs provided by MTO (MTO, 2002). Data for hourly traffic flows is usually available for different highways. There are different models to calculate the throughput values. The model used for SZUDA, when it was developed initially, is the generic throughput model discussed in previous section.

1.3 Work Zone Throughputs Models

Many work zone throughput models have been created using the data from across North America, employing a number of different tactics to arrive at their estimate. In general these models can be classified in three categories as follow:

Mathematical Model (M)
Simulation Model (S)
Artificial Intelligence (AI)

The most common model type is the mathematical model; models tend to use very fewer variables and are easier to understand; whereas simulation models and artificial intelligence models are more complex and require many variables to run the models. These models are difficult to adapt and reproduce and as such will not be discussed in detail. The characteristics used by researchers in nine different models are summarized in Table 1.1:

1.4 Research, Scope and Objectives

The objectives of the phase I study period (2007- Measuring Highway Work Zone Throughput) were to develop a model predicting the traffic throughput values for highway work zones in Southern Ontario during forced flow conditions and to develop a model on evaluation of user delay costs at work zones. The major two objectives that the phase I research group had are given below:

- To determine traffic throughput on highways at work zones in Southern Ontario during forced flow conditions
- Based on the estimates of different throughput values, refine model output for evaluation of user delay costs at work zones

The results from phase I study period were promising and provided further incentive to research. One of the main recommendations of the study was to continue data collection effort and to refine the models (Hicks, 2009).

Therefore, the three major objectives that the research group had for phase II study period are given below:

- Carry out an extensive data collection effort on the Southern Highways work zones during the 2009 and 2010 construction seasons to refine the Generic Model and Highway Specific Model developed in phase I of the study period
- Identify the significant variables within all the site characteristics that reduces the traffic throughput and causes delays at the construction work zones
- Refine the SZUDA model by updating the values of newly proposed Generic Model and Highway Specific Model and the significant variables to better predict the traffic throughput in highway work zone and reduce user delay cost

Table 1.1 Previous Work zone Capacity Models

Capacity Models	Models								
	Rouphail and Tiwari 1985	**Sarasua etal., 2004**	**Krammes and Lopez 1994**	**Kim etal., 2000**	**Al-Kaisy and Hall 2003**	**Karim and Adeli 2003a**	**Adeli and Jiang 2003**	**Zhang et al., 1996**	**Karim and Adeli 2003b**
Model Type*	**M**	**M**	**M**	**M**	**M**	**AI**	**AI**	**S**	**S**
Non Flagging Site	X	X	X	X	X	X	X	X	X
Work Activity	X	X	X	X	X	X	X	X	X
Heavy Vehicle	X	X	X	X	X	X	X		X
No. of Open Lanes	X	X	X	X		X	X	X	X
Light Conditions					X	X	X	X	
Lane Width					X	X	X		X
Total No. of Lanes						X	X	X	X
Lateral Distance				X					
Length of Closure				X		X	X		X
Driver Population					X		X		X
Side of Closure				X	X	X			X
Ramps			X		X	X	X		
Work Zone Speed						X	X		X
Work Duration							X		X
Weather					X		X		
Crossover					X		X		
Grade				X		X	X		
Traffic Management				X					X
Work Zone Location							X		
Pavement Condition							X		
Site ID (on database)									X
Start Time									X
Construction Cost									X
Maintenance Cost									X
Flow Rate									X
*** M - Mathematical S - Simulation AI - Artificial Intelligence**									

1.5 Organization of Thesis

Chapter one provides an introduction to the research object. It also provides a brief background on phase I study period research results and provides the scope and objective of the work. Chapter two discusses the literature review on work zone throughput capacity with general work zone studies including user delay cost and the factors affecting work zones. Chapter three describes the methodology used to conduct this research. Chapter four presents the data collection method, site characteristic details and throughput measurement. Chapter five contains an analysis and result of the research with generic and highway specific models. Chapter six presents the Simplified work Zone User Delay Analysis (SZUDA) model with associated case study analysis. Chapter seven provides the conclusion and proposes recommendations with potential for further development in the future. All the site reference and other information are provided in Appendix A while Appendix B contains detailed information on the SZUDA analysis.

Chapter 2 Literature Review

This chapter reviews some of the selected relevant research involving work zone capacity, user delay costs and work zone safety. The first part of the literature review discusses the work zone throughputs and capacity estimation as presented in the Highway Capacity Manual (HCM, 2000). The majority of the work zone lane closures have dealt with traffic control and safety and very little information was found in the literature on the construction work zone capacity and throughput. The later part of this chapter attempts to summarize some of the research on this subject in the literature.

2.1 Work Zone Capacity

In this research, the term capacity is not going to be used as the maximum flow rate. However, the highway work zone throughput will represent the number of vehicles per hour per lane (vphpl) that could pass a specific point in the work zone during forced flow conditions. The throughput is obtained by measuring flow at construction work zone at different sites. The measured flows are assumed to be maximum with respect to available capacity.

MTO currently uses vphpl for highway work zones; however, vphpl is not often used in academic studies or in highway design as it does not account for the effect that larger vehicles have on traffic flows. The heavy vehicles have more effect on the traffic flow because they occupy an extra space on the road, and they have lower accelerating and decelerating rates, allowing fewer vehicles to pass through.

2.1.1 Highway Capacity Manual

The Highway Capacity Manual (HCM) is a document used by most North American transportation agencies for estimating the work zone throughputs. A key objective of capacity analysis is to estimate the maximum number of vehicles that a facility can accommodate within a reasonable safety factor during a specific time period. However, many facilities can be observed to operate poorly at or near capacity. In view of that, capacity analysis also estimates the maximum amount of traffic that a facility can accommodate while maintaining its prearranged level of operation (HCM, 2000).

The HCM defines the capacity as “the maximum hourly rate at which vehicles or persons realistically can be expected to traverse a point or uniform section of a lane or roadway during a precise time period under given roadway, geometric, traffic, environmental and control conditions; generally expressed as vehicle per hour, passenger cars per hour, or persons per hour” (HCM, 2000). The HCM presents the analysis in two different categories: short term maintenance work zones and long term construction work zone; the primary difference between these two types of construction work zones is the use of barriers to segregate the work area. Short term work zones use traffic cones, drums and other temporary channeling devices, whereas long term work zones normally require portable concrete barriers for segregation of a work area.

The most common method to estimate work zone capacity is outlined in Transportation Research Boards Highway Capacity Manual (Equation 22-2, HCM 2000).

$$C = (C_b) \times (N) \times (I) - (R) \qquad \text{Equation 2-1}$$

Where:

C_b = 1600vphpl (for a short term work zone)

N = Number of lanes

I = Work intensity (±10% for intensity and location of the work activity)

R = Addition or Subtraction of vehicles due to ramp in work zone

The HCM recommended 1600 vphpl as a base capacity value for the short term construction work zones regardless of lane closure configuration and 1750 vphpl for the long term construction work zones.

In addition to HCM, MTO also maintains a list of suggested work zone capacities in the Generic Lane Closure Times manual (TPISS, 2003) and design values for each type of highway. According to the number of open lanes, this report shows different capacity values, as shown in Table 2.1 (NCHRP, 2001).

Table 2.1 MTO Design Capacity Values

Type of Roadway	**Capacity (vphpl)**	
	TPISS	**NCHRP**
Two Lane Highway (Alternating Flow)	850	850
Multi-Lane Highway	1400	1405-1570
Freeway	1800 (1600 on weekends)	1405-1610

2.1.2 South Carolina Model

The study conducted by Sarasua is based on the data collected from South Carolina's short term interstate construction work zone sites (Sarasua, 2004). Sarasua suggested a base capacity value of 1460 passenger car per hour per lane (pcphpl). The model is almost identical to the earlier model proposed by Krammes and Lopezl, except that it alters the base capacity instead of including a variable to account for ramps (Eq 2-2).

$$C = (C_b + I) \times f_{hv} \times N \qquad \text{Equation 2-2}$$

Where:

C = Capacity (in passenger cars per hour per lane [pcphpl])

C_b = Base Capacity = 1460

I = Work Intensity Factor

f_{hv} = Heavy Vehicle Factor

N = Number of Lanes

The Heavy Vehicle (HV) factor calculated using equation: = 1 / (1 + (%HV x (PCE-1))

The research suggested that in various speed ranges, the passenger car equivalents (PCEs) were different and therefore modifications were applied on PCEs for various speed groups to calculate the capacity of the work zone. Table 2.2 shows the PCEs values for the speed ranges.

Table 2.2 PCE values for Speed Ranges

Speed (mph)	PCE Value
0-15	2.47
15-30	2.22
30-45	1.90
45-60	2.90

The data collected on 85 percentile passenger car volumes has suggested the following capacities:

- 2-to-1 lane closures = 1,426 pcphpl,
- 3-to-1 lane closures = 1,280 pcphpl
- 3-to-2 lane closures = 1,791 pcphpl

By using speed ranges and evaluating different pcphpl values, the study suggested that the work zone should be able to pass between 1200 to 1400 pcphpl at capacity flow. The researchers also suggested that the model would also work for long-term work zones.

2.1.3 Texas Model

The Krammes and Lopez model is based on 45 hours of data collected from 33 work zones in Texas between 1987 and 1991 (Krammes, 1994). The model starts with a base capacity and then makes adjustments for work intensity, heavy vehicles and ramps within or near the work zone as shown in Equation 2-3. The studies become the basis for HCM 2000 methodology as the model starts with a base capacity Cb=1600 and then makes some adjustments for work intensity. The work intensity factor represents an addition or subtraction of 10% of the base capacity depending on the amount of activity occurring in the work zone. The model does not provide guidelines for values for R except that R should not exceed 50% of the determined capacity of the lane. The heavy vehicle factor (fhv) is defined by the Highway Capacity Manual (HCM). As heavy vehicles not only take up more space on a road, but also accelerate at slower rates, and need more space for braking. The model presented an equation for the estimation of capacity including these factors as described below:

$$C = (C_b + I - R) \times f_{hv} \times N \qquad \text{Equation 2-3}$$

Where:

C = Capacity (in passenger cars per hour per lane [pcphpl])

C_b = Base Capacity = 1600

I = Work Intensity Factor= $\pm 0.10 \times C_b$

R = Ramps within 150m (500ft) of the Work Zone $\leq 0.5 \times C_b$

f_{hv} = Heavy Vehicle Factor

N = Number of Lanes

2.1.4 Ontario Model

Al-Kaisy and Hall (2003) reported their findings on the data collected from six long-term reconstruction sites of Ontario with different types of lane closures. The researchers have developed two types of site specific capacity models, additive and multiplicative models as shown in eq. 2-4 and 2-5.

$$C = Cb + I1 + I2 + I3 + ... + In \qquad \text{Equation 2-4}$$

Where:

C = Capacity (in passenger cars per hour per lane [pcphpl])

Cb = Base Capacity = 1600

Ii = Impact from various factors

$$C = Cb \times f1 \times f2 \times f3 \times f4 \times ... \times fn \qquad \text{Equation 2-5}$$

Where:

fn = Adjustment factors

The factors identified by the researchers effecting the capacity were heavy vehicles, driver population, light conditions, weather, work activity and land configuration and the most significant factors that affect the capacity are heavy vehicles and driver population.

Overall, in the proposed work zone capacity model, the multiplicative capacity model seems the most promising for two different reasons: it provides a reasonable estimate for the effect of heavy vehicles when compared to the additive models, and its multiplicative format is easy to understand (Al-Kaisy, 2003).

2.1.5 Maryland State Highway Administration Model

Kim, Lovell and Paracha presented a model that includes a wider range of site characteristics for estimating the freeway work zone capacity (Kim, 2001). The data have been collected from twelve short term work zone sites in Maryland to generate a model for estimating capacity. The model is geared towards lane closures on highways that normally have four lanes open in one direction. This model starts with a base capacity and adjusts for seven different site characteristics as shown in Equation 2-6.

$$C = 1857 - 168.1 \times (NUMCL) - 37.0 \times (LOCCL) - 9.0 \times (HV) + 92.7 \times (LD) - 34.3 \times (WL) - 106.1 \times (WIH) - 2.3 \times (WG \times HV) \quad \text{Equation 2-6}$$

Where:

C = Capacity in vehicles per hour per lane [vphpl]

NUMCL = Number of closed lanes

LOCCL = Location of closed lanes (right = 1, left = 0)

HV = Percentage of heavy vehicles on the road

LD = Lateral distance to the open lanes (m)

WL = Work zone length (km)

WI = Work intensity (heavy = 1)

WG = Work zone grade (%)

The multiple regression model was developed to compare with the HCM model, and the study results suggested that the base capacity values are from 1857 to 1407 vphpl which is indicative of the short term work zone. However, the model includes many site characteristics in which some of them have a little effect on the overall capacity and/or low level of statistical significance.

2.2 General Work Zone Studies

General work zone studies have mainly focused on different elements of the construction work zones such as traffic management techniques, user and worker safety, speed limitations and quality of construction.

2.2.1 Traffic Management Techniques

Agencies are now applying traffic management techniques by preparing traffic control plans and lane closure strategies for work zones to determine the anticipated traffic delays at particular times of the day. Levine and Kabat addressed in their early analysis the issues related to construction work zone lane closures and identified three problems related to highways work zones (Levine, 1984).

- Optimum time to perform work
- Public is warned about the work
- Protect workers from errant motorists

Unfortunately the work zone is a space within an existing highway where active maintenance, rehabilitation and reconstruction work is carried out continuously (Karim, 2003), and typically generates congestion which can increase the accident rates (FHWA, 1998a). Over 700 people were killed in work zone crashes last year (FHWA, 2010), and in between 1990 and 2000 more than 30 construction workers were killed in Ontario highway work zones (Niekerk, 2000).

2.2.2 Safety

Safety is the overriding principal with respect to the field work. A strategy to choose the appropriate lane closure is developed based on different parameters such as work zone length, traffic volume, duration of project, accident information and estimated project cost. This information can be useful to estimate the user travel time, vehicle operating cost, traffic control cost, and the expected number of crashes (Pal, 1996). Another study in Oklahoma adopted the use of additional "STATE LAW MERGE NOW" static signing as a law and placed in the advance warning areas approximately half a mile upstream from freeway merge areas (Schrock, 2009). The study was based on the early merge concept which encourages drivers to merge into the correct lane in advance of the work zone's merge area. The results shows that the sites having "STATE LAW MERGE NOW" signing in place approaching work zone did not reduce the percentage of vehicles that remain in the closed lane but it appears that the signs do improve safety. Figure 2.1 and 2.2 shows the "STATE LAW MERGE NOW' signs. The signs encourage drivers to start considering their merge maneuvers, so that by the time drivers reached the merge area they are more likely to make the merge without the need to vie for position against other drivers (Schrock et al., 2009). However, previous research has indicated that this strategy does not affect work zone capacity (Tarko, 1998). Other research shows that the work zone length and duration of work were more significant factors, and one long work zone was safer than two short work zones (Venugopal, 2000). Another study showed that work zones involving two lane undivided highways are the most dangerous with 19.1% more injuries than other configurations (Khattak, 2003). Distraction of the drivers was also a safety issue which involved the presence of workers, construction barriers, heavy construction machinery and other paraphernalia associated with the work zones which can lead to rear-end collision.

Figure 2.1 For Left Lane Closure

Figure 2.2 For Right Lane Closure

2.2.3 Speed

In general, reduced speeds are effective and safer for the drivers as well as the construction workers in the work zone as they reduce the frequency and intensity of accidents (Nemeth, 1985). A study conducted by Migletz found that drivers reduced their speed while approaching the work zones by approximately 7 km/hr even if the limitation signs were not posted and by 14.5 km/hr if speed limitation signs indicated a speed reduction (Migletz, 1999). Reduced speed signs with fine warnings will also help in low speed while approaching the construction work zones as shown in Figure 2.3.

Figure 2.3 Reduce Speed Signs

Another study found that heavy vehicles with low speed from congestion in the work zone resulted in fluctuated traffic flow rates (Jiang, 1999). This results in additional costs to drivers passing through the work zone at lower speeds. Merging traffic can also be a problematic where late merges are in effect. Drivers are directed to use both lanes until the taper point is reached and this ca results in delays. This approach may be effective under heavy congestion conditions with slow traffic, but at moderate congestion with higher speeds drivers have difficulty with the late merge (Schrock, 2009).

A new approach has been proposed called a dynamic late merge system. This dynamic late merge system automatically implements a late merge when congestion is present, and it is removed when congestion is light (McCoy, 2001). The early merges were shown to reduce the throughput of vehicles through the work zone, whereas "late-merging" will increase road capacity by 18% and lead to 75% fewer merging conflicts (Stidger, 2003). Late merging can reduce queue lengths by 50% and reduce driver frustration (Pesti, 1999). To encourage late merging, warning systems work well until congested conditions occur. Additional signs such as "Use Both Lanes to Merge Point" several kilometres before the lane closure and "Merge Here - Take Your Turn" at the beginning of the taper help to increase late merging in congested conditions (Pesti, 1999). Finally another study determined that a shift of work zone one metre toward the traffic can reduce vehicle speeds by approximate three kilometres per hour (Rister, 2002).

2.2.4 Work Zone Timings and quality of Construction

Work zone timing for construction operations is a challenge as contractors are often unable to perform continuous work in a highway construction zone due to operational constraints which may effect both productivity and the quality of work for new construction. The factors that decrease the quality of work include the timing of lane closures and discontinuity of work. Most of the sites are restricted to night lane closures to ensure that the highways are open during the day or during peak travel periods which indicate that the work is being performed under less favorable lighting conditions (Bryden, 2002). Thus, often construction must stop each morning for opening to traffic and then closure again at night increases in cold joints in the pavement which allows water to enter in the pavement structure. This can cause de-bonding of surface layers, mixture of stripping, and aging of asphalt resulting in accelerated pavement failure (Tighe, 2006).

2.3 User Delays

The evaluation of user delays related to work zones is an aspect for all road users and transportation agencies to consider. Work zones disrupt the traffic and cause delays which affect thousands of people traveling through these work zone areas. These work zones result in an additional cost for the drivers who pass through these work zones or construction areas at slower speeds which increases the travel time and consumption of fuel while waiting in the queues. The presence of work zones on highways and freeways counts for 24% of nonrecurring delays. Five percent of all highway congestion is caused by nonrecurring delays. In terms of road incidents, work zones account for two percent of crashes in highways, therefore reduced speed limits are in effect in highway work zones to lower the risk both to motorists and workers (Francis, 2008).

Many transportation agencies across North America try to account for user delay costs in their decision making process. However, the difficulty is in evaluating the real economic value of user delay costs. This is further complicated by the absence of a standard quantification method for analysis of user delay costs. There are a number of major variables considered as increases in the user delay costs. These include: highway type, geometric characteristics, construction factors such as time and length of job, and traffic handling method (Benekohal, 2003).

Research into user delay costs demonstrates that, throughout the lifecycle of the facility, the user delay costs imposed on drivers, businesses and industries caused in work zones may outweigh the initial construction and agency costs (Saleem, 2008). However, scheduling maintenance activities to off-peak periods may result in an increased maintenance cost, as well as extended project durations. Therefore, innovative techniques are required to reduce congestion on the work zone to promote economic growth.

In general, there are three categories of user delay costs which are used in a life-cycle cost analysis and the economy are vehicle operating cost (VOC), delay costs, and accidental and safety related costs. User delay costs can be divided into three categories which are described herein:

2.3.1 Vehicle Operating Costs (VOC)

The VOC may include: fuel, tires, maintenance and other costs resulting from the additional time that a vehicle has spent in the work zone. The VOC can be categorized as follow (FHWA, 1998).

- Speed Change: The speed under normal conditions is compared to speed during the presence of a work zone
- Queuing: Time spent in a stop position or queue within work zone

2.3.2 Crash and Safety Costs

The literature review indicates that the crash rate may increase once there is a construction work zone. Studies show that there are two main locations where most of the crashes happen, adjacent to the work zone where the merge point is located (Khattak, 2003), and within the work zone, where fewer lanes are available to traffic (Garber, 2002). All the crash costs are more associated with work zone conditions which involve lane width or limited space, grade, signage, time of the construction (day/night), speed and lack of construction procedures. Due to the difficulty in accurately quantifying crash costs, most agencies do not include them in their analysis.

MTO GDM Chapter-B 2002 provides the nine step procedure for calculating the queue and delay for each hour of analysis period (MTO, 2002). Some values used in the analysis are:

- Base capacity of short term work zone = 1800 veh/h/lane
- Delay Cost

  Passenger Car = $10/h/veh
  Heavy Vehicle = $50/h/veh
  Mixed Traffic = $15/h/veh

2.3.3 Delay Costs

The delay costs results in additional travel time within the work zone. In short, vehicles spend more time slowing and idling on the facility during construction as compared to during normal operations. The additional time is calculated between two points due to work zone delays (Carr, 2000). The factors involved in the work zone delays are:

- Speed Delay: Speed reduction from normal conditions to work zone conditions
- Queue Delay: Delay due to queues formed upstream of work zone
- Diversion Delay: Delay due to traveling on detour route around the work zone

The data collected throughout this research work will also be used to achieve valuable information on user delay cost associated with the work zone to help decision makers in their initial decision making process.

2.4 Factors Effecting Work Zones

Many factors affect the work zone throughput. The understanding of these factors is important for throughput measurement and the capacity of the work zone. Various studies have been completed however, given variation between areas; it is often difficult to compare them. Most studies involve the development of mathematical models for estimating the work zone capacity by applying certain correction factors to the base capacity. Base capacity is defined as the “Set of specified standard conditions which assume good traffic, weather and geometric conditions with no impediments to the traffic flow” (HCM, 2000).
Table 2.3 shows some of the studies conducted by researchers using factors affecting work zone capacity but several studies did not include the key factors which can reduce the capacity in the work zone. As many factors are correlated to each other.

This section discusses a number of factors which have been suggested as important for work zone construction capacity, including:

- Presence of Heavy Vehicles
- Light Condition (i.e. day time vs night time)
- Weather Conditions (i.e. dry, wet, etc.)
- Work Zone Configuration (i.e. one lane)
- Type of Work Activity

Table 2.3 Summary of Work Zone Delay

Factors	Models						
	(Illimois Model) Rouphail and Tiwari 1985	(South Carolina Model) Sarasua etal., 2005	(Texas Model) Krammes and Lopez 1994	(Maryland State Highway) Kim etal., 2001	(Ontario Model) Al-Kaisy and Hall 2003	(CRB Model) Karim and Adeli 2003a	(Neuro-Fuzzy Logic Model) Adeli and Jiang 2003
Heavy Vehicle	X	X	X	X	X	X	X
Driver Population				X	X		X
Light Conditions					X	X	X
Work Zone					X	X	
Weather Condition				X	X		X
Work Activity	X	X	X	X	X	X	X
Ramps			X	X	X	X	X
Lane Width			X		X	X	X
Grade				X		X	X
Length of Work Zone				X		X	X
Work							X
Lateral				X			
Pavement Condition				X			X

2.4.1 Presence of Heavy Vehicle

Heavy vehicles occupy more space on the roadway and have reduced maneuvering capacity as compared with the passenger cars. This reduces the traffic carrying ability of the travelling lanes. Furthermore, the presence of heavy vehicles reduces the flow of traffic as they accelerate and decelerate more slowly and require larger amounts of space while merging at the end of the bottle neck. The study suggested that with freeway conditions these impacts create more frequent gaps in front and behind heavy vehicles (Krammes, 1989).

The data collected from different construction work zone sites and also data from non-work zone sites were used to develop Passenger Car Equivalent (PCE) factors for queue discharge flow (Al-Kaisy, 2001). The results have shown that the effect of heavy vehicles is greater in the queue discharge flow than during free-flow operations (Al-Kaisy, 2003). The study also found the mean PCE value of 2.36 for heavy vehicles including buses versus 1.5 as provided in the Highway Capacity Manual (HCM, 2000).

2.4.2 Light Condition

Light condition generally refers to night versus day. As shown in Table 2.3, of the seven models only three have considered the lightning condition during their research. Al-Kaisy and Hall investigated in their research the effect of darkness on freeway construction zone and the results have shown that the capacity decreases during the darkness by roughly 5%, for a facility with good illumination (Al-Kaisy, 2000). The HCM suggested the reduction in the capacity around 13% and 19% for six and four lane facilities respectively (HCM, 2000).

2.4.3 Weather Conditions

The data collected during this research was mostly related to short term construction work zones and has been noticed that the weather conditions were clear. This shows that normally weather conditions such as heavy rain, snow, strong winds and fog did not affect the short term work zones as compared to the long term work zones where Temporary Concrete Barriers (TCB) were used. The 1997 Highway Capacity Manual states that rain usually leads to a 10-20% capacity reduction on normal freeways and that higher reduction are possible during heavy rainy conditions (TRB, 1997). The study conducted by Venugopal reported an approximate 10% capacity reduction due to rain at the short term maintenance site (Venugopal, 2000).

2.4.4 Work Zone Configuration

The work zone configuration refers to the location of the closed lanes, such as the closure of the driving lanes versus the closure of the passing lanes as shown in Figure 2.4. Al-Kaisy investigated the factors where four lanes were reduced to two in each direction. The results have shown that the passing lane closure resulted in 6% lower capacities as compared to the closure of the driving lanes (Al-Kaisy, 2002).

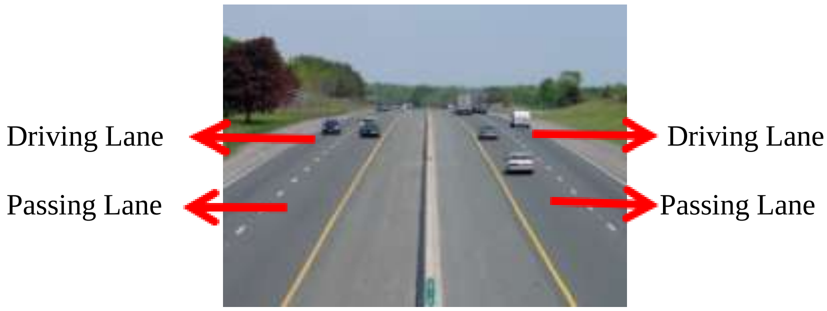


Figure 2.4 Driving Lane/ Passing Lane

2.4.5 Type of Work Activity

Studies have shown that the effect of work activity is very difficult to quantify as it is more of a qualitative or subjective term (HCM, 2000). The HCM defines the work activity as the number of workers on the site, the size and number of work vehicles and the construction equipment in use. Therefore, on the basis of professional judgment, the HCM recommends that 1600 pcphpl is an average over a variety of conditions. An investigation by Al-Kaisy on this factor showed that work activity on the site is the reason for the capacity drop which varied in wide range, as the values are as low as 1.85% and as high as 12.5% (Al-Kaisy, 2002).

2.5 Summary

This chapter has summarized the literature review related to work zone capacity models and their base capacities including the variables which are taken into account while developing the models. General work zone studies with traffic management techniques, work zone timings involving quality of construction, speed within work zone and some safety factors were also identified. The chapter also discussed the user delay costs related to work zones including vehicle operating costs, delay costs and the crash costs. Finally, this chapter discussed some important factors affecting work zones to provide the understanding for throughput measurement and the capacity of the work zone. Overall, the outcome of the literature review is that the construction work zone throughput is influenced by a number of factors.

Various studies have been cited in this chapter which relates to work zones and associated throughput. However, the models still need some improvements because these models have been shown to not relate to the current Southern Ontario highways situation. This knowledge has been used as a basis for this research to identify the factors and the relationship between them to ensure proper estimation of work zones throughput.

Chapter 3 Research Methodology

3.1 Purpose of Research

During Phase I of this project, a paradox was uncovered. It was anticipated that during construction work zone closures, forced flow conditions would occur. However, at many of the sites, forced flow conditions were not observed. This indicates that the construction work zones hours could potentially be extended. Conversely, at other sites, forced flow conditions were observed but the throughput was significantly lower than the standard values used by MTO (1600-1800 vphpl), which indicated that the construction work zone hours should be reduced. This research is directed at examining the throughput capacity of Southern Ontario highway work zones and the factors that result in low throughput. It is also directed at improving the calculation of user delays on Southern Ontario highways through updating and refinement of the SZUDA model.

3.2 Data Collection Methodology

MTO provided a list of construction sites where queuing conditions were anticipated. The three required characteristics for a site to be qualified for data collection include:

1) Extended Lane Closure: Sites where a lane closure was required to complete the work and/or usually for a long period of time.
2) Partial Lane Closure: Sites where there was a reduction of traffic lanes available (i.e. 2-to-1, 3-to-2 or 3-to-1). Any closure involves a lane narrowing.
3) Adequate Amount of Traffic Demand: Any sites that observed regular queuing conditions on work zone site beyond the taper.

Once a suitable site was identified, a visit was made by the research group. This involved contact with the MTO Contract Administrator, the MTO contractor on site and the retained MTO consultant who was administering the contract. A site characteristic form was developed in the research and it was completed for each site. The number of vehicles passing through the site and the type of vehicles were recorded at 15 minute intervals. Figure 3.1 shows a general view of the construction work zone and a two lane highway is converted into one lane with the use of barrels. As shown in the figure, the square in red at the start of the tapper is the area where researcher setup for the data collection. On fifteen minute intervals, the number of vehicles passing through the construction work zone site has been recorded.

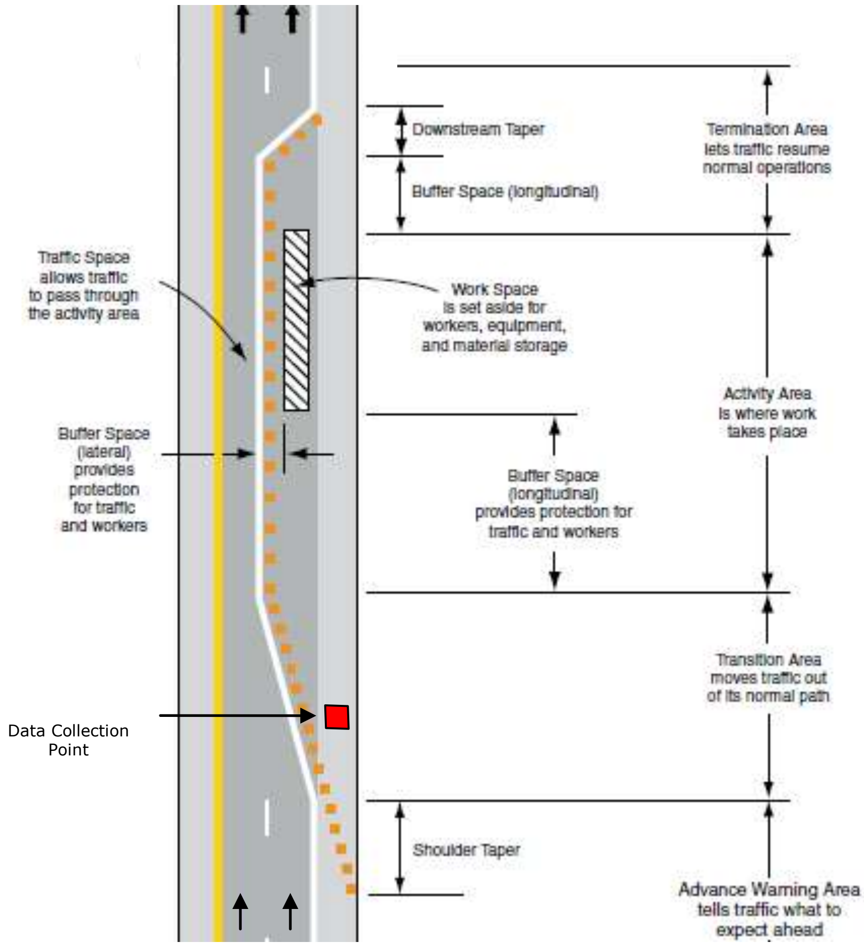


Figure 3.1 Component Areas of a Temporary Work Zone with Data Collection Point (FHWA)

3.3 Research Approach

The protocol for this research was developed by the research group in phase I of this project. However, it was reviewed and updated to include a few additional items in this phase of the research. A thorough review of MTO's work zone policies and MTO Book 7 was carried out. A list of all potential construction sites was provided by the MTO for data collection. This included contact information for the Contract Control Officers (CCO) responsible for each site, as well as the Contractor Administrator (CA). The protocol for site visits involved:

- Contacting each CCO and CA for each construction project to identify if the work zones met the desired characteristics.

- If the work zone met one of the three criteria based on the discussion with CCO and or CA, the research team then confirmed the project details including site access, data collection locations, times of traffic congestion and the lane closure schedules.
- Meetings were then held with the respective CCO/CA on site. This involved reviewing all contractor MTO site safety requirements, details of the work zone operations, confirmation of the exact location for the data collection and finally agreeing upon when and how data would be collected.

For this study, data was collected when the work zone was under queuing conditions. The three desired characteristics as mentioned in section 3.1 were identified for data collection. For consistency, data collection was performed in a similar manner to the study performed by the IBI Group in 2007 (IBI, 2007), and Phase one of the study (2007/2008). Although more data were collected in this study, it was important that similar protocols were followed to allow for comparisons. On fifteen minute intervals, the number of vehicles passing through the site was recorded. In the first phase of 2009 construction season the vehicles were split into two categories, passenger vehicles, and heavy vehicles. The heavy vehicle was defined using the HCM specification "any vehicle with more than four tires touching the pavement" (HCM, 2004).

3.4 Sites Characteristics

Data were collected and recorded on sites where three lanes were narrowed to one lane, three lanes were narrowed to two lanes and two lanes were narrowed to one lane. Site characteristics varied drastically from location to location based on site geometrics, type of work operation and closure layout at the various different locations. There were also a number of other elements recorded on the site characteristics form that provide useful insight into the work zone closures. Based on the model used to analyze traffic flow and user costs, additional information was taken from these data sheets to assist in the new model development. Completed site characteristics forms, along with the maps of sites and recorded volume data, can be found in Appendix A.

To investigate the effects of site characteristics on work zone throughput, site characteristics were recorded in the standard site characteristic form as shown in Table 3.1. Once a site was deemed suitable for data collection, a site visit was made. At all work zones visited, site characteristics were recorded. Consistency in recording the site characteristics allows the research group to compare the effect of these variables on throughput values further.

Table 3.1 Research Site Characteristic Form

Date	Facility Type
Contract Number	Driver Population
Location	% Heavy Vehicles
Weather	Grade of Road
Starting Time	Speed Limit (km/hr)
End Time	Curve of Road
Day of Week	Length of Work Zone
Time of Day	Duration of Closure
Assigned Lane	Intersections
Lane Width (m)	Type of Traffic Control
Direction of Traffic	Pavement Condition
Shoulder Type	Distractions
Lane Closure	List of Photos Taken
OPP Presence	Other Comments

Based on Table 3.1, it is important to note that some of the recorded site characteristics involved more specific identifiers as compared to the previous study. These include the OPP presence, assigned lane, time of the day and length of work zone. Each characteristic was assigned a binary identifier indicating its state for the modeling. Furthermore, a binary identifier has been added in the table to see the impact on traffic throughput in work zones.

As further discussed in chapter four, some of the binary identifiers were shown to be significant in this research while in other cases, they were not significant. Table 3.2 shows all the site characteristics with the binary identifier (dummy variables).

Table 3.2 Description of Binary Codes for Site Characteristics

Presence of Police	1 – Ontario Provincial Police (OPP) present on site during lane closure
	0 – OPP were not present
Weekend/Weekday	1 – Data was collected on a weekend (Saturday or Sunday)
	0 – Data was collected on a weekday
Time of Closure Night/Day	1 – Data was collected after dark (when headlights were required)
	0 – Data was collected during the day
Number of Lanes Closed	1 – Two or more lanes closed, narrowing down to one lane open during construction
	0 – One lane closed, leaving one lane open during construction
Lane Closure Right/Left	1 – Right side of freeway was closed
	0 – Left side of freeway was closed
Lane Closure Barrels/Barrier Wall	1 – Barrels were used as the method of lane closure
	0 – Concrete barrier wall used as the method of lane closure
Grade of Road 3% or more/0-3%	1 – The grade of the road was more than 3%
	0 – The grade of the road was between 0 and 3%

3.5 Summary

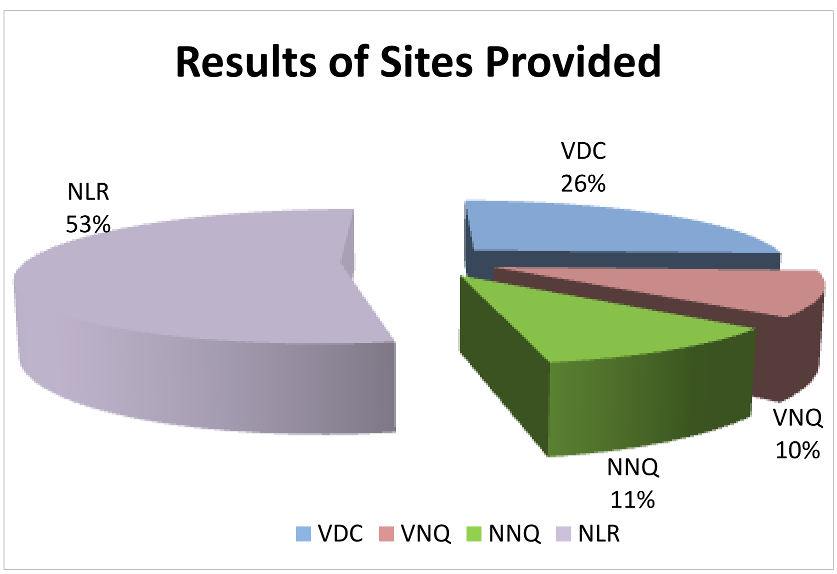
The purpose of this research is directed at examining throughput capacity of Southern Ontario highway work zones under MTO jurisdiction. This research is necessary as low throughput results in associated user delays and potentially poor quality construction. The development of accurate models and quantification of road user delays with an evaluation model (SZUDA) is important for long life pavements and good highway management. The data collection methodology was based on three required characteristics for a site namely an extended lane closure, partial lane closure or regular over capacity situations. The protocol for this research was developed in consultation with the MTO and a list of sites for data collection including the information of the contacted person was provided. The research team was then responsible for contacting the CCO and CA and determining if the project was suitable. Secondly if it was suitable the research team discussed the project details including site access, data collection locations, times of traffic congestion and lane closure schedules with the CCO and CA. Finally, a face to face meeting was arranged with the CCO/CA on site where the research team could review all the contractor site safety requirements and the specific details of the lane closures.

Data were collected on various highways and combined with previous data that were collected in 2007 and 2008, in phase I of the study. A more detailed site characteristics form was generated to collect data to further advance the research and understanding of throughput and user delays. The identified variables have been assigned with the binary codes for the development of the generic as well as highway specific models in the next chapter of the thesis.

Chapter 4 Data Sources and Data Collection

4.1 Sites Contacted and Visited

The research project began in July of 2009 and the contract information list was provided by MTO including contact information for the Contract Control Officers (CCO) and Contract Administrator (CA) responsible for each site. The majority of the sites focused on pavement rehabilitation projects which is typical for MTO. In total, 65 of the site location details have been provided by MTO. Of these, 29 locations were not visited due to the No Visit, Lack of Response from MTO contacts (NLR), eleven locations were not visited due to No Queuing (NNQ), nine locations were visited but were not acceptable due to No Queuing (VNQ), 16 locations were Visited and Data were Collected (VDC). This breakdown is represented in Figure 4.1. This figure shows that only 36% of the sites on the list were visited. Despite the fact that all were contacted, 53% did not respond, 11% did not expect queuing and 10% of the sites that were visited were expected to have queuing. However, no queuing was observed. At some sites this indicates that the times prearranged for lane closures are restricted to times when the capacity exceeds the demand. At all of these sites, allowing a longer road closure would not be a detriment to users and could potentially allow the contractor to improve both quality and speed of construction work by working a longer shift.



NLR	- No visit; Lack of Response
NNQ	- No visit; Lack of Queuing Report
VNQ	- Site Visited; No Queuing or site not suitable for data collection
VDC	- Site visited; Data Collected

Figure 4.1 Details of Sites Contacted and Visited

Most of the sites visited during the 2009 and 2010 construction season were located in MTO's central and east region. Queuing conditions were not present at most of the sites in the west region and therefore no data were collected at those sites.

With all the difficulties in finding qualified sites for data collection and arranging with the site contacts to visit the work zone the research team made 24 site visits in the 2009 construction season and 60 site visits in the 2010 construction season. The data were collected on most of the sites and 53 of these visits were with the forced flow condition from 15 different projects on Hwy 400, 401, 417, 427 and Hwy QEW.

4.2 Data Collected

The same protocol for both the 2009 and 2010 construction season was used. Safety is an overriding principal with respect to field work, and the first issue was to find a safe location on the site where data could be safely and effectively collected. The vehicle counts were split into two categories: passenger vehicles and heavy vehicles. Finally, some sites photos and videos were taken to provide additional information.

The details of the sites including the follow up details are shown in Tables 4.1 and 4.2. As shown in these tables, only some of the sites were deemed appropriate for a site visit based on the construction schedule, availability, and/or observations of queuing conditions on site by site contacts. In total 84 days were spent on sites and 81 hours of 15 minute data were collected from both the 2009 and 2010 construction seasons.

Table 4.1 Sites Visited Year 2009 Construction Season

S. No.	**Contract Number**	**Location**	**Hwy**	**Site Visited**	**Data (Hrs)**	**Description**
1	2007-2027	QEW Widening, 406 to Garden City Skyway.	QEW	No	-	NLR
2	2007-2026	Third Line to Burloak (HOV)	QEW	No	-	NLR
3	2007-2125	Trafalgar to Third Line (HOV)	QEW	No	-	NLR
4	2009-2015	Bronte Road - Burloak Drive (HOV)	QEW	Yes	-	VNQ
5	Proj on hold.	Rehab WB Collector Lanes Jane Street to Kipling Road	401	No	-	NLR
6	2009-2026	Paving - MacLaughlin Road to Winston Churchill Blvd.	401	Yes	-	VNQ
7	2009-2025	Paving - Winston Churchill Blvd to Trafalgar Road	401	No	-	NLR
8	2008-2004	from Highway 401 to Highway 427	409	No	-	NLR
9	2009-2021	James Snow Pkwy to Halton/Wellington Bdy	401	Yes	8.25	VDC
10	2009-2039	Selective Resurfacing. Various Sections	401,403,6	Yes		VNQ
11	2007-2028	QEW to Hwy 401 SB Core Lanes	427	No	-	NLR
12	2008-2003	QEW to Hwy 401 NB Core Lanes	427	Yes	2.25	VDC
13	2009-2002	EB Express - Warden Avenue to Markham	401	No	-	NLR

S. No.	Contract Number	Location	Hwy	Site Visited	Data (Hrs)	Description
14	2009-2040	401 West Bound, 427 northbound and southbound Selective Resurfacing	401	No	-	NLR
15	2009-2041	401 Eastbound, Hwy 427, 404 Selective Resurfacing.	401	No	-	NLR
16	2008-2018	King Road Interchange	400	Yes	1.25	VDC
17	2009-2030	Major Mackenzie to 16th	404	Yes	-	VNQ
18	2005-2014	Stevenson Rd Interchange and 401 Resurfacing	401	Yes	3	VDC
19	2009-23xx	Pavement Rehabilation Hwy 404 - Port Union	401	No	-	NLR
20	2009-23xx	Pavement Rehabilitation Port Union to Brock Road	401	No	-	NLR
21	2009-2037	Simcoe/York/Durham selective resurfacing.	various	Yes	-	VDC
22	2009-2032/33	401 From Markham Rd. to Neilson Rd.	401	Yes	-	VDC
23	2008-3004	East of Oxford Road to 4.1 km east of Drumbo Road	Hwy 401	No	-	NLR
24	2009-3023	Sports World to Grand River	Hwy 8	No	-	NLR
25	2009-3251	Woodstock - Branfort	Hwy 403	No	-	NLR
26	2009-3014		Hwy 401	No	-	NLR
27	2009-3001	from Colborne Road to Modeland Road	Hwy 402	No	-	VNQ
28	2008-4009	6 laning in Kingston and paving	Hwy 401	No	-	NNQ
29	2009-4020	Between Brownson Rd and Parkdale	Hwy 417/OQW	Yes	1.5	VDC

Table 4.2 Sites Visited Year 2010 Construction Season

S. No.	Contract Number	Location	Hwy	Site Visited	Data (Hrs)	Results
1	2010-2031	Carpool Lot at Hwy 410 & Williams Pkwy	410	Yes	0.75	VDC
1	2010-2023	1 KM S of North Shore Blvd. to Brant St.	QEW	No	-	NLR
2	2010-2022	Advance Grading for Merritt Rd. IC - Phase 2	406	No	-	NNQ
3	2010-2021	Steeles Ave to N of Langstaff Rd.	400	Yes	4	VDC
4	2010-2020	Hwy 403/407 IC to Hwy 6 Resurfacing	403	No	-	NLR
5	2010-2018	N Jct Hwy 12 - Simcoe Rd 16 IC	400	No	-	NNQ
6	2010-2017	Garden City Skyway Pier Repairs (Contract # 6)	QEW	No	-	NLR
7	2010-2015	Soffit Patches of 6 Bridges	QEW/ 401/403	No	-	NLR

S. No.	Contract Number	Location	Hwy	Site Visited	Data (Hrs)	Results
8	2010-2008	VMS Upgrade & Expansion - QEW and Gardiner Expressway (Toronto, Mississauga, Burlington, Niagara)	QEW	No	-	NLR
9	2010-2006	St. Vincent Street UP	400	No	-	NNQ
10	2010-2001	Hwy 404Ex Green Lane to N. of Queensville	404	No	-	NNQ
11	2009-2048	Noise Barrier, East & West of Rougemount Dr. Scarborough	401	No	-	NNQ
12	2009-2043	VMS Upgrade from Weston Road to Kennedy Road	401	No	-	NNQ
13	2009-2042	Noise Barrier @ Keele St.	401	No	-	NLR
14	2009-2036	ATMS Comm. Upgrade from Upper Middle Rd to Cawthra Rd, including Downsview & Burlington Oper.Centres	403	No	-	NLR
15	2009-2034	Deck Repair from Truck Fire 401/404 Ramp	401	No	-	NLR
16	2009-2031	Hwy 410/403 IC to Hurontario	410	No	-	NNQ
17	2009-2029	Replacement of 10 OH Sign Structures along Hwy 401 within GTA	401	Yes	1.75	VDC
18	2009-2026	McLaughlin Rd to 1 km west of Winston Churchill Blvd.	401	No	-	NLR
19	2009-2025	Winston Churchill Blvd. to Trafalgar Road, Resurfacing	401	No	-	NLR
20	2009-2020	Jane St. to Kipling Ave. W'b Coll	401	Yes	2.25	VDC
21	2009-2017	Hwy 93 to Forbes Rd SBL & CPR	400	No	-	NNQ
22	2009-2015	Burloak Drive to Guelph Line	QEW	Yes	11.25	VDC
23	2009-2010	Wilson Street wester'ly to Hamilton/Brant boundary	403	No	-	
24	2009-2009	S. of Lyons Creek Road to N. of Netherby Road	QEW	No	-	NNQ
25	2009-2005	bridge rehab various locations, Hamilton	403	unsafe	-	NLR
26	2009-2003	Merritt Road Structure	406	No	-	NLR
27	2008-2018	King Rd. Interchange, York Region	400	Yes	6	VDC
28	2008-2017	Hwy 401 E/b & W/B Hoggs Hollow	401	Yes	4	VDC
29	2008-2005	Patrol Yard near Hurontario IC	401	No	-	NLR
30	2008-2004	From Hwy 401 to Hwy 427	409	Yes	3.75	VDC
31	2008-2003	Hwy 427 N/B express lanes from QEW to Hwy 401	427	Yes	1	VDC

S. No.	Contract Number	Location	Hwy	Site Visited	Data (Hrs)	Results
32	2007-2125	Trafalgar Rd to Third Line. - Widening	QEW	Yes	2.5	VNQ
33	2007-2031	QEW/Hurontario I/C	QEW	Yes	1.5	VDC
34	2007-2027	Hwy 406 to Garden City Skyway Bridge, widening	QEW	No	-	NLR
35	2007-2026	Third Line to Burloak Drive	QEW	Yes	18.5	VDC
36	2005-2014	Stevenson Rd. new interchange	401	Yes	7	VDC

4.3 Photos and Video Images

Whenever possible, photos and videos were taken at sites visited shown in Appendix A. some challenges did include taking photos and videos at night. These documents provide a general understanding of lane closure layout. Additionally, in some situations, photos and videos can show the driver population and type of vehicles (e.g. number of axles on heavy vehicles) traveling through the zone.

4.4 Obstacles to Research

Arranging site visits was a major challenge during this research. For example, while most of the CCOs and CAs tried their best to help the research, some were not responsive and did not inform the research group about the closure schedules and closure layouts. Every effort was made with MTO to improve communication. However, still there were gaps based on the last minute nature of construction.

Another issue involved arranging for site visits with appropriate staff so that the team was aware of the closure schedules, time and dates. Most of the site contacts were not responsive to emails unless it was followed by repeated phone calls. Because a limited number of calls could be made on a daily basis and because the closure schedules were usually finalized close to the actual date, our team missed some closures. On a couple of the sites, the research team contacts were added to the email list of the consultants (CAs), thereby receiving closure notifications to the involved parties. This was very efficient as the research team could go through the closure notifications and if there was a closure that appeared to meet our criteria, the team would contact the site contact person to finalize the site visit arrangements.

The site contacts on a couple of projects insisted that the research group have permission from the contractor to go on site. Unfortunately, the contractors were not aware of the research at all and therefore they had to be contacted by CCOs, which slowed the process.

Another challenge was related to the construction vehicles entering the work zone. On many occasions, construction vehicles entering the work zone parked in front of the researchers, thereby interfering with the data collection process. Overall, despite all the obstacles the data were collected from various sites.

4.5 On Site Observations

Work zone capacity is a function of several interacting variables related to the site conditions. There are a wide variety of factors that are believed to be affecting the work zone capacity. During the process of data collection it has been noticed that some of the data collection site characteristics or the identifiers to develop the model lies in the same configurations, such as time of closure (day/ night), grade of road in the work zone and day of the week. Most of the site characteristics varied drastically from location to location and were recorded in the site characteristics form, outlined in Section 3.3.

4.5.1 Time of Closure (day/ night)

Most of the data collection was completed during the night time in this research. Consequently, out of 58 site visits, only three of the sites visit involved data collecting during the day as shown in Figure 4.2. In total, six hours of data were collected during the day from three different site configurations as mentioned in the previous section. This is likely a major reason for some of the changes in the phase I versus phase II models. There is only one occasion in which barrels were used during the day lane closure.

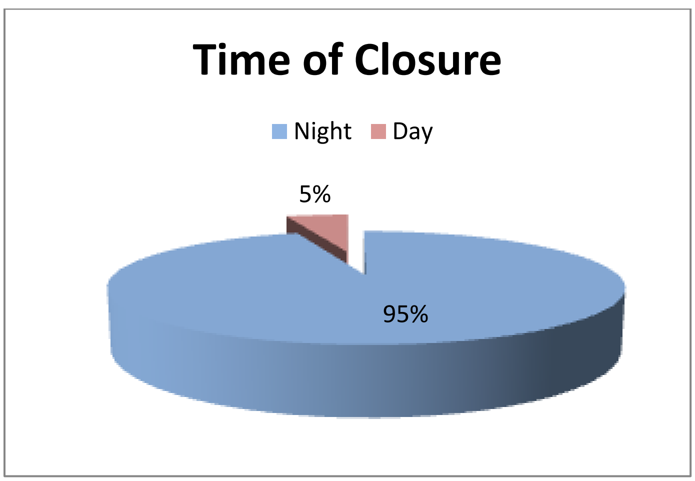


Figure 4.2 Time of Closure

4.5.2 Grade of Road

Only one of the 58 data collection site visits involved a grade. The grade of the road was greater than 3% as shown in Figure 4.3. During the creation of the model, the grade of the road was not determined to be a significant parameter. This partially based on the timing of the construction projects and the highways where construction was being carried out in 2009 and 2010 during the research.

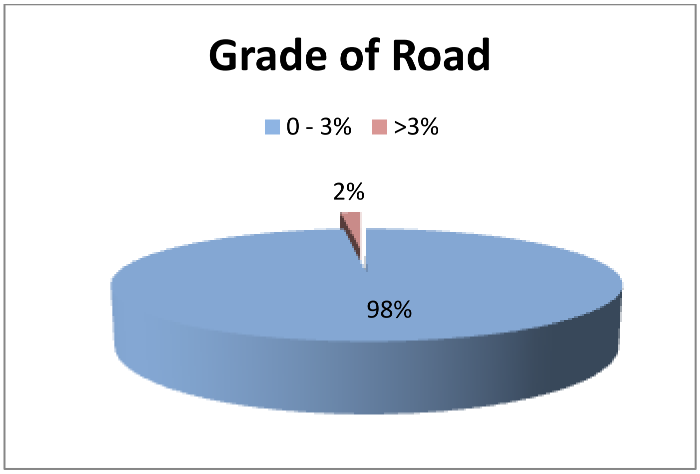


Figure 4.3 Grade of Road

4.5.3 Weekend/ Weekday

The weekend and weekday were determined to be a significant parameter for both the generic and highway specific models in the phase I of the study period. During the data collection effort in phase II of the study period, only four out of 58 sites visits have the weekend input as shown in Figure 4.4. When the models were reevaluated with the 2010 data, the weekend factor was not found to be significant factor. This is a reflection of MTO policy to try to reduce weekend closures.

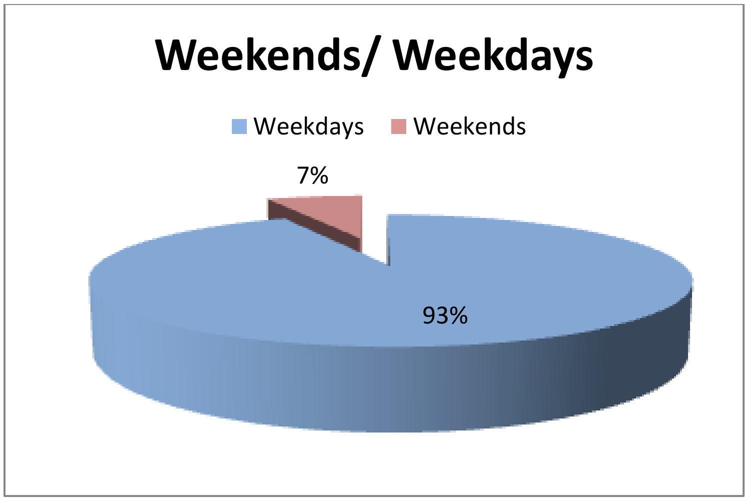


Figure 4.4 Weekends/ Weekdays

4.5.4 Police Presence

During the data collection in the 2008 and 2009 construction seasons, it was noticed that out of 58 sites visits, only eight of the sites had the police present. This parameter is a significant variable for this research as further discussed later.

Table 4.3 provides a brief summary of all the visited sites.

Table 4.3 Summary of Site Characteristics from All Visited Sites

Total Sites	Total Sites ID's	Total Hours	OPP Presence	Weekend/ Weekday	Night/Day	2 or more lanes closed	Right(1)/Left lane closed(0)	Barrels/Barrier wall	Grade: >3% or between 0 - 3%
16	58	81	8/58	4/58	3/58	49/58	22/58	55/58	1/58

Table 4.4 summarizes the details of the site characteristics with the binary code and includes the number of hours of data collected at each site in detail. Each site has been assigned with the site ID, which shows the name of the highway and number of site visits on each site. For example, "h401" is the name of the highway and "h401aS1" shows the site visit number one on that particular highway.

Table 4.4 Summary of Site Characteristics from All Visited Sites

Site	Date	Site ID	Data(Hour)	Hour Data (vphpl)	OPP Presence	Weekend/ Weekday	Night/Day	2 or more lanes closed	Right(1)/Left lane closed(0)	Barrels/Barrier wall	Grade: >3% or between 0 - 3%
2008-2003	30-Jul-09	h427S1	0.5	1183	0	0	1	0	0	1	0
	19-Sep-09	h427S2	1.75	1269	0	1	1	1	1	1	0
	15-Jun-10	h427S3	1	1265	0	0	1	0	0	1	0
2009-2021	10-Aug-09	h401aS1	1	884	0	0	1	1	0	1	0
	24-Aug-09	h401aS2	0.75	1037	0	0	1	1	0	1	0
	31-Aug-09	h401aS3	1	1020	0	0	1	1	1	1	0
	09-Sep-09	h401aS4	0.75	803	0	0	1	1	0	1	0
	30-Sep-09	h401aS5	1.25	1037	0	0	1	1	0	1	0
	01-Oct-09	h401aS6	1	1097	0	0	1	1	1	1	0
	07-Oct-09	h401aS7	1.25	872	0	0	1	1	0	1	0
	16-Oct-09	h401aS8	1.75	944	0	0	1	1	1	1	0
2005-2014	07-Oct-09	h401bS1	2	1040	0	0	1	1	0	1	0
	14-Oct-09	h401bS2	1	1012	1	0	1	1	0	1	0
	28-May-10	h401bS3	2	1188	0	0	1	1	0	1	0

Site	Date	Site ID	Data(Hour)	Hour Data (vphpl)	OPP Presence	Weekend/ Weekday	Night/Day	2 or more lanes closed	Right(1)/Left lane closed(0)	Barrels/Barrier wall	Grade: >3% or between 0 - 3%
	29-May-10	h401bS4	1.25	1122	0	1	1	1	0	1	0
	07-Jun-10	h401bS5	0.5	988	0	0	0	1	1	1	0
	07-Jun-10	h401bS6	3.25	832	0	0	1	1	1	1	0
2010-2031	28-Jun-10	h401cS1	0.75	1956	0	0	1	1	1	1	0
2008-2017	05-Jun-10	h401dS1	4	1693	0	1	0	0	0	0	0
2009-2020	16-Aug-10	h401eS1	1	862	0	0	1	0	0	1	0
	17-Aug-10	h401eS2	1.25	922	0	0	1	0	1	1	0
2008-2018	14-Aug-09	h400aS1	1.25	1097	1	0	1	1	1	1	0
	15-Jun-10	h400aS2	1.25	1250	0	0	1	1	0	1	0
	18-Aug-10	h400aS3	1.5	1308	0	0	1	1	1	1	0
	30-Aug-10	h400aS4	1.25	1213	0	0	1	0	0	1	0
	01-Sep-10	h400aS5	2	961	0	0	1	0	1	1	0
2010-2021	26-Jul-10	h400bS1	1	1035	0	0	1	1	0	1	0
	05-Aug-10	h400bS2	1.5	1312	0	0	1	0	0	1	0
	05-Aug-10	h400bS3	1.5	1120	0	0	1	1	1	1	0
2008-2004	09-Jun-10	h409S1	1.5	1474	0	0	1	1	0	1	0
	09-Jun-10	h409S2	1	1279	0	0	1	1	0	1	1
	10-Jun-10	h409S3	1.25	1603	0	0	1	1	0	1	0
2007-2026	21-Jun-10	hQEWaS1	0.75	828	0	0	1	0	1	1	0
	21-Jun-10	hQEWaS2	1.25	1198	0	0	1	1	1	1	0
	28-Jun-10	hQEWaS3	0.75	827	0	0	1	1	1	1	0
	07-Jul-10	hQEWaS4	1.5	1323	0	0	1	1	0	1	0
	09-Jul-10	hQEWaS5	1	1190	1	0	1	0	0	1	0
	11-Jul-10	hQEWaS6	0.75	1281	0	1	1	0	0	1	0
	13-Jul-10	hQEWaS7	1	1474	0	0	1	0	0	1	0
	14-Jul-10	hQEWaS8	1	1340	0	0	1	0	0	1	0
	19-Jul-10	hQEWaS9	0.75	1234	0	0	1	0	0	1	0
	19-Jul-10	hQEWaS10	1.75	1267	0	0	1	1	0	1	0
	20-Jul-10	hQEWaS11	2.75	1235	0	0	1	1	0	1	0
	21-Jul-10	hQEWaS12	0.75	1308	0	0	1	0	1	1	0
	29-Jul-10	hQEWaS13	1.5	1421	0	0	1	1	0	1	0
	03-Aug-10	hQEWaS14	0.5	587	0	0	1	1	0	0	0
	06-Aug-10	hQEWaS15	2.5	1122	0	0	1	1	0	1	0
2007-2031	05-Jul-10	hQEWbS1	0.5	1468	0	0	1	1	1	1	0
	06-Jul-10	hQEWbS2	1	1233	0	0	1	0	1	1	0
2007-2125	19-May-10	hQEWcS1	1	558	0	0	1	0	0	1	0
	20-May-10	hQEWcS2	1.5	818	0	0	1	0	0	1	0
2009-2015	08-Jul-10	hQEWdS1	2.5	1147	1	0	1	1	0	1	0
	11-Jul-10	hQEWdS2	2	814	1	1	1	1	0	1	0
	13-Jul-10	hQEWdS3	2.5	912	1	0	1	1	1	1	0
	19-Jul-10	hQEWdS4	1.75	1034	1	0	1	1	0	1	0
	25-Jul-10	hQEWdS5	2.5	1023	1	1	1	1	1	1	0
2009-4020	23-Sep-09	h417S1	1.5	1744	0	0	0	0	1	0	0
2009-2031	27-May-10	h410cS1	1.75	1204	0	0	1	1	1	1	0

4.6 Throughput Measurement

Table 4.5 shows the average throughput value in terms of vehicle per hour per lane (vphpl) and the associated standard deviations for each visit. The table was generated with the average mean throughput of each site visit with the standard deviation to compare the models. The result shows that there was variation between sites and within each site. This would be expected as each highway has different characteristics. Furthermore, along a highway variation would also be expected. Although a generic model representing all highways is desirable, it would also be important to develop a highway specific model to properly and accurately reflect differences.

Table 4.5 Values of Sites Visited with Mean and Standard Deviation

				Throughput (vphpl)	
Site Code	**Site ID**	**Visit Dates**	**Data (hrs)**	**Mean**	**St. Dev**
h427S1	2008-2003	30-Jul-09	0.5	1183	139
h427S2		19-Sep-09	1.75	1269	110
h427S3		15-Jun-10	1	1265	329
h401aS1	2009-2021	10-Aug-09	1	884	116
h401aS2		24-Aug-09	0.75	1043	216
h401aS3		31-Aug-09	1	1020	99
h401aS4		09-Sep-09	0.75	803	82
h401aS5		30-Sep-09	1.25	1037	359
h401aS6		01-Oct-09	1	1097	542
h401aS7		07-Oct-09	1.25	872	351
h401aS8		16-Oct-09	1.75	944	264
h401bS1	2005-2014	07-Oct-09	2	1040	132
h401bS2		14-Oct-09	1	1012	117
h401bS3		28-May-10	2	1188	174
h401bS4		29-May-10	1.25	1122	177
h401bS5		07-Jun-10	0.5	988	147
h401bS6		07-Jun-10	3.25	832	118
h401dS1	2008-2017	05-Jun-10	4	1693	275
h401eS1	2009-2020	16-Aug-10	1	862	173
h401eS2		17-Aug-10	1.25	922	219
h400aS1	2008-2018	14-Aug-09	1.25	1097	220
h400aS2		15-Jun-10	1.25	1250	284
h400aS3		18-Aug-10	1.5	1310	64
h400aS4		30-Aug-10	1.25	1213	365
h400aS5		01-Sep-10	2	961	128
h400bS1	2010-2021	26-Jul-10	1	1035	328
h400bS2		05-Aug-10	1.5	1312	476
h400bS3		05-Aug-10	1.5	1120	403
h409S1	2008-2004	09-Jun-10	1.5	1474	107
h409S2		09-Jun-10	1	1279	95
h409S3		10-Jun-10	1.25	1603	218
hQEWaS1	2007-2026	21-Jun-10	0.75	828	215
hQEWaS2		21-Jun-10	1.25	1198	112
hQEWaS3		28-Jun-10	0.75	827	414

Site Code	Site ID	Visit Dates	Data (hrs)	Throughput (vphpl)	
				Mean	St. Dev
hQEWaS4		07-Jul-10	1.5	1323	121
hQEWaS5		09-Jul-10	1	1190	228
hQEWaS6		11-Jul-10	0.75	1281	348
hQEWaS7		13-Jul-10	1	1474	431
hQEWaS8		14-Jul-10	1	1340	500
hQEWaS9		19-Jul-10	0.75	1234	228
hQEWaS10		19-Jul-10	1.75	1267	193
hQEWaS11		20-Jul-10	2.75	1235	320
hQEWaS12		21-Jul-10	0.75	1308	228
hQEWaS13		29-Jul-10	1.5	1421	154
hQEWaS14		06-Aug-10	2.5	1122	230
hQEWbS1	2007-2031	05-Jul-10	0.5	1468	249
hQEWbS2		06-Jul-10	1	1233	510
hQEWdS1	2009-2015	08-Jul-10	2.5	1147	332
hQEWdS2		11-Jul-10	2	814	181
hQEWdS3		13-Jul-10	2.5	912	105
hQEWdS4		19-Jul-10	1.75	1034	202
hQEWdS5	2009-2015	25-Jul-10	2.5	1023	82
h417S1	2009-4020	23-Sep-09	1.5	1744	209
h401cS1	2009-2031	27-May-10	1.75	1204	298

4.7 Summary

This chapter discussed a brief summary of the sites contacted and visited during the research. In total 84 site visits were made in 2009 and 2010 and of the 84 site visits, on 53 of the site visits, queuing was observed. The highways that were visited included highway 400, 401, 417, 427, 409 and Hwy QEW. Various work zone throughput variables have been identified and analyzed. Only 26% of the sites that were visited showed forced flow condition which shows that the construction time can be extended. Overall, the new data indicate there may be opportunity for longer road closures which could potentially allow the contractor to improve both quality and speed of construction work by working over longer shifts. Furthermore, the chapter discussed the factors that are believed to be affecting the work zone capacity. Also, the average throughput table was generated with the average mean of each site visit with the standard deviation to compare the models.

Chapter 5 Data Analysis

5.1 Data Analysis

The data used for analysis were collected from Southern Ontario freeways that exhibited the forced flow conditions with the desired characteristics. All the freeways are owned and operated by Ministry of Transportation of Ontario. The collected traffic data and the site characteristic details were analyzed to calculate the throughput capacity of the freeway work zones. There are various methods for analyzing the data to calculate the capacity as discussed in the literature review. This study has adopted a simplified method to calculate the throughput of the work zone by presenting a mathematical model which is straight forward to compute. Multiple linear regressions were used to develop the additive model to estimate the throughput of the work zones. The variables used in the model for the regression had binary values (0 and 1) and the variables that were not significant are not included in the model. The variables having statistically significant effects were included in the model.

5.1.1 Data Used for Analysis

In phase I of the study, (2007/ 2008) two models were developed, as mentioned previously in chapter 1, to predict the throughput capacity of Southern Ontario highway work zones. The generic model has a base capacity of 1666 vphpl with the noted significant variables of: presence of barrels, number of lanes closed, time of the construction (i.e. day vs night) and day of the week (i.e. weekdays vs weekends). The highway specific model has a base capacity of 1702 vphpl with the significant variables identified as: number of lanes closed, day of the week (i.e. weekdays vs weekends), Hwy 400/ 401 and Hwy QEW. In phase II of this study the same basic protocol has been followed to calculate the throughput of the work zones. However, additional data was also collected. Also, some of the significant variables that were identified in phase I were not found to be significant in this phase II portion of the research.

5.1.2 Moving (Rolling) Average

The moving average method has been used to extract the limited amount of fifteen minutes data into as many hours of data as possible. Comparing the alternative way of multiplying each fifteen minutes interval by four to extract the data, this moving average method provides hourly data with lower variance and an extra hour. A sample moving average calculation is presented in Table 5.1.

Table 5.1 Moving Average Calculation Sample Table

	15 min Total		Hourly Throughput (Moving Average)
A	263	Sum (A,B)*2	1062
B	268	Sum (A,B,C) x (4/3)	1041
C	250	Sum (A,B,C,D)	1045
D	264	Sum (B,C,D,E)	1019
E	237	Sum (C,D,E) x (4/3)	1014
		Sum (D,E) x 2	

The average site capacity and site characteristics for all locations used to develop the model are shown in Table 5.2. For full fifteen minute data counts, please refer to Appendix A of this document.

Table 5.2 Site Characteristics and Throughput Counts

Site	Site ID	Hour Data (vphpl)	OPP Presence	Weekend/Weekday	Night/Day	2 or more lanes closed	Right(1)/Left lane closed(0)	Barrels/Barrier wall	Grade: >3% or between 0 - 3%
2008-2003	h427S1	1183	0	0	1	0	0	1	0
	h427S2	1269	0	1	1	1	1	1	0
	h427S3	1265	0	0	1	0	0	1	0
2009-2021	h401aS1	884	0	0	1	1	0	1	0
	h401aS2	1037	0	0	1	1	0	1	0
	h401aS3	1020	0	0	1	1	1	1	0
	h401aS4	803	0	0	1	1	0	1	0
	h401aS5	1037	0	0	1	1	0	1	0
	h401aS6	1097	0	0	1	1	1	1	0
	h401aS7	872	0	0	1	1	0	1	0
	h401aS8	944	0	0	1	1	1	1	0
2005-2014	h401bS1	1040	0	0	1	1	1	1	0
	h401bS2	1012	1	0	1	1	0	1	0
	h401bS3	1188	0	0	1	1	0	1	0
	h401bS4	1122	0	1	1	1	0	1	0
	h401bS5	988	0	0	0	1	1	1	0
	h401bS6	832	0	0	1	1	1	1	0
2010-2031	h401cS1	1956	0	0	1	1	1	1	0
2008-2017	h401dS1	1693	0	1	0	0	0	0	0
2009-2020	h401eS1	862	0	0	1	0	0	1	0
	h401eS2	922	0	0	1	0	1	1	0
2008-2018	h400aS1	1097	1	0	1	1	1	1	0
	h400aS2	1392	0	0	1	1	0	1	0
	h400aS3	1311	0	0	1	1	1	1	0
	h400aS4	1213	0	0	1	0	0	1	0

Site	Site ID	Hour Data (vphpl)	OPP Presence	Weekend/Weekday	Night/Day	2 or more lanes closed	Right(1)/Left lane closed(0)	Barrels/Barrier wall	Grade: >3% or between 0 - 3%
	h400aS5	961	0	0	1	0	1	1	0
2010-2021	h400bS1	1035	0	0	1	1	0	1	0
	h400bS2	1312	0	0	1	0	0	1	0
	h400bS3	1120	0	0	1	1	1	1	0
2008-2004	h409S1	1474	0	0	1	1	0	1	0
	h409S2	1279	0	0	1	1	0	1	1
	hQEWaS2	1198	0	0	1	1	1	1	0
	hQEWaS3	827	0	0	1	1	1	1	0
	hQEWaS4	1323	0	0	1	1	0	1	0
	hQEWaS5	1190	1	0	1	0	0	1	0
	hQEWaS6	1281	0	1	1	0	0	1	0
	hQEWaS7	1474	0	0	1	0	0	1	0
	hQEWaS8	1340	0	0	1	0	0	1	0
	hQEWaS9	1234	0	0	1	0	0	1	0
	hQEWaS10	1267	0	0	1	1	0	1	0
	hQEWaS11	1235	0	0	1	1	0	1	0
	hQEWaS12	1308	0	0	1	0	1	1	0
	hQEWaS13	1421	0	0	1	1	0	1	0
	hQEWaS15	1122	0	0	1	1	0	1	0
2007-2031	hQEWbS1	1468	0	0	1	1	1	1	0
	hQEWbS2	1233	0	0	1	0	1	1	0
2009-2015	hQEWdS1	1147	1	0	1	1	0	1	0
	hQEWdS2	1220	1	1	1	1	0	1	0
	hQEWdS3	912	1	0	1	1	1	1	0
	hQEWdS4	1034	1	0	1	1	0	1	0
	hQEWdS5	1023	1	1	1	1	1	1	0
2009-4020	h417S1	1744	0	0	0	0	1	0	0
2009-2031	h410cS1	1204	0	0	1	1	1	1	0

5.2 Proposed Work Zone Throughput Models

A model to predict construction work zone throughput was proposed based on all the data that was collected in this research. The effects of different variables on the work zone throughput are expressed as capacity reductions (losses) of base capacity. In other words, the base capacity would be the expected throughput under non work zone conditions. Additionally, it has been noticed that there is a significant link between night time closures and the use of barrels to close lanes as shown in section 4.5.1. There is only one instance in which barrels were used during a day time closure.

The fifteen minute vehicle counts and the site characteristics were used to perform multiple linear regressions to determine which characteristics were statistically significant. For a variable (site characteristic) to remain in the model it had to exhibit P-values less than 5%, otherwise it was removed from the model.

5.3 Generic Model

This generic model (GM) is a mathematical model which includes the throughput capacity of 1727 vphpl with the reduction in the base capacity due to some significant variables, such as the use of barrels, presence of police, right or left lane closed and number of lanes closed. The equation produced through this analysis is shown in Equation 5-1.

Construction Lane Throughput = 1727 – 490 x B – 111 x P – 95 x L – 83 x R Equation 5-1

Where:

B = 1 if barrels; 0 if concrete barriers used

P = 1 if police is presence; 0 otherwise

L = 1 if 2 or more lanes closed; 0 otherwise

R = 1 if right lane closed; 0 otherwise

The R-Square value (0.80) for this equation is acceptable and comparable with other throughput values in the literature (Montgomery, 2003). Additionally, the validity of the individual characteristic regression coefficients can also be seen. The P-values for the base value ($9.1x10^{-252}$), barrels ($6.0x10^{-14}$), police presence ($2.6x10^{-05}$), 2 or more lanes closed ($9.5x10^{-05}$), and right lane closed ($2.3x10^{-06}$) are well below the acceptable 0.05 cut off. As shown in equation 5.1, all the coefficients are negative, which causes a reduction in the number of vehicles that can flow through the lane within the construction work zone. The use of barrels for closures causes drivers to drive with greater caution and thus slows traffic and reduces the throughput. This is potentially due to the fact, the barrels move and the drivers reduce speed when travelling next to them. The presence of police also reduces the capacity of the work zone where drivers drive the vehicles with extra caution especially at the merge point. Throughput of the work zone is lessened with a greater number of lanes closed due to the extra stages of merging required to enter the site. Finally, a right lane closure has some contribution towards the capacity drop. In phase I of the study period some of these variables which are significant in the phase II of the study period were insignificant due to the limited amount of data collection as the data were collected at only 20 different sites. In addition, some of the variable which was determined to be significant in the phase I of the study period such as night time and weekend were eliminated in the phase II because they were insignificant. This is likely related to the fact that very few day time sites were visited because queuing was mostly expected at the night work zone projects. Also MTO policies on many Southern Ontario highways result in night closures.

5.3.1 Accuracy of Generic Model

The accuracy of the newly proposed generic model can be found by comparing the estimated throughput values produced by the proposed generic model and the actual average throughput values collected on site. The outputs are presented in two ways. Firstly, there is a numerical presentation in which Table 5.3 shows the comparison between the predicted throughput values generated by the generic model (GM) and the average throughput values within two standard deviations of the mean at each respective site. The generic model outputs provide a framework to estimate the capacity of each site based on its characteristics. The proposed generic model result is shown to have 88% (or 44 out of 50 sites) have predicted throughput capacity within two standard deviation of the mean (shaded yellow) in phase II of the study period.

Table 5.3 Comparison of GM Estimate with Standard Deviation of Mean (vphpl)

Site Code	Site ID	Actual Throughput (vphpl)		St. Dev. Range		Predicted GM Throughput
		Mean	St. Dev	Low	High	
h427S1	2008-2003	1183	192	991	1375	1237
h427S2		1269	192	1077	1461	1142
h427S3		1265	192	1073	1457	1237
h401aS1	2009-2021	884	253	631	1137	1142
h401aS2		1043	253	790	1296	1142
h401aS3		1020	253	767	1273	1142
h401aS4		803	253	550	1056	1031
h401aS5		1037	253	784	1290	1059
h401aS6		1097	253	844	1350	1142
h401aS7		872	253	619	1125	1142
h401aS8		944	253	691	1197	1059
h401bS1	2005-2014	1040	144	896	1184	1059
h401bS2		1012	144	868	1156	1059
h401bS3		1188	144	1044	1332	1142
h401bS4		1122	144	978	1266	1142
h401bS5		988	144	844	1132	1059
h401bS6		832	144	688	976	1059
h401dS1	2008-2017	1693	275	1419	1968	1651
h401eS1	2009-2020	862	196	666	1058	1237
h401eS2		922	196	726	1118	1031

Site Code	Site ID	Actual Throughput (vphpl)		St. Dev. Range		Predicted GM Throughput
		Mean	St. Dev	Low	High	
h400aS1	2008-2018	1097	184	913	1281	1059
h400aS2		1392	184	1066	1434	1142
h400aS3		1311	184	1127	1495	1059
h400aS4		1213	184	1029	1397	1237
h400aS5		961	184	777	1145	1154
h400bS1	2010-2021	1035	402	633	1437	1142
h400bS2		1312	402	910	1714	1237
h400bS3		1120	402	718	1522	1059
h409S1	2008-2004	1474	101	1373	1575	1142
h409S2		1279	101	1178	1380	1142
hQEWaS2	2007-2026	1198	273	925	1471	1059
hQEWaS3		827	273	597	1143	1059
hQEWaS4		1323	273	1048	1594	1142
hQEWaS6		1281	273	1008	1554	1237
hQEWaS7		1474	273	1201	1747	1237
hQEWaS8		1340	273	1067	1613	1237
hQEWaS9		1234	273	961	1507	1237
hQEWaS10		1267	273	994	1540	1237
hQEWaS11		1235	273	962	1508	1142
hQEWaS12		1308	273	1035	1581	1154
hQEWaS13		1421	273	1158	1704	1142
hQEWaS15		1122	273	849	1395	1142
hQEWbS1	2007-2031	1468	379	1089	1847	1059
hQEWbS2		1233	379	854	1612	1154
hQEWdS1	2009-2015	1147	180	967	1327	1031
hQEWdS2		814	180	634	994	1031
hQEWdS3		912	180	732	1092	948
hQEWdS4		1034	180	854	1214	1031
hQEWdS5		1023	180	843	1203	1031
h401cS1	2009-2031	1204	298	906	1502	1059

Finally, the calculations are shown graphically in Figure 5.1. The actual throughputs measured at the various work zone sites are donated by black crosses while the predicted generic model throughput values are donated by purple circles. The red squares and the green triangles show two standard deviations of the mean. As shown in the Figure, the predicted throughput values (purple circles) generated by the newly proposed generic model are within the range of the standard deviation and generally very close to the actual throughput values measured at site (black cross). This improved calculation will be very useful for planning and organization of work zones.

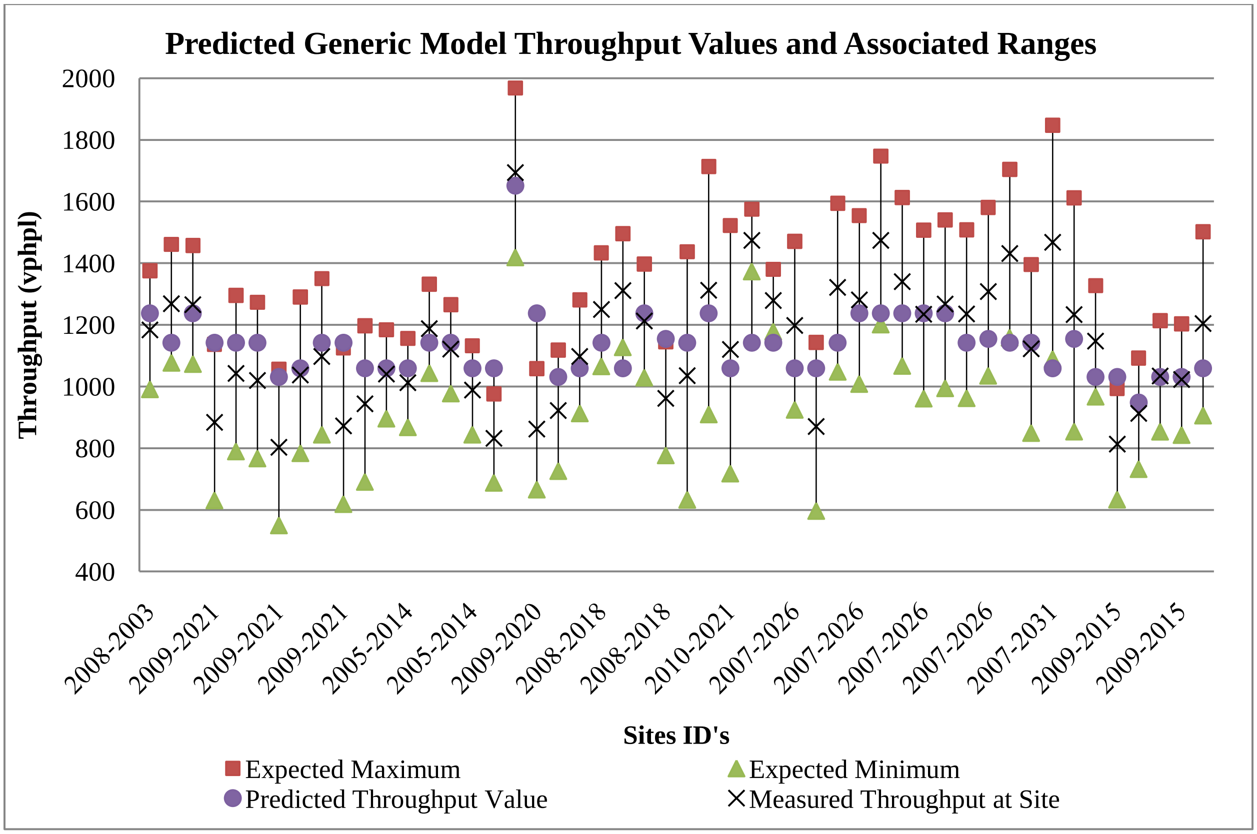


Figure 5.1 Graphical Output of Predicted Generic Model Throughput Values

The predicted throughput values generated by the newly proposed generic model (GM) were then compared with the actual throughput values that were collected during phase I of the study period. Table 5.4 shows the results. In short, with the newly proposed generic model 17 of the 20 sites are shown within the range (shaded yellow) while with phase I generic model only 12 of the 20 sites fit into the range. Thus, the new generic model greatly improves the prediction of throughput capacity. Figure 5.2 summarizes these findings. As noted the predicted throughput (purple circles) are within the two standard deviation for 17 of the 20 sites.

Table 5.4 Site Comparison of Newly Proposed GM Estimate vs Phase I Actual Throughput

		Actual Throughput (vphpl)		**St. Dev. Range**		**Predicted GM**
Site Code	**Site ID**	**Mean**	**St. Dev**	**Low**	**High**	**Throughput**
h401S1	2005-2014	1190	238	952	1428	1142
h401S2		1298	238	1060	1536	1059
h401S3		1233	238	995	1471	1142
h401S4		1134	238	896	1372	1142
h401S5		1141	238	903	1379	1059
h401S6		1155	238	917	1393	1059

Site Code	Site ID	Actual Throughput (vphpl)		St. Dev. Range		Predicted GM Throughput
		Mean	St. Dev	Low	High	
h400S1	2006-2024	1182	300	882	1482	1059
h400S2		1011	300	711	1311	1059
hQEWS1	2007-2252	828	325	503	1153	1059
hQEWS2		1098	325	773	1423	1059
hQEWS3		810	325	485	1135	1059
hQEWS4	2007-2027	1168	124	1044	1292	1154
hQEWS5		1353	124	1229	1477	1154
hQEWS6	2007-2031	830	225	605	1055	1142
hQEWS7		954	225	729	1179	1142
hQEWS8	2007-2125	1019	102	917	1121	1142
h427S1	2008-2003	1564	164	1400	1728	1644
h427S2	2007-2028	1755	212	1543	1967	1644
h427S3		1726	212	1514	1938	1644
h427S4		1625	212	1413	1837	1644

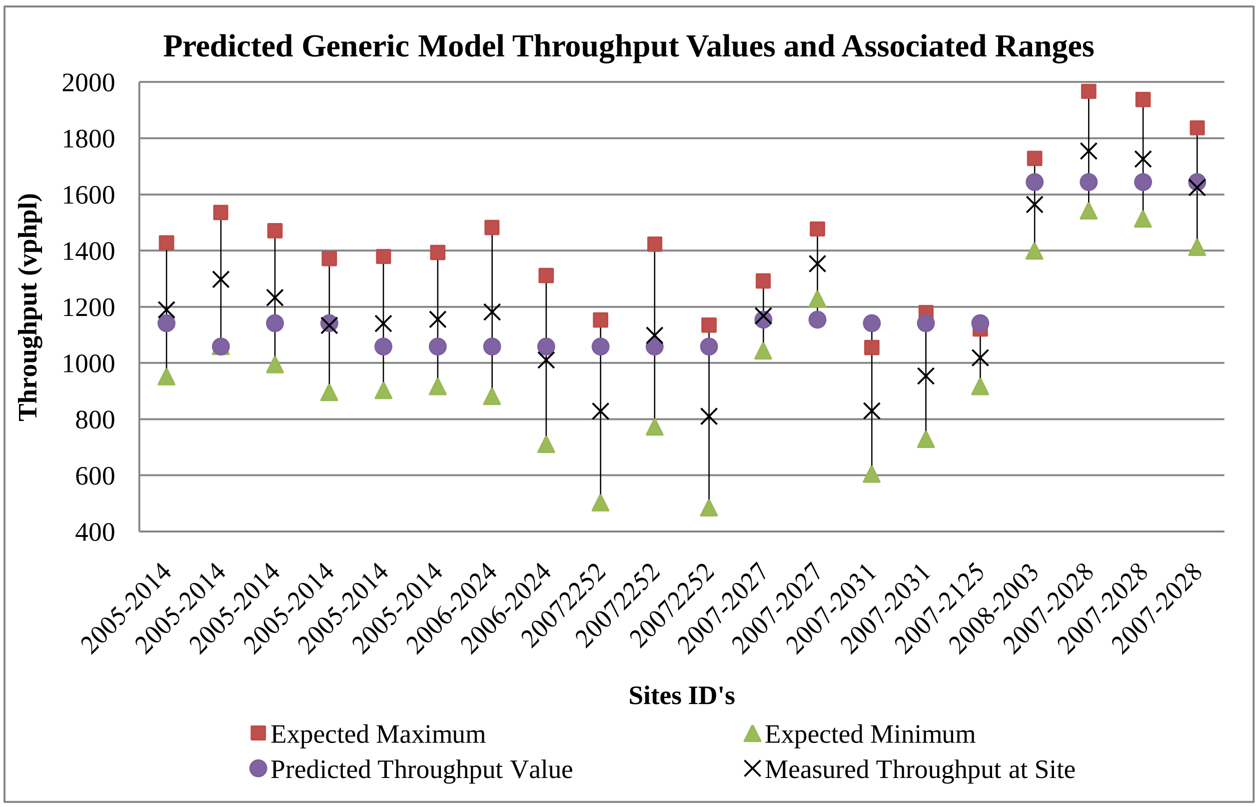


Figure 5.2 Graphical Output of Predicted Generic Model Throughput Values (Phase I)

5.4 Highway Specific Model

The throughput predicted by the generic model was observed to be lower than the MTO values (1800 vphpl). However, on many of the sites visited during phase I and II of the study construction season, there were no forced flow conditions which indicated that the construction work zone hours could potentially be extended. During phase I, it was concluded that one throughput model for all work zones may not have been an optimal solution. Therefore, it was decided to develop highway specific models (HSM). Furthermore, the identifiers included in the linear regression analysis (in addition to the site characteristics), the highway identifier was statistically significant. While this is only a small sample of highways, the result of this indicates that the throughput of a highway work zone is sensitive to the road travelled upon.

Highway specific models in this research were developed for Hwy 427, 400, 401 and QEW. However, the regression analysis for Hwy 427 was not determined to be statistically significant so the throughput of Hwy 427 is assumed to be the base capacity of highway specific model. However, in further it would be suggested that more data be collected on Hwy 427 to determine if a model can be developed. The highway specific model is a mathematical model which includes the throughput capacity of 1753 vphpl with the reduction in the throughput due to specific highway characteristics on Hwy 400/ 401 and Hwy QEW as well as a significant drop in the capacity due to the presence of barrels. There is also some small contribution on the capacity drop due to the presence of police, right or left lane closed and number of lanes closed. The equation produced through this analysis is shown in Equation 5-2.

$$\textbf{Construction Lane Throughput} = 1753 - 145 \times D_A - 107 \times D_B - 413 \times B - 119 \times P - 89 \times L - 80 \times R$$

Equation 5-2

Where:

D_A = 1 if Hwy 400/ 401; 0 otherwise

D_B = 1 if Hwy QEW; 0 otherwise

B = 1 if barrels; 0 if concrete barriers used

P = 1 if police is presence; 0 otherwise

L = 1 if 2 or more lanes closed; 0 otherwise

R = 1 if right lane closed; 0 otherwise

The validation of the highway specific model equation resulted in R-Square value (0.82) which is slightly higher than the generic model. This means that 82% of the variability in the data is accounted for in this model. Additionally, the validity of the individual characteristic regression coefficients can also be observed. The P-values ($2.1x10^{-221}$) for the base value, ($7.7x10^{-07}$) for Hwy 400/ 401, (0.000172) for Hwy QEW, for barrels ($3.04x10^{-30}$), for police presence ($1.1x10^{-05}$),for 2 or more lanes closed (0.00214), and right lane closed ($3.2x10^{-60}$) are well below the acceptable 0.05 minimum of statistical significance. Based on the individual characteristics of each highway, the equations are logical with actual engineering operations and best practices. For example on the Hwy QEW, the average throughput of 21 site visits on different sections of the highway is approximately 1159 vphpl which is close to the base capacity of highway specific model after subtracting the significant variables namely Hwy QEW, barrels, right lane closed or number of lane closed from the base throughput capacity.

5.4.1 Accuracy of Highway Specific Model

The procedure to calculate the accuracy of the highway specific model is the same as the aforementioned generic model. Table 5.5 shows the comparison between the predicted values generated by the newly proposed highway specific model and the average throughput values within the average of two standard deviation of the mean of each site of the actual throughput. The analysis of the results shows that 45 out of 50 sites values fall within the two standard deviation of the mean (shaded yellow).

Table 5.5 Site Comparison of HSM Estimate within Standard Deviation of Mean (in vphpl)

Site Code	Site ID	Actual Throughput (vphpl)		St. Dev. Range		Predicted HSM Throughput
		Mean	St. Dev	Low	High	
h427S1	2008-2003	1183	192	991	1375	1330
h427S2		1269	192	1077	1461	1241
h427S3		1265	192	1073	1457	1330
h401aS1	2009-2021	884	253	631	1137	1096
h401aS2		1043	253	790	1296	1096
h401aS3		1020	253	767	1273	1096
h401aS4		803	253	550	1056	987
h401aS5		1037	253	784	1290	1026
h401aS6		1097	253	844	1350	1106
h401aS7		872	253	619	1125	1106
h401aS8		944	253	691	1197	1026
h401bS1	2005-2014	1040	144	896	1184	1066
h401bS2		1012	144	868	1156	1066
h401bS3		1188	144	1044	1332	1106
h401bS4		1122	144	978	1266	1106
h401bS5		988	144	844	1132	1026
h401bS6		832	144	688	976	1026
h401dS1	2008-2017	1693	275	1419	1968	1608

Site Code	Site ID	Actual Throughput (vphpl)		St. Dev. Range		Predicted HSM Throughput
		Mean	St. Dev	Low	High	
h401eS1	2009-2020	862	196	666	1058	1195
h401eS2		922	196	726	1118	1115
h400aS1	2008-2018	1097	184	913	1281	907
h400aS2		1392	184	1066	1434	1274
h400aS3		1311	184	1127	1495	1026
h400aS4		1213	184	1029	1397	1195
h400aS5		961	184	777	1145	1115
h400bS1	2010-2021	1035	402	633	1437	1066
h400bS2		1312	402	910	1714	1195
h400bS3		1120	402	718	1522	1026
h409S1	2008-2004	1474	101	1373	1575	1251
h409S2		1279	101	1178	1380	1251
hQEWaS2	2007-2026	1198	273	925	1471	1185
hQEWaS3		827	273	597	1143	1064
hQEWaS4		1323	273	1048	1594	1144
hQEWaS6		1281	273	1008	1554	1233
hQEWaS7		1474	273	1201	1747	1233
hQEWaS8		1340	273	1067	1613	1233
hQEWaS9		1234	273	961	1507	1233
hQEWaS10		1267	273	994	1540	1144
hQEWaS11		1235	273	962	1508	1144
hQEWaS12		1308	273	1035	1581	1153
hQEWaS13		1421	273	1158	1704	1144
hQEWaS15		1122	273	849	1395	1144
hQEWbS1	2007-2031	1468	379	1089	1847	1064
hQEWbS2		1233	379	854	1612	1153
hQEWdS1	2009-2015	1147	180	967	1327	1025
hQEWdS2		814	180	634	994	1025
hQEWdS3		912	180	732	1092	937
hQEWdS4		1034	180	854	1214	1025
hQEWdS5		1023	180	843	1203	945
h401cS1	2009-2031	1204	298	906	1502	1171

Figure 5.3 shows the newly proposed highway specific model. The actual throughput values measured at each site and the predicted site specific model throughput values with the associated range of the two standard deviation of the mean. As shown in the figure, the predicted throughput values (purple circles) generated by the newly proposed generic model are well within the range of the standard deviation of the mean. In addition, the actual throughput values are shown to be similar.

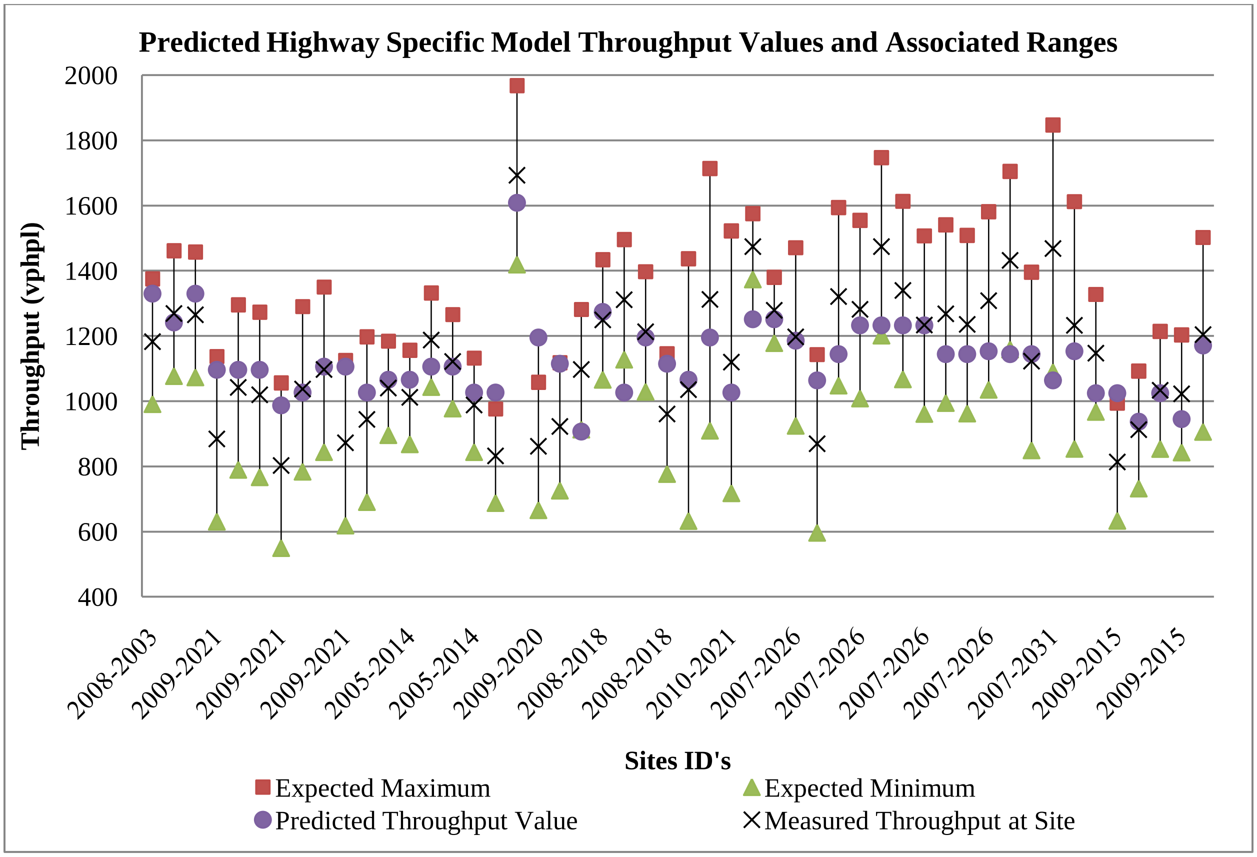


Figure 5.3 Graphical Output of Predicted Highway Specific Model Throughput Values

Similar to the generic model, the results were compared with the predicted values generated by the newly proposed highway specific model and the actual throughput average values collected in the phase I of the study period. Table 5.6 shows the results are better than the results in the phase I study period as 16 of the 20 sites had values within the two standard deviation of the mean (shaded yellow). Conversely, when the phase I highway specific model is used, only 13 of the 20 sites fit into the range of the two standard deviation of the mean.

Table 5.6 Site Comparison of HSM Estimate vs Phase I (Study Period)

Site Code	Site ID	Actual Throughput (vphpl)		St. Dev. Range		Predicted HSM Throughput
		Mean	St. Dev	Low	High	
h401S1	2005-2014	1190	238	952	1428	1106
h401S2		1298	238	1060	1536	1026
h401S3		1233	238	995	1471	1106
h401S4		1134	238	896	1372	1106
h401S5		1141	238	903	1379	1026
h401S6		1155	238	917	1393	1026

Site Code	Site ID	Actual Throughput (vphpl)		St. Dev. Range		Predicted HSM Throughput
		Mean	St. Dev	Low	High	
h400S1	2006-2024	1182	300	882	1482	1026
h400S2		1011	300	711	1311	1026
hQEWS1	2007-2252	828	325	503	1153	1064
hQEWS2		1098	325	773	1423	1064
hQEWS3		810	325	485	1135	1064
hQEWS4	2007-2027	1168	124	1044	1292	1153
hQEWS5		1353	124	1229	1477	1153
hQEWS6	2007-2031	830	225	605	1055	1144
hQEWS7		954	225	729	1179	1144
hQEWS8	2007-2125	1019	102	917	1121	1144
h427S1	2008-2003	1564	164	1400	1728	1566
h427S2	2007-2028	1755	212	1543	1967	1673
h427S3		1726	212	1514	1938	1673
h427S4		1625	212	1413	1837	1673

The calculations are also shown graphically in Figure 5.4, the majority of the predicted highway specific model throughput values (purple circle) are well within the range of the standard deviation of the mean.

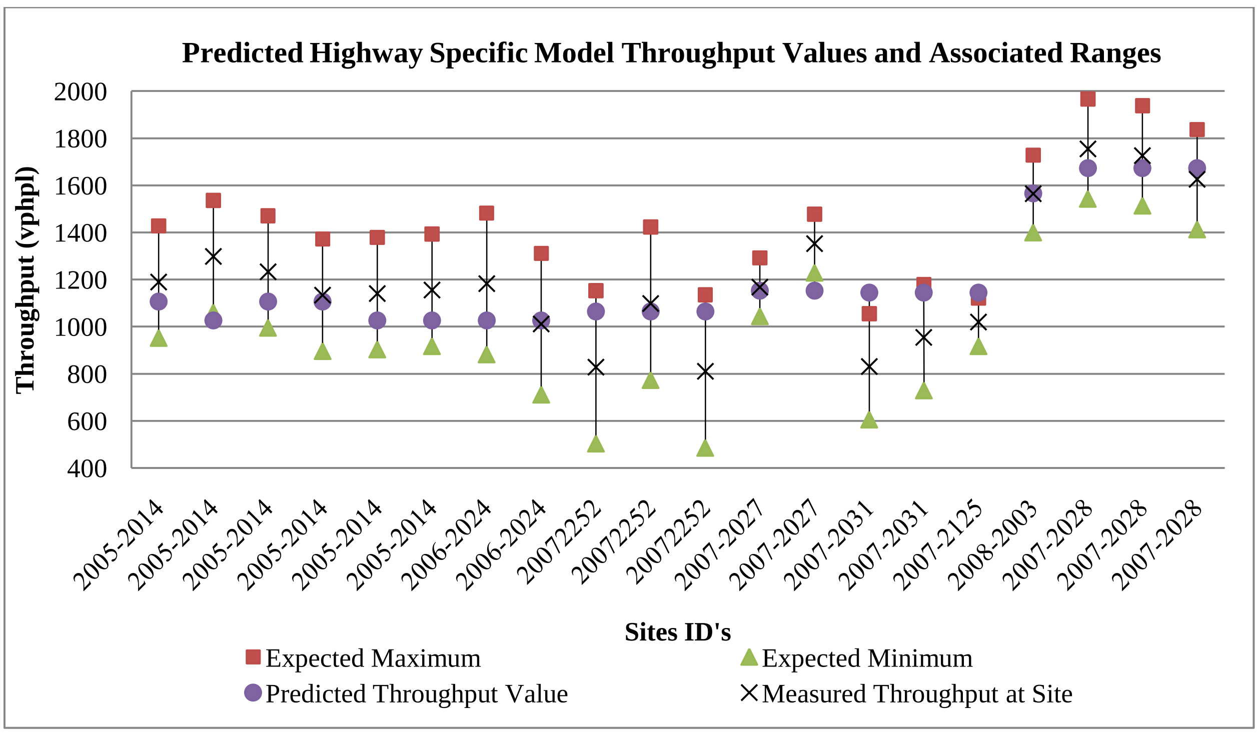


Figure 5.4 Graphical Output of Predicted Highway Specific Model Throughput Values (Phase I)

The results are based on the overall data collection during the course of the study periods. In total 20 sites were visited with forced flow conditions in phase I and 50 sites were visited with forced flow condition in phase II of the study period. The models were compared by using the predicted values generated by newly proposed generic model and highway specific model with the actual throughput average values collected for both study periods. As shown in Table 5.7, the newly proposed models predicted values are within the standard deviation of the mean with the actual throughput average values of phase I study period. The results are better and table 5.7 provides the summary of the models.

Table 5.7 Summary of the Models

Newly Proposed Models	Phase I Results	Phase II Models Compared with Phase I Data	Phase II Results	Total
Generic Model	12/20	17/20	44/50	61/70
Highway Specific Model	13/20	16/20	45/50	61/70

5.5 Heavy Vehicle Analysis

Previous studies have shown that heavy vehicles or trucks play an important role in the work zone capacity and throughput, when the percentage of trucks increases, the number of vehicles that can pass through a site decreases (IBI, 2007). During this research, all the data collected to estimate the throughput were carried out using the unit vehicles per hour per lane (vphpl), as per MTO requirements the calculation has been done on vphpl and the heavy vehicles is not supported during the analysis. The data have been collected for the user delay calculations and for future research. Figure 5.5 provides the heavy vehicles data collected on different sites with their Site ID's and the detail site information can be seen in Table 4.1 with the site ID's and their locations. The figure shows that there is little correlation between heavy vehicles and throughput. Further data would help contribute to this evaluation.

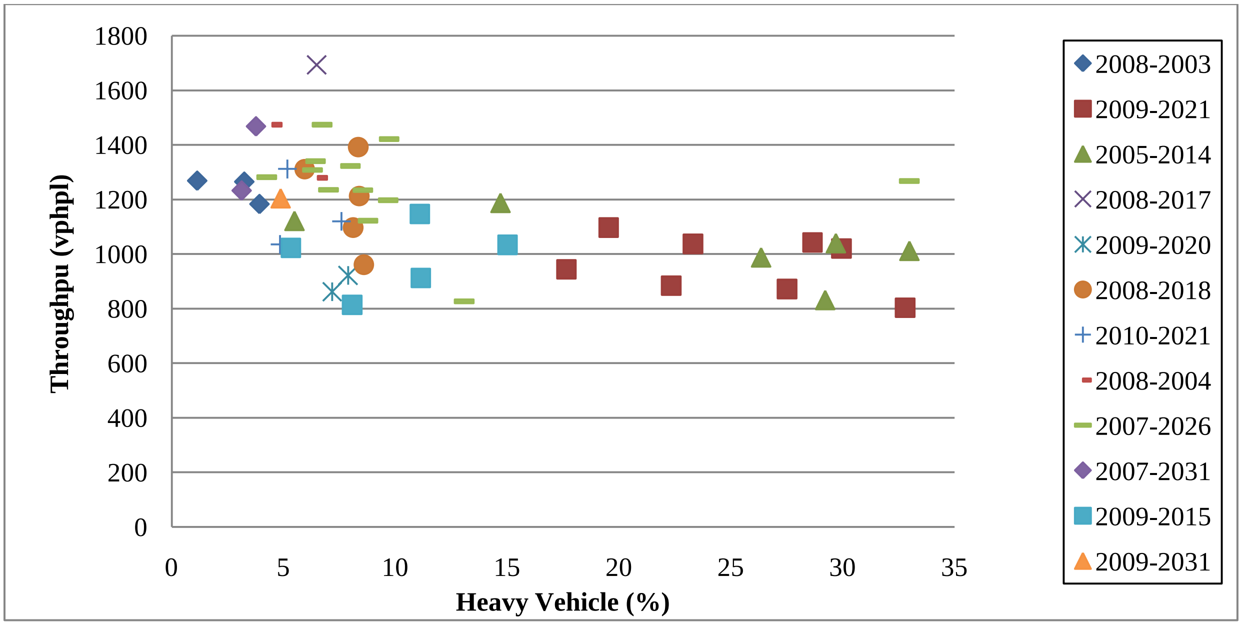


Figure 5.5 Throughput of Freeway vs Percentage of Heavy Vehicle

5.6 Summary

This chapter includes the data analysis of data collected from Southern Ontario highway sites that exhibit the forced flow conditions with the desired characteristics. The site characteristics have been assigned with a binary code (0 and 1) which has been used in the models for the regression analysis. The variables that were not significant are not included in the model. The multiple linear regressions were used to develop the additive models to estimate the throughput of the work zones. In phase II of the study period, the results of the generic model with the base capacity of 1727 vphpl is more realistic as 44 out of 50 sites actual throughput values lies within the two standard deviation of the mean. Whereas, for the same throughput data for the phase I study period, the new generic model predicted 16 out of 20 sites lies within two standard deviation of the mean. The same evaluation protocol was followed for the highway specific model which has the base capacity of 1753. Of the sites, 45 out of 50 sites fit within the two standard deviation of the mean. Comparing with the phase I study period, 16 out of 20 sites throughput values are within the standard deviation with the new highway specific model predicted throughput values. More than 85% of the actual throughput values are within the two standard deviation of the mean which indicates that the generic and the highway specific model are appropriate models for MTO to use for predicting construction work zone capacity throughput. These predictions will provide valuable insight to MTO for planning and design of construction work zones.

Chapter 6 SZUDA Model for User Delay

The Simplified work Zone User Delay Analysis (SZUDA) model is a simple spread sheet based model designed to calculate the user delay cost associated with work zones which was developed during phase I of this research (Hicks, 2009). This model is easy to operate with limited inputs and can be used by agencies and decision makers to provide quick feedback on the impacts of changing lane closure schedules on road user delays and the associated costs. It is further examined in this chapter.

6.1 User Delays

User delay costs and economic impacts become a large part of all roadway construction projects. Reduction of speed through a work zone will cause slowing and queuing delays. These delays are associated with the approach to the work zone where drivers first reduce speed (and increase travel time) as compared to normal free flow conditions. Reducing the speed limits enhances safety for both the construction workers and the traveling public. The FHWA recognized these user delay costs and their effect on every roadway construction project but consistently has not been considered or integrated into the highway projects planning and design process (Hardy, 2007). Various transportation agencies calculate user delay costs to help them determine the suitable construction zone configurations and potential incentives for early construction completion. When calculated, user delay costs are often so large that they normally exceed the agency cost, particularly for transportation investments being considered for high-traffic areas. Although user costs do not come directly from an agency budget, they need to be considered. Nonetheless, as future traffic demand pushes user delay costs ever higher, it becomes increasingly important to include these costs in a total cost analysis. The methodology developed to calculate the user delay costs is based on the Simplified work Zone User Delay Analysis (SZUDA) model developed in phase I of this study period. A simplified approach by using the real time data collected during this research and improved generic and highway specific models base capacity and the significant variables were used to calculate user delay costs. The strategy to develop this methodology is to encourage contractors to develop new and innovative techniques for completing the work, so a high quality product is produced with limited delays.

6.2 SZUDA Model Inputs

This model requires a limited number of inputs such as the number of vehicles per hour during regular hours expected to travel along that section of road where the construction work zone is required. The second input requires information on the construction site characteristics corresponding to the generic and highway specific models. These site characteristics have been assigned with codes (0, 1, 2, 3 and 4) to each hour of the week to determine the lane closure timing. For example, in the hourly construction hours schedule the codes are assigned the values as, (0=Lane Open, 1=Left Lane Closed, 2=Right Lane Closed, 3=Police Presence (Right Lane), 4=Police Presence (Left Lane). The third input is the number of lanes that facility has and the number of lanes need to be closed for construction or maintenance. The fourth and the final input is the desired road closure timing. In short, all these inputs are needed to estimate the work zone throughput and the user delay cost.

SZUDA is an interactive tool which allows decision makers to estimate the impact of lane closure strategies on work zone delays and their associated user delay costs. In addition, SZUDA is able to incorporate a few extra details if they are known, such as additional information about the traffic, percentage of heavy vehicle. Once the vehicle hours are calculated using demand data, throughput estimation and lane closure hours, an estimation of user delay costs is also calculated. Table 6.1 shows the dollar amount associated with a passenger car to calculate the user delay cost on daily and weekly basis (MTO 2002).

Table 6.1 SZUDA Assumptions

Description	**Assumptions**
Passenger Car Cost	$10 Veh./Hr
Heavy Vehicle Cost	$50 Veh./Hr
Mixed Vehicles Traffic Cost	$15 Veh./Hr
MTO Design Value	1800 vphpl

The SZUDA input tables and graphs are presented in Appendix B. Figure 6.1 shows the functionality of the SZUDA model.

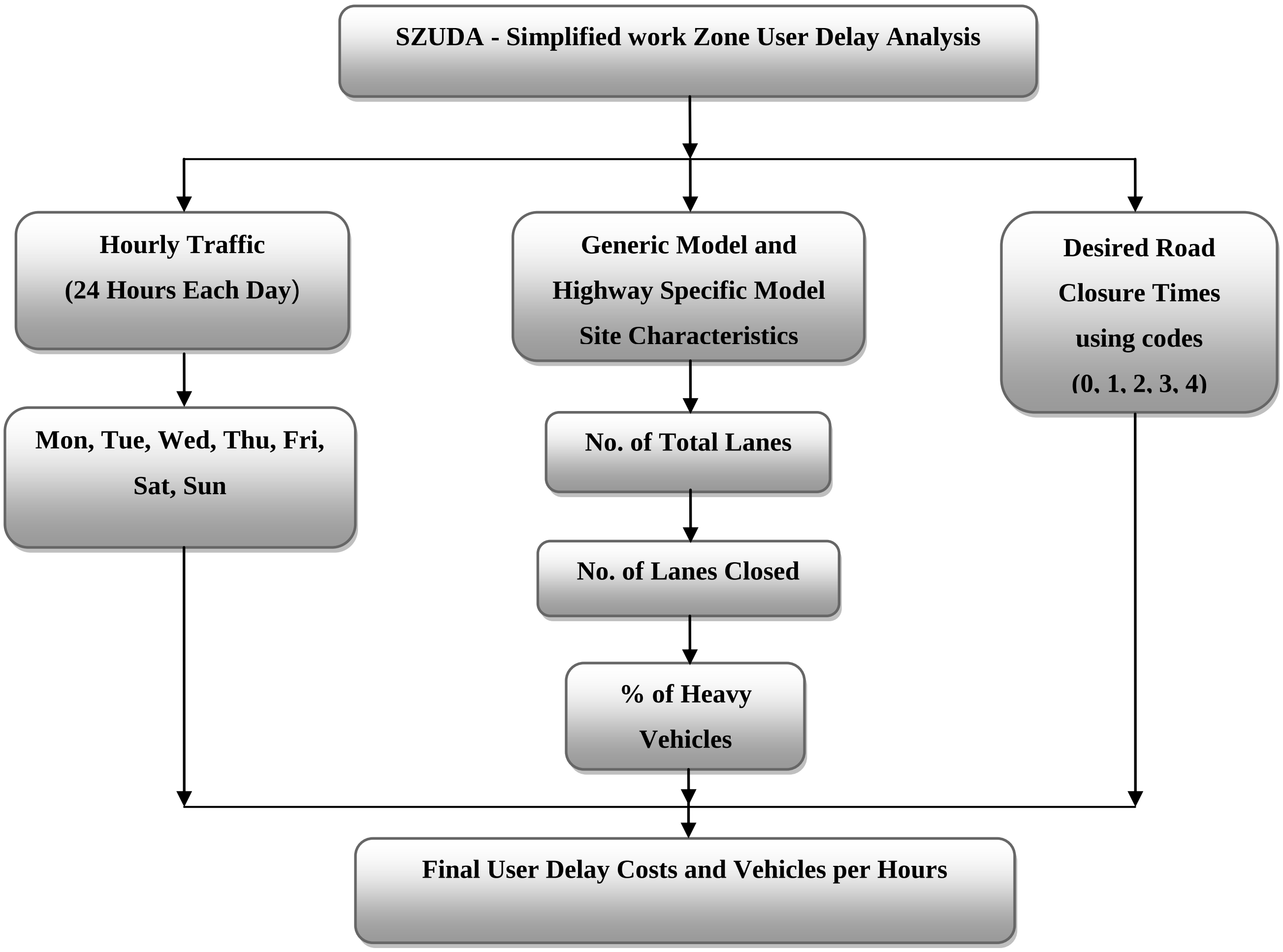


Figure 6.1 SZUDA Model Inputs Chart

The SZUDA model is updated with the new base capacities of the generic model as well as the highway capacity model. The variables effect the throughput of the work zone must be evaluated to calculate the user delays. At this point, the normal throughput of the road can also be determined based on a standard flow rate per lane and total number of lanes indicated. Taking into consideration the effect of the site characteristics, the final throughput values are calculated. Once the demand and throughput of the road for each hour is known, an hourly comparison of arrivals and departures is performed. The calculation is performed by using the Equation 6-1 and work sheet is shown in Appendix B.

Queue Length = P + D – T Equation 6-1

Where:

P = Previous Queue Length (vehicles)

D = Demand for that hour (vehicles)

T = Throughput for that hour and Queue Length > 0 (vehicles)

The outputs of the SZUDA model are presented in two ways. Firstly, there is a numerical presentation which summarizes the user delay cost and the vehicles that would be queued during the lane closure. Second the calculation are presented graphically on a chart showing the traffic demand, road throughput and the queue length associated to the lane closure.

6.3 SZUDA Generic Model Output

Table 6.2 shows the numerical output values of the vehicles and delay cost per day and finally the sum of total number of vehicles per week and the user delay cost of the week. Due to the improved base capacity and the significant variables such as presence of police and right lane closed of the new generic model, the user delay cost is found to be lower than the phase I SZUDA model values. Note that all the traffic data used in the calculation are the same as what is used in the phase I of the study period. The difference can be seen by comparing the values of user delay cost in Table 6.2 and Table 6.3.

Table 6.2 SZUDA New Generic Model Output

RESULTS	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Total (Per.week)**
User Delays (vehicles)	1481	1500	1518	3557	4624	1983	3997	**18660**
Delay Costs	$20,734	$21,000	$21,252	$49,798	$64,736	$27,762	$55,958	**$261,240**

Table 6.3 Previous SZUDA Generic Model Output

RESULTS	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Total (Per.week)**
User Delays (vehicles)	3865	3944	3871	5972	7824	7553	7789	**40818**
Delay Costs	$54,110	$55,216	$54,194	$83,608	$109,536	$105,742	$109,046	**$571,452**

The results indicate that the total user delay cost generated using the new generic model in SZUDA is $310,212 per week lower than the previously generated cost using generic model in SZUDA. The new generic model base capacity and the variables which are significant results in higher throughput values as compared to the phase I generic model values used in SZUDA model.

Figures 6.2 and 6.3 show the graphical presentation of the SZUDA model. The blue line represents the normal hourly traffic flow, the pink represents the calculated work zone throughput, and the green represents the resulting number of vehicles left in a queue for that hour.

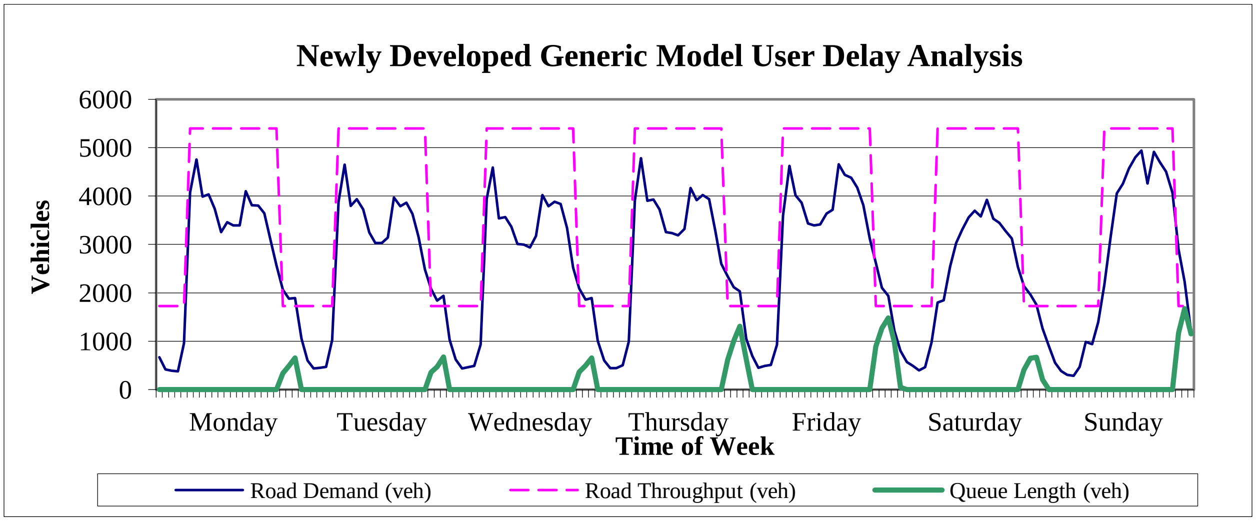


Figure 6.2 Graphical Output from SZUDA (GM)

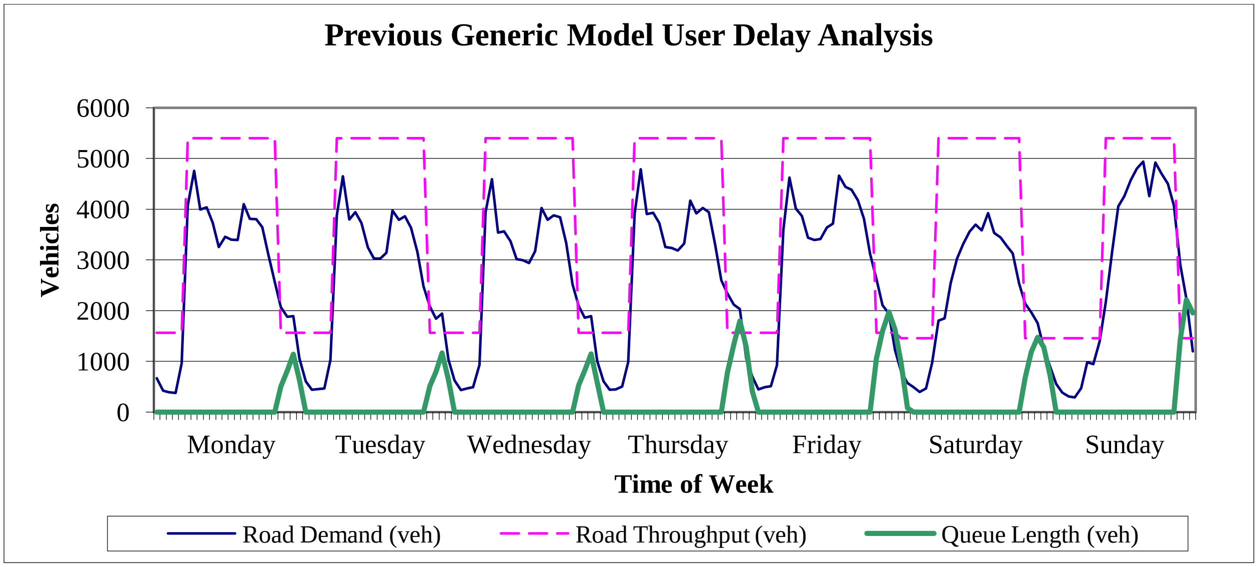


Figure 6.3 Graphical Output from SZUDA (GM)

As shown in Figure 6.3, the traffic flow exceeds the demand of the work zone and an excessive queue forms (e.g. Thursday, Friday and Saturday nights), which indicates that the proposed lane closure plan should be modified. The modification is presented in Figure 6.2 where the traffic flow (green line) is well below the traffic demand. In some cases, the lane closure times can be extended to accelerate construction activity and improve the durability of work.

6.4 SZUDA Highway Specific Model Output

The same protocol has been followed for the SZUDA highway specific model output. The new highway specific model has more significant variables than phase I highway specific model, so each significant variable was assigned a code as discuss in section 6.2. Table 6.4 shows the output values of the user delay vehicles per hour and the delay cost per day and finally the sum of dollar amount of the week. Note that all the traffic data used in the calculation are the same as what were used in the phase I of the study period to perform a clear comparison. The difference can be seen by comparing the values of user delay cost in Table 6.4 and Table 6.5.

Table 6.4 SZUDA New Highway Specific Model Output

RESULTS	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Total (Per.week)**
User Delays (Vehicles)	2655	2674	2646	4747	6009	3768	4711	**27210**
Delay Costs	$37,170	$37,436	$37,044	$66,458	$84,126	$52,752	$65,954	$**380,940**

Table 6.5 Phase I SZUDA Highway Specific Model Output

RESULTS	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Total (Per.week)**
User Delays (Vehicles)	3085	3104	3076	5177	6654	5668	6328	**33092**
Delay Costs	$43,190	$43,456	$43,064	$72,478	$93,156	$79,352	$88,592	$**463,288**

The numerical results of the new highway specific model indicate that the total user delay cost generated using refined SZUDA model is as low as $82,348 per week as compared with phase I SZUDA model using highway specific model values. This seems that the newly generated highway specific model base capacity and the variables which are significant provides better throughput and lower user delay cost than phase I highway specific model values used in SZUDA model. Although the difference is low because new highway specific model have more significant variables than phase I highway specific model as shown in Figures 6.4 and 6.5, the graphical presentation of highway specific model values.

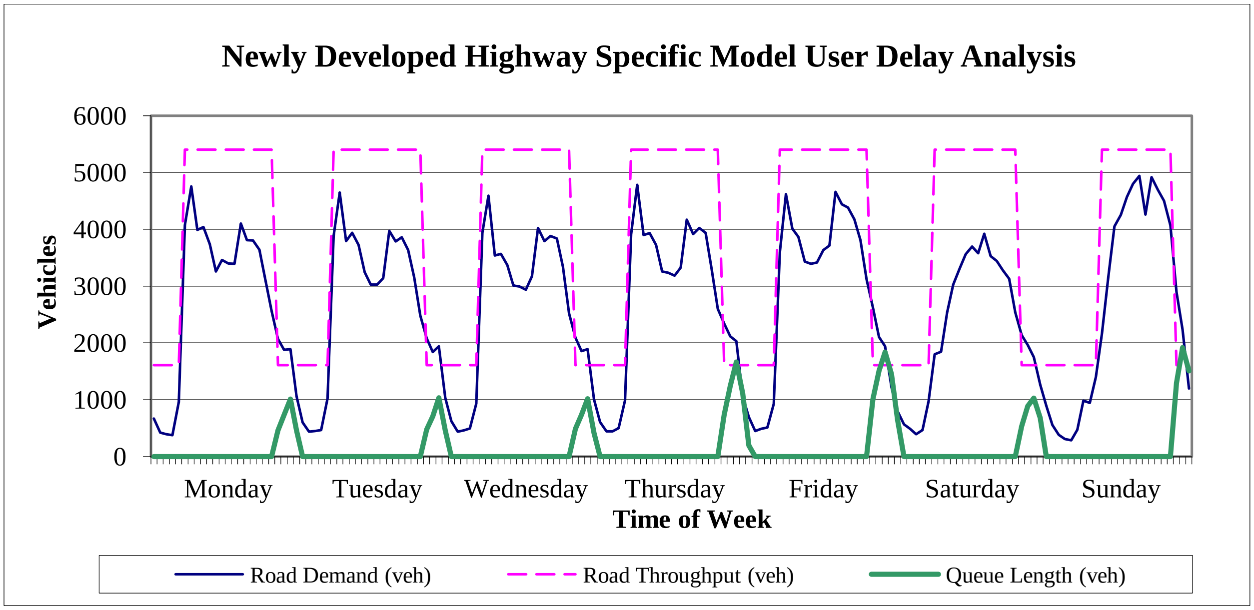


Figure 6.4 Graphical Output from SZUDA (HSM)

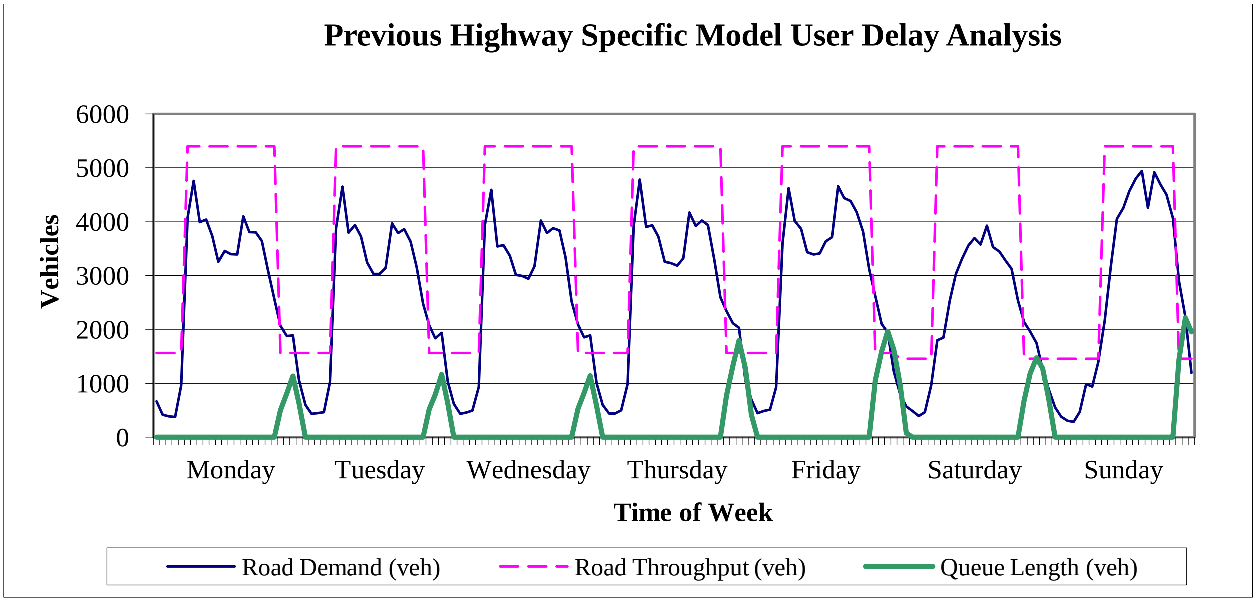


Figure 6.5 Graphical Output from SZUDA (HSM)

6.5 Case Study I

This case study uses the SZUDA model to examine various lane closure times. It examines adding an hour or two hours to the lane closure window to provide the contractor with a longer working shift. This additional time can significantly improve the productivity and can reduce the frequency and amount of cold joints in the pavement which results in improved quality. This is particularly important a many of the current construction projects involve pavement rehabilitation and thus ability to reduce construction cold joints will provide longer lasting pavements. This also means that the construction work will be completed sooner, and can lead to better pavement durability. The results herein provide a clear comparison of user delays by changing the lane closure schedule.

The case study uses throughput values and costs from the calculations performed in the SZUDA work sheet and the data used for the normal hourly traffic from a west bound section of Highway 401 in Oshawa. Table 6.6 provides desired road closure charts which allow delaying the start of the lane closure as well as adding an hour or two of the lane closure to expedite the construction activity.

Table 6.6 Alterations to Lane Closure Times on Friday night and Sunday Morning

Construction Hours (0=Lane Open, 1=Left Lane Closed, 2=Right Lane Closed, 3=Police Presence (Right Lane), 4= Police Presence (Left Lane), >> Change in Status for example)							
Hour	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
0:00	1	1	1	1	1	1	1
1:00	1	1	1	1	1	1	1
2:00	1	1	1	1	1	1	1
3:00	1	1	1	1	1	1	1
4:00	1	1	1	1	1	1	1
5:00	0	0	0	0	0	1	1
6:00	0	0	0	0	0	0>>1	1
7:00	0	0	0	0	0	0>>1	1
8:00	0	0	0	0	0	0	1
9:00	0	0	0	0	0	0	0>>1
10:00	0	0	0	0	0	0	0
11:00	0	0	0	0	0	0	0
12:00	0	0	0	0	0	0	0
13:00	0	0	0	0	0	0	0
14:00	0	0	0	0	0	0	0
15:00	0	0	0	0	0	0	0
16:00	0	0	0	0	0	0	0
17:00	0	0	0	0	0	0	0
18:00	0	0	0	0	0	0	0
19:00	0	0	0	0	0	0	0
20:00	1	1	1	1	1>>0	1	0
21:00	1	1	1	1	1	1	1
22:00	1	1	1	1	1	1	1
23:00	1	1	1	1	1	1	1

As shown in the Figure 6.4, a significant queue is likely to form on the Friday night and by delaying the lane closure by one hour, 8PM to 9PM, this can improve the throughput and reduce the queue by 67% from 6009 (vehicles*hour) to 1961 (vehicles*hour), as shown in Table 6.7 (shaded yellow). This delaying in the lane closure by one hour also improves the throughput for Saturday and reduces the queue by 17% (Shaded green).

Table 6.7 SZUDA Result of Various Lane Closure Scenarios

User Delay (Vehicle * Hour)								
	Mon	**Tue**	**Wed**	**Thu**	**Friday**	**Sat**	**Sunday**	**Week Total**
Original Lane Closures	2655	2674	2646	4747	6009	3768	4711	27210
Friday Closing Delayed (From 9PM)	2655	2674	2646	4747	**1961**	**3123**	4711	22517
Saturday/Sunday Opening Delayed	2655	2674	2646	4747	**1961**	**3745**	**5268**	23696

During the case study, the lane closure times have also been extended to improve the productivity of construction activity and that impacts the user delay costs. In this case, adding two hours of lane closure time to Saturday morning and one hour on Sunday morning as shown in Table 6.6 may improve the productivity and provide the contractor with a longer work shift in which to complete continuous work. As shows in Table 6.7 (shaded yellow) very little impact on user delays where only 10% drop in the throughput. The graphical results can be seen by comparing Figure 6.4 and Figure 6.6.

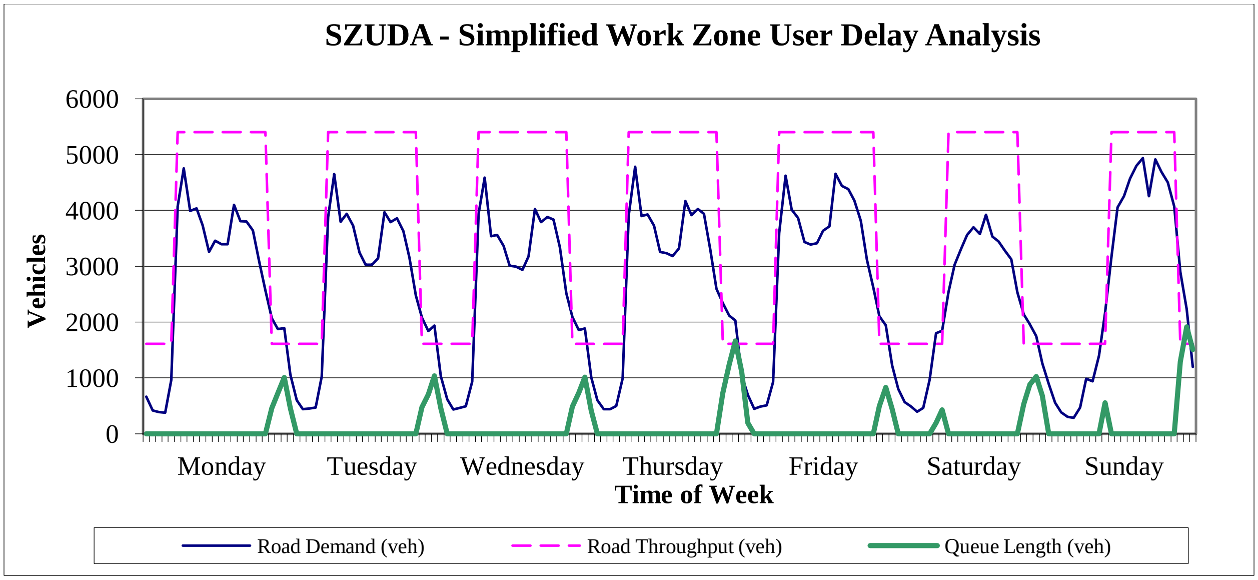


Figure 6.6 SZUDA Result of Changes to Lane Closure Schedule

As mentioned previously the maximum service flow rate at the highway segments is determined as 1800 vphpl and the delay cost suggested by MTO is $ 15 for mixed traffic in the year 2002 has been increased to $24 based on the inflation rate. Using Equation 6-1, Table 6.8 provides the total delay cost site experiencing the forced flow condition during that construction work zone week.

$$P2 = P1 \times \left(1 + \frac{r}{100}\right)^{t} \qquad \text{Equation 6-1}$$

Where:

P2	=	Current User Delay Cost ($)
P1	=	User Delay Cost for the Year 2002 ($)
r	=	Interest Rate (%)
t	=	Number of Years

Table 6.8 SZUDA Result for User Delay Cost

	User Delay Week Total (Veh./Week)	**Delay Cost ($/Hr/Veh)**	**User Delay Cost ($/Week)**
Original Lane Closures	27210	$24	$653040
Friday Closing Delayed (From 9PM)	22517	$24	$540408
Saturday/Sunday Opening Delayed	23696	$24	$568704

The results of case study I show that by delaying the lane closure time by one hour during the peak hours, it will result in a significant drop on the user delay costs and associated queuing as shown in Table 6.8. Overall, the total amount saved towards the user delay cost is $84,336 for the week and two hours of extra lane closure time for the contractor to improve productivity and quality of work which can lead towards the savings on future maintenance costs.

It is important to note that if the hourly traffic data is available for the area or specific highway section, the road closures can be better planned to reduce delays based on the section of highway. Also, the SZUDA model can provide MTO decision makers with a customize lane closure schedules to both maximize contractor opportunities and minimize user delays.

There are some weaknesses of SZUDA model in its current state is that the queues are evaluated at the end of each hour and the vehicles in the queue at the point in time were not necessarily in the queue the entire hour. Therefore, SZUDA model over-estimated the road user delay cost.

6.6 Case Study II

This case study is based on the real time data collection in this research on Hwy QEW Burlington location. A simplified method has been used to calculate the user delay cost in this case. The case study is based on the hypothesis that construction work zones reduce the traffic flow and result in an economic loss to road users. Table 6.9 provides all the site information with actual throughput count (vphpl) during the forced flow condition. The total vehicle per hour per lane traffic count is compared with the normal capacity of the highway segments of 1800 (vphpl) to determine the total reduction in the throughput capacity. The reduction is than converted into a total reduction using the forced flow time site, whereas, the forced flow time is the time that particular site experienced delays during the construction in that particular day. Using Equation 6-1, the suggested per hour per vehicle delay cost would be $ 24 for mixed traffic assuming the inflation rate of 6% for eight years time. Table 6.9 provides the total delay cost of each site experiencing the forced flow condition during that construction work zone hour.

Table 6.9 Total Reduction and User Delay Costs (Hwy QEW)

Site Code	Actual Throughput (vphpl)	MTO (vphpl)	Reduction with MTO (vphpl)	Forced Flow Time (hours)	Total Reduction	Delay Cost ($/hour)	Total Delay Cost ($ each day)
hQEWaS2	1198	1800	602	1.25	753	$24	$18,060
hQEWaS3	827	1800	973	0.75	730	$24	$17,514
hQEWaS4	1323	1800	477	1.5	716	$24	$17,172
hQEWaS6	1281	1800	519	0.75	389	$24	$9,342
hQEWaS7	1474	1800	326	1	326	$24	$7,824
hQEWaS8	1340	1800	460	1	460	$24	$11,040
hQEWaS9	1234	1800	566	0.75	425	$24	$10,188
hQEWaS10	1267	1800	533	1.75	933	$24	$22,386
hQEWaS11	1235	1800	565	2.75	1554	$24	$37,290
hQEWaS12	1308	1800	492	0.75	369	$24	$8,856
hQEWaS13	1421	1800	379	1.5	569	$24	$13,644
hQEWaS14	1122	1800	678	2.5	1695	$24	$40,680
hQEWbS1	1468	1800	332	0.5	166	$24	$3,984
hQEWbS2	1233	1800	567	1	567	$24	$13,608
hQEWdS1	1147	1800	653	2.5	1633	$24	$39,180
hQEWdS2	814	1800	986	2	1972	$24	$47,328
hQEWdS3	912	1800	888	2.5	2220	$24	$53,280
hQEWdS4	1034	1800	766	1.75	1341	$24	$32,172
hQEWdS5	1023	1800	777	2.5	1943	$24	$46,620

In total, 29 hours of forced flow condition (throughput delays) from 19 different sections of Hwy QEW were calculated. The total user delay cost is $450,168 for all the sites which experienced the forced flow condition. On average, $15,523 in delay costs has been calculated for each hour during construction lane closure. For example, if a site has closed one lane for 10 hours and the site experience three hours of forced flow condition, then the total approximate user delay cost of that site will be $46,569 for each day.

The same protocol has been used with the newly proposed highway specific model predicted values with the base capacity of 1753 with some significant variables to calculate the impact of user delay cost shown in Table 6.10.

Table 6.10 User Delay Cost (Hwy QEW)

Site Code	Actual Throughput (vphpl)	Highway Specific Model (vphpl)	Reduction (vphpl)	Forced Flow Time (Hours)	Total Reduction (vphpl)	Delay Cost ($/hour)	Total Delay Cost ($/day)
hQEWaS2	1198	1185	-13	1.25	0	$24.00	$0
hQEWaS3	827	1064	237	0.75	178	$24.00	$4,266
hQEWaS4	1323	1144	-179	1.5	0	$24.00	$0
hQEWaS6	1281	1233	-48	0.75	0	$24.00	$0
hQEWaS7	1474	1233	-241	1	0	$24.00	$0
hQEWaS8	1340	1233	-107	1	0	$24.00	$0
hQEWaS9	1234	1233	-1	0.75	0	$24.00	$0
hQEWaS10	1267	1144	-123	1.75	0	$24.00	$0
hQEWaS11	1235	1144	-91	2.75	0	$24.00	$0
hQEWaS12	1308	1153	-155	0.75	0	$24.00	$0
hQEWaS13	1421	1144	-277	1.5	0	$24.00	$0
hQEWaS14	1122	1144	22	2.5	55	$24.00	$1,320
hQEWbS1	1468	1064	-404	0.5	0	$24.00	$0
hQEWbS2	1233	1153	-80	1	0	$24.00	$0
hQEWdS1	1147	1025	-122	2.5	0	$24.00	$0
hQEWdS2	814	1025	211	2	422	$24.00	$10,128
hQEWdS3	912	937	25	2.5	63	$24.00	$1,500
hQEWdS4	1034	1025	-9	1.75	0	$24.00	$0
hQEWdS5	1023	945	-78	2.5	0	$24.00	$0

The case study indicates that the newly proposed highway specific model performs better. Only four occasions (shaded yellow) the actual throughput exceeds the highway specific model predicted throughput values. Overall this results in a drop of the user delay costs. The results of this case study show that there is a need to consider user delay costs during the planning process of the project to minimize the construction work zone delays.

6.7 Case Study III

This case study is based on the data collected in this research on Hwy 401 at Milton. Similar to case study II, the user delay costs have been calculated during the forced flow conditions. Table 6.11 provides the site information of Hwy 401 with the actual throughput count (vphpl) of various sites during the forced flow condition. Using Equation 6-1, the suggested per hour per vehicle delay cost would be $ 24 for mixed traffic assuming the inflation rate of 6% for eight years time. Table 6.11 provides the total delay cost of each site experiencing the forced flow condition during that construction work zone hour.

Table 6.11 Total Reduction and User Delay Costs (Hwy 401)

Site Code	Actual Throughput (vphpl)	MTO (vphpl)	Reduction with MTO (vphpl)	Forced Flow Time (hours)	Total Reduction (vphpl)	Delay Cost ($/hour)	Total Delay Cost ($ each day)
h401aS1	884	1800	916	1	916	$24	$21,984
h401aS2	1043	1800	757	0.75	568	$24	$13,626
h401aS3	1020	1800	780	1	780	$24	$18,720
h401aS4	803	1800	997	0.75	748	$24	$17,946
h401aS5	1037	1800	763	1.25	954	$24	$22,890
h401aS6	1097	1800	703	1	703	$24	$16,872
h401aS7	872	1800	928	1.25	1160	$24	$27,840
h401aS8	944	1800	856	1.75	1498	$24	$35,952
h401bS1	1040	1800	760	2	1520	$24	$36,480
h401bS2	1012	1800	788	1	788	$24	$18,912
h401bS3	1188	1800	612	2	1224	$24	$29,376
h401bS4	1122	1800	678	1.25	848	$24	$20,340
h401bS5	988	1800	812	0.5	406	$24	$9,744
h401bS6	832	1800	968	3.25	3146	$24	$75,504
h401dS1	1693	1800	107	4	428	$24	$10,272
h401eS1	862	1800	938	1	938	$24	$22,512
h401eS2	922	1800	878	1.25	1098	$24	$26,340

Overall, 25 hours of forced flow condition (throughput delays) from 17 different sections of Hwy 401 data was used to calculate the user delay cost. The dollar amount of $425,310 at all of the sites experienced the forced flow condition with an average of $17,012 delays for each hour of the construction lane closure. For example, if the site has had a lane closure for 10 hours and the site experienced three hours of forced flow condition, then the total approximate user delay cost of that site will be $51,037 for each day.

The same protocol has been used with the newly proposed highway specific model predicted values with the base capacity of 1753 with some significant variables to calculate the impact of user delay cost shown in Table 6.12.

Table 6.12 User Delay Cost (Hwy 401)

Site Code	Actual Throughput (vphpl)	Highway Specific Model (vphpl)	Reduction (vphpl)	Forced Flow Time (hours)	Total Reduction (vphpl)	Delay Cost ($/hour)	Total Delay Cost ($/day)
h401aS1	884	1096	212	1	212	$24	$5,088
h401aS2	1043	1096	53	0.75	40	$24	$954
h401aS3	1020	1096	76	1	76	$24	$1,824
h401aS4	803	987	184	0.75	138	$24	$3,312
h401aS5	1037	1026	-11	1.25	0	$24	$0
h401aS6	1097	1106	9	1	9	$24	$216
h401aS7	872	1106	234	1.25	293	$24	$7,020
h401aS8	944	1026	82	1.75	144	$24	$3,444
h401bS1	1040	1066	26	2	52	$24	$1,248
h401bS2	1012	1066	54	1	54	$24	$1,296
h401bS3	1188	1106	-82	2	0	$24	$0
h401bS4	1122	1106	-16	1.25	0	$24	$0
h401bS5	988	1026	38	0.5	19	$24	$456
h401bS6	832	1026	194	3.25	631	$24	$15,132
h401dS1	1693	1608	-85	4	0	$24	$0
h401eS1	862	1195	333	1	333	$24	$7,992
h401eS2	922	1115	193	1.25	241	$24	$5,790

The results of this case study indicate that the newly proposed highway specific model has slightly lower user delay costs of $ 53,772 as compare to the older models based on throughput.

6.8 Summary

This chapter gives a brief description of the SZUDA model and the associated analysis of the model. The model is a simple spread sheet based model, designed to calculate the user delay cost. The model has been updated with the base capacity and significant variables of the newly developed GM and HSM. A chart has been developed to give an overall view of the model inputs and data requirements. Furthermore, the chapter also discussed the inputs and outputs of the model with some results in numerical and graphical format. The result show that the newly developed generic model and highway specific model are more realistic and the base throughput capacity is close to MTO values of 1800 vphpl. Three case studies are presented in which the results shows that delaying the lane closure time by one hour during the peak hours will result in a significant drop on the user delay cost. This shows that adding an hour or two to the lane closure time can improve productivity and the quality of the construction work which can lead towards the saving on future maintenance costs. SZUDA can provide MTO decision makers with a means to customize lane closure schedules to both maximize contractor opportunities and minimize user delays. MTO will then be able to compare the vehicle delays depicted in this model to tolerances acceptable to the road users.

Chapter 7 Conclusions and Recommendations

7.1 Conclusions

In this study the throughput data obtained for the Highway Infrastructure Innovation Funding Program (HIIFP) under the Ministry of Transportation Ontario research project was used to develop throughput capacity models for Southern Ontario highways. The research was conducted in two phases during the course of four construction season from 2007 to 2010 and has been carried out with the cooperation of the University of Toronto. The models developed in the phase I of the study have been presented in Section 1.2. In phase II of the research the data were collected on most of the sites and 53 of these site visits were with the forced flow condition from 15 different projects on Hwy 400, 401, 417, 427 and Hwy QEW. In total, 84 days were spent on sites and 81 hours of 15 minute data segments were collected from various construction work zone sites.

The new improved generic model was developed to fit to the Southern Ontario highways, which provides better predictions than the phase I generic model and the capacity models found in the literature. The base capacity value is close to the MTO 1800 vphpl capacity value. The model is an additive model that employs a base throughput capacity of 1727 vphpl with the reduction in the base capacity due to some significant variable.

Construction Lane Throughput = 1727 – 490*B – 111*P – 95*L – 83*R

Where:

B = 1 if barrels; 0 if concrete barriers used

P = 1 if police is presence; 0 otherwise

L = 1 if 2 or more lanes closed; 0 otherwise

R = 1 if right lane closed; 0 otherwise

Furthermore, the improvement on the highway specific model had also been made and a new model was developed to fit the situation of specific highways of Southern Ontario such as Hwy 400/ 401, 427 or Hwy QEW. The highway specific model is an additive model which includes the base capacity of 1753 vphpl throughput during the construction work zones with the reduction in the throughput due to some significant variables.

Construction Lane Throughput = 1753 – 145*D_A – 107*D_B – 413*B – 119*P – 89*L – 80*R

Where:

D_A = 1 if Hwy 400/ 401; 0 otherwise

D_B = 1 if Hwy QEW; 0 otherwise

B = 1 if barrels; 0 if concrete barriers used

P = 1 if police is presence; 0 otherwise

L = 1 if 2 or more lanes closed; 0 otherwise

R = 1 if right lane closed; 0 otherwise

During this research the models developed to predict work zones throughput show that fewer vehicles can pass through a construction work zone than the design values that MTO currently uses. To minimize the traffic delays due to low throughput in the work zones, the lane closure timing should be reduced. However, during the phase of the data collection period a number of construction work zone sites did not display queuing, even though their closure times were based on the same assumptions, practices, and policies. These two contradicting results direct this study to a conclusion that more restrictive closure timings are needed which can benefit both the road users and the contractors.

The user delay costs associated with the construction work zones are very important and these need to be quantified appropriately. These user delay cost estimates can provide transportation agencies with their decisions while selecting any projects. The user delay cost calculation is based on Simplified work Zone User Delay Analysis (SZUDA) model, which was developed during phase I of this research. The SZUDA model can estimate the user delay cost and the impacts of lane closure strategies on traffic delays, measured as number of vehicles delayed at some point during the hour. The modified SZUDA model helps to provide a better understanding of the relation between the throughput, and the work zone significant variables or site characteristics.

7.2 Recommendations

It is recommended that efficient and effective construction, rehabilitation and maintenance methods should be applied to make sure all the procedures and protocols are clearly understood and followed by all highway agencies. It is necessary to have a good communication and share the information among designers, contractors and other highway agencies, especially to the general public. There is a need to introduce smarter highway technology in which high-tech overhead signs will display variable speed limits, lane status and real-time traffic information, so drivers know what is happening ahead. This smarter highway technology will increase roadway efficiency and help drivers travel more safely. It is also recommended that the late-merge techniques can be applied at the busy or heavy throughput construction work zones. Dynamic late-merge technique can smooth out the traffic flow and hence can help in reducing the length of the queues at busy construction work zone sites.

During the data collection some of the work zone sites have lane closures with more than one lane open and for the model development the throughput were calculated as vphpl, so the collected data were divided by the number of lanes to have vphpl. It is recommended that the throughput data should be collected for each lane separately because lane parallel to the work zone may have lower throughput than the other lane. It is also recommended to use the automated traffic counting devices along-with the manual traffic count for data collection to provide consistency in practice.

Designing of shoulders on high volume roads is one of the recommendations to accommodate future construction, rehabilitation and maintenance activities. Presence of police on work zones can improve the safety for the motorist as well as the construction workers. It is important to have some improvement in construction work zone engineering practices by enforcement of traffic laws and regulations, education to the drivers, designers, and highway workers, and improvement in the agency policies and procedures.

During the night time lane closure it is recommended that continuous checking to traffic control devices by the traffic control crew is vital to ensure all the devices are in working condition and at proper location and position. It was found that conveying information to road users was lacking and the signs that indicated when and where closures were to occur were not always up to date. Devices that are damaged, dislodged or not clear must be adjusted and replaced quickly to maintain smooth traffic flow and safe operation.

It is recommended that MTO continue to collect data from construction work zone sites with differing conditions and locations. The new set of data collection can be further used to test the accuracy of newly proposed generic and highway specific models during this research. The increased amount of data will allow models to be refined providing for more accurate throughput estimate and the costs incurred due to user delay.

Additionally, the modified SZUDA model helps in determining the throughput by using significant variables input codes which mean that SZUDA allows the user to specify characteristics specific to the site they are working on. SZUDA model is easy to use and by adopting SZUDA model will help in determining the suitable times with regards to lane closure times for road closures. The SZUDA model can also be further developed by refining the model based on additional data and adding sensitivity to the evaluation through interpolation of the hourly normal traffic volumes.

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Appendix A: Project Data

This appendix holds all the data collected from the sites with forced flow condition for this project. The document is organized in such a manner that all the information of one site is placed as one annexure in a sequence.

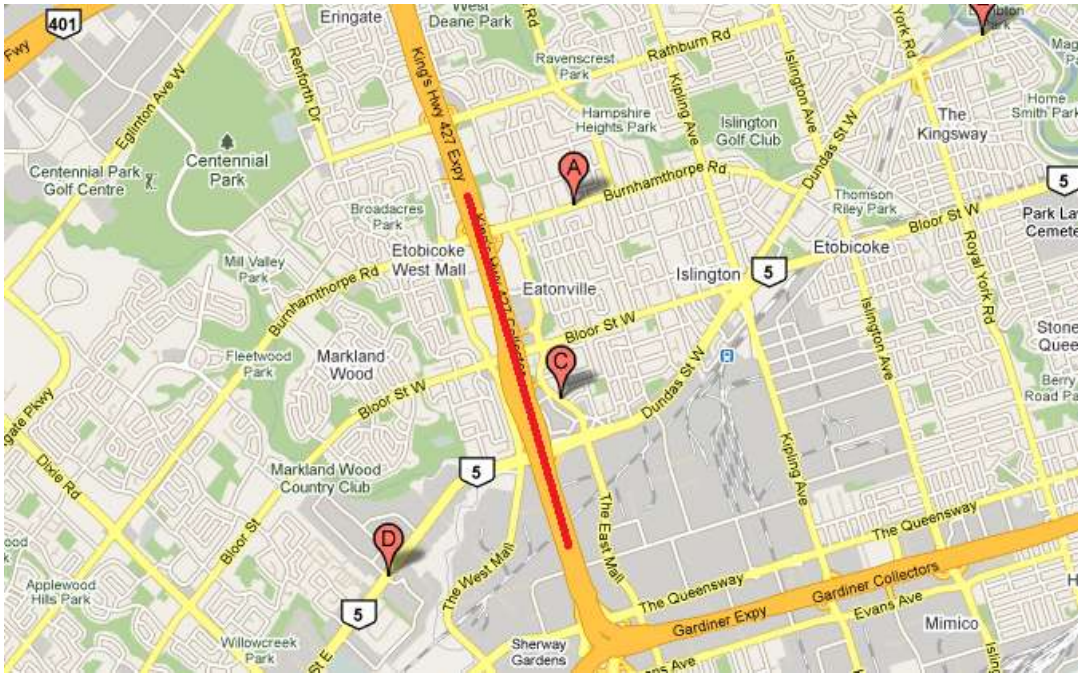
Site 1 2008-2003, Hwy 427 N.

1. Site Visit 1 – July 30, 2009

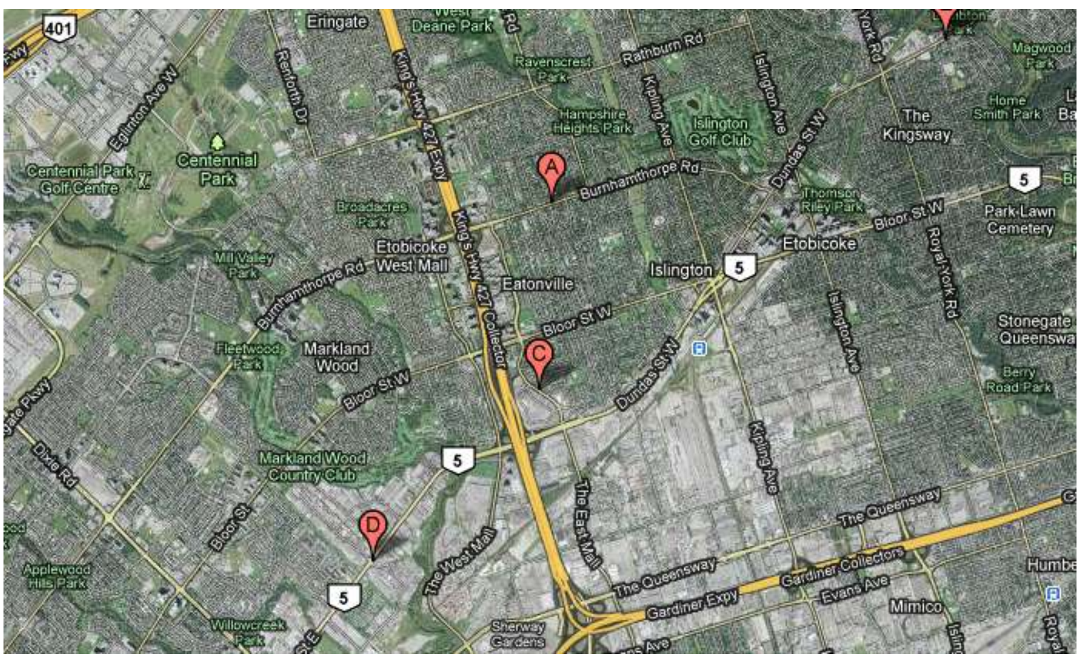
1.1 Site Characteristics Form for Site 2008-2003

Date	30-Jul
Name of the Site	2008-2003
Location	427- Browns Line to The Queens Way
Weather	Clear
Starting Time	10:18 PM
End Time	
Day of Week	Thursday
Time of Day	Night
Assigned Lane	2 Right Lanes open
Lane Width (m)	3.75
Direction of Traffic	NB Collector
Shoulder Type	Grooved (No shoulder in Open lanes)
Lane Closure	3-to-2
OPP Presence	N/A
Time of OPP Presence	N/A
Facility Type	
Driver Population	
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	
Duration of Closure	22:00-05:00
Intersections	Browns Line to Queens Way
Type of Traffic Control	Barrels
Pavement Condition	Fully Paved
Distractions	
List of Photos Taken	**#1,2. 427 NB Collector Looking North, #3,4. 427 NB collector looking south**
Other Comments	***An on ramp is located at the end of the closure***

1.2 Map of Location of Site 2008-2003



1.3 Aerial View of Site 2008-2003



1.4 Data Collected from Site 2008-2003 on July 30, 2009

Evaluation Days July 30, September 03, 19

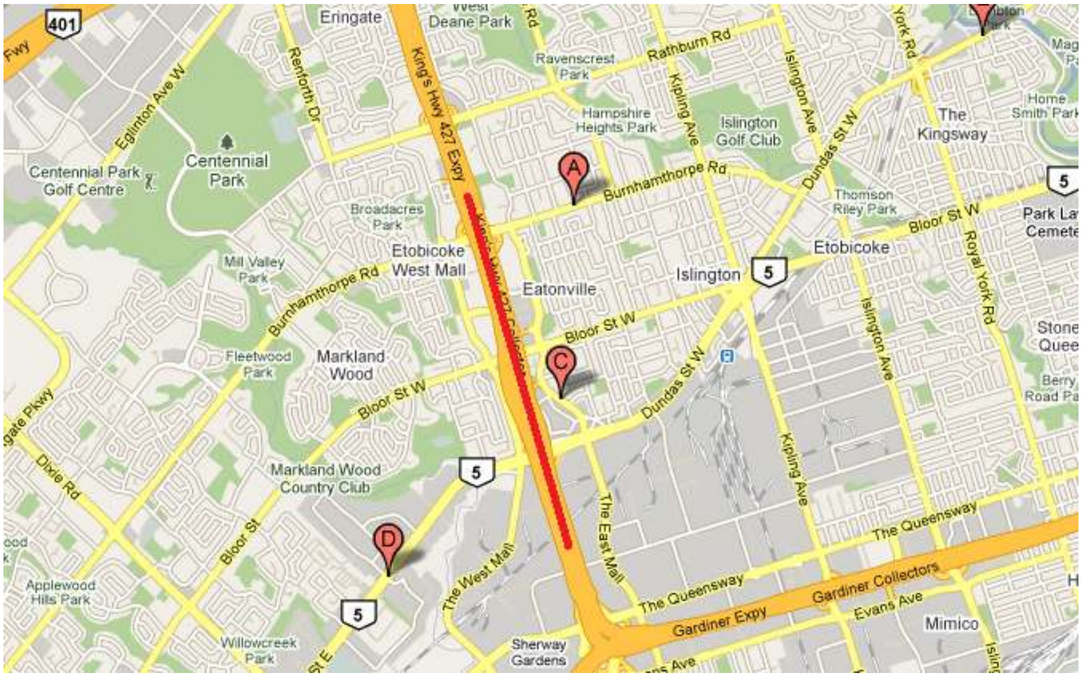
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
22:18:00	22:33:00	0:15:00	597	-	-	19	0	15	0	0.25	1194	0	0	38	1232
22:33:00	22:48:00	0:15:00	540	-	-	27	0	15	0	0.25	1080	0	0	54	1134

2. Site Visit 2 – Sep 19, 2009

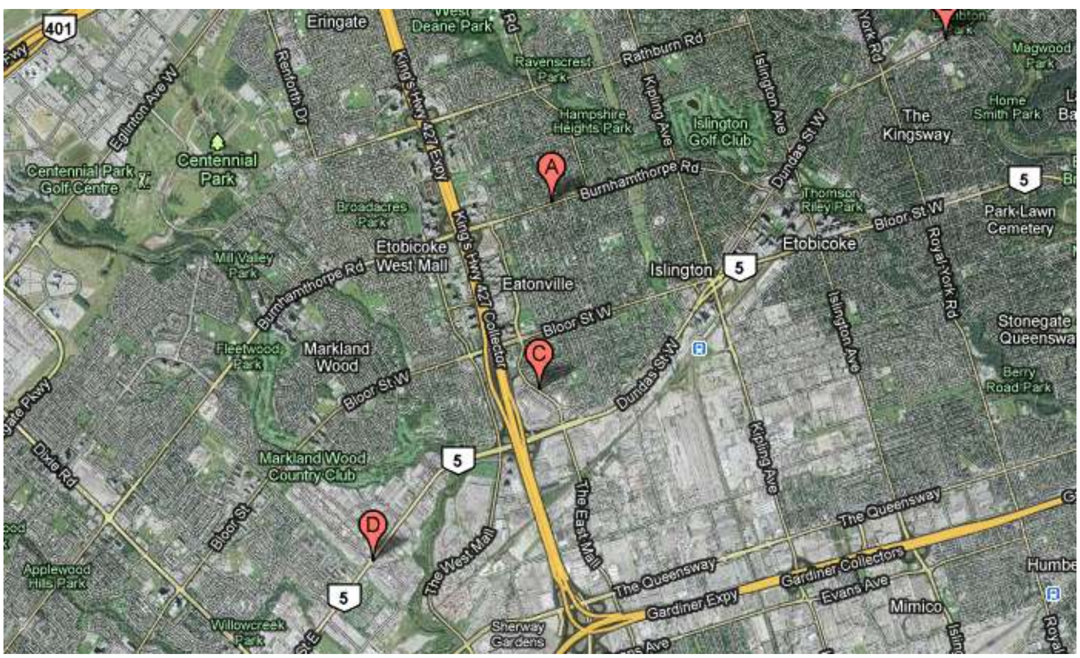
2.1 Site Characteristics Form for Site 2008-2003

Date	Sep 19/2009
Name of the Site	2008-2003
Location	Hwy 427 Exp, QEW to 401, Bloor/Burnhamthorpe
Weather	Clear
Starting Time	08:45pm
End Time	12:00am
Day of Week	Saturday
Time of Day	Night
Assigned Lane	Right lane only
Lane Width (m)	3.7 m
Direction of Traffic	NB
Shoulder Type	Paved Completely
Lane Closure	2 Left lanes + Shoulder
OPP Presence	-
Time of OPP Presence	-
Facility Type	6 Lane divided highway
Driver Population	Cars, Commuter Vehicles + some trucks
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	2km
Duration of Closure	22:00 - 5:00
Intersections	Hwy 427/Bloor-Burnhamthorpe
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated, TCB
Pavement Condition	Good
Distractions	Hard to get in the construction zone
List of Photos Taken	-
Other Comments	Need proper instruction for the CA on site

2.2 Map of Location of Site 2008-2003



2.3 Aerial View of Site 2008-2003



2.4 Data Collected from Site 2008-2003 on Sep 19, 2009

Evaluation Days July 30, September 03, 19

Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
21:40:00	21:54:00	-	291	-	-	6	0	15	0	0.25	1164	0	0	24	1212
21:57:00	22:11:00	-	308	-	-	3	0	15	0	0.25	1232	0	0	12	1256
22:14:00	22:28:00	-	327	-	-	2	0	15	0	0.25	1308	0	0	8	1324
22:38:00	22:52:00	-	318	-	-	6	0	15	0	0.25	1272	0	0	24	1320
22:55:00	23:09:00	-	336	-	-	1	0	15	0	0.25	1344	0	0	4	1352
23:12:00	23:26:00	-	311	-	-	4	0	15	0	0.25	1244	0	0	16	1276
23:37:00	23:51:00	-	304	-	-	3	0	15	0	0.25	1216	0	0	12	1240

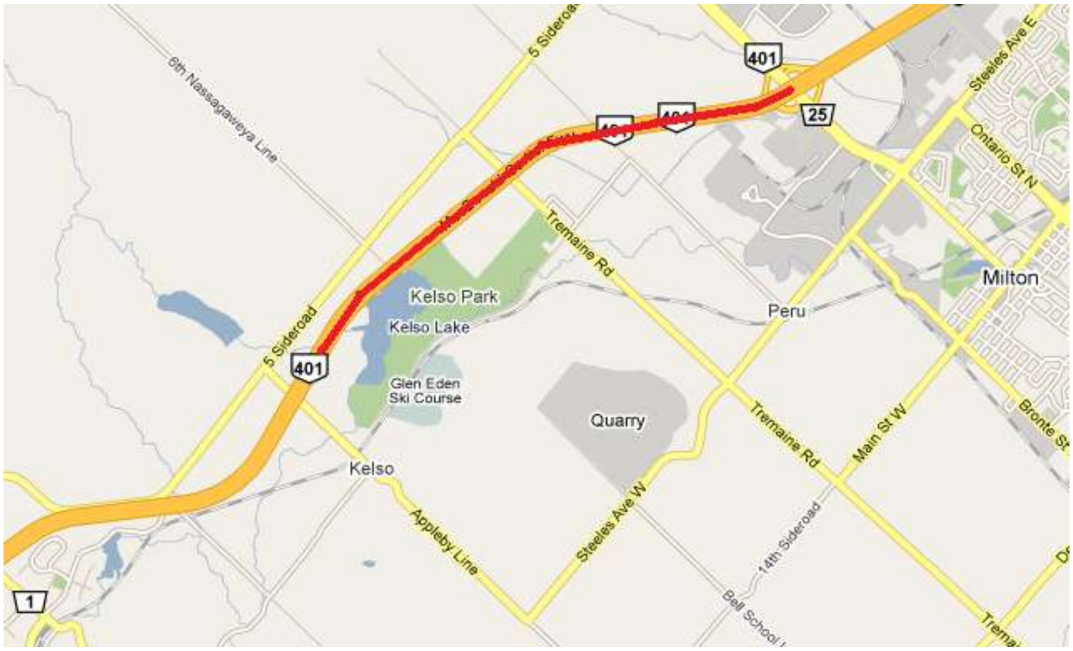
Site 2 2009-2021, Hwy 401Guelf line to HWY 25.

1. Site Visit 1 – Aug 10, 2009

1.1 Site Characteristics Form for Site 2009-2021

Date	10-Aug
Name of the Site	2009-2021
Location	401- Guelf line to HWY 25
Weather	Clear
Starting Time	11:13 PM
End Time	
Day of Week	Monday
Time of Day	Night
Assigned Lane	1 Right lane open-2 left lanes & left shoulder closed
Lane Width (m)	3.75
Direction of Traffic	WB
Shoulder Type	Grooved
Lane Closure	3-to-1
OPP Presence	N/A
Time of OPP Presence	N/A
Facility Type	Six Lane divided highway
Driver Population	
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	4.65Km
Duration of Closure	22:00-08:00
Intersections	Guelf line to HWY 25
Type of Traffic Control	Barrels
Pavement Condition	Fully Paved
Distractions	
List of Photos Taken	**#1. 401 WB Looking West, #2. 401 WB looking East, Video #1. 401 WB Looking at west & then East**
Other Comments	

1.2 Map of Location of Site 2009-2021



1.3 Aerial View of Site 2009-2021

1.4 Data Collected from Site 2009-2021 on Aug 10, 2009

Evaluation Days August 10, 24, 31, September 09, 30, Oct 01, 07 and 16

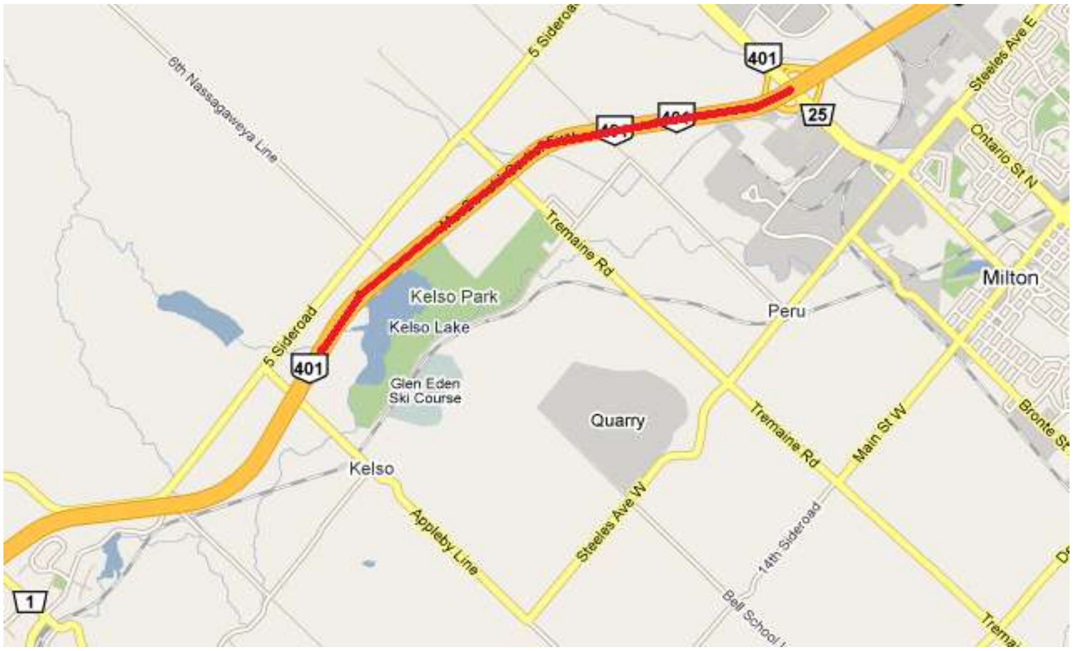
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:15:00	23:30:00	0:15:00	197	-	-	45	0	15	0	0.25	788	0	0	180	1148
23:31:00	23:48:00	0:15:00	167	-	-	55	0	15	0	0.25	668	0	0	220	1108
0:01:00	0:16:00	0:15:00	150	-	-	58	0	15	0	0.25	600	0	0	232	1064
0:19:00	0:34:00	0:15:00	177	-	-	39	0	15	0	0.25	708	0	0	156	1020

2. Site Visit 2 – Aug 24, 2009

2.1 Site Characteristics Form for Site 2009-2021

Date	24-Aug
Name of the Site	2009-2021
Location	401- Btw Ecquesing Line-Boston Church Rd.
Weather	Clear
Starting Time	11:02 PM
End Time	0:11
Day of Week	Monday
Time of Day	Night
Assigned Lane	1 right lane open-2 left lanes closed
Lane Width (m)	3.75
Direction of Traffic	East
Shoulder Type	Fully Paved
Lane Closure	3-to-1
OPP Presence	-
Time of OPP Presence	-
Facility Type	six lane divided highway
Driver Population	-
% Heavy Vehicles	-
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	5.4
Duration of Closure	-
Intersections	Ecquesing Line-Boston Church Rd.
Type of Traffic Control	Barrels
Pavement Condition	Fully Paved
Distractions	-
List of Photos Taken	**No photos available**
Other Comments	

2.2 Map of Location of Site 2009-2021



2.3 Aerial View of Site 2009-2021

2.4 Data Collected from Site 2009-2021 on Aug 24, 2009

Evaluation Days August 10, 24, 31, September 09, 30, Oct 01, 07 and 16

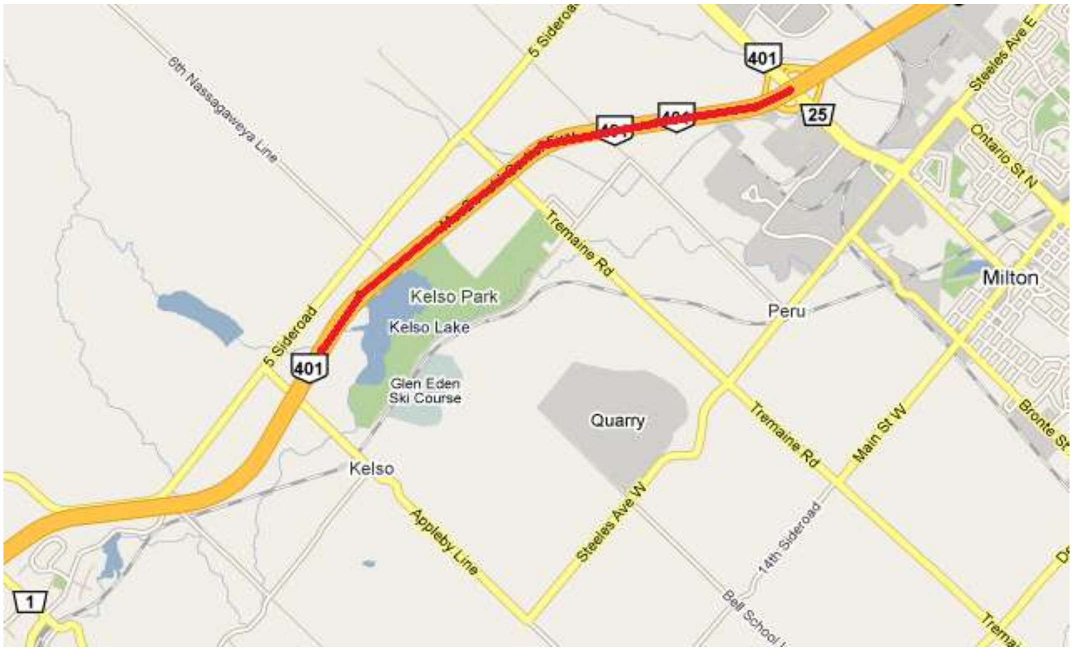
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:02:00	23:17:00	0:15:00	226	-	-	65	0	15	0	0.25	904	0	0	260	1424
23:20:00	23:35:00	0:15:00	174	-	-	78	0	15	0	0.25	696	0	0	312	1320
23:43:00	23:58:00	0:15:00	161	-	-	78	0	15	0	0.25	644	0	0	312	1268

3. Site Visit 3 – Aug 31, 2009

3.1 Site Characteristics Form for Site 2009-2021

Date	31-Aug
Name of the Site	2009-2021
Location	401- between 1st line and guelft line
Weather	Clear
Starting Time	10:33 PM
End Time	
Day of Week	Monday
Time of Day	Night
Assigned Lane	1 right lane open. 2 left lane and left shoulder closed
Lane Width (m)	3.75
Direction of Traffic	East
Shoulder Type	Gravel
Lane Closure	3-to-1
OPP Presence	-
Time of OPP Presence	
Facility Type	six lane divided highway
Driver Population	
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	8Km
Duration of Closure	-
Intersections	1st line and Guelf Line
Type of Traffic Control	Barrels
Pavement Condition	Fully Paved
Distractions	Presence of pavement machinery- hauling trucks parked on the behgining of the taper on the signle lane closure part
List of Photos Taken	**#1. Looking west on 401 EB, #2. Looking east on 401 EB**
Other Comments	

3.2 Map of Location of Site 2009-2021



3.3 Aerial View of Site 2009-2021

3.4 Data Collected from Site 2009-2021 on Aug 31, 2009

Evaluation Days August 10, 24, 31, September 09, 30, Oct 01, 07 and 16

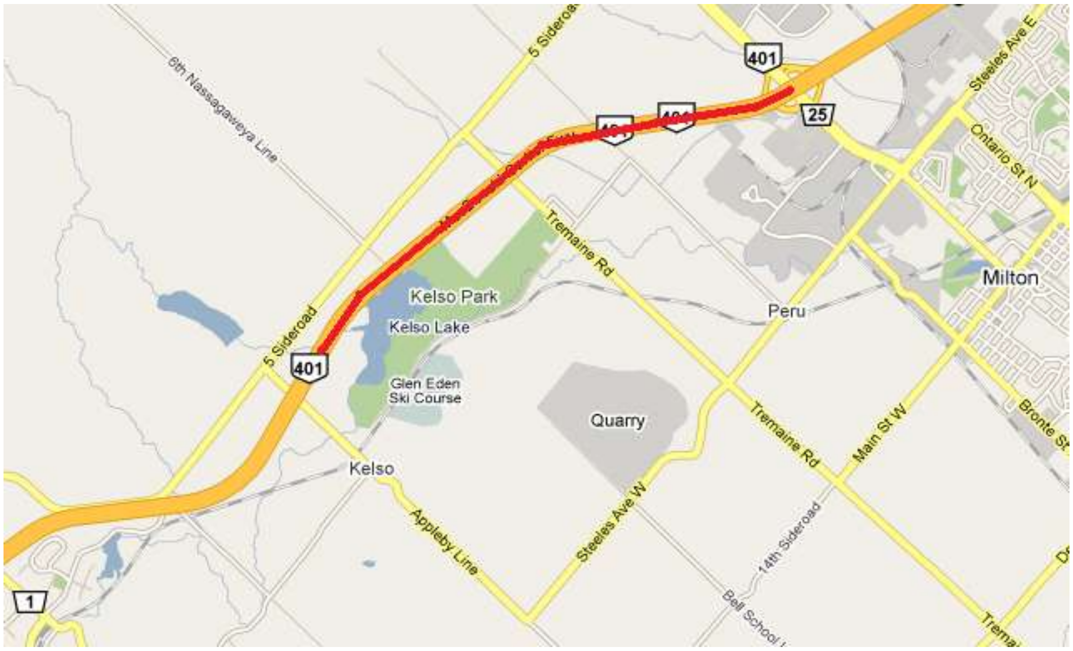
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
22:33:00	22:48:00	0:15:00	180	-	-	66	0	15	0	0.25	720	0	0	264	1248
22:49:00	23:04:00	0:15:00	204	-	-	64	0	15	0	0.25	816	0	0	256	1328
23:06:00	23:21:00	0:15:00	163	-	-	80	0	15	0	0.25	652	0	0	320	1292
23:22:00	23:37:00	0:15:00	168	-	-	95	0	15	0	0.25	672	0	0	380	1432

4. Site Visit 4 – Sep 09, 2009

4.1 Site Characteristics Form for Site 2009-2021

Date	Sep 09/2009
Name of the Site	2009-2021
Location	Hwy 401, Milton
Weather	Clear
Starting Time	12:00am
End Time	01:15am
Day of Week	Wednesday
Time of Day	Night
Assigned Lane	Left lane only
Lane Width (m)	3.7 m
Direction of Traffic	EB
Shoulder Type	Paved Completely
Lane Closure	2 Right lane + Shoulder
OPP Presence	-
Time of OPP Presence	-
Facility Type	6 Lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	3km
Duration of Closure	11am to 5am
Intersections	Hwy 401/Trafalgar
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated
Pavement Condition	Good
Distractions	-
List of Photos Taken	#1. Looking east on 401 EB, #2. Looking west on 401 EB
Other Comments	Traffic started to dissipate in middle of the last 15 min interval recorded

4.2 Map of Location of Site 2009-2021



4.3 Aerial View of Site 2009-2021

4.4 Data Collected from Site 2009-2021 on Sep 09, 2009

Evaluation Days August 10, 24, 31, September 09, 30, Oct 01, 07 and 16

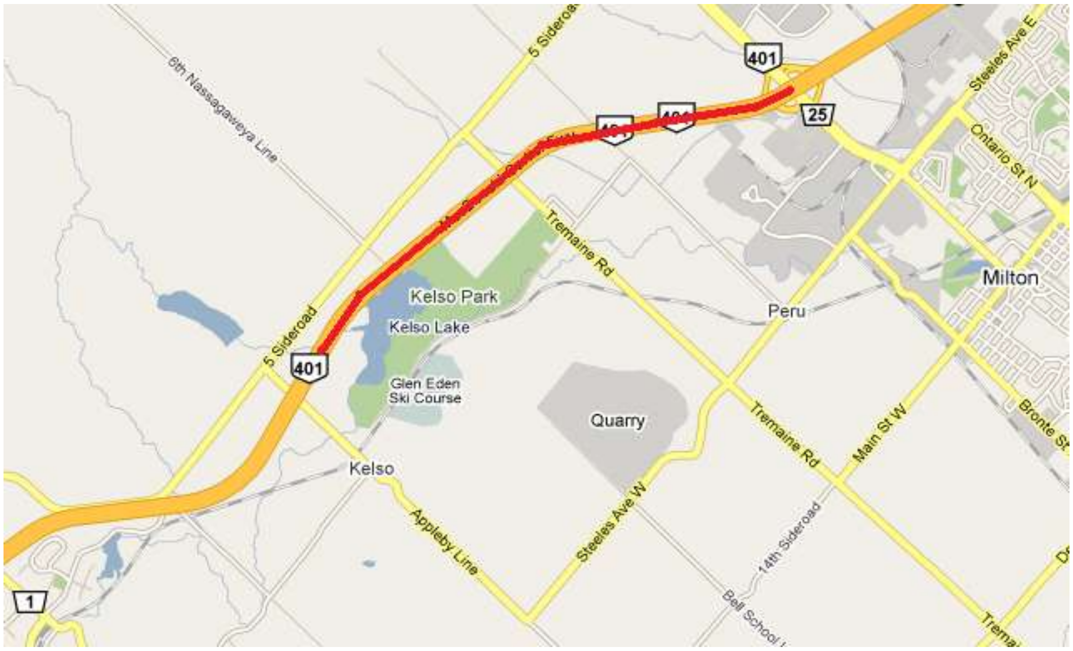
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
0:13:00	0:28:00	0:15:00	140	-	-	57	0	15	0	0.25	560	0	0	228	1016
0:30:00	0:45:00	0:15:00	146	-	-	64	0	15	0	0.25	584	0	0	256	1096
0:47:00	1:02:00	0:15:00	116	-	-	74	0	15	0	0.25	464	0	0	296	1056

5. Site Visit 5 – Sep 30, 2009

5.1 Site Characteristics Form for Site 2009-2021

Date	Sep 30/2009
Name of the Site	2009-2021
Location	Hwy 401, Milton
Weather	Clear
Starting Time	10:00pm
End Time	01:15am
Day of Week	Wednesday
Time of Day	Night
Assigned Lane	Left lane
Lane Width (m)	3.7 m
Direction of Traffic	WB
Shoulder Type	Paved Completely
Lane Closure	2 Right lane + Shoulder
OPP Presence	-
Time of OPP Presence	-
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	4km +
Duration of Closure	11:00pm to 05:00am
Intersections	Hwy 401 between James Snow /Hwy 25
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated
Pavement Condition	Good
Distractions	Construction Vehicles
List of Photos Taken	2
Other Comments	Data Collected

5.2 Map of Location of Site 2009-2021



5.3 Aerial View of Site 2009-2021

5.4 Data Collected from Site 2009-2021 on Sep 30, 2009

Evaluation Days August 10, 24, 31, September 09, 30, Oct 01, 07 and 16

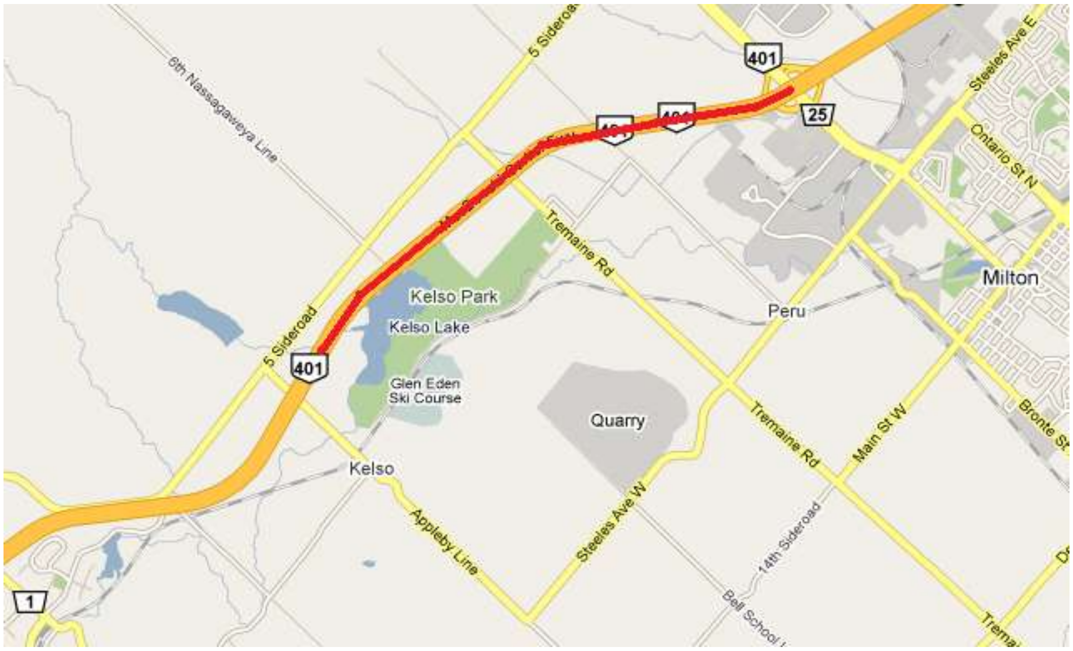
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:33:00	23:47:00	0:15:00	236	-	-	51	0	15	0	0.25	944	0	0	204	1352
23:50:00	0:04:00	0:15:00	241	-	-	57	0	15	0	0.25	964	0	0	228	1420
0:06:00	0:20:00	0:15:00	223	-	-	58	0	15	0	0.25	892	0	0	232	1356
0:30:00	0:44:00	0:15:00	183	-	-	51	0	15	0	0.25	732	0	0	204	1140
0:46:00	1:00:00	0:15:00	120	-	-	71	0	15	0	0.25	480	0	0	284	1048

6. Site Visit 6 – Oct 01, 2009

6.1 Site Characteristics Form for Site 2009-2021

Date	Oct 01/2009
Name of the Site	2009-2021
Location	Hwy 401, Milton
Weather	Clear
Starting Time	11:00pm
End Time	01:00am
Day of Week	Thursday
Time of Day	Night
Assigned Lane	Right lane
Lane Width (m)	3.7 m
Direction of Traffic	WB
Shoulder Type	Paved Completely
Lane Closure	2 Left lane + Shoulder
OPP Presence	-
Time of OPP Presence	-
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	4km +
Duration of Closure	11:00pm to 05:00am
Intersections	Hwy 401 between James Snow /Hwy 25
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated
Pavement Condition	Good
Distractions	Construction Vehicles
List of Photos Taken	2
Other Comments	Data Collected

6.2 Map of Location of Site 2009-2021



6.3 Aerial View of Site 2009-2021

6.4 Data Collected from Site 2009-2021 on Oct 01, 2009

Evaluation Days August 10, 24, 31, September 09, 30, Oct 01, 07 and 16

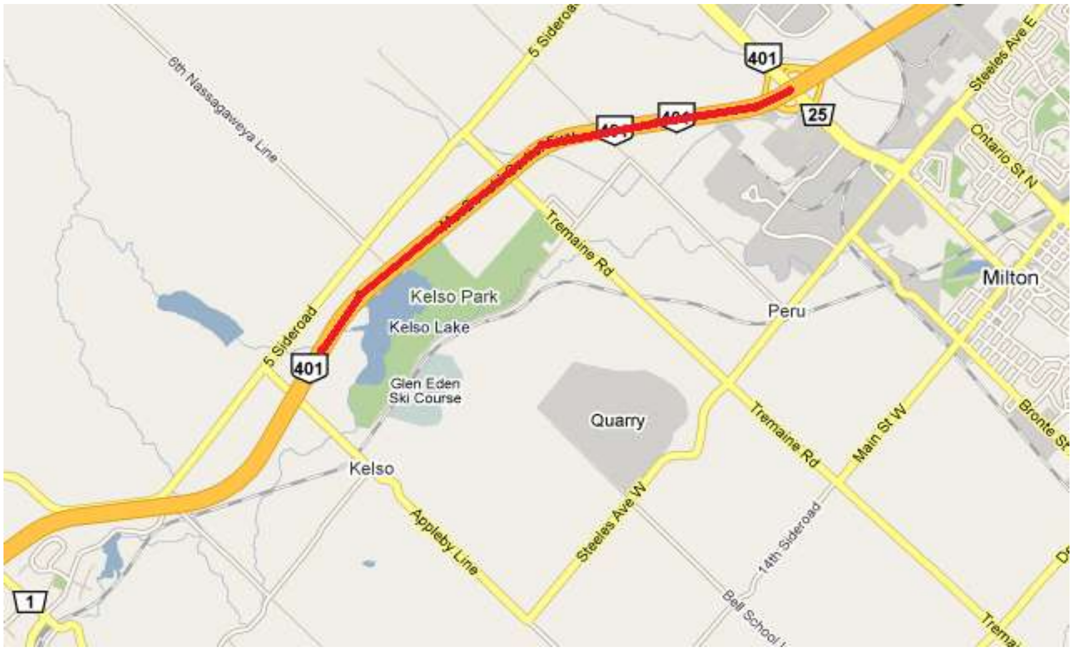
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:18:00	23:32:00	0:15:00	265	6	35	41	0	15	0	0.25	1060	24	140	164	1388
23:35:00	23:49:00	0:15:00	266	10	35	45	0	15	0	0.25	1064	40	140	180	1424
23:52:00	0:06:00	0:15:00	235	8	51	59	0	15	0	0.25	940	32	204	236	1412
12:17:00	0:31:00	0:15:00	118	4	47	51	0	15	0	0.25	472	16	188	204	880

7. Site Visit 7 – Oct 07, 2009

7.1 Site Characteristics Form for Site 2009-2021

Date	Oct 07/2009
Name of the Site	2009-2021
Location	Hwy 401, Milton
Weather	Clear
Starting Time	10:50pm
End Time	01:10am
Day of Week	Wednesday
Time of Day	Night
Assigned Lane	Right lane
Lane Width (m)	3.7 m
Direction of Traffic	WB
Shoulder Type	Paved Completely
Lane Closure	2 Left lane + Shoulder
OPP Presence	-
Time of OPP Presence	-
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	4km +
Duration of Closure	11:00pm to 05:00am
Intersections	Hwy 401 between Hwy 25/Exit 320
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated
Pavement Condition	Good
Distractions	Construction Vehicles
List of Photos Taken	2
Other Comments	Data Collected

7.2 Map of Location of Site 2009-2021



7.3 Aerial View of Site 2009-2021

7.4 Data Collected from Site 2009-2021 on Oct 07, 2009

Evaluation Days August 10, 24, 31, September 09, 30, Oct 01, 07 and 16

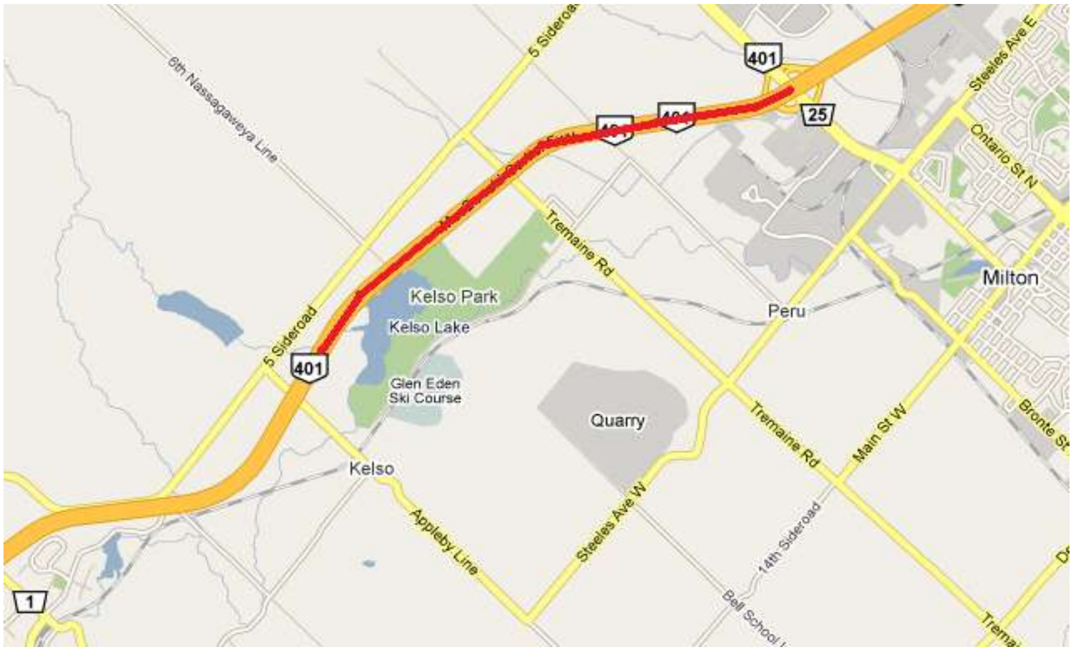
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:15:00	23:29:00	0:15:00	162	15	40	55	0	15	0	0.25	648	60	160	220	1088
23:32:00	23:46:00	0:15:00	192	11	31	42	0	15	0	0.25	768	44	124	168	1104
23:49:00	0:03:00	0:15:00	177	4	37	41	0	15	0	0.25	708	16	148	164	1036
0:10:00	0:24:00	0:15:00	136	8	57	65	0	15	0	0.25	544	32	228	260	1064
0:27:00	0:41:00	0:15:00	70	9	44	53	0	15	0	0.25	280	36	176	212	704

8. Site Visit 8 – Oct 16, 2009

8.1 Site Characteristics Form for Site 2009-2021

Date	Oct 16/2009
Name of the Site	2009-2021
Location	Hwy 401, Milton
Weather	Clear
Starting Time	10:30pm
End Time	02:00am
Day of Week	Friday
Time of Day	Night
Assigned Lane	left lane
Lane Width (m)	3.7 m
Direction of Traffic	WB
Shoulder Type	Paved Completely
Lane Closure	2 right lane + Shoulder
OPP Presence	-
Time of OPP Presence	-
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	4km +
Duration of Closure	11:00pm to 09:00am
Intersections	Hwy 401 West of Gulph Line
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated
Pavement Condition	Good
Distractions	Construction Vehicles, Dumping Trucks
List of Photos Taken	2
Other Comments	Data Collected

8.2 Map of Location of Site 2009-2021



8.3 Aerial View of Site 2009-2021

8.4 Data Collected from Site 2009-2021 on Oct 16, 2009

Evaluation Days August 10, 24, 31, September 09, 30, Oct 01, 07 and 16

Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:02:00	23:16:00	0:15:00	247	8	16	24	0	15	0	0.25	988	32	64	96	1180
23:19:00	23:33:00	0:15:00	240	7	20	27	0	15	0	0.25	960	28	80	108	1176
23:36:00	23:50:00	0:15:00	202	4	40	44	0	15	0	0.25	808	16	160	176	1160
0:00:00	0:14:00	0:15:00	198	13	48	61	0	15	0	0.25	792	52	192	244	1280
0:18:00	0:32:00	0:15:00	164	11	28	39	0	15	0	0.25	656	44	112	156	968
0:35:00	0:49:00	0:15:00	153	8	29	37	0	15	0	0.25	612	32	116	148	908
1:00:00	1:14:00	0:15:00	161	7	45	52	0	15	0	0.25	644	28	180	208	1060

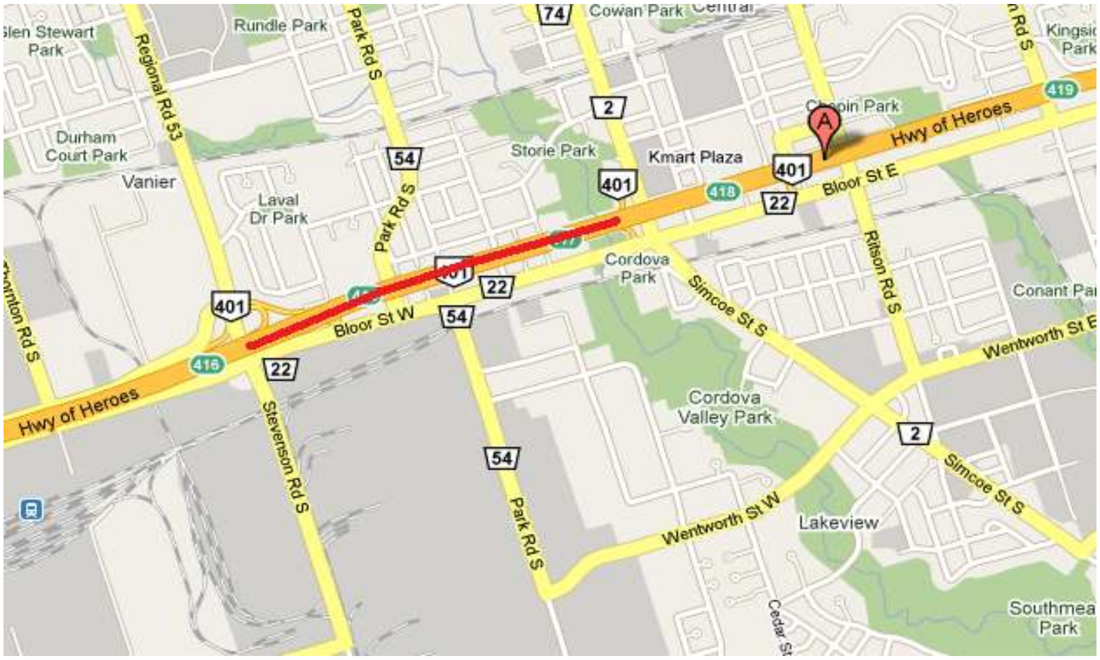
Site 3 2005-2014, Hwy 401(Stevenson Rd and Simcoe St) Oshawa.

1. Site Visit 1 – Oct 07, 2009

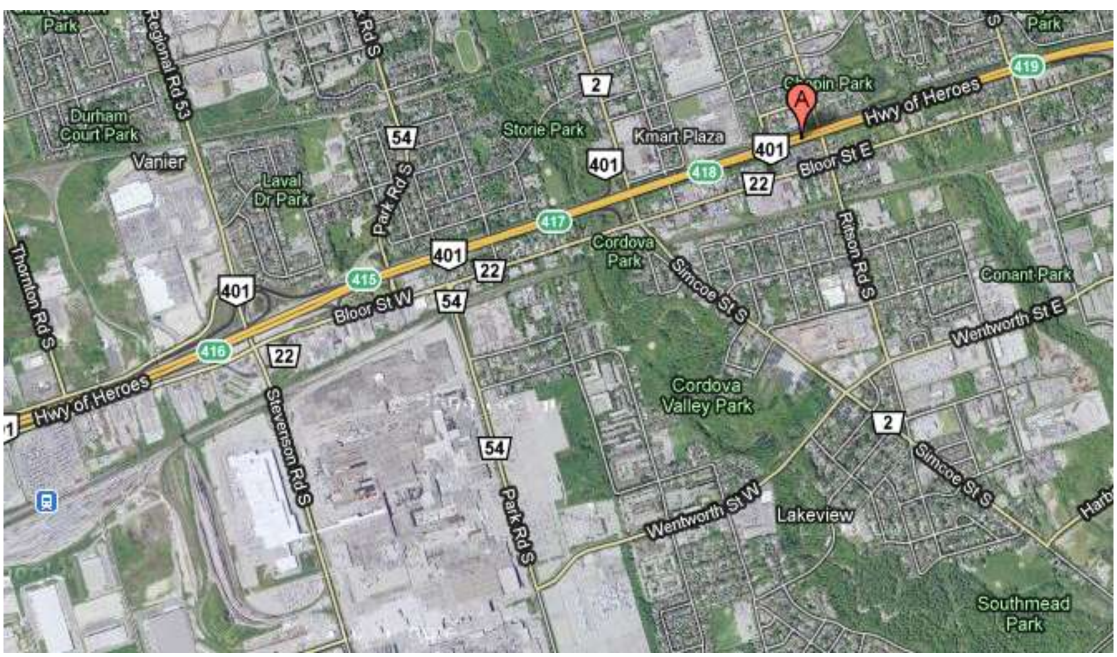
1.1 Site Characteristics Form for Site 2005-2014

Date	07-Oct
Name of the Site	2005-2014
Location	401- Between Stevenson Rd and Simcoe St (Oshawa)
Weather	Clear
Starting Time	9:20 PM
End Time	0:45
Day of Week	Wednesday
Time of Day	Night
Assigned Lane	1 Left lane and LHS open, 2 right lanes and RHS close
Lane Width (m)	3.75
Direction of Traffic	East
Shoulder Type	Fully Paved
Lane Closure	3-to-1
OPP Presence	-
Time of OPP Presence	
Facility Type	six lane divided highway
Driver Population	Heavy Truck presence + commuter traffic
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	1Km
Duration of Closure	10PM-7AM
Intersections	Stevenson Rd and Simcoe St.
Type of Traffic Control	Barrels
Pavement Condition	Fully Paved
Distractions	Night Time, Workers Present, heavy construction machinery working, Incorrect message board look at the comment section bellow
List of Photos Taken	
Other Comments	***1. Safety Issues: No hard hats for some staff, many trucks and construction cars did not have beacon lights or their lights were off.2. Incorrect signing and message board about 1KM ahead of closure the board says "all 401 lanes open tonight"***

1.2 Map of Location of Site 2005-2014



1.3 Aerial View of Site 2005-2014



1.4 Data Collected from Site 2005-2014 on Oct 07, 2009

Evaluation Days Oct 07, 14 and May 28and 29, 2010

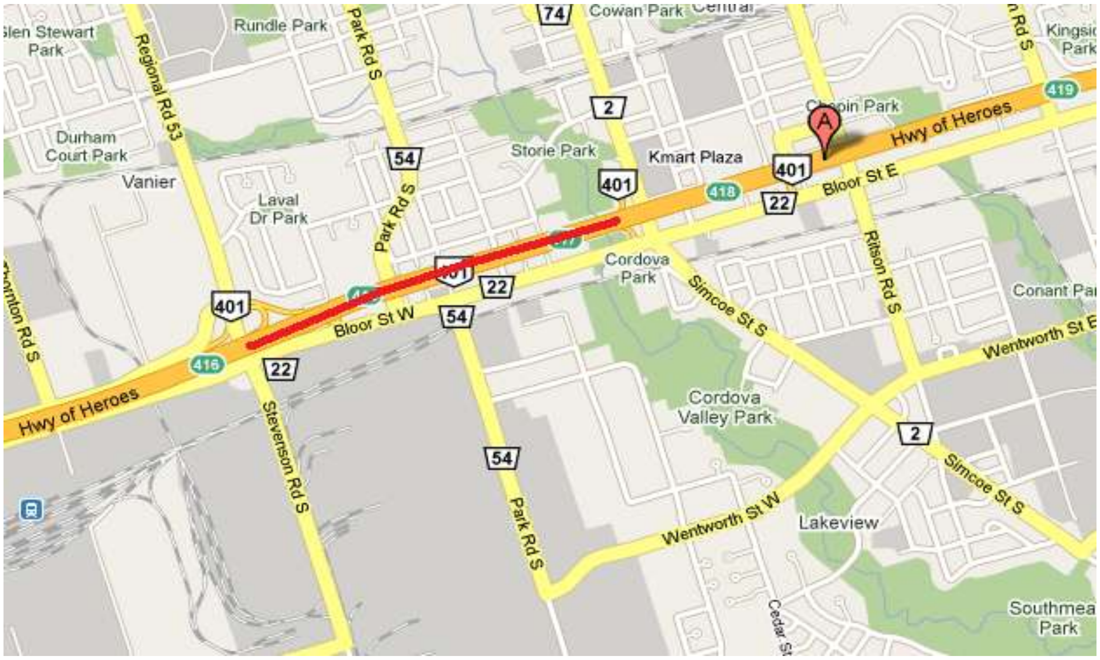
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
21:20:00	21:35:00	0:15:00	202	10	66	76	0	15	0	0.25	808	40	264	304	1112
21:39:00	21:54:00	0:15:00	223	5	55	60	0	15	0	0.25	892	20	220	240	1132
22:05:00	22:20:00	0:15:00	193	7	64	71	0	15	0	0.25	772	28	256	284	1056
23:10:00	23:25:00	0:15:00	205	3	62	65	0	15	0	0.25	820	12	248	260	1080
23:28:00	23:43:00	0:15:00	167	7	79	86	0	15	0	0.25	668	28	316	344	1012
23:46	0:01	0:15:00	205	4	49	53	0	15	0	0.25	820	16	196	212	1032
0:05	0:20	0:15:00	161	5	76	81	0	15	0	0.25	644	20	304	324	968
0:25	0:40	0:15:00	118	8	110	118	0	15	0	0.25	472	32	440	472	944

2. Site Visit 2 – Oct 14, 2009

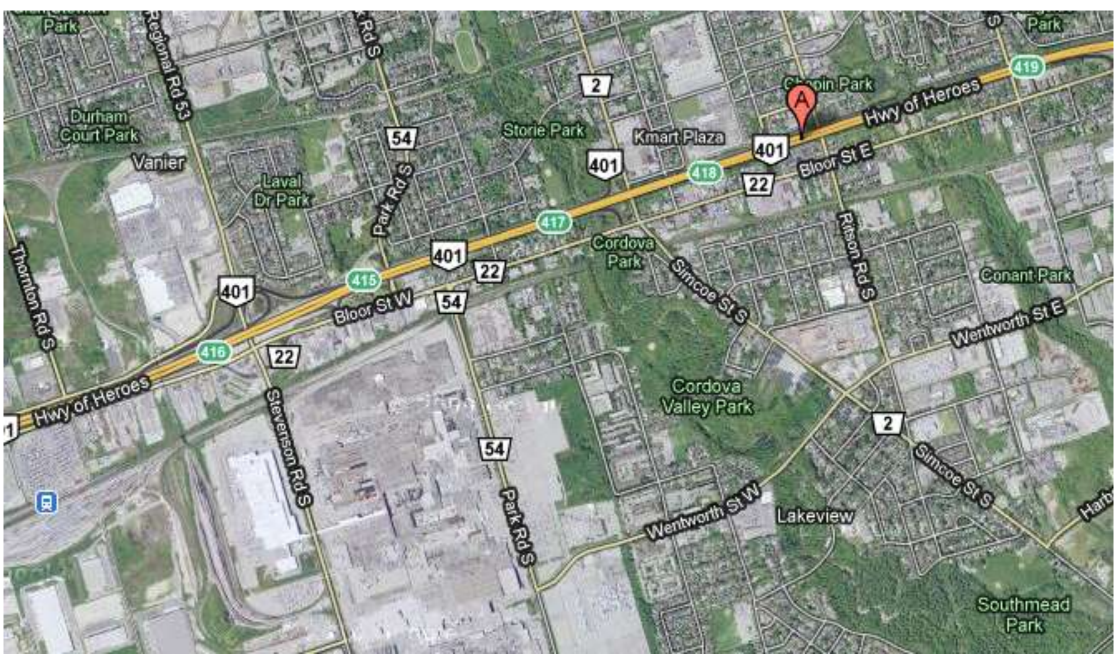
2.1 Site Characteristics Form for Site 2005-2014

Date	14-Oct
Name of the Site	2005-2014
Location	401- Between Stevenson Rd and Simcoe St (Oshawa)
Weather	Clear
Starting Time	10:43 PM
End Time	23:58
Day of Week	Wednesday
Time of Day	Night
Assigned Lane	1 Left lane and LHS open, 2 right lanes and RHS close
Lane Width (m)	3.75
Direction of Traffic	East
Shoulder Type	Fully Paved
Lane Closure	3-to-1
OPP Presence	-
Time of OPP Presence	
Facility Type	six lane divided highway
Driver Population	Heavy Truck presence + commuter traffic
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	1Km
Duration of Closure	10PM-7AM
Intersections	Stevenson Rd and Simcoe St.
Type of Traffic Control	Barrels
Pavement Condition	Fully Paved
Distractions	Night Time, Workers Present, heavy construction machinery working, Incorrect message board look at the comment section bellow
List of Photos Taken	**No photos> camera was broken**
Other Comments	-

2.2 Map of Location of Site 2005-2014



2.3 Aerial View of Site 2005-2014



2.4 Data Collected from Site 2005-2014 on Oct 14, 2009

Evaluation Days Oct 07 and 14

Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
22:43:00	22:58:00	0:15:00	182	6	80	86	0	15	0	0.25	728	24	320	344	1416
23:01:00	23:16:00	0:15:00	173	5	84	89	0	15	0	0.25	692	20	336	356	1404
23:17:00	23:32:00	0:15:00	157	7	82	89	0	15	0	0.25	628	28	328	356	1340
23:43:00	23:58:00	0:15:00	166	4	66	70	0	15	0	0.25	664	16	264	280	1224

3. Site Visit 3 – Oct 28, 2010

3.1 Site Characteristics Form for Site 2005-2014

Date	28-MAY, 2010
Hwy No:	401
Location	Hwy 401, Btw Thickson rd & Stevenson rd, Oshawa, (Eastbound)
Weather	Clear
Starting Time	10:52 PM (MAY 28)
End Time	00:59 AM (MAY 29)
Day of Week	Friday (Weekday)
Time of Day	Night
Assigned Lane	2 left lanes and left shoulder closed, right lane open
Lane Width (m)	3.75
Direction of Traffic	East
Shoulder Type	Fully Paved
Lane Closure	3-to-1
OPP Presence	No
Time of OPP Presence	N/A
Facility Type	6 lane divided highway
Driver Population	Commuter traffic and trucks
% Heavy Vehicles	
Grade of Road	
Speed Limit (km/hr)	100
Curve of Road	
Length of Work Zone	2.5 Km
Duration of Closure	21:00 – ?
Intersections	Thickson rd & Stevenson rd
Type of Traffic Control	Barrels, signal arrow signs, message signs
Pavement Condition	Fully paved
Distractions	Night, Workers and Construction machinery
List of Photos Taken	
Other Comments	* Several kilometers to the closure, there was sign that all lanes on 401 are open tonight! * At the beginning of data collection one ramp was open
Free Flow?	No
Queue Length (Km)	

3.2 Map Of Location Of Site

3.3 Aerial View Of Site

3.4 Data Collected From Site On May 28, 2010

Road Hwy 401, Eastbound
Location Hwy 401, Btw Thickson rd & Stevenson rd, Oshawa, (Eastbound)
Evaluation Days

Date Friday, May 28, 2010

Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
22:52:00	23:07:00	00:15:00	234	7	38	45	0	15	0	0.25	936	28	152	180	1116
23:07:00	23:22:00	00:15:00	271	6	25	31	0	15	0	0.25	1084	24	100	124	1208
23:22:00	23:37:00	00:15:00	243	6	39	45	0	15	0	0.25	972	24	156	180	1152
23:37:00	23:52:00	00:15:00	243	7	42	49	0	15	0	0.25	972	28	168	196	1168
23:59:00	0:14:00	00:15:00	294	17	27	44	0	15	0	0.25	1176	68	108	176	1352
0:14:00	0:29:00	00:15:00	269	7	39	46	0	15	0	0.25	1076	28	156	184	1260
0:29:00	0:44:00	00:15:00	264	9	20	29	0	15	0	0.25	1056	36	80	116	1172
00:44:00	0:59:00	00:15:00	211	10	47	57	0	15	0	0.25	844	40	188	228	1072

4. Site Visit 4 – Oct 29, 2010

4.1 Site Characteristics Form for Site 2005-2014

Date	29-MAY, 2010
Hwy No:	401
Location	Hwy 401, Btw Thickson rd & Stevenson rd, Oshawa, (Eastbound)
Weather	Clear
Starting Time	10:35 PM (MAY 29)
End Time	00:55 AM (MAY 30)
Day of Week	Saturday (Weekend)
Time of Day	Night
Assigned Lane	3 right lanes closed, left lane open
Lane Width (m)	3.75
Direction of Traffic	East
Shoulder Type	Fully Paved
Lane Closure	4-to-1
OPP Presence	No
Time of OPP Presence	N/A
Facility Type	8 lane divided highway
Driver Population	Mostly commuter traffic
% Heavy Vehicles	
Grade of Road	
Speed Limit (km/hr)	100
Curve of Road	
Length of Work Zone	3.1 Km
Duration of Closure	22:00 – 7:00
Intersections	Thickson rd & Stevenson rd
Type of Traffic Control	Barrels & lighted arrow signs
Pavement Condition	Fully paved
Distractions	Night, Construction trucks
List of Photos Taken	#1 looking East, #2 Looking West
Other Comments	* The speeds are measured in the first time interval when the queue length is 1.2 Km
Free Flow?	No
Queue Length (Km)	1.2 Km

4.2 Map Of Location Of Site

4.3 Aerial View Of Site

4.4 DATA COLLECTED FROM SITE ON May 29, 2010

Road Hwy 401, Eastbound
Location Hwy 401, Btw Thickson rd & Stevenson rd, Oshawa, (Eastbound)
Evaluation Days

Date Saturday, May 29, 2010

Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
23:35:00	23:50:00	0:15:00	288	4	13	17	0	15	0	0.25	1152	16	52	68	1220
23:50:00	0:05:00	0:15:00	274	5	15	20	0	15	0	0.25	1096	20	60	80	1176
0:05:00	0:20:00	0:15:00	255	4	9	13	0	15	0	0.25	1020	16	36	52	1072
0:20:00	0:35:00	0:15:00	274	4	8	12	0	15	0	0.25	1096	16	32	48	1144
0:40:00	0:55:00	0:15:00	234	9	6	15	0	15	0	0.25	936	36	24	60	996

Site 4 2008-2018, Hwy 400 - 2.7km north & south of Kings Rd.

1. Site Visit 1 – Aug 14, 2009

1.1 Site Characteristics Form for Site 2008-2018

Date	14-Aug
Name of the Site	2008-2018
Location	400-2.7 km north & south of Kings Rd.
Weather	Clear
Starting Time	10:03 PM
End Time	
Day of Week	Friday
Time of Day	Night
Assigned Lane	1 left lane open-2 right lanes & right shoulder closed
Lane Width (m)	3.75
Direction of Traffic	South
Shoulder Type	Fully Paved
Lane Closure	3-to-1
OPP Presence	yes
Time of OPP Presence	
Facility Type	six lane divided highway
Driver Population	
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	5.4
Duration of Closure	21:00-09:00
Intersections	400SB to Kings Rd.
Type of Traffic Control	Barrels
Pavement Condition	Fully Paved
Distractions	
List of Photos Taken	**#1. 400 SB Looking South, #2. 400 SB looking North**
Other Comments	

1.2 Map of Location of Site 2008-2018

1.3 Aerial View of Site 2008-2018

1.4 Data Collected from Site 2008-2018 on Aug 14, 2009

Evaluation Days Aug 14, 2009 and Aug 18, 2010

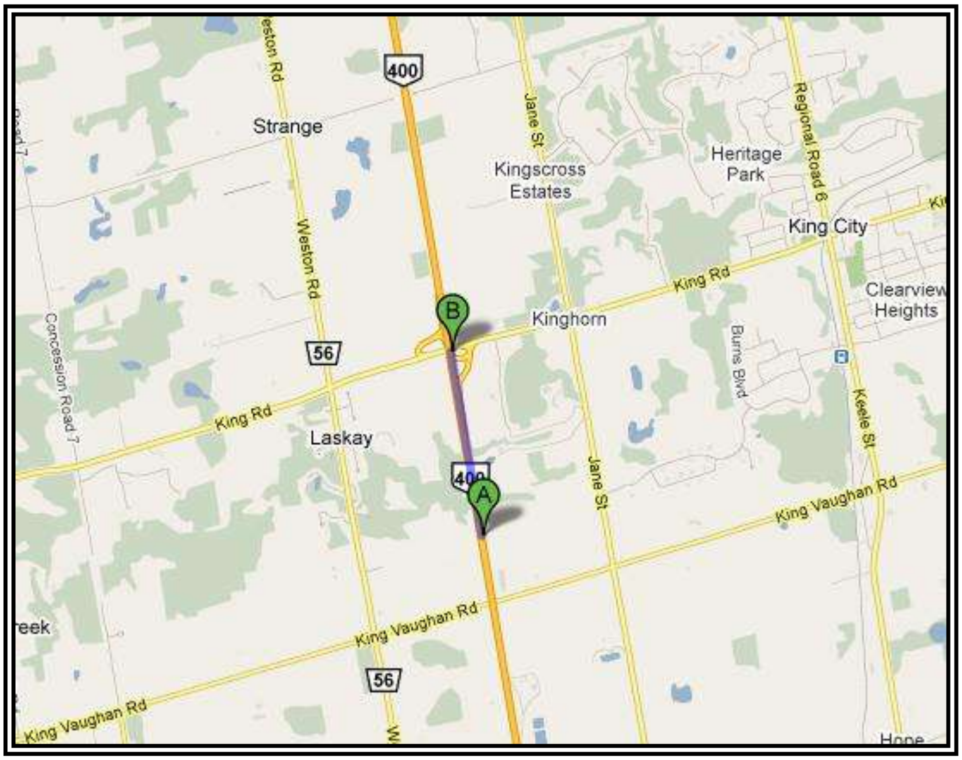
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
22:03:00	22:18:00	0:15:00	248	-	-	19	0	15	0	0.25	992	0	0	76	1144
23:10:00	23:25:00	0:15:00	263	-	-	25	0	15	0	0.25	1052	0	0	100	1252
23:27:00	23:42:00	0:15:00	245	-	-	24	0	15	0	0.25	980	0	0	96	1172
23:43:00	23:58:00	0:15:00	256	-	-	21	0	15	0	0.25	1024	0	0	84	1192
23:59:00	0:14:00	0:15:00	245	-	-	22	0	15	0	0.25	980	0	0	88	1156

2. Site Visit 2 – Aug 1, 2010

2.1 Site Characteristics Form for Site 2008-2018

Date	18-August, 2010
Hwy No:	400
Location	Hwy 400, 1.5 Km to the South of the King Rd to King Rd, Northbound
Weather	Clear
Starting Time	9:40 PM
End Time	11:15 PM
Day of Week	Wednesday
Time of Day	Night
Assigned Lane	2 Right lanes & right shoulder closed, 1 left lane open
Lane Width (m)	3.75
Direction of Traffic	North
Shoulder Type	Paved, Left shoulder closed by TCB
Lane Closure	3-to-1
OPP Presence	No
Time of OPP Presence	N/A
Facility Type	6 lane divided Hwy
Driver Population	Mostly commuter traffic
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	1.5 Km
Duration of Closure	9:30 Pm - 5:00 Am
Intersections	Teston Rd & Aurora Rd
Type of Traffic Control	Barrels, lighted arrow signs
Pavement Condition	Complete
Distractions	Night, Construction work
List of Photos Taken	#1: Looking North #2: Looking South
Other Comments	
Free Flow?	No
Queue Length (Km)	3.5 Km

2.2 Map Of Location Of Site



2.3 Aerial View Of Site

2.4 Data Collected From Site On August 18, 2010

Road Hwy 400, Northbound
Location Hwy 400, 1.5 Km to the South of the King Rd to King Rd, Northbound

Evaluation Days

Date Wednesday, August 18, 2010

Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
9:400:00	21:55:00	0:15:00	299	5	11	16	0	15	0	0.25	1196	20	44	64	1260
21:55:00	22:10:00	0:15:00	315	4	16	20	0	15	0	0.25	1260	16	64	80	1340
22:10:00	22:25:00	0:15:00	303	5	13	18	0	15	0	0.25	1212	20	52	72	1284
22:25:00	22:40:00	0:15:00	309	8	13	21	0	15	0	0.25	1236	32	52	84	1320
22:45:00	23:00:00	0:15:00	320	4	10	14	0	15	0	0.25	1280	16	40	56	1336
23:00:00	23:15:00	0:15:00	304	10	18	28	0	15	0	0.25	1216	40	72	112	1328

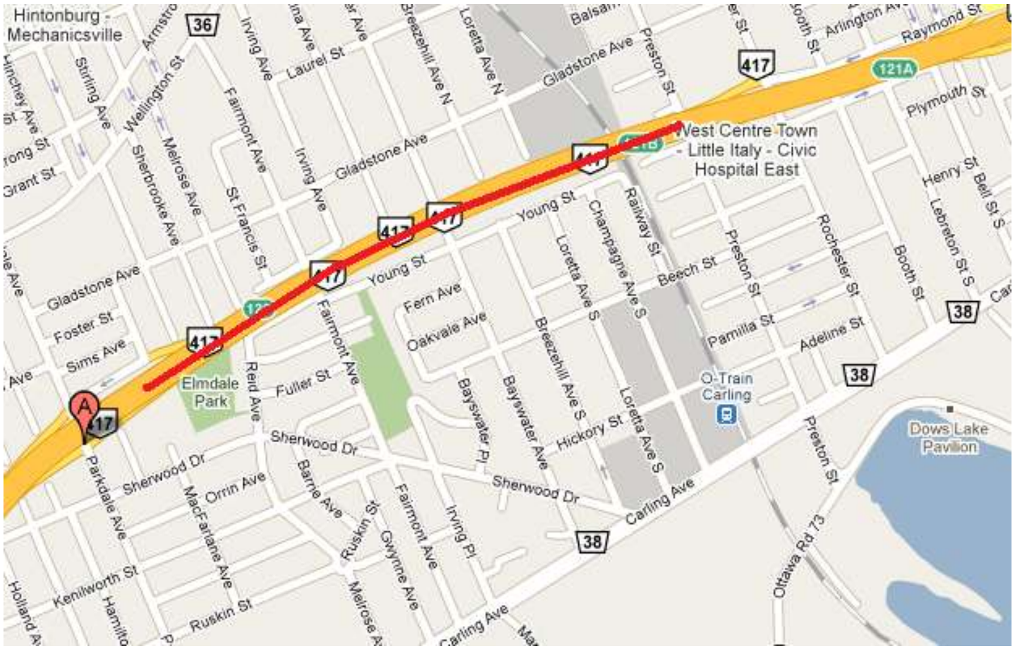
Site 5 2009-4020, Hwy 417 (Parkdale Ave. And Bronson Ave.)

1. Site Visit 1 – Sep 23, 2009

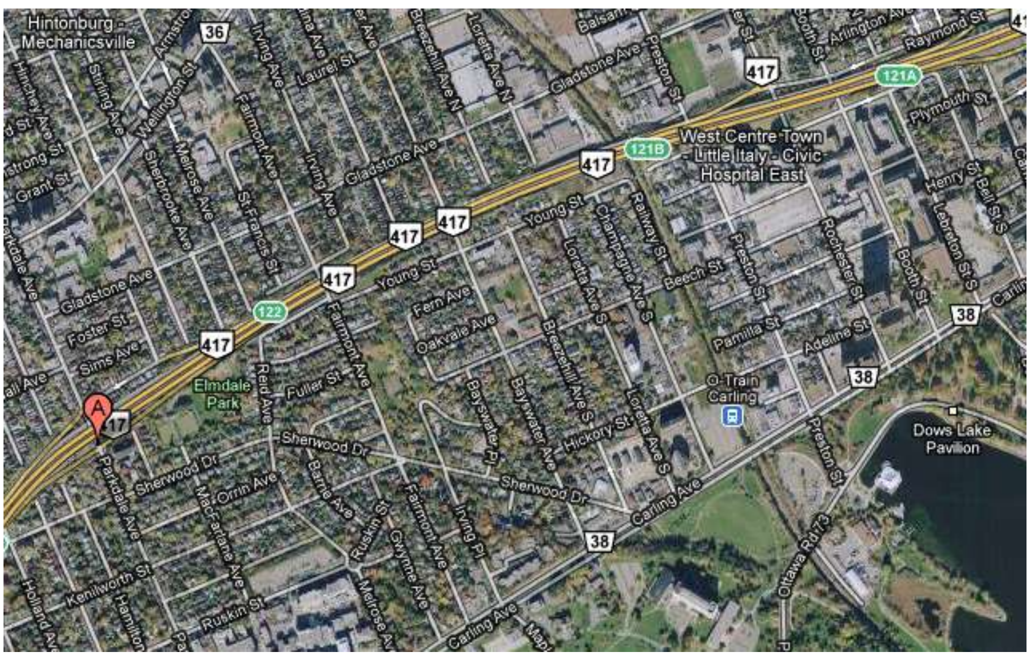
1.1 Site Characteristics Form for Site 2009-4020

Date	Sep 23/2009
Name of the Site	2009-4020
Location	Hwy 417, Ottawa
Weather	Cloudy, Light Showers
Starting Time	02:00pm
End Time	05:30pm
Day of Week	Wednesday
Time of Day	Afternoon
Assigned Lane	Left 3 lanes
Lane Width (m)	3.7 m
Direction of Traffic	WB
Shoulder Type	Paved Completely
Lane Closure	Right lane
OPP Presence	-
Time of OPP Presence	-
Facility Type	4 Lane highway WB
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	1km
Duration of Closure	Full time TCB closure
Intersections	Hwy 417 between Bronson Ave/Parkdale
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated
Pavement Condition	Good
Distractions	Hard to get in and out from the construction site
List of Photos Taken	2
Other Comments	Data Collected

1.2 Map of Location of Site 2009-4020



1.3 Aerial View of Site 2009-4020



1.4 Data Collected from Site 2009-4020 on Sep 23, 2009

Evaluation Days Sep 22, 23 and 24, 2009

Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
14:46:00	15:00:00	0:15:00	1251	-	-	64	0	15	0	0.25	5004	0	0	256	5516
15:04:00	15:18:00	0:15:00	1272	-	-	56	0	15	0	0.25	5088	0	0	224	5536
15:22:00	15:36:00	0:15:00	1246	-	-	51	0	15	0	0.25	4984	0	0	204	5392
16:05:00	16:19:00	0:15:00	1243	-	-	43	0	15	0	0.25	4972	0	0	172	5316
16:23:00	16:37:00	0:15:00	1231	-	-	59	0	15	0	0.25	4924	0	0	236	5396
16:50:00	17:04:00	0:15:00	1296	-	-	36	0	15	0	0.25	5184	0	0	144	5472

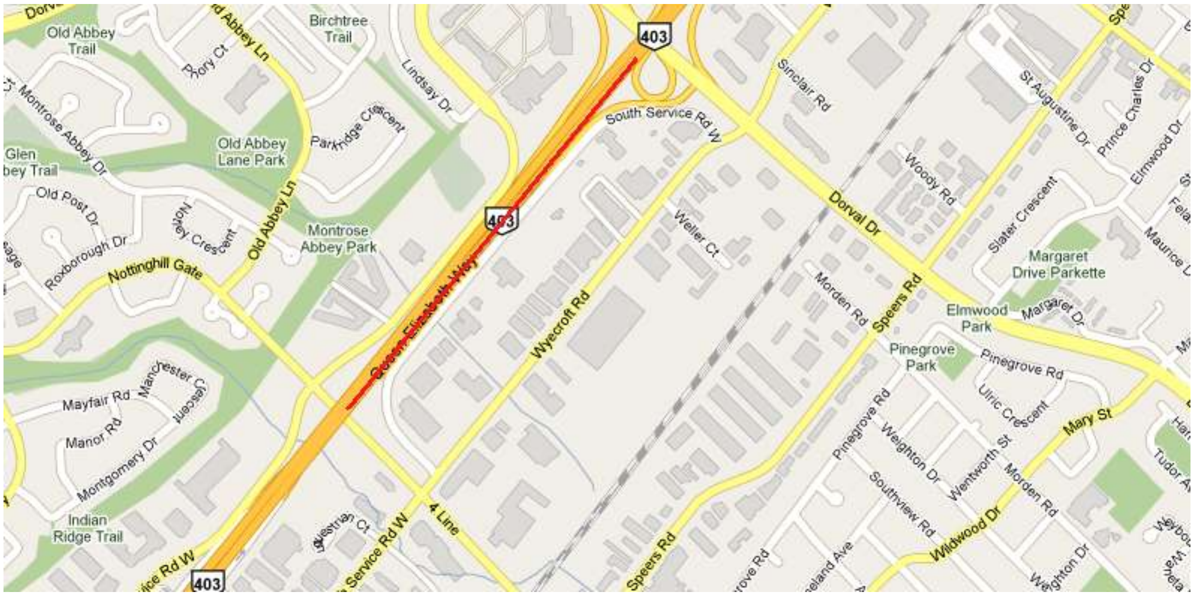
Site 6 2007-2125, Hwy QEW, Milton Between Third Line and Dorval Dr.

1 Site Visit 1 – May 19, 2010

1.1 Site Characteristics Form for Site 2007-2125

Date	May 19/2010
Name of the Site	2007-2125
Location	Hwy QEW, Milton
Weather	Clear
Starting Time	10:30pm
End Time	01:00am
Day of Week	Wednesday
Time of Day	Night
Assigned Lane	Two Right lanes
Lane Width (m)	3.7 m
Direction of Traffic	EB
Shoulder Type	Paved Completely
Lane Closure	1 Left lane + Shoulder
OPP Presence	-
Time of OPP Presence	-
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	2km +
Duration of Closure	10:30pm to 07:00am
Intersections	Hwy QEW EB and Forth Lane
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated and TCB
Pavement Condition	Good
Distractions	Construction Vehicles, Dumping Trucks
List of Photos Taken	2
Other Comments	Data collected but no queuing condition

1.2 Map of Location of Site 2007-2125



1.3 Arial View of Site 2007-2125

1.4 Data Collected from Site 2007-2125 on May 19, 2010

Evaluation Days May 19 and 20, 2010

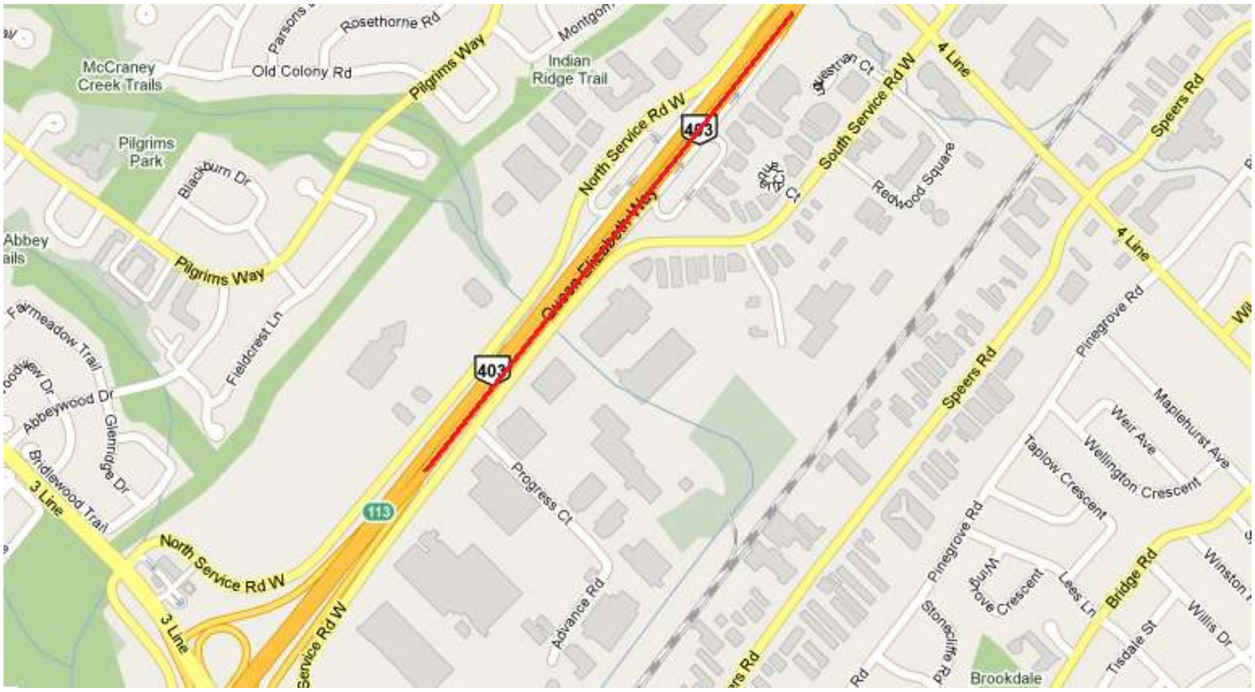
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:20:00	23:34:00	-	241	11	37	48	0	15	0	0.25	964	44	148	192	1156
23:38:00	23:52:00	-	233	13	39	52	0	15	0	0.25	932	52	156	208	1140
23:56:00	0:10:00	-	229	12	38	50	0	15	0	0.25	916	48	152	200	1116
0:12:00	0:26:00	-	215	16	31	47	0	15	0	0.25	860	64	124	188	1048

2 Site Visit 2 – May 20, 2010

2.1 Site Characteristics Form for Site 2007-2125

Date	May 20/2010
Name of the Site	2007-2125
Location	Hwy QEW, Milton
Weather	Clear
Starting Time	10:00pm
End Time	12:30am
Day of Week	Thursday
Time of Day	Night
Assigned Lane	Two Right lanes
Lane Width (m)	3.7 m
Direction of Traffic	EB
Shoulder Type	Paved Completely
Lane Closure	1 Left lane + Shoulder
OPP Presence	-
Time of OPP Presence	-
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	2km +
Duration of Closure	10:00pm to 07:00am
Intersections	Hwy QEW EB and Third Lane
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated and TCB
Pavement Condition	Good
Distractions	Construction Vehicles, Dumping Trucks
List of Photos Taken	2
Other Comments	Data collected but no queuing condition

2.2 Map of Location of Site 2007-2125



2.3 Arial View of Site 2007-2125

2.4 Data Collected from Site 2007-2125 on May 20, 2010

Evaluation Days May 19 and 20, 2010

Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
22:28:00	22:42:00	-	431	14	41	55	0	15	0	0.25	1724	56	164	220	1944
22:46:00	11::00 PM	-	417	11	44	55	0	15	0	0.25	1668	44	176	220	1888
23:03:00	23:17:00	-	450	12	47	59	0	15	0	0.25	1800	48	188	236	2036
23:22:00	23:36:00	-	374	12	42	54	0	15	0	0.25	1496	48	168	216	1712
23:42:00	23:56:00	-	225	13	47	60	0	15	0	0.25	900	52	188	240	1140
0:02:00	0:16:00	-	221	14	38	52	0	15	0	0.25	884	56	152	208	1092

Site 7 2009-3001, Hwy 402, Sarnia. Indian Road Ramp Closed

1. Site Visit 1 – June 14, 2010

1.1 Site Characteristics Form for Site 2009-3001

Date	June 14/2010
Name of the Site	2009-3001
Location	Hwy 402, Sarnia
Weather	Cloudy
Starting Time	07:00am
End Time	09:30am
Day of Week	Monday
Time of Day	Morning
Assigned Lane	Two Left lanes
Lane Width (m)	3.5 m
Direction of Traffic	WB
Shoulder Type	Partially paved
Lane Closure	Right ramp
OPP Presence	-
Time of OPP Presence	-
Facility Type	4 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	1km
Duration of Closure	Full day closure
Intersections	Hwy 402 WB and Indian Road
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated and TCB
Pavement Condition	Surface destrace with longitutional cracks
Distractions	-
List of Photos Taken	2
Other Comments	Data collected but no queuing condition

1.2 Map of Location of Site 2009-3001

1.3 Arial View of Site 2009-3001

1.4 Data Collected from Site 2009-3001 on June 14, 2010

Evaluation Days June 14, 2010

Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
7:40:00	7:54:00	-	149	7	39	46	0	15	0	0.25	596	28	156	184	780
7:57:00	8:11:00	-	146	6	31	37	0	15	0	0.25	584	24	124	148	732
8:13:00	8:27:00	-	189	3	29	32	0	15	0	0.25	756	12	116	128	884
8:30:00	8:44:00	-	138	4	24	28	0	15	0	0.25	552	16	96	112	664

Site 8 2010-2031, Hwy 401, Mississauga. Hurontario St. and Hwy 401

1. Site Visit 1 – June 28, 2010

1.1 Site Characteristics Form for Site 2010-2031

Date	June 28/2010
Name of the Site	2010-2031
Location	Hwy 410, Mississauga
Weather	Clear
Starting Time	11:00pm
End Time	01:30am
Day of Week	Monday
Time of Day	Night
Assigned Lane	One left lane
Lane Width (m)	3.7 m
Direction of Traffic	EB
Shoulder Type	Paved Completely
Lane Closure	2 Right lane + Shoulder
OPP Presence	-
Time of OPP Presence	-
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	500m
Duration of Closure	11:30pm to 06:00am
Intersections	Hwy 401 EB and Hwy 10 (Hurontario Street)
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated
Pavement Condition	Good
Distractions	-
List of Photos Taken	2
Other Comments	Data collected

1.2 Map of Location of Site 2010-2031

1.3 Arial View of Site 2010-2031

1.4 Data Collected from Site 2010-2031 on June 28, 2010

Evaluation Days June 28, 2010

Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:57:00	0:01:00	-	431	14	41	55	0	15	0	0.25	1724	56	164	220	1944
0:12:00	0:26:00	-	417	11	44	55	0	15	0	0.25	1668	44	176	220	1888
0:27:00	0:41:00	-	450	12	47	59	0	15	0	0.25	1800	48	188	236	2036

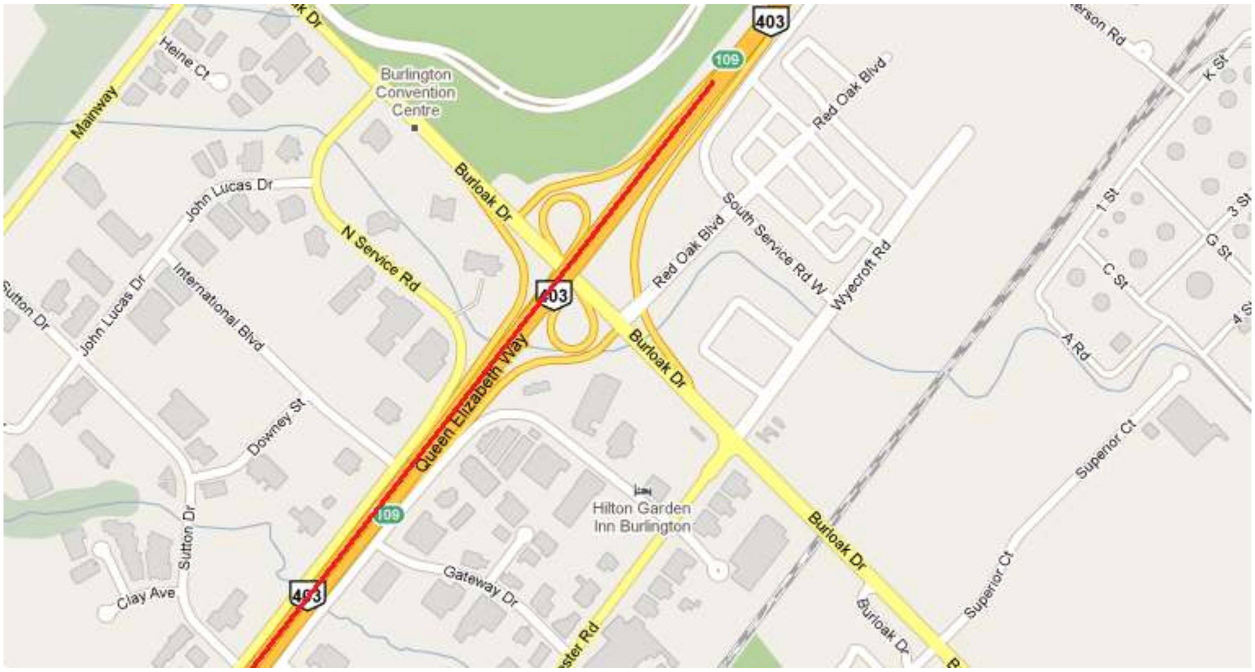
Site 9 2009-2015, Hwy QEW, Burlington. Burloak Dr. to Appleby Line

1. Site Visit 1 – July 08, 2010

1.1 Site Characteristics Form for Site 2009-2015

Date	July 08/2010
Name of the Site	2009-2015
Location	Hwy QEW, Burlington
Weather	Clear
Starting Time	09:30pm
End Time	01:00am
Day of Week	Thursday
Time of Day	Night
Assigned Lane	One Right lane
Lane Width (m)	3.7 m
Direction of Traffic	WB
Shoulder Type	Paved Completely
Lane Closure	2 Left lane + Shoulder
OPP Presence	Yes
Time of OPP Presence	Full night
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	1KM
Duration of Closure	09:30pm to 05:00am
Intersections	Hwy QEW WB and Burlock Dr.
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated and TCB
Pavement Condition	Good
Distractions	Construction vehicles right in front of the video camera
List of Photos Taken	2
Other Comments	Data collected. At 11:34pm OPP shutdown completely for 6min. because of boring under the Hwy.

1.2 Map of Location of Site 2090-2015



1.3 Arial View of Site 2009-2015

1.4 Data Collected from Site 2009-2015 on July 08, 2010

Evaluation Days July 08, 11, 13, 19, 25 and Aug 02

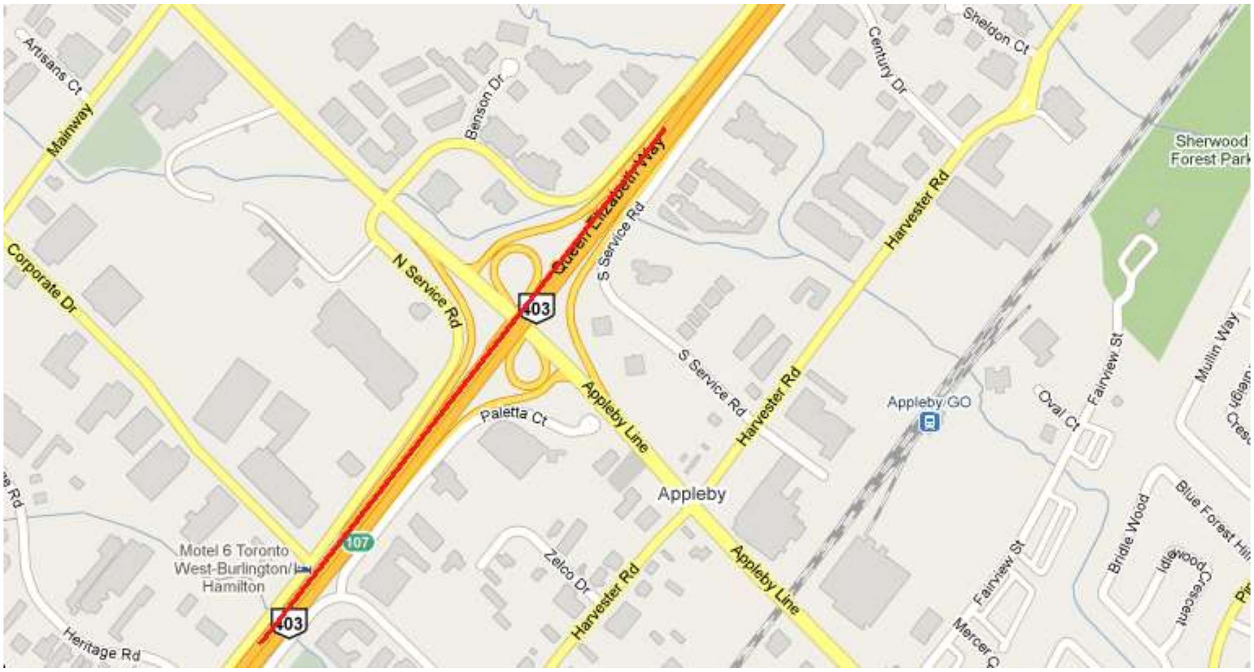
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
22:11:00	22:25:00	-	232	12	20	32	0	15	0	0.25	928	48	80	128	1056
22:26:00	22:40:00	-	304	9	18	27	0	15	0	0.25	1216	36	72	108	1324
22:42:00	22:56:00	-	291	6	16	22	0	15	0	0.25	1164	24	64	88	1252
22:57:00	23:11:00	-	273	12	14	26	0	15	0	0.25	1092	48	56	104	1196
23:12:00	23:26:00	-	192	5	30	35	0	15	0	0.25	768	20	120	140	908
23:27:00	23:41:00	-	71	1	17	18	0	15	0	0.25	284	4	68	72	356
23:42:00	23:56:00	-	194	8	18	26	0	15	0	0.25	776	32	72	104	880
23:57:00	0:11:00	-	219	12	13	25	0	15	0	0.25	876	48	52	100	976
0:12:00	0:26:00	-	210	12	24	36	0	15	0	0.25	840	48	96	144	984
0:27:00	0:41:00	-	256	7	27	34	0	15	0	0.25	1024	28	108	136	1160

2. Site Visit 2 – July 11, 2010

2.1 Site Characteristics Form for Site 2009-2015

Date	July 11/10
Name of the Site	2009-2015
Location	Hwy QEW, Burlington
Weather	Clear
Starting Time	10:30pm
End Time	02:00am
Day of Week	Sunday
Time of Day	Night
Assigned Lane	One Right lane
Lane Width (m)	3.7 m
Direction of Traffic	WB
Shoulder Type	Paved Completely
Lane Closure	2 Left lane
OPP Presence	Yes
Time of OPP Presence	Full night
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	1KM
Duration of Closure	10:30pm to 05:00am
Intersections	Hwy QEW WB and Walkers Line
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated and TCB
Pavement Condition	Good, Newly paved
Distractions	Construction vehicles and OPP
List of Photos Taken	2
Other Comments	Data collected

2.2 Map of Location of Site 2090-2015



2.3 Arial View of Site 2009-2015

2.4 Data Collected from Site 2009-2015 on July 11, 2010

Evaluation Days July 08, 11, 13, 19, 25 and Aug 02

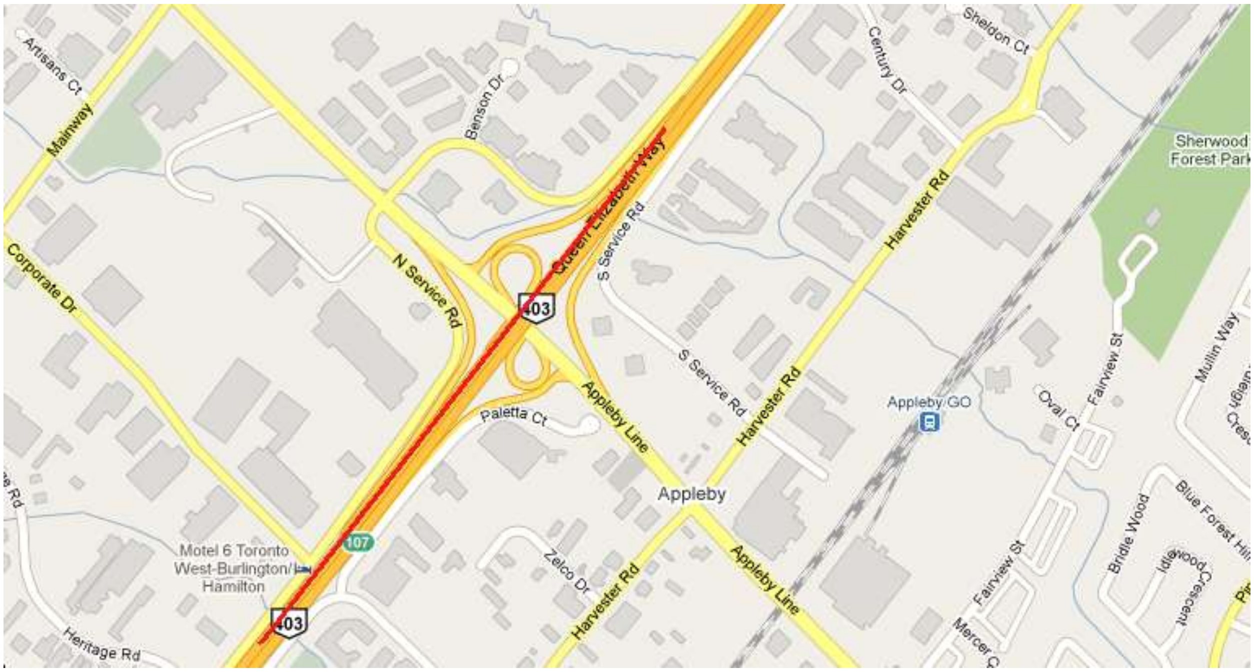
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:23:00	23:37:00	-	210	8	7	15	0	15	0	0.25	840	32	28	60	900
23:38:00	23:52:00	-	198	11	5	16	0	15	0	0.25	792	44	20	64	856
23:55:00	0:09:00	-	208	11	14	25	0	15	0	0.25	832	44	56	100	932
0:10:00	0:24:00	-	191	9	8	17	0	15	0	0.25	764	36	32	68	832
0:28:00	0:42:00	-	189	7	10	17	0	15	0	0.25	756	28	40	68	824
0:59:00	1:13:00	-	184	5	9	14	0	15	0	0.25	736	20	36	56	792
1:14:00	1:28:00	-	138	6	32	38	0	15	0	0.25	552	24	128	152	704
13:30:00	1:44:00	-	135	13	19	32	0	15	0	0.25	540	52	76	128	668

3. Site Visit 3 – July 13, 2010

3.1 Site Characteristics Form for Site 2009-2015

Date	July 13/2010
Name of the Site	2009-2015
Location	Hwy QEW, Burlington
Weather	Clear
Starting Time	10:00pm
End Time	01:00am
Day of Week	Tuesday
Time of Day	Night
Assigned Lane	One Left lane
Lane Width (m)	3.7 m
Direction of Traffic	WB
Shoulder Type	Paved Completely
Lane Closure	2 Right lanes
OPP Presence	Yes
Time of OPP Presence	Full night
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	1KM
Duration of Closure	10:30pm to 05:00am
Intersections	Hwy QEW WB and Appleby Line
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated and TCB
Pavement Condition	Good, Newly paved
Distractions	Construction vehicles, TCB wall for the video and OPP
List of Photos Taken	2
Other Comments	Data collected

3.2 Map of Location of Site 2009-2015



3.3 Arial View of Site 2009-2015

3.4 Data Collected from Site 2009-2015 on July 13, 2010

Evaluation Days July 08, 11, 13, 19, 25 and Aug 02

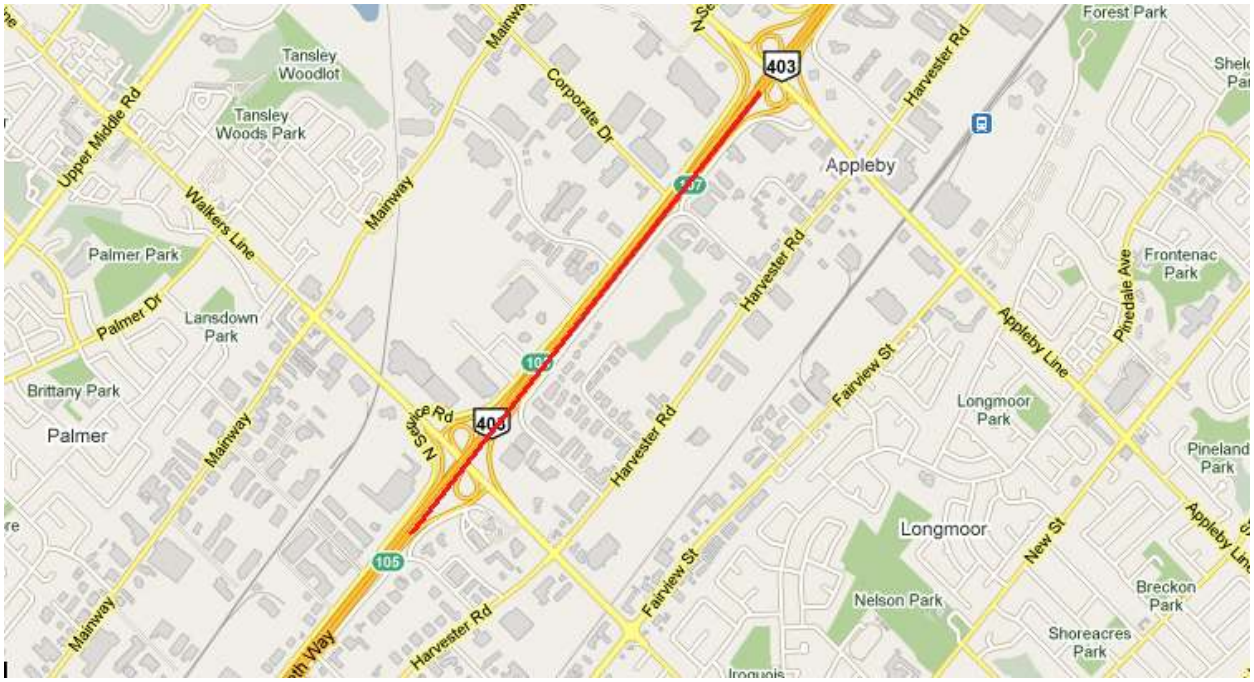
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
22:34:00	22:48:00	-	212	10	16	26	0	15	0	0.25	848	40	64	104	952
22:49:00	23:03:00	-	221	9	22	31	0	15	0	0.25	884	36	88	124	1008
23:04:00	23:18:00	-	203	5	14	19	0	15	0	0.25	812	20	56	76	888
23:19:00	23:33:00	-	197	5	19	24	0	15	0	0.25	788	20	76	96	884
23:34:00	23:48:00	-	195	11	12	23	0	15	0	0.25	780	44	48	92	872
23:49:00	0:03:00	-	234	4	8	12	0	15	0	0.25	936	16	32	48	984
0:04:00	0:18:00	-	191	7	16	23	0	15	0	0.25	764	28	64	92	856
0:19:00	0:33:00	-	192	8	22	30	0	15	0	0.25	768	32	88	120	888
0:34:00	0:48:00	-	186	10	21	31	0	15	0	0.25	744	40	84	124	868
12:49:00	1:03:00	-	197	8	26	34	0	15	0	0.25	788	32	104	136	924

4. Site Visit 4 – July 19, 2010

4.1 Site Characteristics Form for Site 2009-2015

Date	July 19/2010
Name of the Site	2009-2015
Location	Hwy QEW, Burlington
Weather	Clear
Starting Time	11:00pm
End Time	01:00am
Day of Week	Monday
Time of Day	Night
Assigned Lane	One Right lane
Lane Width (m)	3.7 m
Direction of Traffic	EB
Shoulder Type	Paved Completely
Lane Closure	2 Left lanes + Shoulder
OPP Presence	Yes
Time of OPP Presence	Full night
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	1KM
Duration of Closure	11:00pm to 05:00am
Intersections	Hwy QEW EB and Walkers Line
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated and TCB
Pavement Condition	Good, Newly paved
Distractions	Construction vehicles, TCB wall for the video and OPP
List of Photos Taken	2
Other Comments	Data collected. Traffic dissipate after 12:30am

4.2 Map of Location of Site 2009-2015



4.3 Arial View of Site 2009-2015

4.4 Data Collected from Site 2009-2015 on July 19, 2010

Evaluation Days July 08, 11, 13, 19, 25 and Aug 02

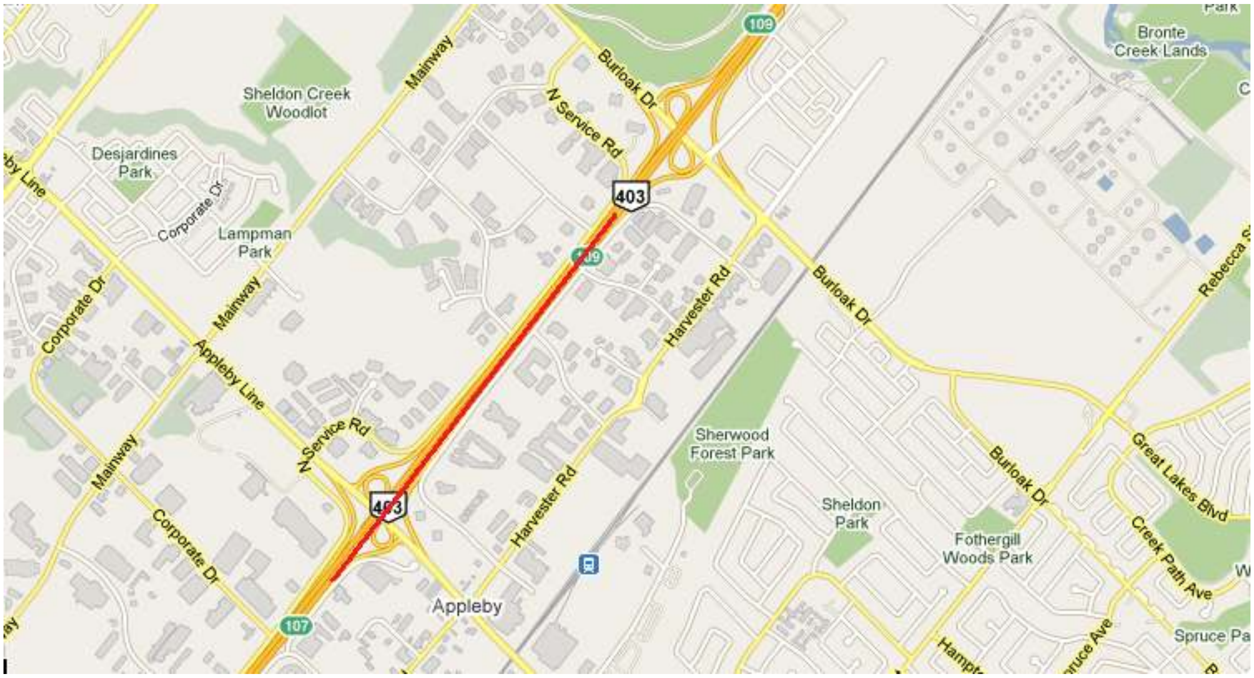
Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:07:00	23:21:00	-	217	5	22	27	0	15	0	0.25	868	20	88	108	976
23:22:00	23:36:00	-	213	2	24	26	0	15	0	0.25	852	8	96	104	956
23:37:00	23:51:00	-	224	11	31	42	0	15	0	0.25	896	44	124	168	1064
23:52:00	0:06:00	-	223	8	56	64	0	15	0	0.25	892	32	224	256	1148
0:07:00	0:21:00	-	217	9	43	52	0	15	0	0.25	868	36	172	208	1076
0:22:00	0:36:00	-	224	13	48	61	0	15	0	0.25	896	52	192	244	1140
0:37:00	0:51:00	-	178	13	28	41	0	15	0	0.25	712	52	112	164	876

5. Site Visit 3 – July 25, 2010

5.1 Site Characteristics Form for Site 2009-2015

Date	July 25/2010
Name of the Site	2009-2015
Location	Hwy QEW, Burlington
Weather	Clear
Starting Time	11:00pm
End Time	02:00am
Day of Week	Sunday
Time of Day	Night
Assigned Lane	One Left lane
Lane Width (m)	3.7 m
Direction of Traffic	EB
Shoulder Type	No Shoulder
Lane Closure	2 Right lanes
OPP Presence	Yes
Time of OPP Presence	Full night
Facility Type	6 lane divided highway
Driver Population	Trucks, Commuter Vehicles
% Heavy Vehicles	
Grade of Road	-
Speed Limit (km/hr)	80
Curve of Road	-
Length of Work Zone	1KM
Duration of Closure	11:00pm to 05:00am
Intersections	Hwy QEW EB and Appleby Line
Type of Traffic Control	Lane arrows, lighted signs, Barrel separated and TCB
Pavement Condition	Good, Newly paved
Distractions	Construction vehicles, TCB wall for the video and OPP
List of Photos Taken	2
Other Comments	Data collected

5.2 Map of Location of Site 2009-2015



5.3 Arial View of Site 2009-2015

5.4 Data Collected from Site 2009-2015 on July 25, 2010

Evaluation Days July 08, 11, 13, 19, 25 and Aug 02

Start Time	Finish Time	Lag Time	PV	Small HV	Large HV	Total HV	Hour	Minute	Second	Time (Hr)	PV Vol	S HV Vol	L HV Vol	Total HV Vol	Total Vol
23:16:00	23:30:00	-	252	5	6	11	0	15	0	0.25	1008	20	24	44	1052
23:31:00	23:45:00	-	258	3	7	10	0	15	0	0.25	1032	12	28	40	1072
23:48:00	0:02:00	-	239	4	7	11	0	15	0	0.25	956	16	28	44	1000
0:03:00	0:17:00	-	256	6	2	8	0	15	0	0.25	1024	24	8	32	1056
0:18:00	0:32:00	-	225	3	9	12	0	15	0	0.25	900	12	36	48	948
0:34:00	0:48:00	-	254	4	5	9	0	15	0	0.25	1016	16	20	36	1052
0:51:00	1:05:00	-	225	5	15	20	0	15	0	0.25	900	20	60	80	980
1:06:00	1:20:00	-	235	4	11	15	0	15	0	0.25	940	16	44	60	1000
1:21:00	1:35:00	-	229	3	13	16	0	15	0	0.25	916	12	52	64	980
1:36:00	1:50:00	-	231	5	17	22	0	15	0	0.25	924	20	68	88	1012

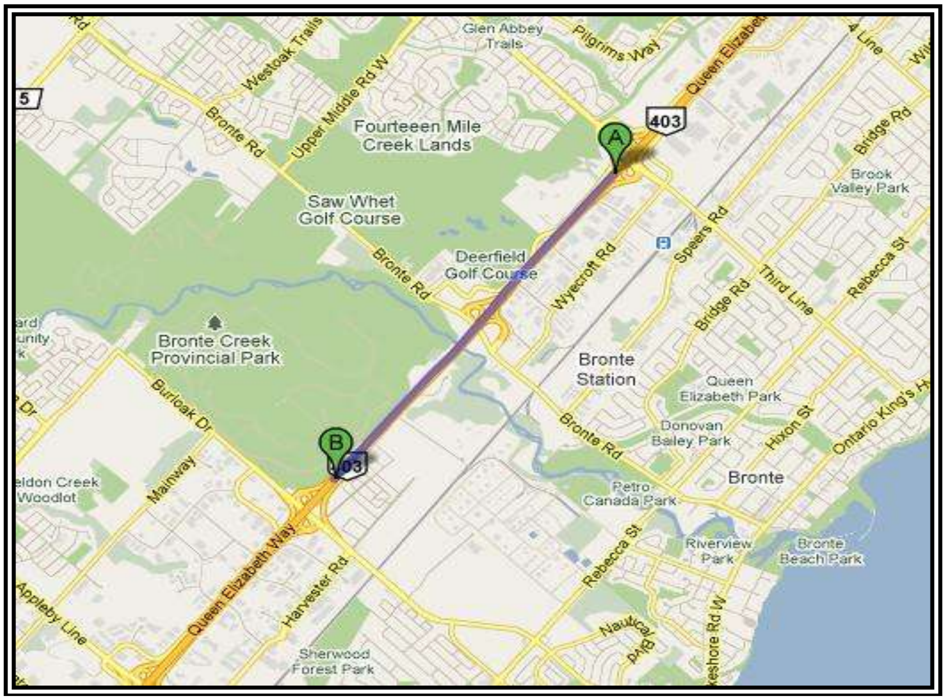
Site 10 2007-2026, Hwy QEW, Btw Third Line and Burloak Dr.

1. Site Visit 1 – July 7, 2010

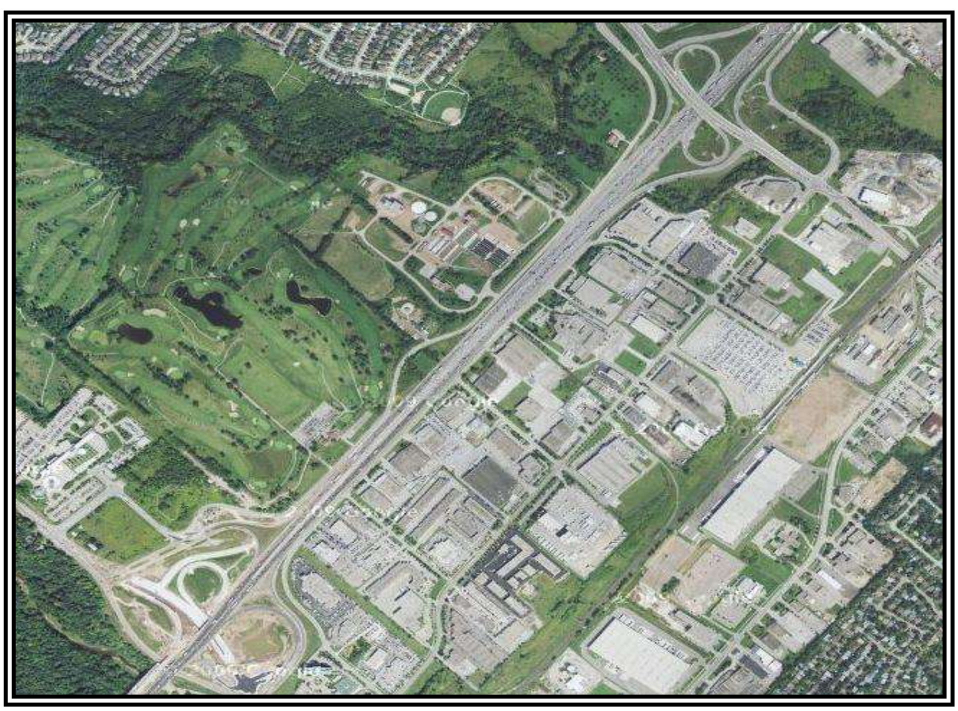
1.1 Site Characteristics Form for Site 2007-2026

Date	7-July, 2010
Hwy No:	QEW
Location	QEW, Btw Third line & Burloak Dr, Westbound
Weather	Clear
Starting Time	10:40 PM (July 7)
End Time	12:15 AM (July 8)
Day of Week	Wednesday
Time of Day	Night
Assigned Lane	2 Left lanes and left shoulder closed, right lane open
Lane Width (m)	3.75
Direction of Traffic	West
Shoulder Type	Paved
Lane Closure	3-to-1
OPP Presence	No
Time of OPP Presence	N/A
Facility Type	6 lane divided Hwy
Driver Population	Mostly commuter traffic
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	1.7 Km
Duration of Closure	10 Pm - 5 Am
Intersections	Third Line & Burloak Dr
Type of Traffic Control	Barrels and lighted arrow signs
Pavement Condition	Complete
Distractions	Night, Construction vehicles and workers
List of Photos Taken	#1: Looking West, #2: looking East
Other Comments	
Free Flow?	No
Queue Length (Km)	

1.1 MAP OF LOCATION OF SITE



1.2 AERIAL VIEW OF SITE



1.3 DATA COLLECTED FROM SITE ON July 7, 2010

Road QEW, Westbound
Location QEW, Btw Third line & Burloak Dr, Westbound
Evaluation Days

Date Wednesday, July 7, 2010

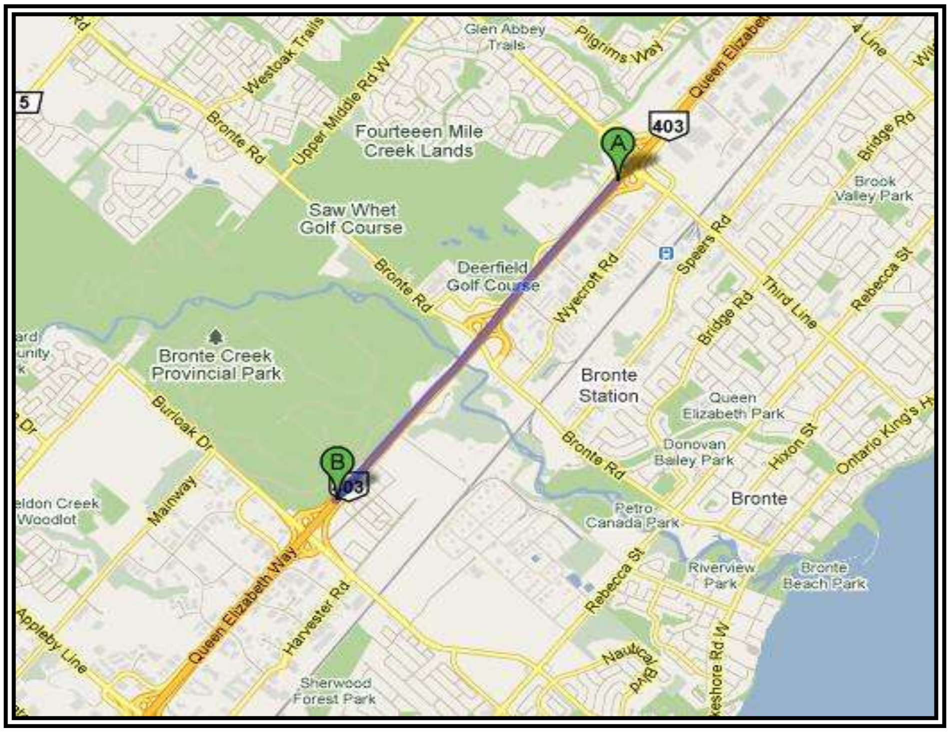
Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
22:40:00	22:55:00	0:15:00	304	3	19	22	0	15	0	0.25	1216	12	76	88	1304
22:55:00	23:10:00	0:15:00	292	5	26	31	0	15	0	0.25	1168	20	104	124	1292
23:10:00	23:25:00	0:15:00	318	5	19	24	0	15	0	0.25	1272	20	76	96	1368
23:25:00	23:40:00	0:15:00	319	3	20	23	0	15	0	0.25	1276	12	80	92	1368
23:45:00	0:00:00	0:15:00	296	6	24	30	0	15	0	0.25	1184	24	96	120	1304
0:00:00	0:15:00	0:15:00	297	4	24	28	0	15	0	0.25	1188	16	96	112	1300

2. SITE VISIT 3 – July 9, 2010

2.1 SITE CHARACTERISTICS FORM FOR SITE 2007-2026

Date	9-July, 2010
Hwy No:	QEW
Location	QEW, Btw Third line & Burloak Dr, Westbound
Weather	Clear
Starting Time	10:45 PM (July 9)
End Time	12:15 AM (July 10)
Day of Week	Friday
Time of Day	Night
Assigned Lane	Left lane and Left shoulder closed, 2 right lanes open
Lane Width (m)	3.75
Direction of Traffic	West
Shoulder Type	Paved
Lane Closure	3-to-2
OPP Presence	yes
Time of OPP Presence	11:30 to 12:15
Facility Type	6 lane divided Hwy
Driver Population	Mostly commuter traffic
% Heavy Vehicles	
Grade of Road	0
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	2
Duration of Closure	10:30 Pm - 5:00 Am
Intersections	Third Line & Burloak Dr
Type of Traffic Control	Barrels and lighted arrow signs
Pavement Condition	Complete
Distractions	Night, Construction vehicles and workers
List of Photos Taken	#1: Looking West, #2: looking East
Other Comments	* There happened an accident @ 11:15 and since it blocked one of the 2 flowing lanes, it made the traffic flow much slower adding to the queue length till 11:45 when the police pulled the cars out of the way
Free Flow?	No
Queue Length (Km)	1.5 Km

2.2 MAP OF LOCATION OF SITE



2.3 AERIAL VIEW OF SITE

2.4 DATA COLLECTED FROM SITE ON July 9, 2010

Road QEW, Westbound
Location QEW, Btw Third line & Burloak Dr, Westbound
Evaluation Days

Date Friday, July 9, 2010

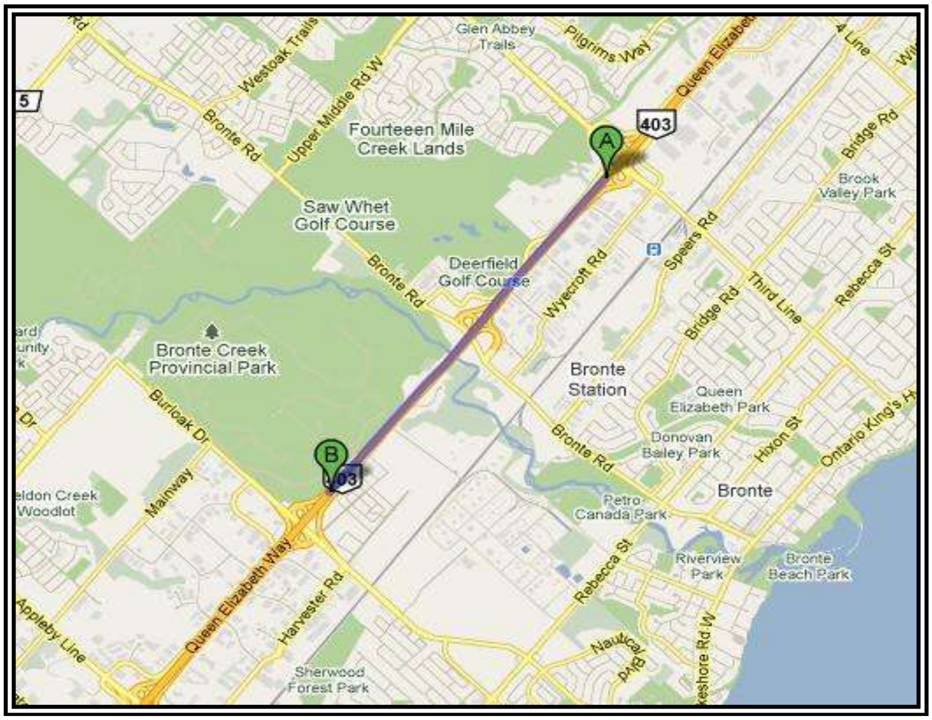
Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
22:45:00	23:00:00	0:15:00	645	3	11	14	0	15	0	0.25	1290	6	22	28	1318
23:00:00	23:15:00	0:15:00	651	15	15	30	0	15	0	0.25	1302	30	30	60	1362
23:45:00	0:00:00	0:15:00	531	11	9	20	0	15	0	0.25	1062	22	18	40	1102
0:00:00	0:15:00	0:15:00	473	7	8	15	0	15	0	0.25	946	14	16	30	976

3. SITE VISIT3 – July 11, 2010

3.1 SITE CHARACTERISTICS FORM FOR SITE 2007-2026

Date	11-July, 2010
Hwy No:	QEW
Location	QEW, Btw Third line & Burloak Dr, Westbound
Weather	Clear
Starting Time	10:15 PM
End Time	11:00 PM
Day of Week	Sunday
Time of Day	Night
Assigned Lane	Left lane and Left shoulder closed, 2 right lanes open
Lane Width (m)	3.75
Direction of Traffic	West
Shoulder Type	Paved
Lane Closure	3-to-2
OPP Presence	No
Time of OPP Presence	N/A
Facility Type	6 lane divided Hwy
Driver Population	Mostly commuter traffic
% Heavy Vehicles	
Grade of Road	0
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	2 Km
Duration of Closure	9:30 Pm - 5:00 Am
Intersections	Third Line & Burloak Dr
Type of Traffic Control	Barrels and lighted arrow signs
Pavement Condition	Complete
Distractions	Night, Construction vehicles and workers
List of Photos Taken	#1: Looking West #2: Looking East
Other Comments	
Free Flow?	No
Queue Length (Km)	

3.2 MAP OF LOCATION OF SITE



3.3 AERIAL VIEW OF SITE

3.4 DATA COLLECTED FROM SITE ON July 11, 2010

Road QEW, Westbound
Location QEW, Btw Third line & Burloak Dr, Westbound
Evaluation Days

Date Sunday, July 11, 2010

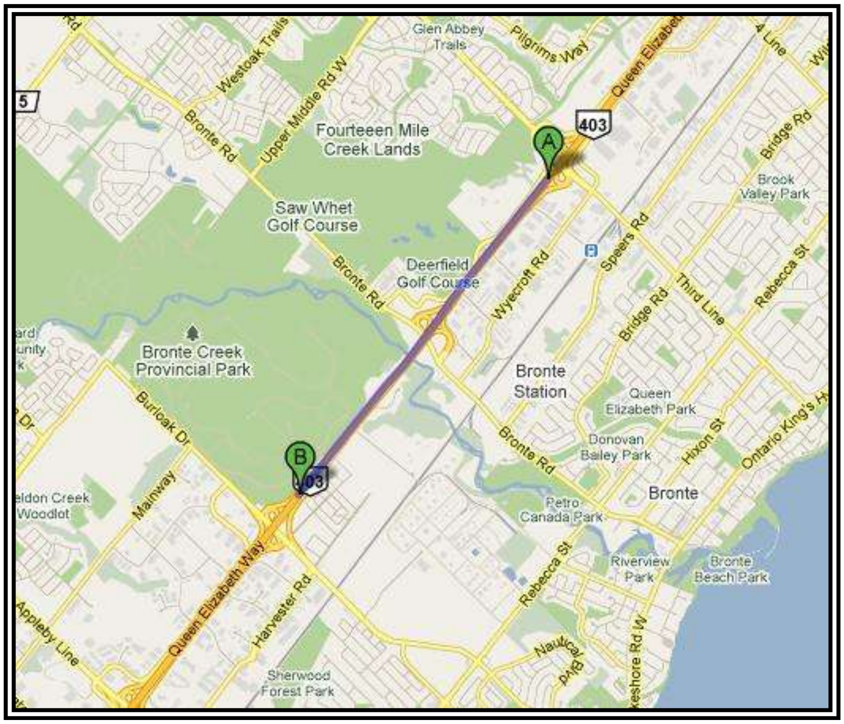
Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
22:15:00	22:30:00	0:15:00	696	9	20	29	0	15	0	0.25	1392	18	40	58	1450
22:30:00	22:45:00	0:15:00	617	13	16	29	0	15	0	0.25	1234	26	32	58	1292

4. SITE VISIT 4 – July 13, 2010

4.1 SITE CHARACTERISTICS FORM FOR SITE 2007-2026

Date	13-July, 2010
Hwy No:	QEW
Location	QEW, Btw Third line & Burloak Dr, Westbound
Weather	Clear
Starting Time	9:30 PM
End Time	10:30 PM
Day of Week	Tuesday
Time of Day	Night
Assigned Lane	Left lane and Left shoulder closed, 2 right lanes open
Lane Width (m)	3.75
Direction of Traffic	West
Shoulder Type	Left is paved but there is no right shoulder
Lane Closure	3-to-2
OPP Presence	No
Time of OPP Presence	N/A
Facility Type	6 lane divided Hwy
Driver Population	Mostly commuter traffic
% Heavy Vehicles	
Grade of Road	0
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	2 Km
Duration of Closure	9:30 Pm - 5:00 Am
Intersections	Third Line & Burloak Dr
Type of Traffic Control	Barrels and lighted arrow signs
Pavement Condition	Complete
Distractions	Night, Construction vehicles and workers
List of Photos Taken	No photo was taken on this site
Other Comments	* No right shoulder, a third right ramp lane entering Bronte Rd
Free Flow?	No
Queue Length (Km)	

4.2 MAP OF LOCATION OF SITE



4.3 AERIAL VIEW OF SITE

4.4 DATA COLLECTED FROM SITE ON July 13, 2010

Road QEW, Westbound
Location QEW, Btw Third line & Burloak Dr, Westbound
Evaluation Days

Date Tuesday, July 13, 2010

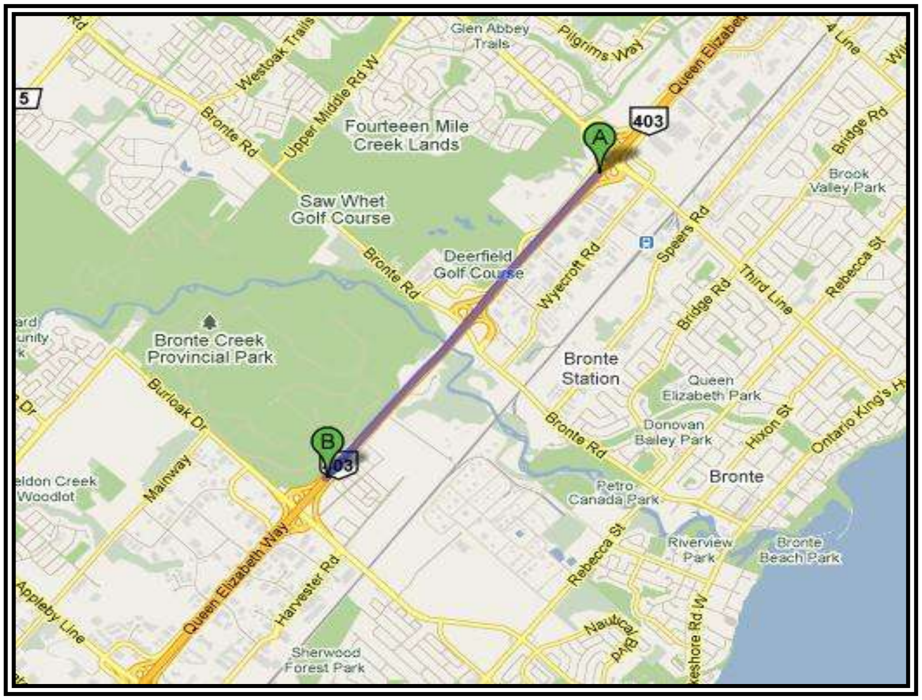
Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
21:30:00	21:45:00	0:15:00	654	10	30	40	0	15	0	0.25	1308	20	60	80	1388
21:45:00	22:00:00	0:15:00	665	15	48	63	0	15	0	0.25	1330	30	96	126	1456
22:00:00	22:15:00	0:15:00	772	13	30	43	0	15	0	0.25	1544	26	60	86	1630
22:15:00	22:30:00	0:15:00	660	17	34	51	0	15	0	0.25	1320	34	68	102	1422

5. SITE VISIT 5 – July 14, 2010

5.1 SITE CHARACTERISTICS FORM FOR SITE 2007-2026

Date	14-July, 2010
Hwy No:	QEW
Location	QEW, Btw Third line & Burloak Dr, Westbound
Weather	Clear
Starting Time	9:45 PM
End Time	10:45 PM
Day of Week	Wednesday
Time of Day	Night
Assigned Lane	Left lane and Left shoulder closed, 2 right lanes open
Lane Width (m)	3.75
Direction of Traffic	West
Shoulder Type	Left is paved but there is no right shoulder
Lane Closure	3-to-2
OPP Presence	No
Time of OPP Presence	N/A
Facility Type	6 lane divided Hwy
Driver Population	Mostly commuter traffic
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	2 Km
Duration of Closure	9:30 Pm - 5:00 Am
Intersections	Third Line & Burloak Dr
Type of Traffic Control	Barrels and lighted arrow signs
Pavement Condition	Complete
Distractions	Night, Construction vehicles and workers
List of Photos Taken	#1: Looking West #2: Looking East
Other Comments	* No right shoulder, a third right ramp lane entering Bronte Rd
Free Flow?	No
Queue Length (Km)	

5.2 MAP OF LOCATION OF SITE



5.3 AERIAL VIEW OF SITE

5.4 DATA COLLECTED FROM SITE ON July 14, 2010

Road QEW, Westbound
Location QEW, Btw Third line & Burloak Dr, Westbound
Evaluation Days

Date Wednesday, July 14, 2010

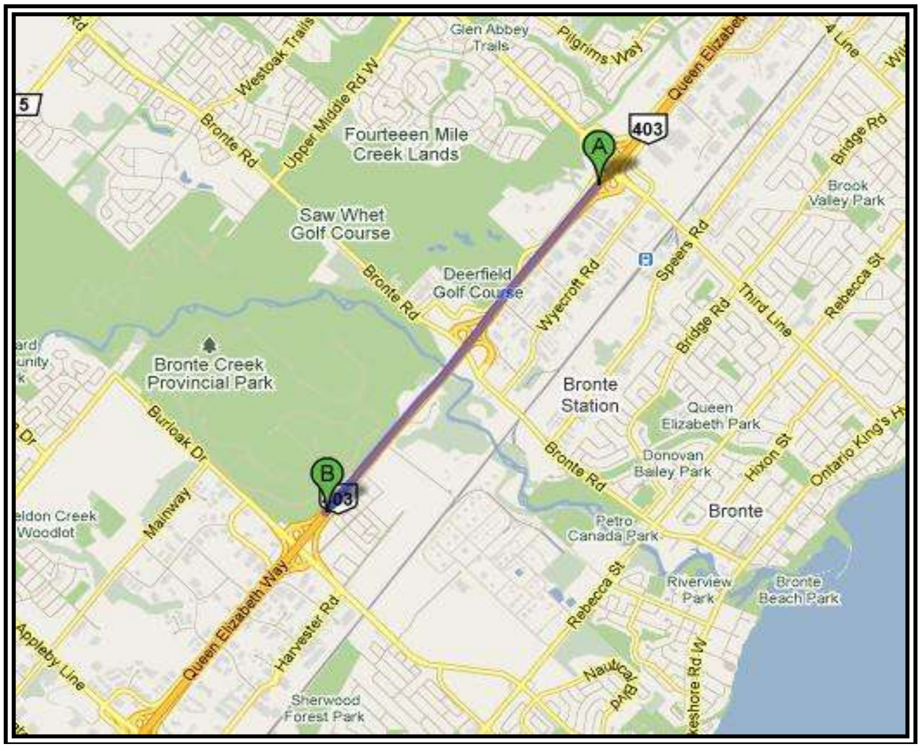
Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
21:45:00	22:00:00	0:15:00	647	10	46	56	0	15	0	0.25	1294	20	92	112	1406
22:00:00	22:15:00	0:15:00	696	12	32	44	0	15	0	0.25	1392	24	64	88	1480
22:15:00	22:30:00	0:15:00	599	11	23	34	0	15	0	0.25	1198	22	46	68	1266

6. SITE VISIT 6 – July 19, 2010

6.1 SITE CHARACTERISTICS FORM FOR SITE 2007-2026

Date	19-July, 2010
Hwy No:	QEW
Location	QEW, Btw Third line & Burloak Dr, Westbound
Weather	Clear
Starting Time	9:50 PM
End Time	10:35 PM
Day of Week	Monday
Time of Day	Night
Assigned Lane	Left lane and Left shoulder closed, 2 right lanes open
Lane Width (m)	3.75
Direction of Traffic	West
Shoulder Type	Left is paved but there is no right shoulder
Lane Closure	3-to-2
OPP Presence	No
Time of OPP Presence	N/A
Facility Type	6 lane divided Hwy
Driver Population	Mostly commuter traffic
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	2 Km
Duration of Closure	9:30 Pm - 11:00 Pm
Intersections	Third Line & Burloak Dr
Type of Traffic Control	Barrels and lighted arrow signs
Pavement Condition	Complete
Distractions	Night, Construction vehicles and workers, Construction trucks parked close to barrells
List of Photos Taken	#1: Looking West #2: Looking East
Other Comments	* No right shoulder, a third right ramp lane entering Bronte Rd
Free Flow?	No
Queue Length (Km)	2.5 Km

6.2 MAP OF LOCATION OF SITE



6.3 AERIAL VIEW OF SITE

6.4 DATA COLLECTED FROM SITE ON July 19, 2010

Road QEW, Westbound
Location QEW, Btw Third line & Burloak Dr, Westbound
Evaluation Days

Date Monday, July 19, 2010

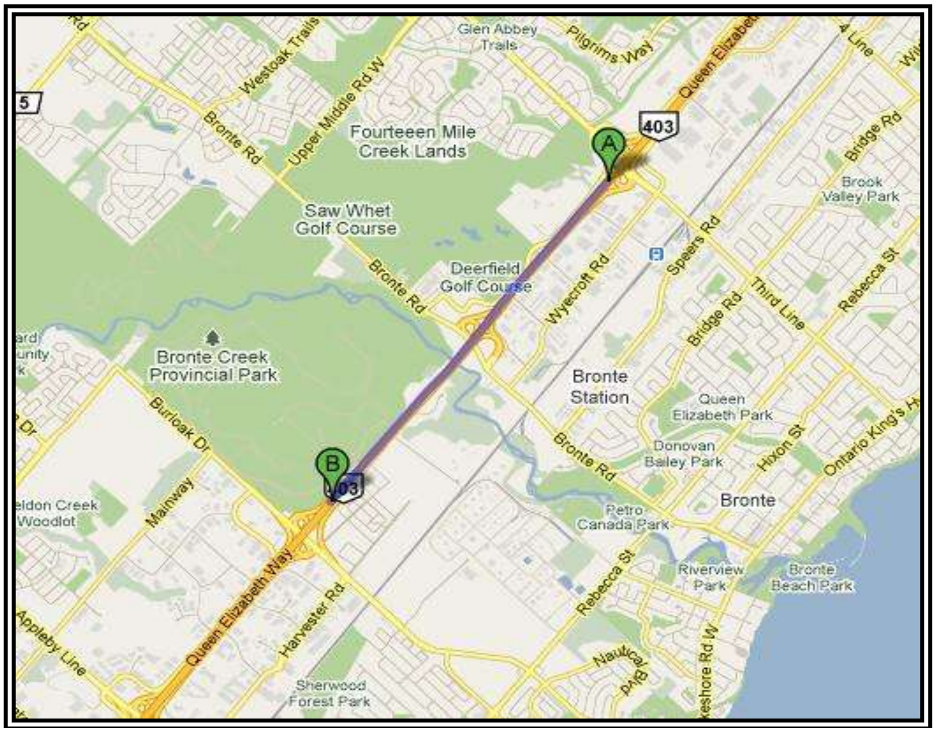
Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
21:50:00	22:05:00	0:15:00	591	16	38	54	0	15	0	0.25	1182	32	76	108	1290
22:05:00	22:20:00	0:15:00	571	13	34	47	0	15	0	0.25	1142	26	68	94	1236
22:20:00	22:35:00	0:15:00	549	12	27	39	0	15	0	0.25	1098	24	54	78	1176

7. SITE VISIT 7 – July 19, 2010

7.1 SITE CHARACTERISTICS FORM FOR SITE 2007-2026

Date	19-July, 2010
Hwy No:	QEW
Location	QEW, Btw Third line & Burloak Dr, Westbound
Weather	Clear
Starting Time	11:10 PM (July 19)
End Time	1:00 AM (July 20)
Day of Week	Monday
Time of Day	Night
Assigned Lane	2 Left lanes and Left shoulder closed, right lane open
Lane Width (m)	3.75
Direction of Traffic	West
Shoulder Type	Paved
Lane Closure	3-to-1
OPP Presence	No
Time of OPP Presence	N/A
Facility Type	6 lane divided Hwy
Driver Population	Mostly commuter traffic
% Heavy Vehicles	
Grade of Road	Level
Speed Limit (km/hr)	100
Curve of Road	Straight
Length of Work Zone	2 Km
Duration of Closure	11:00 Pm - 5:00 Am
Intersections	Third Line & Burloak Dr
Type of Traffic Control	Barrels and lighted arrow signs
Pavement Condition	Complete
Distractions	Night, Construction vehicles and workers, Construction trucks parked close to barrells
List of Photos Taken	#1: Looking West #2: Looking East
Other Comments	* This form and the previous form belong to the same site visit in the same night. This form is the data from the time when second lane was closed.
Free Flow?	No
Queue Length (Km)	2.5 Km

7.2 MAP OF LOCATION OF SITE



7.3 AERIAL VIEW OF SITE

7.4 DATA COLLECTED FROM SITE ON July 19, 2010

Road QEW, Westbound
Location QEW, Btw Third line & Burloak Dr, (Westbound)
Evaluation Days

Date Monday, July 19, 2010

Start Time	Finish Time	Lag Time	PV	SHV	LHV	Total HV	Hour	Minute	Second	Time (hr)	PV Vol	SHV Vol	LHV Vol	Total HV Vol	Total Vol
23:10:00	23:25:00	0:15:00	309	6	28	34	0	15	0	0.25	1236	24	112	136	1372
23:25:00	23:40:00	0:15:00	301	6	17	23	0	15	0	0.25	1204	24	68	92	1296
23:40:00	23:55:00	0:15:00	307	8	15	23	0	15	0	0.25	1228	32	60	92	1320
23:55:00	0:10:00	0:15:00	322	4	9	13	0	15	0	0.25	1288	16	36	52	1340
0:15:00	0:30:00	0:15:00	275	8	16	24	0	15	0	0.25	1100	32	64	96	1196
0:30:00	0:45:00	0:15:00	278	9	27	36	0	15	0	0.25	1112	36	108	144	1256
0:45:00	1:00:00	0:15:00	239	6	28	34	0	15	0	0.25	956	24	112	136	1092

Appendix B: SZUDA Output Tables

1. Working Portion of SZUDA - Inputs and Calculations

Day	Hour	Traffic	WZ Operating	Throughput	Difference	Cumulative
	0:00	667	1	1608	-941	0
	1:00	420	1	1608	-1188	0
	2:00	390	1	1608	-1218	0
	3:00	375	1	1608	-1233	0
	4:00	961	1	1608	-647	0
	5:00	4074	0	5400	-1326	0
	6:00	4756	0	5400	-644	0
	7:00	3989	0	5400	-1411	0
	8:00	4038	0	5400	-1362	0
	9:00	3735	0	5400	-1665	0
	10:00	3256	0	5400	-2144	0
	11:00	3457	0	5400	-1943	0
Monday	12:00	3396	0	5400	-2004	0
	13:00	3394	0	5400	-2006	0
	14:00	4100	0	5400	-1300	0
	15:00	3807	0	5400	-1593	0
	16:00	3803	0	5400	-1597	0
	17:00	3642	0	5400	-1758	0
	18:00	3100	0	5400	-2300	0
	19:00	2566	0	5400	-2834	0
	20:00	2067	1	1608	459	459
	21:00	1876	1	1608	268	727
	22:00	1890	1	1608	282	1009
	23:00	1059	1	1608	-549	460
Next Day	0:00	603	1	1608	-1005	0
	1:00	438	1	1608	-1170	0
	2:00	450	1	1608	-1158	0
	3:00	467	1	1608	-1141	0

2. Site Characteristics required for SZUDA - Generic Model

Construction Site Characteristics

No. of Total Lanes	3	
No. of Lanes Closed	2	
Closure Type	1	Choose one:
		1 = concrete, 2=barrels
%HV	10%	0% uses mixed cost

3. Site Characteristics required for SZUDA – Highway Specific Model

Construction Site Characteristics

No. of Total Lanes	3	
No. of Lanes Closed	2	
Hwy 427	0	Choose one:
Hwy 400 or 401	1	0=no, 1=yes
Hwy QEW	0	
%HV	10%	0% uses mixed cost

4. Table of Lane Closure time Inputs from SZUDA

Construction Hours (0=Lane Open, 1=Left Lane Closed, 2=Right Lane Closed, 3=Police Presence (Right Lane), 4= Police Presence (Left Lane)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0:00	1	1	1	1	1	1	1
1:00	1	1	1	1	1	1	1
2:00	1	1	1	1	1	1	1
3:00	1	1	1	1	1	1	1
4:00	1	1	1	1	1	1	1
5:00	0	0	0	0	0	1	1
6:00	0	0	0	0	0	0	1
7:00	0	0	0	0	0	0	1
8:00	0	0	0	0	0	0	1
9:00	0	0	0	0	0	0	0
10:00	0	0	0	0	0	0	0
11:00	0	0	0	0	0	0	0
12:00	0	0	0	0	0	0	0
13:00	0	0	0	0	0	0	0
14:00	0	0	0	0	0	0	0
15:00	0	0	0	0	0	0	0
16:00	0	0	0	0	0	0	0
17:00	0	0	0	0	0	0	0
18:00	0	0	0	0	0	0	0
19:00	0	0	0	0	0	0	0
20:00	1	1	1	1	1	1	0
21:00	1	1	1	1	1	1	1
22:00	1	1	1	1	1	1	1
23:00	1	1	1	1	1	1	1