Probabilistic Analysis and Design of Freeway Deceleration Speed Change Lanes

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Ahmed Abdelnaby

Bachelor of Science in Civil Engineering

Department of Civil and Environmental Engineering
Carleton University

Ottawa-Carleton Institute of Civil and Environmental Engineering

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Abstract

In highway design, knowledge about the design parameters and inputs is imperfect. Current geometric design guides provide deterministic methods for the design requirements by using conservative values to consider uncertainty. The design of freeway deceleration speed change lanes (SCLs) depends on the manner of deceleration, initial speed, and final speed at the SCL. SCL length should provide drivers with enough distance to diverge at a reasonable speed and decelerate comfortably. The purpose of this research is to develop probabilistic methodology for evaluating and designing freeway deceleration SCLs using reliability analysis. Models were developed to evaluate the operational performance of SCLs using field data. Three different methodologies were used for evaluating SCL length. PNC, which corresponds to the probability that drivers require a deceleration length longer than what is provided at the SCL, was calculated for each study site. Design graphs were developed to design based on PNC for lengths below 300 m.

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Table of Contents

Abstract.....	II
Acknowledgements	III
List of Tables	VIII
List of Figures.....	X
Chapter One: Introduction.....	1
1.1 Background.....	1
1.2 Problem Definition	3
1.3 Objectives	4
1.4 Scope of Research	5
1.5 Thesis Organization.....	5
Chapter Two: Literature Review	6
2.1 Interchanges and Speed Change Lanes in Design Guides.....	6
2.2 Driver Behaviour.....	15
2.3 Safety and Operational Performance of SCLs.....	21
2.4 Reliability Analysis in Highway Design.....	26
2.5 Summary.....	32
Chapter Three: Data Description.....	34
3.1 Study Area and Selected Sites.....	34
3.2 Geometric Characteristics of the Study Sites.....	37
3.3 Available Speed Data.....	37
3.4 Data Reprocessing.....	42

3.5	Collision Data.....	52
Chapter Four: Data Analysis.....		54
4.1	Summary of Reprocessed Data.....	54
4.2	Statistical Tests on Reprocessed Data.....	56
4.2.1	Distribution Testing of SCL Speed Profiles.....	56
4.2.2	ANOVA Single Factor Mean Tests.....	58
4.3	Comparison of Original and Reprocessed Data.....	61
4.3.1	Time and Distance to Decelerate.....	62
4.3.2	Final Speeds.....	63
4.3.3	Initial and Gore Speeds.....	65
4.3.4	Deceleration Distance and Total Travelled Distance	66
4.3.5	Overall Deceleration Rate.....	67
4.3.6	Correlation Between Variables.....	69
Chapter Five: Probabilistic Methodology		71
5.1	Reliability Analysis.....	72
5.2	Limit State Function.....	74
5.3	First Order Second Moment (FOSM).....	77
5.4	Monte Carlo Simulation (MCS).....	80
5.5	First Order Reliability Analysis (FORM).....	88
Chapter Six: Results and Discussion.....		92
6.1	First Order Second Moment (FOSM).....	92
6.2	Monte Carlo Simulation (MCS).....	94

6.3 First Order Reliability Analysis (FORM).....	97
6.4 Comparison Between FOSM, MCS, and FORM.....	98
6.4 Relationship to Safety.....	102
Chapter Seven: Design Application	109
7.1 Initial Assumptions and Regression Models.....	109
7.2 Design Application Using MCS.....	111
Chapter Eight: Conclusions and Recommendations	115
8.1 Conclusions.....	115
8.2 Recommendations for Future Studies.....	117
List of References	119
Appendices.....	126
Appendix 1: Summary of Geometric Data of Study Sites.....	127
Appendix 2: Script Estimating Deceleration Point.....	129
Appendix 3: Final Dataset After Reprocessing the Data	134
Appendix 4: Initial Speeds ANOVA Test at Study Sites	165
Appendix 5: FRL and Diverge Speeds ANOVA Test at Each Site.....	169
Appendix 6: Multiple Linear Regression of Deceleration Rate Used in MCS.....	174
Appendix 7: Diagnostics of Deceleration Rate Regression Used in MCS.....	183
Appendix 8: Multiple Linear Regression between Mean of the Parameters and Standard Deviation.....	196
Appendix 9: MCS Script.....	201
Appendix 10: FORM Script.....	206

Appendix 11: MCS Design Application Script	211
Appendix 12: Speed Profiles	214
Appendix 13: Frequency of Demand Length Output for MCS Using the Dataset of Each Site	219

List of Tables

Table 2.1 : Minimum Deceleration Lengths for Flat Grades with 2% or Less, Adopted from AASHTO (2011) (Metric).....	13
Table 2.2: Design Length for Deceleration, Adopted from TAC (1999).	13
Table 3.1: Selected Sites	36
Table 3.2: Available Vehicle Speed Profiles at Every Site.	52
Table 3.3: Summary of Collision Data by Site	53
Table 4.1: Distribution of Input Parameters on Study Sites.	55
Table 4.2: Distribution Testing Summary of Reprocessed Data	57
Table 4.3: Summary of Mean FRL, Diverge, and Initial Speeds	59
Table 4.4: Summary of ANOVA at Homogeneous sites.....	61
Table 4.5: Mean Final Speed at Each Site and Relative Ramps Advisory Speeds.....	64
Table 4.6: Summary of Correlation Coefficients and Corresponding P-values before Reprocessing	69
Table 4.7: Summary of correlation Coefficients and Corresponding <i>P</i> -values after Reprocessing.....	69
Table 5.1: Linear Regression for the Dataset of All Sites Combined.....	81
Table 5.2: Regression Coefficients for Prediction of Individual Vehicle's Deceleration Rate.	82
Table 6.1: Results of FOSM Using the Dataset of Each Site.	93
Table 6.2: Results of FOSM Using the Dataset of All Sites Combined.	94
Table 6.3: MCS Results Using the Dataset of Each Site's.....	96
Table 6.4: MCS Results Using the Dataset of All sites Combined.	96

Table 6.5: FORM results Using the Dataset of Each Site.....	96
Table 6.6: FORM results Using the Dataset of Each Site All Sites Combined.	96

List of Figures

Figure 2.1: Limited Type SCL, Parallel Configuration.	10
Figure 2.2: Limited Type SCL, Taper Configuration.	10
Figure 2.3: Extended Type Deceleration SCL.	12
Figure 2.4: Example of Type A Weaving (Adopted from HCM, 2000).....	16
Figure 2.5: Example of Type B weaving (Adopted from HCM, 2000).....	17
Figure 2.6: Example of Type C Weaving (Adopted from HCM, 2000).....	17
Figure 2.7: Typical ramp-weave segment based on the HCM definition of weaving length.....	18
Figure 2.8: Part of Recommended Minimum Ramp Terminal Spacing, (Adopted form AASHTO, 2011).	19
Figure 3.1: Study Area (Google Earth Imagery)	35
Figure 3.2: Speed Profile Sample for a passenger car on Bronson Ave. W-NS.....	40
Figure 3.3: Summary of Speed Profiles on Bronson Ave. W-NS	41
Figure 3.4: Initial Data Organization	42
Figure 3.5: Schematic of SCL Lengths.....	46
Figure 3.6: Long SCL and Deceleration Point within l_3	47
Figure 3.7: Long SCL and deceleration point within l_2	48
Figure 3.8: Short SCL and Deceleration Point within l_2	49
Figure 3.9: Speed Profiles before Reprocessing	50
Figure 3.10: Final Speed Profiles after Reprocessing.....	50
Figure 3.11: Summary of Re-processed Data	51

Figure 4.1: Time Spent on the SCL before Decelerating (dots represent each vehicle and cross represents the mean value of vehicles at each site).	62
Figure 4.2: Distance Spent on the SCL before Decelerating (dots represent each vehicle and cross represents the mean value of vehicles at each site).....	63
Figure 4.3: Ramp's Advisory Speeds and Mean Final Speeds at All Sites.....	64
Figure 4.4: Comparison between Initial and Final Speeds	65
Figure 4.5: Deceleration Distance and TotalTravelled Distance.	66
Figure 4.6: Mean Overall Deceleration Rate before and after Reprocessingthe Data.	68
Figure 4.7: Standard Deviation of Overall Deceleration Rate before and after Reprocessing the Data.....	68
Figure 5.1: Speed Profiles of Individual Vehicles at Bronson Ave. (W-NS)	76
Figure 5.2: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10 for All SCLs Combined.	83
Figure 5.3: Residuals Plot for Each Predicted Deceleration Rate Using Equation 5.10 at All Sites Combined	83
Figure 5.4: Residuals Histogram for All Sites Combined	84
Figure 6.1: Mean Demand Length Using FOSM and MCS Using the Dataset of Each Site.	99
Figure 6.2: Standard Deviation of Demand L Using FOSM and MCS using the Dataset of each site.....	99
Figure 6.3: PNC Using the Dataset of Each Site (FOSM, MCS, and FORM).	100
Figure 6.4: PNC Using the Dataset of All Sites Combined (FOSM, MCS, and FORM).	100

Figure 6.5: FOSM PNC Results Using the Dataset of Each Site and Total Collisions	
Frequency (Through and SCL)	103
Figure 6.6: FOSM PNC Results Using the Dataset of Each Site and SCL Collisions	
Frequency.....	103
Figure 6.7: MCS PNC Results Using the Dataset of Each Site and Total Collisions	
Frequency (Through and SCL)	104
Figure 6.8: MCS PNC Results Using the Dataset of Each Site and SCL Collisions	
Frequency.....	104
Figure 6.9: FORM PNC Results Using the Dataset of Each Site and Total Collisions	
Frequency (Through and SCL)	105
Figure 6.10: FORM PNC Results Using the Dataset of Each Site and SCL Collisions	
Frequency.....	105
Figure 6.11: FOSM PNC Results Using the Dataset of All Sites Combined and Total	
Collisions Frequency (Through and SCL).....	106
Figure 6.12: FOSM PNC Results Using the Dataset of All Sites Combined and SCL	
Collisions Frequency	106
Figure 6.13: MCS PNC Results Using the Dataset of All Sites Combined and Total	
Collisions Frequency (Through and SCL).....	107
Figure 6.14: MCS PNC Results Using the Dataset of All Sites Combined and SCL	
Collisions Frequency	107
Figure 6.15: FORM PNC Results Using the Dataset of All Sites Combined and Total	
Collisions Frequency (Through and SCL).....	108

Figure 6. 16: FORM PNC Results Using the Dataset of All Sites Combined and SCL	
Collisions Frequency	108
Figure 7.1: Design Curves for Limited SCLs Based on 85th Percentile Final/Gore Speed and PNC for Lengths ≤ 300 m.	113
Figure 7.2: Design Curves for Limited SCLs Based on 85th Percentile Final/Gore Speed and PNC Including $L > 300$ m.....	114

Chapter One

1.0 Introduction

1.1 Background

Transportation networks are designed to provide safe and efficient movements for people, goods, and services. One of the most important components of transportation networks is roads network. Functionally, roads are classified in American Association of State Highway and Transportation Officials (AASHTO) into principal and minor arterials, collectors and locals (AASHTO, 2011). On the other hand, the Canadian design guide (TAC) classifies a rural network to freeways, arterials, collectors, and locals; while urban networks are classified into freeways, expressways, arterials, collectors, and locals (TAC, 1999). Depending on every road's function, the geometric and traffic characteristics vary. Similarly, the construction and maintenance costs of every class differ based on its importance and role to provide a specific degree of safety and comfort. In accordance, well designed highway elements are anticipated to provide high level of safety and comfort.

According to the Council of Ministers Responsible for Transportation and Highway Safety, the total length of the Canadian national highway system is 38,047.4 Km, where 91% is paved, among which 10% is poorly paved and 22% is fairly paved (Canada's National Highway System Condition report, 2009). Such a tremendous length indicates a high level of importance for this network of transportation. Safety is an important factor to evaluate potential issues in the network. According to the Road Safety and Motor Vehicle Regulation division in Transport Canada, the number of fatal and

injury collisions in 2010 is 2,000 and 123,141 respectively, which lead to 2227 fatalities, 11,226 serious injuries, and a total of 170,629 injured victims (Canadian Motor Vehicle Traffic Collision Statistics: 2010, 2012). The statistics also show that the frequency of fatal collisions is higher in rural areas with 1,131 collisions compared to 834 in urban areas, where 35 fatal collisions locations were unknown. On the other hand, frequency of injury collisions is lower in rural areas with 29,716 collisions compared to 91,434 collisions in urban areas, where 1,991 collisions locations were unknown. This difference could be related to the degree of congestion and relative operating speeds in rural and urban areas.

It should be noted that more generous geometric design for highway elements are adapted along arterials compared to collector and local roads as they are designed for higher operational speeds and better mobility. Freeways are an important type of arterial roadways which serve in connecting between different locations with a high degree of mobility. According to the Green Book, “Freeways are arterial highways with full control of access. They are intended to provide for high levels of safety and efficiency in the movement of large volumes of traffic at high speeds (AASHTO, 2011).” Freeways are given full control of access, which means that through traffic has the preference in movement and access connections with other roads are given at selected locations using ramps (AASHTO, 2011). In order to provide a full control of access in a safe and efficient manner, a freeway is connected to another freeway or arterial using an interchange. An interchange consists of loops and ramps at both entrances and exits to get drivers to their destination in an efficient manner. A deceleration lane is provided before an exit terminal to get to the ramp’s safe speed and, while an acceleration lane is

provided after an entrance terminal to help the driver in merging to the roadway safely. Both deceleration and acceleration lanes are auxiliary lanes provided to help the drivers to increase or decrease their speed and are referred to in AASHTO as Speed Change Lanes (SCLs) (AASHTO, 2011). If acceleration SCL has an adequate length, the driver would be able to safely merge onto the freeway at a reasonable speed; otherwise an uncomfortable merging would take place which may result in a conflict or a collision. Similarly, if a deceleration SCL has an adequate length, drivers would be able to reach the ramp's speed safely and comfortably, and otherwise an uncomfortable deceleration maneuver would take place which may lead to a conflict or a collision.

1.2 Problem Definition

In transportation engineering, geometric design guides, such as “AASHTO (2011)” and “TAC (1999)”, use a deterministic approach for the design requirements of road elements, including the design of deceleration SCLs and horizontal and vertical curves. In this approach, conservative percentile values are used to consider uncertainty (e.g. 85th percentile) (Fatema & Hassan, 2013; Hassan, Sarhan & Salehi, 2012; Ibrahim & Sayed, 2011). Using such approach as discussed by Ibrahim & Sayed (2011) has two main shortcomings.

- First, percentile values selection is not based on safety measures but only on practical experience, which makes the safety margin of the design output to be unknown.

- Second, there is no quantitative measure of the safety implications resulting from deviating from the design recommendations (e.g., providing sight distance, braking distance ...etc. that is different from design guides).

Furthermore, the reliability of design guides could be debated as they are based on old studies and possibly outdated design values from the 1930s (Fitzpatrick, 2012). On the other hand, probabilistic methodologies using the reliability analysis could be an alternative. Given a level of confidence and the probabilistic characteristics of design parameters, operational performance and safety could be quantified. This would provide more accuracy and flexibility in design (Hassan, Sarhan & Salehi, 2012; Fatema & Hassan, 2013).

1.3 Objectives

The main purpose of this study is to develop a probabilistic approach for evaluating the operational performance of deceleration SCLs. Probabilistic models are developed considering the distribution of actual driver behaviour based on field data. The premise of the probabilistic approaches is explored using the available collision data. Furthermore, a design aid for deceleration SCLs is developed based on the required operational performance. The data utilized in this study were previously gathered by El-Basha's (2006) for a study on modeling drivers' behavior, which makes this thesis a continuation of El-Basha's (2006) work. El-Basha's (2006) data were reprocessed for the purpose of this study. The probabilistic models are developed using the First-Order Second Moment (FOSM) method, Monte Carlo simulation (MCS), and First-Order Reliability Method (FORM).

1.4 Scope of Research

The scope of this study is limited to freeway interchanges connecting to lower class roads and excludes freeway-to-freeway connections. The data were collected as mentioned earlier by El-Basha (2006) and this research will be limited to the same data collection conditions, such as dry conditions and of peak periods (favorable traffic conditions). Establishing a relation between safety and operational performance is out of the scope of this study; however the study will explore the premise of a relationship between the developed models and safety. Extended SCLs, which are extended from an entrance ramp to an exit ramp, are affected by both merging and diverging vehicles and the associated weaving manoeuvres and are beyond the scope of this research.

1.5 Thesis Organization

Chapter 1.0 is an introduction to this study. Chapter 2.0 reviews design guide criteria for SCL design and presents a review of previous studies and research on the topics of safety and operation of SCLs and reliability analysis. Chapter 3.0 describes the data preparation for the purpose of this study. Then, Chapter 4.0 shows analysis of the database obtained for this study. In Chapter 5.0, probabilistic modeling techniques are used to quantify the operational performance of deceleration SCLs. Chapter 6.0 summarizes the results and compares the operational performance results to collision data at the study sites. Chapter 7.0 provides a design application example of the developed design models. Finally, Chapter 8.0 presents a summary of the study findings with recommendations for future research.

Chapter Two

2.0 Literature Review

This chapter covers a review of design guides criteria and relevant research concerned with freeway diverge areas. Section 2.1 provides a review of current design guides such as the American Association of State Highway and Transportation Officials (AASHTO, 2011) and the Transportation Association of Canada (TAC, 1999). Section 2.2 covers drivers' behaviour on the freeways' diverge areas, specifically freeway right lanes (FRL) and speed change lanes (SCLs). Section 2.3 discusses previous research conducted in safety and operations on SCLs and FRLs. Finally, Section 2.4 covers studies on reliability analysis and design in highway engineering.

2.1 Interchanges and Speed Change Lanes in Design Guides

An interchange is defined by AASHTO “as a system of interconnecting roadways in conjunction with one or more grade separations that provides for the movement of traffic between two or more roadways or highways on different levels (AASHTO, 2011).” There are many types of interchanges varying from simple to complex. A designer usually tries to achieve simplicity and uniformity. Some of the basic interchange configurations are available in AASHTO (2011), such as: trumpet, three-leg directional, diamond, partial and full cloverleaf, and many others (AASHTO, 2011).

One of the main purposes of an interchange is to ensure uninterrupted traffic flow, but many reasons can warrant an interchange. Following is a list of the current warrants from AASHTO (2011):

- Designation by design: Designing a road as a freeway will warrant having an interchange since uninterrupted traffic flow is needed by design.
- Bottlenecks or spot congestions and road user benefit: If the current facility (e.g. an intersection, a roundabout ...) is not servicing the target capacity, an interchange can be warranted. Also, if the delays at at-grade intersections are user costly (in terms of fuel, time, wear on tires, repairs, etc...), an interchange can be warranted.
- Safety: If a current road facility that has serious safety issues, an interchange can be warranted. An example would be a collision prone intersection with many pedestrian incidents.
- Site Topography: If it is more economical to build an interchange than an at-grade intersection due to the topography of the site, an interchange can be warranted. To illustrate, if the cut and fill would cost more than building an interchange due to the type of soil, an interchange could be a feasible solution.
- Traffic Volume: Volumes that exceed the capacity of at-grade intersections would be a warrant. Interchanges are desirable where heavy traffic volumes need to be continuous without interruptions, which would reduce the traffic's exposure rate to conflicts.

There are other cases where an interchange is required, which are used inside urban areas, such as:

- To provide access to areas that cannot be not served by at-grade means of access within the right of way limits.
- To eliminate a railroad-highway at-grade crossing.
- To provide access to attractions within the proximity of a major arterial, or freeway (For example, a major shopping center on the side of an arterial or freeway).

Interchanges are mainly used to supply access for specific locations, such as the central business district (CBD), diverge into another freeway, etc.... To insure uninterrupted flow on freeways, design guides placed minimum spacing requirement for interchanges allocation. TAC (1999) identifies spacing for interchanges in a highway as 3-8 Km for rural areas and 2-3 Km for urban areas, which is far greater than AASHTO's (2011) values of 3.2 Km (2 mi) in rural and 1.6 (1 mi) in urban areas. Different countries have their different requirements (Pilko, Bared, Edara & Kim, 2012); in the United Kingdom (UK), the minimum spacing is a function of speed that supplies the spacing in meters:

$$\textit{Spacing} = 3.75 * V \quad \textbf{(Equation 2.1)}$$

Where,

- V is speed in km/h; and
- Spacing is in meters.

According to Pilko, Bared, Edara & Kim (2012), in Germany, the minimum spacing is 2.7 Km, while the Australian recommendations are 1.5-2 Km in urban areas and 3.1-8.1 Km in rural areas.

Interchanges consist of three main components: loops, ramps, and speed change lanes (SCL). Generally, a ramp is “turning roadway that connects two or more legs at an interchange” (AASHTO, 2011). A loop is the curved segment that connects two different levels in elevation. A ramp terminal is the parallel portion to the travelled way and it includes:

- Acceleration lane.
- Deceleration lane.
- Weaving section (e.g. in, case of an extended SCL, the weaving area is the length joining the exit and entrance of two ramps in an interchange).

A speed change lane (auxiliary lane) is a separate lane designed for accelerating or decelerating vehicles entering or leaving the road, usually a freeway (AASHTO, 2011). They are warranted on high speed or volume highways or intersections. Deceleration SCLs (scope of this research) can be categorized into two classes; limited-length and extended-length. A Limited deceleration SCL starts from the taper point as a new lane that diverges from the highway and is categorized into taper and parallel as shown in the figures below. Limited deceleration length in AASHTO (2011) is assumed to extend from the point where the width (W_L) of the SCL is 3.6 m (distance between the right edge of the through lane to right edge of tapered wedge) to the point of initial curvature of the exit ramp or where the alignment of the ramp roadway departs from the alignment of the freeway. However, for the purpose of this research, limited deceleration

SCL length included the taper and was measured from the beginning of the taper to the point where pavement edges of the freeway right lane and off-ramp are separated by 1.25 m. Figures 2.1 and 2.2 show the configuration of taper and parallel limited-length SCLs, respectively.

Figure 2.1: Limited Type SCL, Taper Configuration.

Figure 2.2: Limited Type SCL, Parallel Configuration.

There are mainly two types of SCLs, parallel and taper. A parallel design as shown in figure 2.2 consists of: L_d as stated in (TAC, 1999) or L' as stated in (AASHTO, 2011), which is the distance provided for the speed change maneuver between the freeway speed and the ramp. And L_t as called in TAC 1999, which is a gradual change of width and is a transition between the freeway right lane and the SCL. A parallel design is essential where traffic volume on the major highway is near capacity as it provides less confusion to the highway traffic or where through and diverging traffic volumes are sufficiently high (AASHTO, 2011). A tapered deceleration SCL (Figure 2.1) is provided for drivers to slightly decelerate using a sufficient L_d or L' . According to AASHTO (2011), taper divergence should be between 2 – 5 degrees; where in the past edition AASHTO (2004), SCLs should have a taper rate between 8:1 and 15:1 (Longitudinal: Transverse), which is equivalent to 3.8 – 7.1 degrees. A taper is designed to allow vehicles to depart the through travel lane using minimum braking. Using a taper that is too short may require vehicles a forced or high deceleration rate (Federal Highway Administration, 2004). It should be noted that the term “deceleration rate” is used in the highway literature to refer to the decrease in speed over time or distance; this term is used in the same context throughout this study. It was reported in a study of ramp entrances and exits design that was based on a nationwide NCHRP survey that most states in the United States of America (U.S.) prefer using a taper design for exit ramps. Seventy five percent of the states use a parallel design for entrance ramps and most states comply with AASHTO’s minimum length for deceleration SCLs design. However, some states use lengths are less than the minimum recommended by AASHTO (Koepke, 1993).

An extended SCL, the other class of SCLs, is the lane that connects an entrance ramp with an exit ramp. Extended SCLs are referred to as weaving segments, which according to TAC (1999) should be continued for a distance of 700 m to 900 m. TAC (1999) does not go beyond HCM (2000) definition of a weaving segment length, which is measured from the point where the right edge of the freeway through lane is 0.6 m away from the left edge of the entrance ramp, to a point where the freeway right edge and the exit ramp left edge are 3.7 meters apart. On the other hand, AASHTO (2011) depends on HCM (2010) definition of weaving length. In HCM (2010) weaving length is the distance between the end points of any barrier markings that prohibit or discourages lane changing maneuver. For the purpose of this research, extended SCL length is measured from the point where the freeway mainline and the on-ramp pavement edges are separated by 1.25 meters to the same point on the off ramp. Figure 2.3 shows an illustration of an extended SCL based on both HCM 2000 and HCM 2010 definitions.

The Green Book provides minimum requirements to the design of deceleration lengths for exit terminals. Table 2.1 shows part of the table available in the Green Book 2011 edition. Table 2.2 shows part of the minimum length for deceleration SCLs presented in TAC (1999).

Figure 2.3: Extended Type Deceleration SCL.

Table 2.1: Minimum Deceleration Lengths for Flat Grades with 2% or Less, Adopted from AASHTO (2011) (Metric).

Deceleration Length, L (m) for Design Speed of Exit Curve, V' (Km/h)									
Highway Design Speed, V (Km/h)	Speed Reached, V _a (Km/h)	Stop Condition	20	30	40	50	60	70	80
		For Average Running Speed on Exit Curve V' _a (Km/h)							
		0	20	28	35	42	51	63	70
50	47	75	70	60	45	---	---	---	---
60	55	95	90	80	65	55	---	---	---
70	63	110	105	95	85	70	55	---	---

Where; V = design speed of the highway (Km/h), V_a = average running speed of the highway (Km/h), V' = design speed of exit curve (Km/h), V'_a = average running speed on exit curve (Km/h).

Table 2.2: Design Length for Deceleration, Adopted from TAC (1999).

Speed of Roadway (km/h)		Length of Taper (m)	Length of Deceleration Lane Excluding Taper (m) L _d								
Design	Assumed Operating		Stop Condition	Design Speed of Turning Roadway Curve (km/h)							
				20	30	40	50	60	70	80	
60	55-60	55	90-115	80-110	80-105	70-90	55-60	---	---	---	
70	63-70	65	110-145	105-140	100-130	90-120	75-105	60-70	---	---	
80	70-80	70	130-170	120-165	115-160	105-150	95-130	80-105	---	---	

The upper limit values are based on deceleration-distance curves in the geometric design standards for Ontario highways

AASHTO's deceleration SCL lengths were calculated based on old studies conducted on 1930s with the assumption that most drivers are travelling with speeds less than the average running speeds of the highway (Fitzpatrick, Chrysler & Brewer, 2012); it was argued that these values need to be updated. The 2004 Green Book's deceleration SCL distance values are similar the blue book of 1965 with slight differences (Fitzpatrick, Chrysler & Brewer, 2012). As the 2011 edition values are close to the 2004's edition in terms of deceleration rates, the similarities of the 2011's edition to the blue book may apply. Fitzpatrick, Chrysler & Brewer (2012) believe the following equation was used in the deceleration length calculation in the Green Book.

$$L = v_i - 0.5d_n(t_n^2) + \frac{v_i^2 - v_f^2}{2d} \quad \text{(Equation 2.2)}$$

Where,

- L is the required length by the SCL users to decelerate,
- v_i is initial speed in m/s,
- v_f is driver's final speed after decelerating,
- d_n is deceleration rate without brakes in m/s^2 ,
- t_n is deceleration time without brakes, and
- d is deceleration rate with brakes in m/s^2 .

Fitzpatrick, Chrysler & Brewer (2012) believed that Equation 2.2 was used in AASHTO assuming that there is a 3 seconds deceleration without applying brakes that occur on the taper (Fitzpatrick, Chrysler & Brewer, 2012). In summary, deceleration length calculation in the Green Book assumes a slight deceleration before pressing the brakes. Thus, deceleration rate is not a constant value in AASHTO calculations.

2.2 Driver Behaviour

Drivers' behaviour becomes more complex with the increase of the complexity of the assigned tasks. A limited-length SCL will have less complexity than an extended SCL as weaving manoeuvres may become more challenging on extended SCLs. There is a series of decisions that drivers need to take as they decide to exit a freeway using a limited-length deceleration SCL. First, selecting the diverge point, at which they change lane from the FRL to the SCL, and the corresponding diverge speed. Once on the SCL, a driver may not decelerate immediately if the lane is judged to be too long; slight acceleration or deceleration can take place. Drivers then select a deceleration point to start decelerating, and a corresponding initial deceleration rate. As drivers travel on the SCL, their deceleration rate could increase as they get closer to the gore proximity. Finally, a final speed based on the end conditions of the SCL (e.g., signalized intersection, sharp curve, etc.), would be selected. In case of an extended SCL, in addition to the above tasks, and before entering the SCL, drivers will need to select a satisfactory gap to be able to diverge onto the SCL and get to the ramp, which will depend mainly on the traffic and the configuration of the weaving area.

According to TAC (1999), “weaving sections are roadway segments where the pattern of traffic entering and leaving at contiguous points of access result in vehicle paths crossing each other.” Previously, the Highway Capacity Manual HCM (2000) defined three types of weaving sections depending on how the lane change manoeuvre is performed between the SCL and the right lane of the freeway:

- Type A
 - Almost all vehicles on the ramp are weaving. In this type all weaving vehicles have to make one lane change to complete the manoeuvre.
- Type B
 - One through lane occupies weaving vehicles without the need to change lanes. And the other weaving lane requires a maximum of one lane change.
- Type C
 - One weaving movement does not require a lane change while the other weaving movements need two or more lane changes.

An example of types A, B, and C is shown in Figures 2.4, 2.5, and 2.6, respectively. All Figures associated with each weaving type could be found in HCM (2000).

Figure 2.4: Example of Type A Weaving (Adopted from HCM, 2000).

Figure 2.5: Example of Type B weaving (Adopted from HCM, 2000).

Figure 2.6: Example of Type C Weaving (Adopted from HCM, 2000).

To design a weaving segment, HCM (2000) has a computational process where the Level of Service (LOS) is first defined by the designer. Then an assumed number of lanes and length is taken into the calculation process. After completing the process, the assumptions are verified. In the most recent edition of HCM (2010), weaving is defined as one or more lane change maneuvers, where the number of lanes. A weaving maneuver may be completed with a lane change or without a lane change, which is referred to as

N_{WL} . For a typical ramp weave segment where $N_{WL}=2$, there are two lanes where a weaving maneuver may be completed from as shown in Figure 2.7 below.

Figure 2.7: Typical Ramp-weave Segment Based on the HCM definition of Weaving Length.

In the new HCM edition, the maximum weaving length is not a fixed length, but depends on the point where the segment's capacity is reached. Maximum length of the weaving segment is a function of the weaving-to-total-volume ratio and the number of weaving lanes as shown in equation 2.3 below.

$$L_{Max} = 5,728(1 + VR)^{1.6} - 1,566N_{WL} \quad \text{(Equation 2.3)}$$

If the segments length is less than the maximum L_{Max} , the segment is treated as a weaving segment; otherwise it would be analyzed as a separate ramp junction and basic segment in between. If the length is less than the maximum, the capacity is then determined and the volume to capacity ratio is then found. If the volume to capacity exceeds one, level of serves (LOS) would be "F"; if the ratio is less than one, the lane changing rates would be determined followed by the average speeds of weaving and non-

weaving vehicles. Finally LOS is calculated (Bloomberg, 2008; Transportation Research Center, 2010).

Although there is a change in the weaving segments design criteria, TAC (1999) does not go beyond the HCM 2000 calculation methodology to determine the length of weaving segments. On the other hand, AASHTO 2011 refers to HCM 2010 in regards to the length of weaving segments. If the frequency of lane changes is similar to that in an open road, TAC (1999) considers the section as a no weaving segment. The maximum length of weaving areas is 1000 m (TAC, 1999). Based on TAC, a sufficient weaving length is 800-1000 m within arterial and freeway interchanges, and 550-700 m within arterial interchanges.

Weaving is affected by the spacing of the ramps in an interchange. Based on operational experience and the need of flexibility and adequate signing, AASHTO 2011 provides minimum spacing requirements between different successive combinations of ramps, which ranges between 150 m (500 ft) and 600 m (2000 ft).

* Not Applicable to
Cloverleaf Loop Ramps

Figure 2.8: Part of Recommended Minimum Ramp Terminal Spacing, (Adopted from AASHTO, 2011).

Weaving manoeuvres mainly affect extended SCLs operations because of their configuration as shown in the figure 2.6. Also, drivers who decide to use the SCL to overtake a slow vehicle on the FRL then return to the FRL; or drivers who travel back to the FRL from the SCL because they entered the SCL by mistake affect the operations on both extended and long limited-length SCLs. It can be argued that drivers operations on FRL affect operations on the SCL. To illustrate, if for any reason the leading vehicle on a FRL travels with a slow speed, diverge speed onto the SCL of the following vehicle will be slow. Also, available length for deceleration SCLs may affect the operations on the FRL as well. For example, if the SCL length is judged by the driver to be short, deceleration on the FRL could take place. The finding that drivers sometimes decelerate on the FRL when the SCL is short is verified using the field data studied in the NCHRP 730 report (Torbic, et al., 2012).

Deceleration rates on SCLs vary depending on the type of the SCL and its length. AASHTO does not provide a table of assumed deceleration rates (Torbic, et al., 2012). However, NCHRP 730 provided two methodologies to back-calculate these deceleration rates, using both Equation 2.2 and using a constant deceleration approach. It should be noted that the research back-calculated AASHTO's values using recommended deceleration lane lengths for level grades and compared them to deceleration rates measured from the field. Using both approaches, field deceleration rates were lower than the derived AASHTO values (Torbic, et al., 2012). This indicates that AASHTO (2011) assumed higher deceleration rates than what drivers really use.

Drivers' deceleration behaviour was studied in NCHRP 730 report (Torbic, et al., 2012). It was found that drivers do not apply constant deceleration rates while driving on

the SCL. In another study, speed profile data were collected on deceleration SCLs and FRL and it was found that the magnitude of speed differential between diverging and through vehicles on FRL depends mainly on the SCL length (El-Basha, Hassan & Sayed, 2007). This conclusion suggests that SCL length affect whether deceleration starts on the FRL or on the SCL depending mainly on the available SCL length.

2.3 Safety and Operational Performance of SCLs

If the driver, for any reason, could not merge with the traffic flow before of the end of acceleration SCL, a conflict may happen. In case the mainline drivers and/or the SCL driver do not perform sufficient accommodating maneuvers a collision may occur. Similarly, if the distance to decelerate was judged to be short, harder deceleration would be applied by the SCL driver; that deceleration might also start on the FRL. In case the following vehicles, which could be on the SCL or the FRL, do not perform accommodating maneuvers, a conflict or a collision could take place. These examples relate operational performance to safety. There are many studies that discussed safety and operational performance on SCLs. Collisions are rare events, thus making them harder to model. Trials to model collision frequency were done in a Federal Highway Administration report; however, it was very hard to model the collision frequency on SCLs as collisions were so low at most locations (Bauer & Harwood, 1998). Negative binomial regression was followed in modeling collision frequency, which is recently used among safety researchers.

Many studies found that increasing SCLs lengths would increase safety and decreasing lengths would decrease safety. Cirillo (1970) studied the relation of SCL

lengths to accidents. Data were collected from 20 states for vehicles travelling on interstate highways. The extended SCLs (weaving areas) ranged between 400 ft and 799 ft. Deceleration SCLs were arranged based on their lengths to categories of hundreds (less than 200 ft, between 200 ft and 299 ft,..., and more than 700 ft). It was found that longer SCLs and weaving areas have fewer accidents, when the percentage of merging vehicles is more than 6% of the mainline volume. The results indicated that deceleration SCLs have less reduction in collisions compared to acceleration SCLs, when the SCL length is increased. Even though the number of collisions (collision frequencies) was available in the study, Cirillo (1970) used the accidents rates in the analysis. The analysis carried out for weaving areas considered to some extent the effect of mainline volume on the collision rates by generating collision rate graphs with respect to different ranges of volumes. Also, SCL accident rates graphs were generated with respect to the percent of merging traffic. It should be noted that considering each volume range and percentage of merging traffic separately might have decreased the error of using accident rates; but using rates instead of frequencies could be misleading because locations with lower traffic volumes would have high rates and vice versa. Similar to Cirillo's (1970) findings, a safety evaluation of acceleration and deceleration SCL lengths indicated that deceleration SCLs exhibit higher numbers of accidents compared to acceleration SCLs (Bared, Giering & Warren, 1999). The authors developed accident prediction models using data from 276 exit and 192 entrance ramps. Their findings could be explained by the complexity of the driver's tasks on deceleration SCLs compared to acceleration SCLs as explained in section 2.2. Similar findings were achieved in Sarhan, Hassan & Abd El Halim (2008). In addition to the length, traffic exposure was studied as well in order to

develop safety explicit design graphs (Sarhan, Hassan & Abd El Halim, 2008). An additional finding of this study is that increasing exposure increases collision frequencies on both acceleration and deceleration SCLs.

Chen, Zhou & Lin (2012) studied safety on deceleration lanes on 218 sites in the U.S. Simulation was performed taking into account the number of exit lanes, through movement lanes, exiting volume, design speed on the freeways and exists, and the deceleration lane lengths (Chen, Zhou & Lin, 2012). For both one and two lane exits, crash counts and rates were compared to deceleration lengths. Their study concluded that there is an increasing trend for collisions at longer sites. It should be noted that according to their results collisions decrease with the increase of SCL length; however, when SCLs are very long, collision frequencies and rates start increasing. The authors suggested that from a safety point of view, deceleration SCLs should not be more than 700 ft. Many explanations could be argued; for example, in case of long deceleration lanes, drivers may accelerate causing the extra deceleration distance to have no positive safety effect. Also, as mentioned in section 2.2, drivers may utilize the deceleration SCL for weaving maneuvers. On the other hand, from an operational point of view, the authors provided optimal lengths based on the delay reduction for through traffic compared to different lengths of SCLs at different speeds. It was found that these optimal lengths are higher than the Green Book minimum deceleration lengths (Chen, Zhou & Lin, 2012).

Using a new methodology to determine deceleration lane lengths, Rojas and Garcia (2010) used a conflict indicator named “potential time to lateral or rear-end collision” (PTLRC). This indicator assesses the time between the manoeuvre of the leading vehicle and the collision time if the following vehicle does not perform an

evasive manoeuvre. They studied 10 sites using 2004-2007 collision data. The relationship between collisions rate and the ratio of actual to design length was studied using multiple linear regression (Rojas & Garcia, 2010). The conclusion was that in addition to the actual length, collisions depend also on the ratio of actual to design length. On the other hand, conflict severity or intensity on deceleration lanes depends mainly on the ratio of actual to design length only. The finding of this study is that very short and long deceleration lengths are less safe as explained below:

- If design length is 220 m, to reach optimum safety, available length at site should be 220 m.
- If design guide length is more than 220 m, to reach optimum safety, shorter length should be used.
- If design guide length is less than 220 m, to reach optimum safety, longer length should be used.

Even though a new conflict measure that could be used effectively to evaluate operational performance was developed, the reliability of his study could be questioned for the fact that linear regression was used in modeling accidents. It should be noted that using linear regression assumes normal distribution for the collisions, which was proven wrong (Bauer & Harwood, 1998); using linear regression may not predict the zero collisions due to the value of the intercept; also, using linear regression could result in negative collision frequency, which is not practically possible. Using accident rates as a response variable could be questionable as well; collision frequency should be used instead as explained earlier. Finally, comparing the actual length to the design guide's

deceleration distance length may not be the best technique to evaluate safety since the safety outcome of the design guides equation is generally unknown.

In a recent study, the probability of forced merging from acceleration SCLs onto the FRL was studied to design for SCLs length considering acceleration and gap acceptance behaviour (Fatema & Hassan, 2013). In their paper, the authors compared different estimated reliability measures such as mean probability of failed merging percentages of vehicles with PNC equal/greater than zero with the five-year SCL collision frequency at eight study sites. They found that there is a positive trend between reliability measures, such as the mean probability of failed merging associated with the SCL, and collision frequencies on the study sites. Using the developed models in their study, “AASHTO (2004)” and the Canadian design guide “TAC (1999)” minimum lengths were evaluated as well. It was indicated that these minimum lengths may produce a trend of increasing mean PNC as the design speed of the ramp controlling curve increases.

SCL length is not the only factor that affects safety and operational performance. Safety of right turn SCLs for at grade intersections was studied and it was found that geometry, volume, operational characteristics, are main factors that affect safety (Harwood, Bauer, Potts, Torbic & Richard, 2002). Accident data were collected at 100 intersections with right turn deceleration lanes and 100 intersections without right turn deceleration lanes with similar characteristics. Using Empirical Bayes before and after methodology, it was found that deceleration right-turn lanes improve safety at intersections. In another study, injury severity levels at freeway exit ramps were studied with respect to geometric design, environment, vehicle/driver characteristics, and traffic

features (Wang, Lu & Zhang, 2009). After developing different prediction models, it was found that two-lane configurations of exit ramps increase the injury severity while channelization at ramp terminals connecting to cross roads decreases the severity. Safety performance evaluation of left side off-ramps was carried out in a different study (Chena, Zhou, Zhaob & Hsueh, 2011):

- Using a conflict study that depends on how maneuvers of freeway and ramp drivers are performed.
- Using crash rates, frequency, and severity of a comparison group of right side off-ramps.
- Using negative binomial collision prediction models (CPMs).

The conflict study indicated that locations with two lanes exclusive off-ramps (two obligatory lanes direct driver to the off-ramps) will have slightly higher conflict occurrence than locations with an optional lane (two lanes direct drivers off ramp, where one of the lanes is shared between the freeway and off ramp). It was found that crash rate, frequency, and severity are higher at left side off-ramps compared to right side off-ramps. Finally, the developed CPMs indicated that as volumes at the freeway and the ramp, or lengths of deceleration lane increase, collision frequency increases. On the other hand, when the ramp's length increases, collision frequency decreases. These findings are only related to left-side off-ramps as a special configuration.

2.4 Reliability Analysis in Highway Design

As mentioned earlier, current geometric design guides, such as TAC (1999) and AASHTO (2011), provide deterministic methods for the design requirements based on

data from the 1930s (Fitzpatrick, Chrysler & Brewer, 2012). One of the concerns is that these data are outdated. Another concern is that this deterministic approach might lead to an over or under-presentation of the drivers' population, which may raise the previous concerns about the margin of safety and what might happen if the design violates the design guides. On the other hand, reliability analysis techniques provide an alternative probabilistic approach that assesses the performance of the given system based on a sample with known characteristics and confidence level. Operational performance and safety can be quantified by statistical analysis of field data. Using a probabilistic approach can help in providing an assessment of risk and allows for more flexibility in the design. This can be particularly useful in the design and evaluation of SCLs instead of a deterministic approach that traditionally uses a combination of conservative and non-conservative design parameters (Hassan, Sarhan & Salehi, 2012; Fatema & Hassan, 2013).

There are many techniques to statistically assess a demand and supply in a system. Most of these techniques are approximations with different accuracies which depend mainly on the formulation of the system and the followed evaluation technique. The use of approximation techniques comes as many engineering systems could not be evaluated using an exact method (the integration technique of the performance function). This is mainly due to the complexity of the limit state function (Section 5.1) and setting their limits (Faber, 2007). Even though, the statistical techniques are approximations, they are normally accurate enough for the engineering applications use. Zhao and Ono (1999) compared different statistical techniques to evaluate the probability of supply exceeding demand. Accuracy of different methods was studied in comparison to a

simulation technique called Monte Carlo Simulation (MCS) and it was found that with lower number of variables, more linear function's surface, and lower reliability indices, the accuracy of the used methods becomes high. The used methods were First Order Reliability Method (FORM), Second Order Reliability Method (SORM) and they were compared to MCS. These methods are explained later in Chapter 5.0.

Many transportation systems have been studied and researched using reliability analysis. A doctoral thesis gave a design procedure to design for superelevation based on reliability methods (Abia, 2010). Design and evaluation of the reliability of left turn bays lengths at non-signalized intersections was carried out as well using reliability methods. Furthermore, peak hour delays at signalized intersections were studied using reliability analysis in Abia's (2010) thesis as another application of reliability analysis. This study found that designing superelevation rates using reliability methods results in lower rates than what is used in current practice, which can be accounted for as a cost saving with respect to the embankment. Also for left turn bays lengths for non-signalized intersections, the study found that at 95% level of confidence, the current design practices fail when the degree of saturation, which is the ratio of approaches hourly volume to the capacity of the approach, exceeds 50%. Failure may result in a high level of unsafe braking leading to a conflict or a collision. For the signalized intersection peak hour delays, it was found that using the HCM (2000) methodology, where traffic flow follows a Poisson distribution, for intersection delay analysis is not sufficient. Abia (2010) analyzed signalized intersections that were adjusted to the prevailing traffic conditions. It was found that the HCM (2000) methodology produces more delay (6.2 seconds per vehicle), which results in higher costs.

Models to examine design features such as, stopping sight distance (SSD), horizontal and vertical curvature, and others were applied to reach a cost effective process for designing roads (Zheng, 1997). Probability of noncompliance of a design criterion was used to test drivers' response to different design alternatives. Zheng (1997) developed a driver, vehicle, roadway, interaction model called the Moving Coordinate System Model (MCSD). The model is a reliability based highway framework that takes into account the vehicle dynamics considerations. The upper limit of that framework is the "racing car model," which is used to represent the maximum theoretical demand of the users (drivers) on the highway system. This upper limit was compared to the road design inputs (supply in the highway system). The racing car model is basically a representation of the theoretical limit of the vehicle at a specific operating condition. Probability of noncompliance (PNC) values between the limit and the design inputs were then generated (i.e. demand exceeding supply). The main contribution of this study is that by applying the racing car model, design problems could be detected at roads before construction.

A micro simulation technique, Monte Carlo Simulation (MCS), was used in a study to account for how SCL vehicles accelerate to their merging speed as well as searching for and finding an acceptable gap in the freeway through traffic (Fatema & Hassan, 2013). MCS, as will be explained Section 5.4, was used to account for the variability in driver's speed, acceleration, and gap acceptance characteristics based on field data. The model runs for every SCL using its SCL available length to produce the probability of uncomfortable merging, PNC. The results of the authors' study are summarized earlier in Section 2.3. Fatema & Hassan's (2013) MCS model was later

improved to cover sixteen limited-length SCLs and seven extended-length SCLs (Fatema, Ismail & Hassan, 2014). The model finds the probability of failed maneuvers by simulating vehicles acceleration and gap acceptance assuming that:

- Drivers accelerate from the end of controlling curve up to the point where the pavement edges of the FRL and ramp are 1.25 m apart.
- After that point, drivers accelerate and look for an acceptable up to the end of the SCL.

If drivers reach an acceptable merging speed and an acceptable gap is available on the freeway, a successful merging takes place. In case any of the two criteria is violated a forced merging takes place and is referred to as a failed merging. Using negative binomial regression, Fatema, Ismail & Hassan (2014) showed that including PNC in the regression model showed the best fitted model. Their study is quantitative evidence supporting the probabilistic approach to study safety.

Sarhan & Hassan (2011) argued that the deterministic approach used by the design guides to design for the lateral clearance on horizontal curves is insufficient and may over and/or under-estimate the available sight distance for road users. They developed a new method to calculate the lateral clearance on horizontal curves considering the effect of vertical curvature on the road alignment. A probabilistic approach was used to evaluate the probability of demand sight distance to exceed supply sight distance (called probability of hazard). Variations within the distribution of the following parameters were taken into account when designing: speed, perception and reaction time, deceleration rate, friction coefficient, and driver eye and object heights. Using a selected probability of hazard, a designer can estimate the lateral clearance and

the height at which the lateral clearance is provided. Finally, an example design aid was created for 400 m horizontal curves with a side slop 2:1 (horizontal: vertical) (Sarhan & Hassan, 2011). This study provides a probabilistic technique for design, which could help in granting consistency in the design of road elements in a particular area.

Hassan, Sarhan and Salehi developed probabilistic models to design for freeway acceleration SCLs (Hassan, Sarhan & Salehi, 2012). Limitation of one of the methods was pointed out, which is generating a high standard deviation of the estimated length than the data when using First Order Second Moment (FOSM) method. They found that recommended SCL lengths is nearly constant for curves of design speeds between 50 to 80 km/h as drivers use lower acceleration rates when entering the SCL with high speeds. Recommended SCLs were compared to the Canadian design guide (TAC 1999) and the Green Book (AASHTO 2004). It was found that the recommended design lengths using FOSM method fall within the TAC (1999) recommended lengths range but not with the entire Green Book's values.

Felipe (1996) used First Order Reliability (FORM) Analysis to find the PNC between the demanded radius of horizontal curves by the car/driver system and the supplied radius of the horizontal curve of the road. The data collected for this research were speed, lateral acceleration, and level of comfort. The study found that as the radius of horizontal curves decreases, PNC increases (Felipe, 1996).

PNC values in the literature are usually associated with one mode of failure which is demand exceeding supply. But in a reliability based risk analysis of horizontal curves, You, Sun & Gu (2012) developed two failure types, where each type has its own performance function. The first failure mode is skidding without rolling, and the second

is skidding and rolling (You, Sun & Gu, 2012). They also verified that AASHTO's minimum recommended radius to prevent skidding provides enough safety margins for vehicles in dry conditions. However, minimum radius values were questioned for trucks in wet pavement conditions.

Shin & Lee (2013) used reliability analysis to test the PNC of current horizontal curves for trucks. Two failure modes were tested, which are rollover and sideslip (Shin & Lee, 2013). Using FORM, the study found that rollover is dependent mostly on the vehicle's speed and the steering angle, while sideslip depends on the tire road friction coefficient. The study found that both types of accidents could be reduced by increasing the superelevation rate. The authors found that the current minimum radius values recommended in AASHTO could not ensure sufficient margin of safety in both rollover and sideslip conditions.

2.5 Summary

Many researchers studied safety and operations on highway elements such as deceleration SCLs. Many studies focused on the relationship between geometric configuration and conditions of highway elements and safety. Some of the topics studied are: the effect of SCL length choices on safety; different ramps' configuration choices on safety; and road conditions in terms of sight distance or surface and weather conditions. Part of these studies used simulation techniques quantify or address possible issues in the drivers' performance while travelling on different highway elements. Other studies used probabilistic approaches in order to quantify the difference between what the driver needs in terms of geometry and what is supplied on the actual highway segment or

recommended by the design guides. However, fewer studies linked operations and safety. There is a likely strong relation between safety and operations on highway segments and more research is needed in this topic. The main purpose of this study is to investigate operations on deceleration SCLs using three different reliability approaches and to develop a design aid for practitioners to be able to design SCLs based on the required level of operational performance. The measure developed in this study could be used for future research as a surrogate safety measure to explicitly study safety.

Chapter Three

3.0 Data Description

The study sites used in this research are deceleration SCLs on Highway 417 in Ottawa, Ontario. As this research is continuity to previous research done by El-Basha (2006), the same data will be used in this thesis. The data included drivers speed profiles and geometry of the selected study sites. However, these data were re-processed for the purpose of performing reliability analysis of deceleration SCLs. In addition, to explore the premise of a relationship between the developed models and safety, collision data at the study sites were collected (Sarhan, 2004).

This Chapter is organized in the following order:

- Study area and selected sites.
- Geometric characteristics of the study sites.
- Available speed data collected by El-Basha (2006).
- Data reprocessing for the purpose of this research.
- Collision data.

3.1 Study Area and Selected Sites

El-Basha (2006) collected data from 13 exit ramp terminals at 11 interchanges on Highway 417. The study sites included both limited and extended SCLs. The study site selection was limited to accessible sites with a number of exiting vehicles to

allow good sample size in one hour of data collection. Selection of study sites was controlled by:

- Visibility: Locations with limited visibility at the SCL or the Freeway Right Lane (FRL) were excluded.
- Drivers' distraction: Locations where the operator would be visible to drivers were excluded.
- Safety: Locations with safety hazards to the operators were excluded.

It should be noted that out of 40 candidate exit terminals to collect the speed profiles, 27 sites were excluded because of not meeting the above criteria. Figure 3.1 shows a Google Earth map with the locations of eleven interchanges containing the thirteen SCL sites where data was collection.

Figure 3.1: Study Area (Google Earth Imagery)

Data for the all selected SCLs were collected from interchange overpasses except for Bronson W-NS, which speed data were collected from the roof of an Ottawa-Carleton School Board building located next to Highway 417. Table 3.1 is a summary of the study sites SCLs.

Table 3.1: Selected Sites

No.	SCL Name	Type	Actual Length (m)
1	Bronson Avenue (W-NS)	Limited	212
2	Carp Road (E-NS)	Limited	430
3	Moodie Drive (W-NS)	Limited	292
4	Parkdale Avenue (W-NS)	Limited	179
5	Island Park Drive (E-N)	Limited	58
6	Terry Fox Drive (E-NS)	Limited	388
7	Terry Fox Drive(W-NS)	Limited	446
8	Greenbank/Pinecrest Road (E-NS)	Extended (Dual Exit)	1047
9	St. Laurent Blvd (W-NS)	Extended (Dual Exit)	873
10	Vanier Pkwy (W-NS)	Extended (Dual Exit)	707
11	Eagleson Road (W-NS)	Extended (Single Exit)	697
12	Woodroffe Avenue (E-NS)	Extended (Single Exit)	1320
13	Woodroffe Avenue (W-NS)	Extended (Single Exit)	1358

SCL length includes the taper for limited-length SCL and is measured to the gore area where pavement edges of the freeway right lane and off-ramp are separated by 1.25 m.

As mentioned in Chapter 1.0, extended SCLs, which are extended from an entrance ramp to an exit ramp, are affected by both merging and diverging vehicles and the associated weaving manoeuvres and are beyond the scope of this research. Therefore, only data related to the seven limited-length SCLs were included for further analysis.

3.2 Geometric Characteristics of the Study Sites

El-Basha (2006) obtained the geometric planes of the study sites from Ontario Ministry of Transportation (MTO), Engineering and Title Records (ETR). Plans were validated through field visits to the study sites by the data collection team. The geometric information collected in El-Basha's (2006) thesis included: lengths of deceleration SCLs, transition lengths (from end of SCLs to controlling ramp curves), divergence angle at the gore area, ramp width, lengths of freeway segments, and number of freeway basic lanes. More details on how the geometric data were determined could be found in El-Basha (2006). A summary of the geometric data of the study sites used in this research is available in Appendix 1.

3.3 Available Speed Data

El-Basha (2006) collected 1,524 speed profiles on limited-length SCLs and adjacent freeway right lanes (FRLs) at the seven study sites. Processed data included initial/diverge and final/gore speeds, and the deceleration time and distance. The data were collected using laser guns that track individual vehicles from the diverge point onto the deceleration SCL up to the gore area every 0.05 seconds. In the original data processing by El-Basha (2006), both speeds and distances were corrected for the cosine error due to the equipment's positioning.

Using the readings collected by the laser guns, the speed profiles were processed by El-Basha (2006). Diverge speed, maximum speed, mean speed, gore speed, maximum deceleration rate, mean deceleration rate, overall deceleration rate, and total travelled distance on SCL were estimated for every vehicle. Diverge speed was determined as the first corrected speed data reading of the targeted vehicle as it changes lane from FRL to

SCL, while gore speed is the last speed data reading recorded at the proximity of the gore area. The maximum speed is the maximum value reached by a targeted vehicle on the SCL of all the successive corrected speed readings along the speed profile. Mean speed is the average of all the successive speed data readings of the corrected speed profile. Maximum deceleration rate was calculated as the minimum negative acceleration value of all the successive acceleration rates. Mean deceleration rate was calculated as the average of all successive deceleration rates. Also, the overall deceleration rate was calculated as the average deceleration rate based on the overall distance travelled on the SCL and the overall time elapsed while decelerating. Overall deceleration rate considers the entire vehicle's profile as one interval as shown in Equations 3.1 and 3.2 (El-Basha, 2006). Finally, the total travelled distance on SCL is the total distance travelled on the deceleration lane from the diverge point till the end of the deceleration SCL.

$$d_{Time} = \frac{v_f - v_i}{T} \quad \text{(Equation 3.3)}$$

$$d_{Dis} = \frac{v_f^2 - v_i^2}{2 * D} \quad \text{(Equation 3.4)}$$

Where,

- d_{Time} is the overall deceleration rate for the speed profile based on its time interval (m/sec²).
- d_{Dis} is the overall deceleration rate for the speed profile based on its distance interval (m/sec²).
- v_f is the final speed at the speed profile (m/sec).
- v_i is the initial speed at the first data point on the speed profile (m/sec).
- T is the travel time interval in the speed profile first and last data points (sec).
- D is the distance interval in the speed profile's first and last data points (m).

Figures 3.2 and 3.3 show screen shots of a speed profile sample and the final speed profile's summary, respectively, on Bronson Avenue (W-NS) SCL.

Diverge speeds, gore speeds, maximum speeds, mean speeds, overall deceleration rates, maximum deceleration rates, mean deceleration rates, and total travelled distances for all vehicles on each SCL were summarized as shown in Figure 3.3. In the data processed by El-Basha (2006), each targeted vehicle was categorized as follows:

- “D”: a vehicle that diverged from right lane to SCL.
- “RL”: a vehicle that continued through on the right-lane.
- “Sh”: vehicles with short speed profiles, where the last speed reading did not correspond to the gore area.
- “out”: a corrupted file.
- “HV”: a heavy vehicle.

Speed profiles marked as “Sh” and were not considered for any further analysis in this research as it could be misleading as the last speed reading does not represent the gore speed.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
2	d (m)	Corr. d (m)	d_Inter.	d_scale	s (km/h)	Corr. s (km/h)	s (m/sec)	t (hr)	t (sec)	t_Inter.	t scale	Dec. t (m/s^2)	Dec. d (m/s^2)	Av. Dec.					
3	289	288.734715		0	86.5	86.57947489	24.0498541	20:32.6			0								
4	264	263.709567	25.0251482	25.0251482	81.2	81.28942861	22.5803968	20:33.7	00:01.11	1.11	1.11	-1.323835406	-1.369046095	-1.34644075					Average Deceleration_time = -1.16921682
5	262.87	262.578317	1.13124987	26.156398	81.2	81.2902004	22.5806112	20:33.8	00:00.05	0.05	1.16	0.004287727	0.004279295	0.004283511					Average Deceleration_Dist. = -1.20777061
6	261.72	261.427034	1.15128309	27.3076811	81.2	81.29099616	22.5808323	20:33.8	00:00.05	0.05	1.21	0.00442089	0.004335462	0.004378176					
7	260.62	260.325796	1.10123792	28.408919	81.2	81.29176722	22.5810465	20:33.9	00:00.06	0.06	1.27	0.003569732	0.004391853	0.003980793					
8	258.37	258.073231	2.25256499	30.661484	81	81.09314526	22.5258737	20:34.0	00:00.10	0.1	1.37	-0.551727667	-0.552408829	-0.55206825					
9	257.25	256.951937	1.12129355	31.7827776	80.9	80.9938435	22.4982899	20:34.0	00:00.05	0.05	1.42	-0.551676434	-0.553797219	-0.55273683					
10	256.14	255.840644	1.11129318	32.8940708	80.8	80.89454304	22.4707064	20:34.1	00:00.05	0.05	1.47	-0.551669227	-0.558088806	-0.55487902					
11	255.04	254.739351	1.10129266	33.9953634	80.7	80.79524376	22.4431233	20:34.1	00:00.05	0.05	1.52	-0.551662657	-0.56245909	-0.55706087					Max. Deceleration = -1.77233852
12	253.96	253.658071	1.08128007	35.0766435	80.6	80.69593798	22.4155383	20:34.2	00:00.05	0.05	1.57	-0.551698793	-0.572203035	-0.56195091					Mean Deceleration = -0.97822865
13	252.9	252.596804	1.06126701	36.1379105	80.4	80.49650528	22.3601404	20:34.2	00:00.05	0.05	1.62	-1.107959449	-1.168641719	-1.13830058					Overall Average Deceleration = -1.18849371
14	251.83	251.525515	1.0712898	37.2092003	80.1	80.19696543	22.2769348	20:34.3	00:00.05	0.05	1.67	-1.664110273	-1.733448203	-1.69877924					Diverging Speed = 86.57947489
15	250.76	250.454214	1.07130083	38.2805011	79.8	79.89742995	22.1937305	20:34.3	00:00.05	0.05	1.72	-1.664086026	-1.72694286	-1.69551444					Maximum Speed = 86.57947489
16	245.46	245.147603	5.3066109	43.587112	78.2	78.29965202	21.7499033	20:34.6	00:00.26	0.26	1.98	-1.707027695	-1.83764934	-1.77233852					Mean Speed = 78.20715408
17	244.39	244.076233	1.07136951	44.6584815	77.9	78.00014256	21.6667063	20:34.6	00:00.05	0.05	2.03	-1.663941435	-1.685755831	-1.67484863					End Operating Speed = 69.82693636
18	243.35	243.034891	1.04134267	45.6998242	77.7	77.8007427	21.6113174	20:34.7	00:00.05	0.05	2.08	-1.107776997	-1.150975571	-1.12937628					Deceleration Distance = 83.6981238
19	242.29	241.97351	1.06138038	46.7612046	77.5	77.60136626	21.5559351	20:34.7	00:00.05	0.05	2.13	-1.107646917	-1.126223811	-1.11693536					Time elapsed on SCL = 3.98
20	241.23	240.912118	1.06139253	47.8225971	77.3	77.40199692	21.5005547	20:34.8	00:00.05	0.05	2.18	-1.10760743	-1.123281126	-1.11544428					Diverging Point = 128.2652851
21	240.18	239.860726	1.05139154	48.8739887	77.1	77.20262625	21.445174	20:34.8	00:00.05	0.05	2.23	-1.107614873	-1.131056463	-1.11933567					
22	239.14	238.819336	1.04139036	49.915379	76.9	77.00325407	21.3897928	20:34.9	00:00.05	0.05	2.28	-1.107623176	-1.138982171	-1.12330267					
23	238.09	237.76792	1.05141607	50.9667951	76.7	76.80389774	21.334416	20:34.9	00:00.05	0.05	2.33	-1.107535196	-1.125115126	-1.11632516					
24	237.03	236.706478	1.06144231	52.0282374	76.5	76.60455764	21.2790438	20:35.0	00:00.05	0.05	2.38	-1.107445012	-1.111507972	-1.10947649					
25	235.98	235.655036	1.05144415	53.0796789	76.4	76.5053542	21.2514873	20:35.0	00:00.05	0.05	2.43	-0.551130187	-0.557326762	-0.55422847					
26	234.94	234.613596	1.0414405	54.1211194	76.3	76.40615183	21.2239311	20:35.1	00:00.05	0.05	2.48	-0.551124296	-0.561943648	-0.55653397					
27	233.91	233.582156	1.0314393	55.1525587	76.2	76.30695036	21.1963751	20:35.1	00:00.05	0.05	2.53	-0.551119247	-0.566651065	-0.55888516					
28	232.88	232.550704	1.03145206	56.1840108	76	76.10761733	21.1410048	20:35.2	00:00.05	0.05	2.58	-1.107405775	-1.136375134	-1.12189045					
29	231.86	231.529253	1.02145071	57.2054615	75.8	75.9082826	21.0856341	20:35.2	00:00.05	0.05	2.63	-1.107415152	-1.144509947	-1.12596255					
30	230.92	230.587905	0.9413483	58.1468098	75.6	75.70887983	21.0302444	20:35.3	00:00.05	0.05	2.68	-1.107793178	-1.239065365	-1.17342927					
31	229.81	229.476299	1.11160637	59.2584161	75.4	75.50964563	20.9749016	20:35.3	00:00.05	0.05	2.73	-1.106856668	-1.04564163	-1.07624915					
32	228.81	228.474838	1.00146056	60.2598767	75.1	75.21016815	20.8917134	20:35.4	00:00.05	0.05	2.78	-1.663763767	-1.738864217	-1.70131399					
33	227.86	227.523139	0.95139913	61.2112761	74.9	75.01079189	20.8363319	20:35.4	00:00.05	0.05	2.83	-1.107629205	-1.211505713	-1.16106716					

Figure 3.2: Speed Profile Sample for a passenger car on Bronson Ave. W-NS

2	Vehicle Type	Data File no.	Behaviour	Max. Deceleration	Mean Deceleration	Overall Deceleration	Diverg Speed	Maximum Speed	Mean Speed	End Operating Speed	Travelled Distance	Time Elapsed	Diverging Point	Distance Left (1.25)	Deceleration Distance
3	HV	29	Sh	-2.257885561	-0.987927675	-0.99183632	77.75961806	77.75961806	67.3818696	61.4913497	85.50125227	4.70	113.79	12.71	98.20735347
4	HV	43		-2.284599074	-0.720272982	-0.793127699	91.07371013	93.28503891	88.2809648	80.23486778	90.46552122	3.79	121.8990322	0	90.46552122
5	HV	48		-2.288770612	-1.025568227	-1.0204105	76.35401186	76.35401186	66.4161503	53.49918029	110.6003505	6.313301357	101.3234637	0	110.6003505
6	HV	71		-2.279717309	-0.837488971	-1.175097823	89.56020974	89.76082812	84.0282272	66.51406828	118.7459678	5.417969304	93.17784634	0	118.7459678
7	HV	73		-2.288233323	-0.631717282	-0.881001165	80.55695972	80.76187092	75.0851199	62.88256842	110.6704	5.590365127	101.2534141	0	110.6704
8	HV	102		-2.350104906	-0.987165437	-1.685772495	82.54808708	82.54808708	72.0658872	24.24037448	142.3201978	9.62	69.10278012	0	142.3201978
9	PC	1		-2.249812435	-0.682831321	-1.065069848	82.98266243	83.18497746	78.3014408	69.72740022	72.6379989	3.49	139.8463594	0	72.6379989
10	PC	2		-1.708708312	-0.487729976	-0.494447592	88.47812088	88.48009544	84.3815309	81.64883289	89.65374356	3.88	122.5901759	0	89.65374356
11	PC	3		-2.272070227	-0.863392568	-1.88733033	82.99715975	83.10090107	78.7471138	65.92015027	50.86429947	2.57	161.3696018	0	50.86429947
12	PC	4		-2.281862524	-0.862179079	-0.938841594	93.67715568	93.67715568	84.5724934	79.34399849	99.63181705	4.34	112.1612825	0	99.63181705
13	PC	5		-2.809248688	-0.724576432	-1.147822466	81.47992706	81.58408973	74.3178091	66.30449319	74.14896677	3.734553591	137.7042419	0	74.14896677
14	PC	6		-2.84006744	-0.916272981	-1.40943084	91.88549589	91.88549589	82.0766419	73.5336095	81.69622894	3.68	130.2170889	0	81.69622894
15	PC	7		-1.672675187	-0.586117431	-0.622332303	92.87268819	93.27487225	90.4751282	82.97937885	107.6884582	4.422627098	104.2749506	0	107.6884582
16	PC	8		-2.287514933	-0.351600316	-0.449072396	75.36100903	75.46324015	71.4766865	66.92180949	102.5745208	5.25	109.519125	0	102.5745208
17	PC	9		-1.772338518	-0.978228652	-1.188493712	86.57947489	86.57947489	78.2071541	69.82693636	83.6981238	3.98	128.2652851	0	83.6981238
18	PC	10		-1.241941528	-0.379043479	-0.803838772	89.67173364	92.18139617	86.6667491	76.58684858	104.2857658	4.527141827	107.6776431	0	104.2857658
19	PC	11		-2.279466901	-1.240591234	-1.43478007	85.9833158	85.9833158	73.5121711	67.1221026	76.05097305	3.73	135.9825634	0	76.05097305
20	PC	12		-2.289783624	-0.729973262	-0.806249267	87.37736947	87.37802125	82.060606	75.93749464	88.54211604	3.98	123.0105476	0	88.54211604
21	PC	13		-2.290680319	-1.403723128	-1.159734837	89.28197265	89.28197265	83.1625013	73.93385377	83.2473329	3.68	128.2953126	0	83.2473329
22	PC	14		-2.792607165	-0.715763307	-0.842142986	89.45688578	89.45729469	81.8479241	70.12769457	142.1129337	6.34	70.02078506	0	142.1129337
23	PC	15		-2.291669397	-1.140447597	-1.244761807	92.57177657	92.57236522	84.6276488	70.92901523	109.2197136	4.85	102.8038046	0	109.2197136
24	PC	16		-2.563771064	-0.842593457	-1.083994165	83.1763616	83.1763616	73.3619883	67.22207015	83.5679052	4.18	128.2853035	0	83.5679052
25	PC	17		-2.475423261	-0.721099183	-1.081963713	91.68027089	91.68027089	81.5584935	76.33895034	90.74456105	3.99	121.3490847	0	90.74456105
26	PC	18		-2.227864387	-1.115290883	-1.315610295	90.58478726	90.58478726	87.9034705	73.55406499	80.88550778	3.644967048	131.0678829	0	80.88550778
27	PC	19	Sh	-1.694707777	-0.584634845	-0.576770422	94.08022075	94.38263695	92.4229087	90.0101835	49.62069593	1.98	117.4056775	44.97362661	94.59432254
28	PC	20		-1.943470898	-1.364873659	-1.377577323	93.69030127	93.69030127	83.8543039	77.44096996	76.87182616	3.32	135.2318379	0	76.87182616
29	PC	21		-2.265597373	-0.976966606	-1.175602127	94.47050397	94.47050397	83.7597817	73.40621096	115.2141994	5.01352073	96.73919128	0	115.2141994
30	PC	22		-1.566194629	0.640420101	-0.779197845	84.17757055	88.09788836	85.8304191	73.68319874	83.12759006	3.692200714	128.8258006	0	83.12759006
31	PC	23	Sh	-1.714201058	-0.96241603	-0.620315814	87.06789301	87.17982136	84.2968135	78.31976025	89.69794906	3.93	103.6944972	18.60755376	108.3055028
32	PC	24		-1.416057078	-0.225567671	-0.70809398	80.36579012	80.87193652	79.6797651	67.82671303	100.7228725	4.94449071	111.2305182	0	100.7228725
33	PC	25		-2.298518791	-0.644343602	-1.277166053	87.7860514	87.7860514	83.3685045	72.33146364	74.33922872	3.38	137.6041437	0	74.33922872
34	PC	26		-2.275516255	-1.106005606	-1.187434275	98.48632916	98.48632916	95.3804458	83.03362156	90.43415687	3.643094668	121.5192338	0	90.43415687
35	PC	27		-2.289988613	-0.659860124	-0.668420982	84.3597969	84.3597969	79.1100824	70.52823623	123.6103389	5.75	88.3731064	0	123.6103389
36	PC	28		-2.791981744	-0.996836494	-1.264544224	95.08573289	95.08573289	87.1466841	78.54280852	86.32052773	3.69	125.6629176	0	86.32052773

Figure 3.3: Summary of Speed Profiles on Bronson Ave. W-NS

3.4 Data Reprocessing

Data of SCL vehicles were initially summarized for the purpose of this research to include diverge speed, end operating/gore speed, overall deceleration, and total travelled distance. Figure 3.4 shows the new order of data.

1	Vehicle Ty	Diverg Speed	End Operating Speed	Overall Deceleration	Total Travelled Distance
2	HV	21.59989391	17.08093047	0.99183632	98.20735347
3	HV	25.29825281	22.28746327	0.793127699	90.46552122
4	HV	21.20944774	14.86088341	1.0204105	110.6003505
5	HV	24.87783604	18.47613008	1.175097823	118.7459678
6	HV	22.37693325	17.46738012	0.881001165	110.6704
7	HV	22.93002419	6.733437357	1.685772495	142.3201978
8	PC	23.05073956	19.36872228	1.065069848	72.6379989
9	PC	24.5772558	22.68023136	0.494447592	89.65374356
10	PC	23.0547666	18.31115285	1.88733033	50.86429947
11	PC	26.02143213	22.03999958	0.938841594	99.63181705
12	PC	22.63331307	18.41791478	1.147822466	74.14896677
13	PC	25.52374886	20.42600264	1.40943084	81.69622894
14	PC	25.79796894	23.04982746	0.622332303	107.6884582
15	PC	20.93361362	18.58939152	0.449072396	102.5745208
16	PC	24.04985414	19.39637121	1.188493712	83.6981238
17	PC	24.9088149	21.2741246	0.803838772	104.2857658
18	PC	23.88425439	18.6450285	1.43478007	76.05097305
19	PC	24.27149152	21.09374851	0.806249267	88.54211604
20	PC	24.80054796	20.5371816	1.159734837	83.2473329
21	PC	24.84913494	19.47991516	0.842142986	142.1129337
22	PC	25.71438238	19.70250423	1.244761807	109.2197136
23	PC	23.10454489	18.67279727	1.083994165	83.5679052
24	PC	25.46674191	21.20526398	1.081963713	90.74456105
25	PC	25.16244091	20.43168472	1.315610295	80.88550778

Figure 3.4: Initial Data Organization (Speeds are in m/s, Deceleration in m/s^2 , and distance in m)

Deceleration behaviour on limited SCLs is mainly affected by drivers' choice of initial speed, available distance on SCL, and final speed based on the end conditions of the exit ramp. For example, a sharp controlling curve on the exit ramp will force drivers to reach a low the final speed. El-Basha (2006) used the total travelled distance on SCLs to model drivers' deceleration behavior. However, in many cases, such an assumption might not represent the real conditions. If the SCL is long enough, drivers might maintain

their speed, accelerate, or decelerate slightly. To be able to produce more sound conclusions on the operational performance of the SCLs, the real deceleration point should be investigated. In case deceleration does not occur at the diverge point for a specific vehicle, new deceleration distance, overall deceleration rate and initial speed should be found.

Assuming that drivers decelerate at a constant rate, a MATLAB script (Appendix 2) was developed to estimate the deceleration point for each vehicle. The script assumes the following breakup on the SCL's length:

- l_1 : A distance from the gore where all drivers are decelerating.
- l_2 : A distance upstream l_1 where drivers are likely decelerating at their selected deceleration rate.
- l_3 : A distance upstream l_2 where drivers may have started deceleration or are maintaining a constant speed.

Based on this assumption, the script does the following:

- The script first calculates the deceleration rate from each point in the speed profile to the gore and uses the points within the range of likely deceleration distance l_2 to establish a confidence interval for the deceleration rate.
- The first point of the speed profile, which would be located in l_2 or l_3 , is checked against this confidence interval.
- If the deceleration rate from that point to gore is out of the confidence interval, the driver is assumed not to have started decelerating. The script

then proceeds to the following points to find the first point that falls within the confidence interval.

- The first point within the confidence interval is defined as the deceleration point where the driver starts to decelerate at a constant rate.
- Subsequently, the script determines the initial speed at the deceleration point (v_i), travel time on SCL from the diverge to deceleration point, and adjusted deceleration distance (D) which is the distance travelled during deceleration from the deceleration point to gore.
- Using the speed at the gore as the final speed (v_f), the overall deceleration rate (d) is calculated using the average of Equations 3.5 and 3.6. For the purpose of this research, a positive deceleration rate indicates a decrease in speed, while a negative deceleration rate indicates an increase in speed.

$$d_{Time} = \frac{v_i - v_f}{T} \quad \text{(Equation 3.5)}$$

$$d_{Dis} = \frac{v_i^2 - v_f^2}{2 * D} \quad \text{(Equation 3.6)}$$

It was observed that drivers do not use all of the available SCL length for deceleration. Drivers may require time to perceive the exit terminal and take the decision to diverge into the SCL, which may cause drivers to diverge a distance after the beginning of the SCL. Also, not using the full SCL length is related to drivers' behavior and choice of a diverge point. It was indicated in field data of the NCHRP 730 report that drivers do not use the full length of the SCL (Torbic, et al., 2012). Therefore, there was a need to calculate a variable that would explain how much of the available SCL length is used for deceleration. By knowing the actual length of the deceleration lane (L), the

utilization rate (U) was calculated as D/L . Figures 3.5, 3.6, 3.7, and 3.8 describe the script's methodology.

The script was run for all lanes using 95% confidence interval. As the shortest SCL (Island Park Drive E-N) has a length of 58 m, l_1 was taken 50 m. It was found that many vehicles start deceleration inside the first 150 m before gore, which means that l_2 is less than 100 m. Thus, l_2 was assumed to be 50 m. The script was run for a total number of 41,045 speed readings on all seven limited-length SCLs. Figure 3.9 and 3.10 summarize the speed profiles beforehand after-processing; the script output includes:

- New overall deceleration rates calculated from the new deceleration point to the gore.
- Diverge speed at the diverge point onto the SCL.
- Initial speed at which a vehicle starts deceleration.
- Final/gore speed.
- Total travelled distance on the SCL.
- Deceleration distance used by the driver in deceleration mode.
- Time to decelerate, which is the time spent from diverge to deceleration points.
- Distance to decelerate, which is the distance spent from diverge to deceleration point.

Finally, utilization rate was calculated by dividing the deceleration distance by available SCL length; Figure 3.10 is a schematic of the estimated parameters after reprocessing.

Figure 3.5: Schematic of SCL Lengths.

Figure 3.6: Long SCL and Deceleration Point within I_3 .

Figure 3.7: Long SCL and Deceleration Point within l_2 .

Figure 3.8: Short SCL and Deceleration Point within l_2 .

Figure 3.9: Speed Profiles before Reprocessing

Figure 3.10: Final Speed Profiles after Reprocessing

	C	D	E	F	G	H	I	J	K	L	M	N
1	Mean Deceleration	Adjusted Overall Deceleration	Original Overall Deceleration	Initial Speed	Diverge Speed	Final Speed	Deceleration Distance	Deceleration Length	Deceleration Time	Distance to Decelerate	SCL Length	Utilization Rate
2	1.14821331	1.065069848	1.065069848	23.05074	23.05073956	19.368722	72.6379989	72.6379989	0	0	212	0.34263207
3	0.426243354	0.494447592	0.494447592	24.577256	24.5772558	22.680231	89.65374356	89.65374356	0	0	212	0.422895017
4	0.426243354	1.88733033	1.88733033	23.054767	23.0547666	18.311153	50.86429947	50.86429947	0	0	212	0.239925941
5	0.783017812	0.938841594	0.938841594	26.021432	26.02143213	22.04	99.63181705	99.63181705	0	0	212	0.469961401
6	1.411968939	1.300659083	1.300659083	22.633313	22.63331307	14.125359	119.1636011	119.1636011	0	0	212	0.562092458
7	1.486888097	1.40943084	1.40943084	25.523749	25.52374886	20.426003	81.69622894	81.69622894	0	0	212	0.38535957
8	1.126582621	1.100599922	0.687853912	25.528651	25.79796894	22.434067	66.30969138	117.9480885			212	0.312781563
9	0.439964921	0.449072396	0.449072396	20.933614	20.93361362	18.589392	102.5745208	102.5745208			212	0.483842079
10	0.439964921	1.188493712	1.188493712	24.049854	24.04985414	19.396371	83.6981238	83.6981238			212	0.394802471
11	1.134731699	0.868713366	0.868713366	24.908815	24.9088149	20.155821	123.764882	123.764882			212	0.583796613
12	1.134731699	1.43478007	1.43478007	23.884254	23.88425439	18.645029	76.05097305	76.05097305	0	0	212	0.358731005
13	0.868250654	0.817115765	0.806249267	24.271673	24.27149152	21.099749	87.31102138	88.54211604	0.05	1.231094667	212	0.41184444
14	1.459118562	1.159734837	1.159734837	24.800548	24.80054796	20.537182	83.2473329	83.2473329	0	0	212	0.392676099
15	1.213764323	1.070283559	0.842142986	23.77143	24.84913494	19.479915	86.49081921	142.1129337	2.32	55.62211446	212	0.407975562
16	1.45935624	1.244761807	1.244761807	25.714382	25.71438238	19.702504	109.2197136	109.2197136	0	0	212	0.515187328
17	0.989277318	1.083994165	1.083994165	23.104545	23.10454489	18.672797	83.5679052	83.5679052	0	0	212	0.394188232
18	0.989277318	1.081963713	1.081963713	25.466742	25.46674191	21.205264	90.74456105	90.74456105	0	0	212	0.428040382
19	1.348036182	1.317182626	1.317182626	25.162441	25.16244091	20.038702	87.02701487	87.02701487	0	0	212	0.410504787
20	1.348036182	1.377577323	1.377577323	26.025084	26.02508369	21.511381	76.87182616	76.87182616	0	0	212	0.362602954
21	1.455887571	1.353312102	1.22953456	26.021568	26.24180666	19.317739	111.7062804	128.0891654	0.66	16.38288504	212	0.526916417
22	1.256209117	0.828346108	0.828346108	23.382658	23.38265849	20.038655	89.14886508	89.14886508	0	0	212	0.420513515
23	0.824934531	0.804844465	0.71679742	22.463977	22.32383059	18.31569	104.5702958	113.6579629	0.41	9.087667055	212	0.493256112
24	1.385036719	1.277166053	1.277166053	24.385014	24.38501428	20.092073	74.33922872	74.33922872	0	0	212	0.350656739
25	1.48499031	1.205231654	1.205231654	27.357314	27.35731365	22.710243	95.92441026	95.92441026	0	0	212	0.452473633
26	0.800727795	0.726891712	0.668420982	23.351265	23.43327692	19.591177	110.7008145	123.6103389	0.56	12.90952443	212	0.522173653
27	1.331231257	1.264544224	1.264544224	26.412704	26.41270358	21.817447	86.32052773	86.32052773	0	0	212	0.407172301
28	0.748332064	0.686161799	0.654258941	21.93452	22.98926417	19.396337	108.4389402	116.2048395	0.31	7.765899273	212	0.511504435
29	0.748332064	0.91173373	0.91173373	21.907002	21.90700226	17.225759	99.21163911	99.21163911	0	0	212	0.467979343

Figure 3.11: Summary of Re-processed Data

Figure 3.11 shows a sample excel sheet for Bronson Ave (W-NS) after reprocessing. For the purpose of this study, any profiles with negative overall decelerations (increase in speed) were removed as they violate the assumption of deceleration on the SCL. Trucks were not analyzed separately from passenger cars as they do not have any significant effect on the driver behaviour on freeway diverge areas (El-Basha, 2006). The final database (Appendix 3) after reprocessing included 638 speed profiles on limited-length SCLs, while FRLs contained 866. Table 3.2 summarizes the numbers of available speed profiles by site.

Table 3.2: Available Vehicle Speed Profiles at Every Site.

No.	SCL Site	Length (m)	Number of Tracked SCL Vehicles	Number of Tracked FRL Vehicles
1	Island Park Drive (E-N)	58	85	154
2	Parkdale Avenue (W-NS)	179	90	128
3	Bronson Avenue (W-NS)	212	90	119
4	Moodie Drive (W-NS)	292	85	109
5	Terry Fox Drive (E-NS)	388	114	124
6	Carp Road (E-NS)	430	98	125
7	Terry Fox Drive(W-NS)	446	76	107
Total Number of Speed Profiles			638	866

SCL length includes the taper and is measured to the gore area where pavement edges of the freeway right lane and off-ramp are separated by 1.25 m.

3.5 Collision Data

Collision data from the city of Ottawa were collected by Sarhan (2004) who studied developing explicit safety performance models on freeway merge and diverge areas. Data that are relevant only to the study sites were used. Total collision frequency was used for the purpose of exploring the premise of the followed approach of estimating the operational performance at the study sites. El-Basha (2006) tried to use the same data to model the effect of freeway geometry, traffic exposure, and speed data on collision prediction on freeway diverge areas. However, it was not possible to explicitly model safety due to the limited number of sites. The collision frequencies used were:

- The collision frequency for through and the SCL segments combined (Col_{ThDec}).
- And the collision frequency for the SCL segments only (Col_{Dec}).

Table 3.3 shows a summary of the collision data used.

Table 3.3: Summary of Collision Data for the five years period by Site

SCL	SCL Length	Collisions	
		Through and SCL(Col _{ThDec})	SCL(Col _{Dec})
Island Park Drive E-NS	58	76	8
Parkdale Avenue W-NS	179	110	17
Bronson Avneue W-NS	212	60	16
Moodie Drive W-NS	292	72	5
Terry Fox Drive E-NS	388	15	4
Carp Road E-NS	430	21	3
Terry Fox Drive W-NS	446	18	3

Chapter Four

4.0 Data Analysis

A detailed descriptive summary of the data used is covered in this Chapter. Statistical features of the data before and after reprocessing are presented and discussed. The first section of this chapter will present the statistical distributions of the main parameters defining the final reprocessed speed profiles, which are speeds (initial and final), deceleration rate, and utilization rate. Then, summary of the normal distribution testing for the data is followed. After that, two sets of statistical testing of variance (ANOVA) single factor mean of SCLs speed parameters are covered to check for homogeneity of the data samples. Finally, summary of the differences between the original data as processed by El-Basha's (2006) and the reprocessed data in this research on the SCLs will follow.

4.1 Summary of Reprocessed Data

New values for the mean and standard deviation of every parameter were obtained after applying the Matlab script. Table 4.1 shows the mean and standard deviation values for each parameter and the correlation coefficients of these parameters on each site and for all sites combined. The detailed steps and specific assumptions in applying the presented methodologies to the study SCLs are presented in Chapter 5.0.

Table 4.1: Distribution of Input Parameters on Study Sites.

SCL Site	Mean Values				Standard Deviations				Correlation Coefficients					
	μ_{vi}	μ_{vf}	μ_U	μ_d	σ_{vi}	σ_{vf}	σ_U	σ_d	$\rho_{vi,vf}$	$\rho_{vi,U}$	$\rho_{vi,d}$	$\rho_{vf,U}$	$\rho_{vf,d}$	$P_{U,d}$
Island Park Drive (E-N)	20.576	19.663	0.570	0.540	2.162	2.214	0.153	0.286	0.963	0.172	0.171	0.032	-0.065	0.087
Parkdale Avenue (W-NS)	23.292	20.163	0.416	0.907	2.346	2.457	0.083	0.358	0.854	-0.094	0.498	-0.339	0.051	-0.071
Bronson Avenue (W-NS)	24.188	19.251	0.474	1.070	2.251	2.724	0.094	0.393	0.699	-0.078	0.541	-0.282	-0.087	-0.268
Moodie Drive (W-NS)	28.384	26.621	0.474	0.369	2.575	2.564	0.134	0.175	0.944	-0.019	0.336	-0.080	0.074	-0.382
Terry Fox Drive (E-NS)	28.661	25.979	0.517	0.392	2.391	2.582	0.177	0.203	0.867	-0.015	0.335	-0.176	0.003	-0.442
Carp Road (E-NS)	29.257	26.843	0.503	0.358	2.421	2.249	0.220	0.193	0.864	0.147	0.310	0.017	-0.002	-0.515
Terry Fox Drive (W-NS)	29.499	27.119	0.474	0.371	2.875	2.773	0.205	0.256	0.881	0.017	0.446	-0.105	0.151	-0.463
All Sites Combined	26.350	23.722	0.491	0.569	4.033	4.239	0.166	0.386	0.914	-0.007	-0.209	-0.048	-0.487	-0.262

Speeds are in m/s; deceleration rate is in m/s^2 ; and utilization rate is unitless.

Where,

- v_i is initial speed, v_f is final speed, U is utilization rate, and d is deceleration rate.
- μ is mean value, σ is standard deviation value, and ρ is the correlation coefficient.

4.2 Statistical Tests on Reprocessed Data

To apply the proposed probabilistic approaches discussed in Chapter 5.0, statistical properties of the data should be studied. All statistical testing was performed at a level of significance of 5%, which is frequently used in highway research. It should be noted that the distributions of the parameters or any statistical differences within the data sample are related to the drivers' behavior and choices of initial and final speeds, deceleration, and utilization rates.

4.2.1 Distribution Testing of SCL Speed Profiles

Using Anderson Darling test (Bellosta, 2013), all parameters were tested. The null hypothesis is that the distribution is normal. If the p -value is less than the selected level of significance, the null hypothesis is rejected. Similarly, if the test statistic (AD value) is higher than the critical value, the null hypothesis is rejected. At a level of significance (p -value) of 5%, it was found that the normal distribution is applicable for all parameters except for the utilization rate at Carp Road E-NS (an AD value of 3.22 and a p -value of 0.021) and the deceleration rate at Island Park Drive E-N (an AD value of 2.778 and a p -value of 0.036). Since all data follow a normal distribution except only for these two cases (out of 28 cases), all data were considered to have a normal distribution. Table 4.2 shows a summary of the normality test done in R statistical language using the package “ADGofTest.”

Table 4.2: Distribution Testing Summary of Reprocessed Data

SCL	Parameter	AD Test Value	p -Value	Normality Test Result
Island Park Drive E-N	v_i	0.310	0.930	Normal
	v_f	0.510	0.737	Normal
	U	0.427	0.822	Normal
	d	2.778	0.036	Not Normal
Parkdale Avenue W-NS	v_i	0.744	0.523	Normal
	v_f	0.628	0.621	Normal
	U	0.613	0.636	Normal
	d	0.646	0.605	Normal
Bronson Avenue W-NS	v_i	0.213	0.987	Normal
	v_f	1.237	0.254	Normal
	U	0.534	0.712	Normal
	d	0.936	0.392	Normal
Moodie Drive W-NS	v_i	0.303	0.936	Normal
	v_f	0.512	0.734	Normal
	U	0.281	0.951	Normal
	d	0.508	0.738	Normal
Terry Fox E-NS	v_i	0.627	0.623	Normal
	v_f	0.303	0.936	Normal
	U	1.812	0.117	Normal
	d	1.472	0.183	Normal
	v_i	0.209	0.988	Normal

Carp Road E-NS	v_f	0.211	0.987	Normal
	U	3.112	0.024	Not Normal
	d	0.806	0.476	Normal
Terry Fox W-NS	v_i	0.882	0.425	Normal
	v_f	0.223	0.983	Normal
	U	2.199	0.072	Normal
	d	1.924	0.101	Normal

4.2.2 ANOVA Single Factor Mean Tests

The reprocessed data were tested in this section to identify locations where diverging drivers decelerate on the FRL. This testing was performed as it was observed that mean initial and diverge speeds at SCLs and speeds at FRL are higher at longer SCL sites. Table 4.3 shows a summary of the mean FRL speed, diverge speed onto SCL, and initial speed on SCL. Difference between mean FRL speeds and mean Diverge speeds decrease at longer sites.

For the purpose of identifying locations where diverging drivers decelerate on the FRL, analysis of variance (ANOVA) test is used to check if there is a difference between speed parameters at different sites. Two sets of ANOVA tests were performed on the reprocessed data as explained below.

Table 4.3: Summary of Mean FRL, Diverge, and Initial Speeds

SCL Name	Average Running RL Speeds (m/s)	Mean Diverge Speed Data (m/s)	Mean Initial Speed (m/s)	Difference Between Average FRL & Mean Diverge Speeds (m/s)	Difference Between Mean Diverge and Initial Speeds (m/s)
Island Park Drive (E-N)	24.675	20.576	20.576	4.099	0.000
Parkdale Ave. (W-NS)	26.850	23.277	23.292	3.573	-0.015
Bronson Ave. (W-NS)	26.842	24.254	24.188	2.588	0.065
Moodie Drive (W-NS)	28.947	28.356	28.384	0.591	-0.028
Terry Fox Drive (E-NS)	29.114	28.965	28.661	0.149	0.304
Carp Road (E-NS)	29.864	29.586	29.257	0.278	0.330
Terry Fox Drive (W-NS)	29.850	29.678	29.499	0.172	0.179

A. Initial Speeds at Different SCL Sites

The purpose of this set of ANOVA tests is to identify long and short SCLs. Long SCLs are expected to have higher initial speeds as drivers would have enough distance to decelerate on the SCL. On the other hand, short SCLs are expected to have lower initial speeds as drivers would not have enough deceleration distance on the SCL. Therefore, drivers may start deceleration on the FRL. The null hypothesis in ANOVA test is that the means of initial speed at all long SCL sites are equal. If the p -value is less than the selected level of significance or if the calculated test statistic " $F_{calc.}$ " is greater than the critical value " F_{crit} ", the null hypothesis is rejected.

First, initial speeds at all sites were tested at 5% level of significance. If the null hypothesis was rejected, the data would not be homogenous and initial speeds would

correspond to both long and short SCLs. Then, the shortest site was dropped and the test was repeated for the remaining sites. This process was followed until, for all remaining sites, mean initial speeds were found to have no statistically significant difference. The results of all ANOVA tests are available in Appendices 4. As shown in the appendix, no significant difference was found between the mean initial speeds at Terry Fox Drive (E-NS), Carp Road (E-NS), and Terry Fox Drive (W-NS) (p -value = 0.061, $F_{calc.} = 2.829$, and $F_{crit} = 3.027$). Therefore, these sites were considered as long SCLs, while the rest of the SCLs were considered to be short. This information will be helpful in applying the methodology of Monte Carlo Simulation (MCS) discussed in Section 5.4. The results of this test imply that deceleration on adjacent FRL could be happening on short SCLs. This conclusion is drawn since all vehicles are travelling on the same freeway and should have the same speed distribution.

B. FRL and Diverge Speeds at Each Site

ANOVA test was performed at each site to test the significance of the difference between diverge speeds and FRL speeds at each site. The null hypothesis is that the means of diverge speeds and initial speeds at each site are equal. If the p -value is less than the level of significance or if the test statistic " $F_{calc.}$ " is greater than the critical value " F_{crit} ", the null hypothesis is rejected. At a 5% level of significance, it was found that diverge and FRL speeds are homogenous at Moodie Drive W-NS, Terry Fox Drive (E-NS), Carp Road (E-NS), and Terry Fox Drive (W-NS) (Appendix 5). This test indicates homogeneity between diverge and FRL speeds at each site and does not necessarily imply whether deceleration takes place on the SCLs or not. FRL speeds are affected by

the drivers' behaviour on the SCL. In case drivers diverge at low speeds onto the SCL, if it was judged to be short, the following vehicles on the FRL would be affected and would travel at low speeds. Furthermore, some vehicles may travel on the FRL at low speeds as slow traffic is expected to keep to the right lane of the road. Therefore the test cannot be used to identify if deceleration happens on the FRL before merging onto the SCL. But only to test the homogeneity of SCL diverge speeds and FRL speeds. Summary of the final test for four homogeneous sites is in Table 4.4.

Table 4.4: Summary of ANOVA at Homogeneous sites

SCL	p -value	$F_{calc.}$	F_{crit}
Moodie Drive W-NS	0.088	2.935	3.890
Terry Fox Drive (E-NS)	0.639	0.221	3.881
Carp Road (E-NS)	0.395	0.726	3.884
Terry Fox Drive (W-NS)	0.664	0.189	3.893

4.3 Comparison of Original and Reprocessed Data

As mentioned in Section 3.4, a Matlab script was developed and applied in order to estimate the point where drivers start decelerating. In the original data by El-Basha (2006), the assumption was that drivers used the total travelled distance on the SCL for deceleration. But, if a driver enters a long SCL, they may maintain their speed for some time or even slightly accelerate before applying the brakes to decelerate. After applying the script (Appendix 2), new overall deceleration rates, deceleration distances, and initial

speeds are estimated. Final speeds are to remain the same as they are the end conditions and are not be affected by the script.

4.3.1 Time and Distance to Decelerate

Time and distance between the diverge point to the deceleration point vary depending on the driver's choice of initial speed, available SCL length, utilization rate, and end condition of the SCL. Long SCLs are expected to have a longer time and distance to decelerate. Figures 4.1 and 4.2 show the vehicles time and distance to decelerate, respectively.

Figure 4.1: Time Spent on the SCL before Decelerating (dots represent each vehicle and X represents the mean value of vehicles at each site).

Figure 4.2: Distance Spent on the SCL before Decelerating (dots represent each vehicle and X represents the mean value of vehicles at each site).

As shown in Figures 4.1 and 4.2, the time and distance to decelerate in Island Park Drive (length of 58 m) are both zero as it is a very short SCL. Both values increase with the increase of the available SCL length. Terry Fox Drive W-NS has less mean distance and time to decelerate values than Carp Road E-NS, which could be related to the higher ramp's width and allowed speed at the ramp on Carp Road E-NS compared to Terry Fox Drive W-NS. The geometric characteristics could be found in (Appendix 1)

4.3.2 Final Speeds

As explained in Section 3.4, the script used for reprocessing was developed to estimate the deceleration point on SCLs. Therefore, new initial speeds were found at beginning of deceleration but final speed was not affected. Therefore, for all vehicles, there is no difference in the final speed before and after reprocessing the data. It was

noticed that final speeds are high at SCLs with high ramp advisory speeds. In other words, the geometric configuration of the ramp affects the final speed at the SCL. Table 4.5 and Figure 4.3 show the relationship between each site's final speed and the ramp advisory speed. The table and figure show that as the ramps advisory speed increases (which indicates a more forgiving geometry), the drivers final speed increases.

Table 4.5: Mean Final Speed at Each Site and Relative Ramps Advisory Speeds

SCL Site	Final Speed (km/h)	Ramp Advisory Speed (km/h)
Island Park Drive (E-N)	70.786	40
Parkdale Avenue (W-NS)	72.587	50
Bronson Avenue (W-NS)	69.303	40
Moodie Drive (W-NS)	95.835	50
Terry Fox Drive (E-NS)	93.523	50
Carp Road (E-NS)	96.635	70
Terry Fox Drive (W-NS)	97.627	60

Figure 4.3: Ramp's Advisory Speeds and Mean Final Speeds at All Sites

Initial and Gore Speeds

It was unknown whether drivers slightly accelerate, maintain their speeds, or slightly decelerate before reaching the point of effective deceleration. Thus, the initial speeds (at deceleration point), as estimated by the Matlab script, were compared to the diverge speeds (at diverge point) as shown in Figure 4.4.

Figure 4.4: Comparison between Initial and Diverge Speeds

For all individual SCL vehicles, the difference between initial and diverge speeds ranged between -3.362 and 4.527 m/s (-12.10 and 16.30 km/h), which shows that some vehicles decelerated and some accelerated after diverging into the SCL. The average speed difference was 0.130 m/s (0.47 km/h), which means that on average vehicles' speeds did not change considerably from the diverge to deceleration points. Using the line of equality, Figure 4 shows that the individual vehicle data are close to the line of

equality between diverge and initial speeds. Therefore, the assumption that drivers start decelerating at the deceleration point is confirmed.

4.3.3 Deceleration Distance and Total Travelled Distance

After reprocessing the data, deceleration distances that start from actual deceleration point are estimated. The reduction from total travelled distance to deceleration distance is affected by the driver's choice of not decelerating at the diverge point. Figure 4.5 is a summary of the mean deceleration distance and total travelled distance on SCL at each site.

Figure 4.5: Deceleration Distance and Total Travelled Distance.

The difference between total travelled distance and deceleration distance follows the same trend of the time and time and distance to decelerate on every SCL. As time

spent to decelerate increases, distance to decelerate will increase and available deceleration distance decreases. For all vehicles' profiles, the difference between total travelled distance and deceleration distance ranged between 0.00 at Island Park Drive E-N to 115.39 m at Carp Road E-NS. Mean difference for all vehicle data is 40.04 m and the standard deviation is 43.58 m, which indicates potentially misleading results if the total travelled distances were used without reprocessing.

4.3.4 Overall Deceleration Rate

After reprocessing the data, it was anticipated that original overall deceleration rate values (based on the total travelled distance and total time spent on the SCL) would increase after using the estimated deceleration distance and time in the calculation process. As mentioned in Section 3.3, the overall deceleration calculation depends on the average of both distance deceleration and time deceleration, Equations 3.3 and 3.4. If the total deceleration distance and time decrease, the overall deceleration would increase. Figures 4.6 and 4.7 show the difference between the mean and standard deviations of the overall deceleration rates before and after reprocessing the data.

Figure 4.6: Mean Overall Deceleration Rate before and after Reprocessing the Data.

Figure 4.7: Standard Deviation of Overall Deceleration Rate before and after Reprocessing the Data.

4.3.5 Correlation between Variables

The correlation coefficients between variables changed due to reprocessing the data. To summarize this change, the correlation coefficients of all data combined before and after reprocessing and their corresponding p -values are shown in Tables 4.6 and 4.7.

Table 4.6: Summary of Correlation Coefficients and Corresponding p -values before Reprocessing.

Correlation Coefficient (ρ) and Corresponding p -values				
	v_i	v_f	d^*	U^*
v_i	1	0.906 (<0.001)	-0.273 (<0.001)	0.385 (<0.001)
v_f	0.906 (<0.001)	1	-0.550 (<0.001)	0.361 (<0.001)
d^*	-0.273 (<0.001)	-0.550 (<0.001)	1	-0.460 (<0.001)
U^*	0.385 (<0.001)	0.361 (<0.001)	-0.460 (<0.001)	1

* Before reprocessing utilization (U) and deceleration (d) rates were calculated based on total travelled distance to be able to compare the old parameters to reprocessed parameters.

Table 4.7: Summary of correlation Coefficients and Corresponding P-values after Reprocessing

Correlation Coefficient (ρ) and Respective p -values				
	v_i	v_f	d	U
v_i	1	0.914 (<0.001)	-0.209 (<0.001)	-0.007 (0.429)
v_f	0.914 (<0.001)	1	-0.487 (<0.001)	-0.048 (0.112)
d	-0.209 (<0.001)	-0.487 (<0.001)	1	-0.262 (<0.001)
U	-0.007 (0.429)	-0.048 (0.112)	-0.262 (<0.001)	1

After reprocessing, utilization (U) and deceleration (d) rates were calculated based on deceleration distance.

As explained earlier in Section 4.3.4, deceleration distances are different from total travelled distances, specifically for long SCLs which reduced the utilization rates. Also, this slightly affected the overall deceleration rate as the total time and distance spent on the SCL decreased (increasing trend of time and distance to decelerate) as

discussed in Section 4.3.1. Initial speeds were very close to the diverge speeds, while final speeds did not change. Due to these changes, correlation coefficients between utilization rate and rest of the variables were affected (last column and row). There is no statistically significant correlation between utilization rate and either initial or final speeds after reprocessing the data, as indicated by the p -values. The rest of the coefficients did not change considerably (Tables 4.6 and 4.7).

Chapter Five

5.0 Probabilistic Methodology

In this chapter, a description of the attempted methods to quantify the operational performance of SCLs is presented. Explanation for each method regarding how the methodology is carried out, strengths and/or weaknesses of each approach is covered as well. Estimating PNC for each site is presented in Chapter 6.0 using the methodologies explained in this chapter once for each site's dataset separately and using the dataset of all sites combined data as well. The probabilistic approaches followed in this study are:

- First Order Second Moment (FOSM).
- Monte Carlo Simulation (MCS).
- First Order Reliability Method (FORM).

FOSM calculations were accomplished using Microsoft Excel, while MCS and FORM were completed using Matlab. Excel is commonly used for simple and intermediate statistical calculations, while Matlab is used for more complex mathematical calculations involving simulation and statistical analysis. The developed Matlab scripts could be found in Appendices 9 and 10.

Section 5.1 presents an introduction to reliability analysis. In Section 5.2, the formulated limit state function used for the proposed probabilistic methods is described. Section 5.3 presents the first probabilistic approach, which is FOSM methodology. Then, Section 5.4 presents the second methodology, which is MCS. Finally, Section 5.5 covers the last statistical technique, which is FORM.

5.1 Reliability Analysis

Reliability analysis is a method of evaluating the performance of a system given a sample with known characteristics and confidence level. Reliability analysis simply evaluates the difference between the demand “ D ” and the supply “ S ” sides of a system. If demand exceeds supply the system would fail. Demand and supply could be any functions that describe the system’s behaviour. To evaluate the system, a limit state function “ G ”, which represents difference between supply and demand, is defined as:

$$G = S - D \quad \text{(Equation 5.1)}$$

Then, “ G ” is evaluated using probabilistic approaches. Evaluation approaches could be numerical or analytical, exact or approximate depending on the complexity of the limit state function. The probability of demand exceeding supply is referred to in many engineering fields as the probability of failure (POF), probability of hazard (POH), or probability of noncompliance (PNC). As the probability of demand exceeding supply decreases, the likelihood of system failure decreases.

To be able to apply reliability analysis to any engineering system, information about the system’s failure modes and variables describing the demand and supply sides of the system should be known. For example, in structural engineering, demanded load of a beam could be represented by the maximum load the beam would be exposed to, while supply would be the function representing the beam’s strength or capacity. Similarly, in highway engineering, supply could be available horizontal or vertical curve radius, while demand could be a function representing the demanded radius by the road users. In the two previous examples, failure mode is demand exceeding supply.

Researchers in fields like structural engineering describe the probability of demand exceeding supply as probability of failure. The reason is that if demand exceeds the supply, the system fails or becomes unusable (developing cracks, deformation ...). On the other hand, in highway engineering systems, when demand exceeds supply, other conditions have to be met and/or no evasive actions are to be performed by drivers for the system to fail. For example, a demand stopping sight distance (SSD) that exceeds supply for a driver at a specific location would only mean a collision if an object exists when this driver passes this location (Sarhan & Hassan, 2008). For that reason, this probability is called probability of hazard (POH) or probability of noncompliance (PNC). Many researchers use different terms to describe the condition of demand exceeding supply and it could be argued that this probability could be expressed based on the consequences of exceeding the supply by the demand. The term probability of noncompliance (PNC) will be used to describe the probability of demand exceeding supply since accommodating maneuvers could be performed by the SCL or mainline drivers when demand exceeds supply.

As mentioned earlier, reliability analysis could be conducted using many probabilistic techniques. The following is a list of some of the techniques used in reliability analysis (Mahadevan & Haldar, 2000):

- Direct Integration of the limit state function: an exact method applied for simple limit state functions.
- First Order Second Moment (FOSM), which is a simple, truncated Taylor series to estimate the distribution of the supply, demand, or the difference between them.

- Monte Carlo simulation (MCS), which involves the generation of random numbers to compute the probability distribution of the supply, demand, or the difference between them.
- First and Second Order Reliability Methods (FORM and SORM) are other truncated Taylor series methods that calculate the probability distributions of demand, supply, or the difference between them.

If supply and demand are both normally distributed, independent random variables, then, G (the difference between supply and demand) is normally distributed as well. In this case, PNC can be calculated using the inverse of the standard normal cumulative probability distribution function of a z -score equal to the reliability index (β). Reliability index is a measure used to relate a desired degree of reliability to the performance of an engineering system. For example, an engineering system with a β of 2.5 means that supply will not be exceeded by demand for 99.379 % of the time and PNC would be 0.621%. Generally, using a probabilistic approach helps in:

- Providing an assessment of risk or confidence in the designed system.
- Quantifying under- or over-designing by comparing reliability indices or PNC values to standard or common values used in the field.

5.2 Limit State Function

The deceleration distance used by a specific driver, can be calculated based on the initial speed as the driver starts deceleration, final speed at the end of SCL, and the deceleration rate as follows (kinematics relationship):

$$D = \frac{v_i^2 - v_f^2}{2d} \quad \text{(Equation 5.2)}$$

Where

- D is deceleration distance (m);
- v_i is initial speed (m/s);
- v_f is final speed (m/s); and
- d is deceleration rate (m/s²).

This relationship is based on the assumption that drivers use a constant deceleration rate on the whole SCL available length during their deceleration maneuver. As mentioned previously in Chapter 2.0, according to (Fitzpatrick, et al., 2012), drivers do not use a constant deceleration rate in the deceleration maneuver. However, the assumption of constant deceleration rate was validated visually for the field data used in this study. Speed profiles of all vehicles in each site were drawn and it was observed that the change in successive speeds of individual vehicles is constant. This indicates a constant deceleration rate for the selected limited length SCL sites. Figure 5.1 shows a sample speed profile on Bronson Ave. (W-NS), and Appendix 12 contains the speed profiles for all study sites drawn using Matlab. Therefore, Equation 5.2, which is based on the assumption of constant deceleration rate, was used as the basis to the limit state function for SCL length.

Figure 5.1: Speed Profiles of Individual Vehicles at Bronson Ave. (W-NS)

Equation 5.2 is adjusted for the fact that drivers use a portion of the SCL for deceleration. As mentioned in Chapter 4.0, drivers utilize only a portion of the SCL length to decelerate rather than the whole length. As a result, the deceleration distance in Equation 5.3 could be used to calculate the demand SCL length using the utilization rate (U) developed after reprocessing the data. The limit state function for the demand SCL length (L) can be formulated as:

$$L = \frac{v_i^2 - v_f^2}{2 d \times U} \quad \text{(Equation 5.3)}$$

Given that the supply SCL length is constant for a specific site, which is the actual available SCL length (SL), the limit state function for the difference between supply and demand can be formulated as:

$$G = SL - \frac{v_i^2 - v_f^2}{2 d \times U} \quad \text{(Equation 5.4)}$$

5.3 First Order Second Moment (FOSM)

FOSM is one of simplest statistical techniques that can be used to find the distribution of supply, demand, or limit state function of a system. Mean and variance of the distribution of the function are approximated in a closed form solution using a truncated Taylor series. The function's distribution is estimated using only the first term of Taylor series as follows (Mahadevan & Haldar, 2000):

$$E(Y) = f(\mu_{x1}, \mu_{x2}, \dots, \mu_{xn}) \quad (\text{Equation 5.5})$$

$$Var(Y) = \sum_{i=1}^n \left(\frac{\partial f}{\partial x_i} \right)^2 \sigma_{xi}^2 + \sum \sum_{i \neq j}^n \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} cov[x_i, x_j] \quad (\text{Equation 5.6})$$

Where,

- Y is the dependent variable;
- μ_{xi} and σ_{xi} are mean and standard deviation of independent variable i ;
- $cov[x_i, x_j]$ is the covariance between variables x_i, x_j and equals to $\rho_{xi,xj} \times \sigma_{xi} \times \sigma_{xj}$;
- and
- $\rho_{xi,xj}$ is the correlation coefficient between variables x_i, x_j .

Equations 5.5 and 5.6 can be applied to the limit state function of demand SCL length in Equation 5.3 to establish the distribution of demand SCL length as follows:

$$E(L) = \frac{\mu_{vi}^2 - \mu_{vf}^2}{2 \mu_d \mu_v} \quad (\text{Equation 5.7})$$

$$\begin{aligned}
Var(L) = & \left(\frac{\partial L}{\partial v_i}\right)^2 \sigma_{vi}^2 + \left(\frac{\partial L}{\partial v_f}\right)^2 \sigma_{vf}^2 + \left(\frac{\partial L}{\partial d}\right)^2 \sigma_d^2 + \left(\frac{\partial L}{\partial U}\right)^2 \sigma_U^2 + 2 \frac{\partial L}{\partial v_i} \frac{\partial L}{\partial v_f} \rho_{vi,vf} \sigma_{vi} \sigma_{vf} + \\
& 2 \frac{\partial L}{\partial v_i} \frac{\partial L}{\partial d} \rho_{vi,d} \sigma_{vi} \sigma_d + 2 \frac{\partial L}{\partial v_i} \frac{\partial L}{\partial U} \rho_{vi,U} \sigma_{vi} \sigma_U + 2 \frac{\partial L}{\partial v_f} \frac{\partial L}{\partial d} \rho_{vf,d} \sigma_{vf} \sigma_d + \\
& 2 \frac{\partial L}{\partial v_f} \frac{\partial L}{\partial U} \rho_{vf,U} \sigma_{vf} \sigma_U + 2 \frac{\partial L}{\partial d} \frac{\partial L}{\partial U} \rho_{d,U} \sigma_d \sigma_U
\end{aligned}$$

(Equation 5.8)

Where,

- $E(L)$ is expected or mean SCL length (m);
- μ_{vi} is mean initial speed (m/s);
- μ_{vf} is mean final speed (m/s);
- μ_d is mean deceleration rate (m/s²);
- μ_U is mean utilization rate;
- $\frac{\partial L}{\partial v_i} = \frac{v_i}{d \times U}$;
- $\frac{\partial L}{\partial v_f} = -\frac{v_f}{d \times U}$;
- $\frac{\partial L}{\partial d} = -\frac{v_i^2 - v_f^2}{2d^2 \times U}$; and
- $\frac{\partial L}{\partial U} = -\frac{v_i^2 - v_f^2}{2d \times U^2}$.

Using the mean and standard deviation of the input parameters (v_i , v_f , U , and d) and correlation coefficients taken from Table 4.1, demand length at each site could be found. Finally, PNC, or the probability of demand exceeding supply, could be estimated using the distribution of demand SCL length (L) and the available length at each site (SL). As all variables follow a normal distribution, demand length $E(L)$ was assumed to follow a normal distribution. It should be noted that the limit state function's nonlinearity could cause the output's distribution (demand length) to follow a distribution different from the

input parameters normal distribution. This assumption of normality was verified later after applying MCS discussed in Section 5.4 by graphing the frequency of the demand length shown in Appendix 13. Using the cumulative probability density function of $E(L)$, PNC could be found as follows:

$$PNC = 1 - \phi^{-1} \left(\frac{SL - E(L)}{\sqrt{Var(L)}} \right) \quad \text{(Equation 5.9)}$$

Where,

ϕ^{-1} is inverse cumulative distribution function of a standard normal distribution.

In Equation 5.9, the difference between supply and demand divided by the standard deviation of demand L is basically called the z -score or β . This z -score is the number of standard deviations an observation is above or below the mean.

As shown in the derivation, FOSM is relatively a simple analytical technique with a closed-form solution. However, it has many limitations. First, it suffers lack of invariance of the solution relative to the formulation of the performance function (Kaiser & Dickman, 1962). In other words, the estimated PNC may differ depending on how the limit state function is formulated. Also, FOSM is applicable only for small to moderately nonlinear systems (Dettinger & Wilson, 1981). Therefore, if the model is highly nonlinear, the results of the model would be affected. In addition, FOSM was shown to overestimate the variance of the function (Hassan, et al., 2012), which would in turn impact the estimated value of PNC.

5.4 Monte Carlo Simulation (MCS)

In MCS, parameters of the limit state function are treated as uncertain variables, each follows a specific distribution. Random values for each uncertain variable are generated according to their respective probability distributions, and the model describing the system is executed for each random combination of the input parameters. The results of these simulation runs establish the distribution of the limit state function. The accuracy of this distribution depends on the number of simulation runs performed and the adequacy of the assumed parameter distribution.

It was observed that the deceleration rate (d) has high correlation coefficients that are statistically significant at 5% level of significance to all other independent variables at most sites (v_i , v_f and U) (Appendix 3). Therefore, only v_i , v_f and U were taken as independent variables to be assigned randomly to each driver in the simulation. The mean and standard deviation of these variables and correlation coefficients were taken from Table 4.1 corresponding to the site being simulated or for all sites combined. The variable (d) was assigned to each driver using the following regression equation:

$$\mathbf{d} = \begin{cases} \mathbf{a_1 + a_2 v_i + a_3 v_f + a_4 U} & \text{Data for a specific site} \\ \mathbf{a_1 + a_2 v_i + a_3 v_f + a_4 U + a_5 SL} & \text{Data for all sites combined} \end{cases}$$

(Equation 5.10)

Where,

a_i are regression coefficients.

Table 5.1 shows the linear regression result for the dataset of all sites combined. It should be noted that using all sites combined includes parameters (v_i , v_f and U) that belong to different SCLs lengths (SL), therefore, the supply length was taken as a variable

in predicting the deceleration rate on the SCL as shown in Equation 5.10. As shown in Table 5.1, the actual or supply SCL length (SL) is a significant variable affecting the individual driver's deceleration rate when regression is carried out for the dataset of all sites combined. Using the assumptions of linearity of the relationship between variables, error independence (having no serial correlation), error homoscedasticity (having constant variance for the errors), and error normality distribution, linear regression analysis was performed using the individual vehicle data. Detailed results of the regression analysis are presented in Appendix 6, and the regression coefficients are shown in Table 5.2.

Table 5.1: Linear Regression for the Dataset of All Sites Combined

All Sites Combined

<i>Regression Statistics</i>		
Multiple R	0.921	
R Square	0.849	
Adjusted R Square	0.848	
Standard Error	0.150	
Observations	638	
<i>Parameter</i>	<i>Coefficients</i>	<i>P-value</i>
Intercept	0.547	<0.001
Initial Speed	0.189	<0.001
Final Speed	-0.169	<0.001
Utilization Rate	-0.835	<0.001
SCL Length	-0.002	<0.001

Table 5.2: Regression Coefficients for Prediction of Individual Vehicle's Deceleration Rate.

SCL Name	a_1	a_2	a_3	a_4	a_5	R^2
Island Park Drive (E-N)	0.040	0.557	-0.530	-0.944	---	0.940
Parkdale Avenue (W-NS)	0.046	0.313	-0.273	-2.215	---	0.963
Bronson Avenue (W-NS)	-0.289	0.225	-0.162	-2.024	---	0.927
Moodie Drive (W-NS)	0.060	0.184	-0.173	-0.693	---	0.929
Terry Fox Drive (E-NS)	-0.090	0.146	-0.127	-0.798	---	0.882
Carp Road (E-NS)	0.104	0.128	-0.118	-0.639	---	0.878
Terry Fox Drive (W-NS)	-0.180	0.152	-0.131	-0.801	---	0.843
All Sites Combined	0.547	0.189	-0.169	-0.835	-0.002	0.849

All regression coefficients are significant at 5% level of significance.

The linearity of the relationship between variables and error homoscedasticity were validated for the datasets of each site separately and all sites combined by drawing the line of equality between the observed deceleration rates at each site and the predicted values using Equation 5.10. Figure 5.2 shows this test for the data of all sites combined, and the complete analysis is available in Appendix 7. To test errors' independence, plots between the observations and the residuals were generated similar to the example shown in Figure 5.3. Finally, to test the errors' normality distribution, histogram of the residuals was drawn as shown in Figure 5.4. The diagnostics indicate that all deceleration regression models performed for the datasets of each site separately and all sites

combined do not violate the linear regression assumptions. Complete diagnostics of the regression models for each site and for all sites combined are available in Appendix 7.

Figure 5.2: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10 for All SCLs Combined.

Figure 5.3: Residuals Plot for Each Predicted Deceleration Rate Using Equation 5.10 at All Sites Combined

Figure 5.4: Residuals Histogram for All Sites Combined

To apply MCS to the limit state function in Equation 5.4, the mean and standard deviation of each variable, along with the correlation coefficient between each two variables, were first defined based on field data. Then, uncorrelated random numbers in the range [0, 1] were generated for each of the independent variables in the limit state function. The uncorrelated random numbers were then converted into random, correlated numbers in the range [0, 1] using Cholesky's decomposition method (Mahadevan & Haldar, 2000). Cholesky's decomposition is a triangular decomposition of a matrix C , which finds a triangular matrix B that if multiplied by its transpose will lead back to the matrix C ; thus, $C = B^T B$. Cholesky's decomposition of the correlation matrix was multiplied by the uncorrelated random numbers leading to the correlated random numbers in the range [0, 1]. Then, using inverse of the normal cumulative distribution function, the correlated random numbers in the range [0, 1] were converted to normally

distributed parameters based on the mean and standard deviation of each variable (v_i , v_j , and U). Values were screened to remove all combinations that would create any impossible or unrealistic simulation scenario. The following two conditions represent impossible conditions and corresponding scenarios were removed:

- Negative initial and diverge speeds.
- Utilization rate exceeding 1 or below 0.

Then deceleration values were generated based on the linear regression shown in Equation 5.10 using the coefficients in Table 5.2. Length is calculated for each simulated vehicle based on Equation 5.4. To make sure that outliers are removed, scenarios with the following conditions were also removed from the simulation:

- Difference between final speed and initial speed that is below 0 as this violates the deceleration condition.
- Values that were outside 95% of the normal distribution curve (i.e. values exceeding 1.96 standard deviations) of the following:
 - Deceleration rates.
 - Utilization rates.
 - Difference between initial and final/initial speed.
- Utilization rates that were less than the minimum at each site when using individual sites data; and utilization rates less than the minimum at all sites when using all data combined. This is to remove utilization rates that would be too low based on the available field data. For instance, if the generated utilization rate was 0.03 and the minimum in Terry Fox Drive W-NS is 0.05, the line that contains the 0.03 value of utilization rate

would be removed. This in turn truncates the distribution of utilization rates from the left side resulting in a truncated normal distribution. Right side truncation, i.e. truncating values that exceed the maximum at each site was not performed as high utilization rates do not represent an unwanted scenario. On the other hand, an extremely low U would be a driver who diverged within the gore proximity.

- Deceleration rates that were less than the minimum at each site when using individual sites data; and deceleration rates that were less than the minimum at all sites when using all data combined. This step is done to remove generated combinations of initial and final speeds and utilization rates that do not represent the study sites. Similar to utilization rates, the distribution of deceleration rates is truncated from the left side resulting in a truncated normal distribution. Right side truncation, i.e. truncating values that exceed the maximum at each site was not performed as high deceleration rates do not represent an unwanted scenario. On the other hand, a very low d means one of the following unwanted scenarios: drivers entered the SCL at a low initial speed and left with a low final speed, drivers entered with high initial speed and left with high final speed, and/or drivers utilized a very low portion of the SCL.

Finally, PNC in MCS is calculated as the number of failures ($L > SL$) divided by the number of runs. These steps were followed using the dataset of each site combined.

When the evaluation of the dataset of all sites combined was carried out, the following distributions were used to represent the data:

- Mean and standard deviation of initial speed at long sites, $\mu_{vi_long} = 29.085$ m/s and $\sigma_{vi_long} = 2.472$ m/s.
- Mean and standard deviation of final speed at each site.
- Mean and standard deviation of utilization rate at all sites combined.

Mean and standard deviation of initial speed at long SCL sites were used to avoid the drivers' deceleration behaviour on the FRL as indicated in Section 4.2.2. The mentioned distributions of initial speed, final speed, and utilization rate were used as distributions for the random generated independent parameters. As deceleration rate is predicted for each driver during the MCS procedure, it was necessary to avoid the issue of drivers decelerating on the FRL, which is why the above distributions were used for the generated parameters. These distributions were only followed in the simulation using the dataset of all sites combined. On the other hand, it was not possible to avoid the deceleration condition on the FRL when using the analytical methods (FOSM and FORM) since the deceleration could occur on the FRL, which is the reason mean and standard deviations of the independent parameters were used. The condition of drivers decelerating on the FRL could not be avoided in analytical methods as it was not clear if embedding a function inside the demand distribution would affect the methodology.

It should be noted that attempts to predict mean and standard deviation of each parameter were carried out. Trials were carried to model the distributions (mean and standard deviation) of final speed and utilization rate. However, there were no significant

relations for mean or standard deviation of final speed and utilization rate. Since no independent parameters had any relationship, it was decided to use the distributions that would reflect the sites based on the data as discussed.

A Matlab script was developed to perform the MCS procedure explained in this section (Appendix 9). The simulation started with creating 150,000 combinations of random input parameters. After screening the combinations for unrealistic scenarios and outliers based on the value of each independent parameter, the final number of simulation runs using the datasets for each site separately ranged from 61,756 to 81,628 for each site's simulation and 78,227 to 106,435 runs using the dataset for all sites combined. Summary for the number of runs on each site could be found in Section 6.2. Error of this methodology is inversely proportional to the number of runs as shown in Equation 5.11 (Mahadevan & Haldar, 2000).

$$SE = \frac{\sigma}{N^{0.5}} \quad \text{(Equation 5.11)}$$

Where,

σ is the standard deviation of the MCS simulation and N is the number of runs.

The results discussed in Section 6.2 show that the error of this methodology is very low.

5.5 First Order Reliability Method (FORM)

FORM is another reliability analysis method used to incorporate the uncertainty of the supply and demand. PNC is computed directly by evaluating the limit state function for the difference between supply and demand. Therefore, in the case of SCL length, the limit state function in FORM is the one given in Equation 5.4. FORM has been developed to address some of the technical difficulties in FOSM mentioned in

Section 5.3. Still, this method is a Taylor series expansion but about a point that is on the failure surface of the performance function (Singh, et al., 2007). This failure surface is the surface constrained to a limit state function equal to zero. The point of expansion is determined as the point on the failure surface at the shortest distance to the origin (Singh, et al., 2007). This distance from the origin to the expansion point is a measure of reliability, called reliability index, β .

The methodology used in this study to determine the reliability index and PNC is called the Ellipsoid method. This method was developed by Low & Tang (1997) who showed that β can be estimated by minimizing a quadratic form subject to a specific constraint. Mathematically, the solution can be formulated in a matrix form as follows (Low & Tang, 1997):

$$\beta = \min_{X \in F} \sqrt{(X - \mu)^T C^{-1} (X - \mu)}, \text{ subject to the constraint: } G = 0 \quad (\text{Equation 5.12})$$

Where,

- X is a vector of random variables;
- μ is a vector of corresponding mean values;
- C is the covariance matrix of the variables;
- F is the failure region; and
- G is the limit state function in Equation 5.4.

In applying the methodology to the limit state function in Equation 5.4, the vectors of random variables and corresponding mean values are as follows:

$$X = \begin{bmatrix} v_i \\ v_f \\ d \\ U \end{bmatrix} \rightarrow \mu = \begin{bmatrix} \mu_{v_i} \\ \mu_{v_f} \\ \mu_d \\ \mu_U \end{bmatrix} \quad (\text{Equation 5.13})$$

The covariance matrix can be formulated as:

$$C = \begin{bmatrix} \sigma_{v_i}^2 & \rho_{v_i,v_f} \sigma_{v_i} \sigma_{v_f} & \rho_{v_i,d} \sigma_{v_i} \sigma_d & \rho_{v_i,U} \sigma_{v_i} \sigma_U \\ \rho_{v_f,v_i} \sigma_{v_f} \sigma_{v_i} & \sigma_{v_f}^2 & \rho_{v_f,d} \sigma_{v_f} \sigma_d & \rho_{v_f,U} \sigma_{v_f} \sigma_U \\ \rho_{d,v_i} \sigma_d \sigma_{v_i} & \rho_{d,v_f} \sigma_d \sigma_{v_f} & \sigma_d^2 & \rho_{d,U} \sigma_d \sigma_U \\ \rho_{U,v_i} \sigma_U \sigma_{v_i} & \rho_{U,v_f} \sigma_U \sigma_{v_f} & \rho_{U,d} \sigma_U \sigma_d & \sigma_U^2 \end{bmatrix} \quad (\text{Equation 5.14})$$

Substituting in to Equation 5.12, β will be equal to

$$\min_{X \in F} \sqrt{\begin{bmatrix} v_i - \mu_{v_i} & v_f - \mu_{v_f} & d - \mu_d & U - \mu_U \end{bmatrix} \begin{bmatrix} \sigma_{v_i}^2 & \rho_{v_i,v_f} \sigma_{v_i} \sigma_{v_f} & \rho_{v_i,d} \sigma_{v_i} \sigma_d & \rho_{v_i,U} \sigma_{v_i} \sigma_U \\ \rho_{v_f,v_i} \sigma_{v_f} \sigma_{v_i} & \sigma_{v_f}^2 & \rho_{v_f,d} \sigma_{v_f} \sigma_d & \rho_{v_f,U} \sigma_{v_f} \sigma_U \\ \rho_{d,v_i} \sigma_d \sigma_{v_i} & \rho_{d,v_f} \sigma_d \sigma_{v_f} & \sigma_d^2 & \rho_{d,U} \sigma_d \sigma_U \\ \rho_{U,v_i} \sigma_U \sigma_{v_i} & \rho_{U,v_f} \sigma_U \sigma_{v_f} & \rho_{U,d} \sigma_U \sigma_d & \sigma_U^2 \end{bmatrix} \begin{bmatrix} v_i - \mu_{v_i} \\ v_f - \mu_{v_f} \\ d - \mu_d \\ U - \mu_U \end{bmatrix}} \quad (\text{Equation 5.15})$$

The reliability index β can then be found by substituting the variables in Equation 5.15 and solving for a minimum value with the minimization constraint (Equation 5.16):

$$G = SL - \frac{v_i^2 - v_f^2}{2 d \times U} = 0 \quad (\text{Equation 5.16})$$

Then, using the inverse cumulative distribution function of a normal distribution, PNC is calculated as shown in Equation 5.17.

$$PNC = 1 - \Phi^{-1}(\beta) \quad (\text{Equation 5.17})$$

FORM is accurate enough when the curvature radius of failure surface is large and small number of random variables is present (Zhao & Ono, 1999). However, when the failure surface is highly nonlinear, Second Order Reliability Method (SORM) is more accurate than FORM. One of the limitations of the followed approach is that it suffers from having a maximum PNC of 0.5. This maximum value results from the physical interpretation of the used methodology. Reliability index, β , is found by calculating the minimum distance from the center of the formulated ellipsoid to the failure surface. If that distance is 0, which is the minimum value possible under the square root, PNC will be at the maximum possible value in this method, which is 0.5.

A Matlab script was developed to perform the FORM procedure explained in this section. First the dataset means, standard deviations, correlation coefficients were extracted from an Excel sheet. After that, the limit state function was defined. Then, using a minimization range of two standard deviations above or below the mean, the minimization equation (Equation 5.15) was applied with the condition of a limit state function equal to zero. Finally, PNC was calculated using the inverse cumulative distribution of a normal function (Equation 5.17). The Matlab script could be found in Appendix 10. The methodology was applied once using the dataset of each site and another time using the dataset of all sites combined and the results are followed and discussed in Chapter 6.0.

Chapter Six

6.0 Results and Discussion

This chapter covers the results of the three attempted probabilistic methods. Results are summarized as PNC values, which are compared later in this chapter to the available collision data as a way to explore the premise of the methodology. The first section in this chapter covers the results of FOSM using the dataset of each site and all sites combined. Similarly, Sections 6.2 and 6.3 will cover MCS and FORM, respectively. A comparison between the used methods is followed in Section 6.4. Finally, the trend of change in collision frequency with PNC values is examined to indicate whether a potential relationship between PNC and collisions exists.

6.1 First Order Second Moment (FOSM)

As stated in Section 5.3 FOSM was performed using each site's data and using all sites combined data. Input data from Table 4.1 were used in Equations 5.7 and 5.8 in order to find the demand length. Then, Equation 5.9 was used to find the PNC. Table 6.1 provides a summary of the results using the dataset of each site.

Table 6.1: Results of FOSM Using the Dataset of Each Site.

SCL	Available Length SL (m)	Mean Demand (L) (m)	Standard Deviation of L (m)	β	PNC
Island Park Drive (E-N)	58	59.644	34.501	-0.048	0.519
Parkdale Avenue (W-NS)	179	180.272	73.126	-0.017	0.507
Bronson Avenue (W-NS)	212	211.311	86.880	0.008	0.497
Moodie Drive (W-NS)	292	277.475	157.571	0.092	0.463
Terry Fox Drive (E-NS)	388	361.501	268.022	0.099	0.461
Carp Road (E-NS)	430	376.264	330.748	0.162	0.435
Terry Fox Drive (W-NS)	446	383.550	358.480	0.174	0.431

It can be noticed that due to the high standard deviation of expected demand L , this approach results in high PNC values for long sites (compared to MCS in the following section). The main reason of such PNC values is drivers' adjusted behaviour to account for different SCL lengths.

Repeating the same methodology, PNC values were found for each site using the dataset of all sites combined available in Table 4.1. When the model was executed, the expected demand L was found as 235.449 m with a standard deviation of 184.863 m. Based on this result and applying Equation 5.9 for each site, the following PNC values were calculated for each site (Table 6.2).

Table 6.2: Results of FOSM Using the Dataset of All Sites Combined.

SCL	Available Length SL (m)	β	PNC
Island Park Drive (E-N)	58	-0.960	0.832
Parkdale Avenue (W-NS)	179	-0.306	0.620
Bronson Avenue (W-NS)	212	-0.127	0.551
Moodie Drive (W-NS)	292	0.305	0.380
Terry Fox Drive (E-NS)	388	0.825	0.205
Carp Road (E-NS)	430	1.052	0.146
Terry Fox Drive (W-NS)	446	1.138	0.127

As shown in Table 6.2, and similar to the results using the dataset of each site in Table 6.1, as available SCL length (SL) increases PNC decreases. When using the dataset of all sites combined, the demand length is constant, and therefore the value of PNC at each site depends only on the available SCL length. This explains the difference in trend of changing PNC with SCL length compared to the case of using each site's data.

6.2 Monte Carlo Simulation (MCS)

MCS was performed once using the dataset of each site and another time using the dataset of all sites combined as discussed in Section 5.4. Using the developed Matlab script (Appendix 9), PNC was predicted for each site. Tables 6.3 and 6.4 show number of runs after screening, mean demand L , standard deviation of L , PNC results, and error of demand length for the dataset of each site and for dataset of all sites combined, respectively.

When each site was evaluated using its own dataset, PNC was based on each site's conditions (initial speed, utilization rate, and final speed). For example, in case of short SCLs, the correlated parameters were generated based on the distribution of initial speed, final speed and utilization rate at the site, as well as this site's regression equation for deceleration rate (Table 5.2). Therefore, this approach considers changing driver behaviour, in terms of selection of initial speed, utilization rate, and deceleration rate, depending on the SCL length. On the other hand, when using the dataset of all sites combined, the distribution (mean and standard deviation) of initial speed at long lanes, final speed at each site, utilization rate of the dataset of all sites combined were used for the generated independent parameters. Deceleration rate was predicted using all sites combined regression equation (Table 5.2). Therefore, the PNC results for dataset of all sites combined reflect the expected PNC values if no deceleration was to occur on the FRL.

As shown in the Tables 6.3 and 6.4, error of MCS is low, which is mainly contributed to the high number of runs. PNC results follow the same trend of FOSM method. As the available length increases, PNC decreases. The reason of the high PNC values for the first three sites, when using the dataset of all sites combined (Table 6.4), is the high difference between initial and final speed as the distribution of initial speeds at long sites was used for the generated correlated initial and final speeds.

Table 6.3: MCS Results Using the Dataset of Each Site's.

SCL	Available Length SL (m)	No of Runs	Mean Demand L (m)	Standard Deviation L (m)	PNC	Error (m)
Island Park Drive (E-N)	58	61,756	53.135	14.344	0.515	0.058
Parkdale Avenue (W-NS)	179	66,168	174.255	20.788	0.582	0.081
Bronson Avenue (W-NS)	212	81,628	202.294	28.474	0.432	0.100
Moodie Drive (W-NS)	292	80,106	248.332	77.825	0.195	0.275
Terry Fox Drive (E-NS)	388	78,224	352.800	118.846	0.252	0.425
Carp Road (E-NS)	430	79,269	376.461	153.833	0.226	0.546
Terry Fox Drive (W-NS)	446	69,538	412.523	230.164	0.248	0.873

Table 6.4: MCS Results Using the Dataset of All sites Combined.

SCL	Available Length SL (m)	No of Runs	Mean Demand L (m)	Standard Deviation L (m)	PNC	Error (m)
Island Park Drive (E-N)	58	105,843	569.587	159.863	1	0.491
Parkdale Avenue (W-NS)	179	106,348	589.600	166.607	1	0.511
Bronson Avenue (W-NS)	212	106,435	626.960	176.218	1	0.540
Moodie Drive (W-NS)	292	94,392	206.007	126.859	0.234 9	0.413
Terry Fox Drive (E-NS)	388	101,978	288.956	150.279	0.235 8	0.471
Carp Road (E-NS)	430	91,675	227.327	147.000	0.096 7	0.486
Terry Fox Drive (W-NS)	446	78,227	207.402	132.403	0.048 5	0.473

6.3 First Order Reliability Method (FORM)

FORM was applied to each site using the developed script in Appendix 10. The ellipsoid methodology discussed in section 5.5 was applied to calculate PNC values. Table 6.5 and 6.6 show the results when using the dataset of each site and all sites combined, respectively.

Table 6.5: FORM results Using the Dataset of Each Site.

SCL	Available length SL (m)	PNC
Island Park drive (E-N)	58	0.5000
Parkdale Avenue (W-NS)	179	0.5000
Bronson Avenue (W-NS)	212	0.4885
Moodie Drive (W-NS)	292	0.3606
Terry Fox Drive (E-NS)	388	0.3590
Carp Road (E-NS)	430	0.2572
Terry Fox Drive (W-NS)	446	0.3221

Table 6.6: FORM results Using the Dataset of Each Site All Sites Combined.

SCL	Available length at Site	PNC
Island Park drive (E-N)	58	0.5000
Parkdale Avenue (W-NS)	179	0.5000
Bronson Avenue (W-NS)	212	0.5000
Moodie Drive (W-NS)	292	0.3490
Terry Fox Drive (E-NS)	388	0.2071
Carp Road (E-NS)	430	0.1761
Terry Fox Drive (W-NS)	446	0.1672

As mentioned in Section 5.5, maximum PNC resulting from the methodology used is 0.5. Therefore, PNC values for short SCLs should be evaluated carefully as their actual PNC could exceed 0.5; however, FORM may show it as 0.5. FORM results follow the same trends of the previous two methods used to evaluate PNC at SCLs. As the available length (SL) increases, PNC decreases.

6.4 Comparison between FOSM, MCS, and MCS

When FOSM and MCS were carried out, the values of expected demand L and their respective standard deviations could be found during the process. However, when FORM was carried out, these values were not be generated within the process. Thus, the values for the mean demand L and their standard deviations were compared only for FOSM and MCS. Then, the comparison of PNC values for the three methodologies was carried out. Figure 6.1 shows a comparison of FOSM and MCS with respect to mean demand L using the dataset of each site. Figure 6.2 shows the comparison of the standard deviation using each site's data for FOSM and MCS.

Mean demand length using FOSM is very close to MCS as shown in Figure 6.1. This validates the results of FOSM in estimating demand SCL length. On the other hand, as shown in Figure 6.2, it was found that FOSM methodology overestimates the standard deviations compared to MCS due to the nonlinearity of the limited state function discussed in Section 5.3. This result is similar to the findings of Hassan, Sarhan, & Salehi (2012). Figures 6.3 and 6.4 show a comparison of the PNC results using the three methodologies (FOSM, MCS, and FORM) using the dataset each site and using the dataset of all sites combined, respectively.

Figure 6.1: Mean Demand L Using FOSM and MCS using the Dataset of each site.

Figure 6.2: Standard Deviation of Demand L Using FOSM and MCS using the Dataset of each site.

Figure 6.3: PNC Using the Dataset of Each Site (FOSM, MCS, and FORM).

Figure 6.4: PNC Using the Dataset of All Sites Combined (FOSM, MCS, and FORM).

FORM results suffer from having a maximum PNC of 0.5 due to the physical interpretation of the used methodology, mentioned in Section 5.5. Therefore, the developed FORM model should be applied carefully to sites with short SCL length. As mentioned in Section 6.1, FOSM model using the dataset of each site tends to overestimate PNC on sites with long SCL (where $PNC < 0.5$). This conclusion was validated when the results were compared to MCS. This can be attributed mainly to the model's nonlinearity as it results in high standard deviations. As the model's nonlinearity increases, approximating the standard deviations using a closed form approximation (gradients) reduces the accuracy and results in higher variance. Higher standard deviation in FOSM would reduce the absolute value of the z-score (Equation 5.10). Therefore, FOSM is more appropriate to estimate mean demand SCL length on a specific site, but the PNC results should be interpreted with caution.

The PNC results of the different sites using each site's data are relatively close to each other, while the same results using the data of all sites combined show noticeable differences for each of the three methods used. The close PNC results in Figure 6.3 can be explained by the fact that the data of each site include drivers' adjusted behavior to account for the SCL length. As shown in Table 4.1, as the SCL length decreases, the mean initial speed decreases and mean deceleration rate increases. Such adjustment causes fewer drivers on the shorter SCL to fall within the models' failure zone. On the other hand, the higher mean initial speed and lower mean deceleration rate on longer SCL cause more drivers to fall within the models' failure zone.

6.5 Relationship to Safety

Estimated PNC values and collision data on the study sites were examined for an indication of possible relationship. The trend of change in collision frequency with PNC values was examined using collision data on the through lanes and SCLs in a five-year period (1998-2002). It should be noted that the number of sites in this study does not allow a proper statistical analysis of the relationship between collision frequency and PNC. Rather, the results presented here may only serve as a preliminary evidence of a potential relationship between PNC and collision frequency on exit ramp terminals.

The following figures show the relationship between the total collision frequency (on both through lanes and SCL) as well as collision frequency on the SCL only and the PNC results using the dataset of each site and the dataset of all sites combined, respectively. Figures 6.5 to 6.10 show the relationship between PNC using the dataset of each site and collision frequencies, while Figures 6.11 to 6.16 show the relation between PNC and collision frequencies using the dataset of all sites combined. The figures also show that there is a linear trend line for each plot and shows the corresponding coefficient of determination (R^2). It should be highlighted that collision data should not be modeled using linear regression, and these trend lines are only for illustration of the possible relationship only. As shown in the figures, there is an indication of a relationship between safety performance on the SCL as well as the whole segment (through lanes and SCL) and the PNC of SCLs. As PNC increases, safety performance deteriorates as indicated by higher collision frequencies.

Figure 6.5: FOSM PNC Results Using the Dataset of Each Site and Total Collisions Frequency (Through and SCL)

Figure 6.6: FOSM PNC Results Using the Dataset of Each Site and SCL Collisions Frequency

Figure 6.7: MCS PNC Results Using the Dataset of Each Site and Total Collisions

Frequency (Through and SCL)

Figure 6.8: MCS PNC Results Using the Dataset of Each Site and SCL Collisions

Frequency

Figure 6.9: FORM PNC Results Using the Dataset of Each Site and Total Collisions

Frequency (Through and SCL)

Figure 6.10: FORM PNC Results Using the Dataset of Each Site and SCL Collisions

Frequency

Figure 6.11: FOSM PNC Results Using the Dataset of All Sites Combined and Total

Collisions Frequency (Through and SCL)

Figure 6.12: FOSM PNC Results Using the Dataset of All Sites Combined and SCL

Collisions Frequency

Figure 6.13: MCS PNC Results Using the Dataset of All Sites Combined and Total Collisions Frequency (Through and SCL)

Figure 6.14: MCS PNC Results Using the Dataset of All Sites Combined and SCL Collisions Frequency

Figure 6.15: FORM PNC Results Using the Dataset of All Sites Combined and Total

Collisions Frequency (Through and SCL)

Figure 6.16: FORM PNC Results Using the Dataset of All Sites Combined and SCL

Collisions Frequency

Chapter Seven

7.0 Design Application

This chapter covers a methodology to design the length of limited type SCLs using the reliability method, MCS. Given an estimate of the 85th percentile gore speed and a trial length, the designer should be able to estimate the PNC. Design curves for different combinations of final speeds and SCL lengths were developed and could be used for both evaluation and design. Section 7.1 will cover the initial assumptions and regression models developed to estimate the design parameters. Section 7.2 will cover the design procedure using MCS. The bases of selecting MCS for the design application are the accuracy and its incorporation of the length in predicting the drivers deceleration rates based on the methodology for the dataset of all sites combined (avoiding the issue of FRL deceleration) mentioned in Section 5.4. Based on the initial and final speed, and utilization rate values at different supplied length, deceleration rate values used by drivers were predicted. Previous PNC evaluation (Section 6.2) shows that error of this methodology is very small.

7.1 Initial Assumptions and Regression Models

Generally, the information available at the time of designing SCLs is trial design lengths and assumed final speed at the end of the SCL or the gore area. To be able to design limited-length SCLs based on PNC, regression models were developed to predict all parameters distributions based on the length and 85th percentile gore speed. The developed regression models are based on the means of each parameter on the seven

study sites. These were then used as a distribution for the random generated correlated parameters. Then, deceleration rates were predicted based on these independent correlated parameters. Finally, demand length and PNC were calculated and design curves were developed to estimate PNC based on the selected trial lengths and 85th percentile gore speed. A designer would have to estimate PNC based on only two key parameters, which are 85th percentile gore speed and trial length. Initially, the data known for each SCL are (Table 4.1):

- Mean initial and final speeds, utilization and deceleration rates.
- Standard deviation of initial and final speeds, utilization and deceleration rates.
- Available SCL length.

As explained in chapter 6.2 for MCS using the dataset of all sites combined, the ANOVA test conducted in Section 4.2.2 indicates that deceleration occurs in the FRL. Therefore, the distribution (mean and standard deviation) of initial speed at long SCLs was used for the design application purpose. Mean final speed was modeled using multiple linear regression and was found to depend only on the 85th percentile final speed and its standard deviation. The model has a high R^2 value as shown equation 7.1 (regression output is in Appendix 8).

$$v_f = 1.762 + 0.967v_{f,85th} - 1.310 * \sigma_{v_f}, \quad R^2 = 0.997 \text{ (Equation 7.1)}$$

Utilization rate was found to have no relation with any of the variables. Therefore, mean utilization rate of dataset of all sites combined was used to represent all sites. Standard deviations of utilization rate, final speed were not found to have any significant

relationship with the other variables. Standard deviation of the initial speed depends on only the 85th percentile final speed with R^2 value equal to 0.618 (Equation 7.2). Since only one parameter (standard deviation of initial speed) was found to have a significant relationship, standard deviations of the dataset of all sites combined were used as standard deviations for all variables (v_i , v_f , and, U). Complete regression output could be found in Appendix 8.

$$\text{Std}(v_i) = 1.205 + 0.0047v_{f,85^{th}} \quad R^2 = 0.618 \quad (\text{Equation 7.2})$$

7.2 Design Application Using MCS

MCS was used to generate design curves using the same methodology discussed in Section 5.4. The only difference is that the distribution of final speed was based on the 85th percentile gore speed modeled using the study sites in section 7.1, while the standard deviation of final speed was taken as the standard deviation of the dataset of all sites combined. Following is a summary of the steps used.

1. Eighty fifth percentile gore speed is a trial input by the designer.
2. Trial design length is selected as another input by the designer.
3. Distribution of initial speed is taken as distribution of initial speed at long SCLs where, $\mu_{vi_long} = 29.085$ m/s (107.705 km/h) and $\sigma_{vi_long} = 2.472$ m/s (8.899 km/h).
Similar to that defined in Section 4.2.2.
4. Mean final speed is found using Equation 7.1.
5. Mean utilization rate is the mean of all sites combined dataset's utilization rate (Table 4.1).

6. Standard deviation final speeds and utilization rate were taken as the standard deviation of the dataset all sites combined (Table 4.1).
7. Then, the same procedure described in Section 5.4 is followed starting with:
 - a. Random numbers were generated and correlated using Cholesky's decomposition of the correlation matrix (correlation coefficients are shown in Table 4.1).
 - b. Correlated numbers were then converted to follow the distributions of the means and standard deviations found in steps 3 to 6 using the inverse of the normal cumulative distribution
 - c. Deceleration rate was predicted using Equation 5.11 for the dataset of all sites combined.
 - d. The screening steps mentioned in chapter 5.4 were performed and demand length was calculated.
 - e. PNC was calculated for the selected trial length and 85th percentile gore speed.

Based on the data's range, a range between 23 m/s and 32 m/s (83 km/h and 115 km/h) was used as the 85th percentile final speed. Similarly, supply lengths (*SL*) between 60 m and 400 were used to generate the design curves. MCS design Script could be found in Appendix 11. Figure 7.1 shows a summary of the developed curves.

Figure 7.1: Design Curves for Limited SCLs Based on 85th Percentile Final/Gore Speed and PNC for Lengths ≤ 300 m.

It was found that the design curves work for only for lengths less than 300 m. As can be noticed in Figure 7.1, the 300 m curve PNC value exceeds the 250 m curve at an 85th percentile gore speed of 115 km/h. When the distribution testing was performed to compare the distribution of the generated numbers to the original data, it was found that, for long SCLs (exceeding 300 m) the distribution of utilization and deceleration rates shows lower means and standard deviation than the original dataset values. It could be possible that more data representing a wider range of SCL lengths are further needed and the current database is not enough to represent the distribution of drivers or to design for long SCLs. Figure 7.2 shows the design application using MCS for an SCL length of 350 m in addition to the previous lengths.

Figure 7.2: Design Curves for Limited SCLs Based on 85th Percentile Final/Gore Speed and PNC Including L > 300.

As can be seen in Figure 7.2, at an 85th percentile gore speed of 106 km/h, the PNC value for 350 m is the same PNC for the 300 m SCL. Afterwards, PNC values on the 350 m curve exceed PNC values on the 300 m curve. It was expected that the PNCs for 350 m SCL curve at all points to be lower than 300 m SCL curve, which is not the case. This could be possibly due to the reason discussed earlier.

Chapter Eight

8.0 Conclusions and Recommendations

8.1 Conclusions

Efficient operation of freeway Speed Change Lanes (SCLs) reflects the design capability in accommodating decelerating vehicles on the SCL. In this study, probability of noncompliance (PNC) (demand exceeding supply) between the demand deceleration length by the road users and available supply SCL length was found at seven sites. The seven sites of this study were limited type SCLs from Highway 417 in the City of Ottawa, Ontario. Speed data were taken from El-Basha (2006) and this study is a continuation to his driver behaviour modeling efforts. Speed profiles on SCLs and FRL were used to evaluate each site and draw conclusions about the operational performance on the selected study sites. Three methods were used to evaluate PNC for the study sites: FOSM, MCS, and FORM. The models were developed assuming that drivers do not utilize the full SCL available length. Rather, drivers diverge off the FRL onto the SCL and maintain, accelerate, or decelerate slightly for some distance on the SCL if it is judged to be too long. After that, it was assumed that drivers start the deceleration some distance from the gore area and adopt a constant deceleration rate.

FOSM was found to give a good estimation of the mean demand deceleration length; however, it overestimates the standard deviation compared to the simulation approach (MCS). Due to the high standard deviation, PNC values are either an overestimation at longer sites or an underestimation at shorter sites. MCS is an accurate technique that simulates each driver based on the data's distribution. When the evaluation

was carried out for each site using the dataset of all sites combined in MCS, mean initial speed at long SCLs was used as an initial speed to avoid the possible condition of drivers decelerating at the FRL. Mean final speed at each site, mean utilization rate of the dataset of all sites combined, and parameters' standard deviations of the dataset of all sites combined were used to represent the distribution of the variables at the study sites. FROM, which is based on a truncated Taylor series, is a more accurate procedure than FOSM. However, the ellipsoid approach used has the limitation of a maximum PNC value of 0.5. Therefore, PNCs generated for short lanes should be interpreted carefully.

The trend of change in collision frequency with PNC values was examined using collision data on the through lanes and SCLs in a five-year period (1998-2002). It should be noted that this was not a collision modeling attempt because of the small number of sites available in this study. It was evident that there is an indication of a relationship between PNC and safety on the selected study sites. It was found that there is a trend of decreasing collision frequency with decreasing PNC. Many studies on safety of deceleration SCL found that collision frequency decreases as the SCL length increases as discussed in Section 2.3. However, other studies have reported an opposite trend where collision frequency was found to increase at longer deceleration SCLs (Chen, Liu, Lu & Behzadi, 2009). A possible reason to such result is that drivers may perform acceleration on the SCL, and then decelerate when they are closer to the gore which could eliminate possible effects of the extra length provided. Another reason is that drivers may perform weaving maneuvers on longer SCLs; drivers may change their lane back from the SCL to the FRL either because drivers got to the SCL by mistake or drivers used the SCL to pass

a slower vehicle in the FRL. It should be noted that such maneuvers were not observed on the limited type SCLs of this study.

A design application attempt was performed using MCS. The reason behind the choice of MCS is the accuracy of this technique. FOSM and FORM are less accurate approximation techniques as they are first order truncated Taylor series. However, they are accurate enough for many engineering applications (Section 2.4). Designers would be able to find the PNC of any trial lengths, 85th percentile gore speed, using the generated design curves, which are based on the distribution of mean initial speed of long SCLs of the dataset in this study. Seven design curves for trial design lengths ranging between 60 m and 300 m were developed and it was found that the design application is only applicable to SCL lengths less than 300 m. further dataset might be needed to find more relationships between the study parameters. For example, it was found that there was no relationship between utilization rate distribution and the rest of the parameters' distributions. Utilization rates are lower at long sites. It could be possible that more data at longer SCLs should be examined for a possible relationship.

8.2 Recommendations for Future Studies

Based on the findings of this study, the following are recommended as future work in the area of evaluating operational performance for SCLs:

- The current approach is a way for designers to examine the impact of their design choices of lengths (for $SL < 300\text{m}$) to the operational performance at site. Given enough collision database, developed models could be used to develop a safety-explicit design approach to examine the impact of design decisions on safety

performance. To be able to do so, a statistical relationship between collision frequencies at SCL sites and PNC values needs to be developed.

- For higher accuracy, the same models could be applied using non-constant deceleration rates at long SCLs. The developed models could be expanded to consider deceleration behavior utilizing a low deceleration rate at the beginning of the SCL followed by harder one similar to the methodology of the Green Book discussed in Section 2.1.
- The methodology applied in this study considers only one exit limited type SCLs. It is recommended that the models are expanded to cover dual exit limited-length and extended-length SCLs as well. Special measures should be taken to account for the weaving maneuvers on extended type SCLs. this would help in future assessment of safety on extended SCLs as the same freeway section used in this study was observed to have more collisions on extended SCL compared to limited-length SCL (Sarhan, Hassan, & Abd El Halim, 2008).

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Appendices

Appendix 1: Summary of Geometric Data of Study Sites

Table 1: Geometric Characteristics of Study Sites

SCL Name	SCL Length (m)	Transition Length (m)	SCL Type	Ramp Grade	Ramp Width (m)	Freeway Basic Lanes	Divergence Angle (degrees)	Ramp Advisory Speed (km/h)
Island Park Drive (E-N)	58	22	Taper	Up	6.8	4	18	40
Parkdale Ave. (W-NS)	179	41	Taper	Up	6.1	4	12	50
Bronson Ave. (W-NS)	212	13	Taper	Up	6.1	4	11	40
Moodie Drive (W-NS)	292	83	Parallel	Down	4.8	2	7	50
Terry Fox Drive (E-NS)	388	112	Parallel	Down	4.6	2	6.5	50
Carp Road (E-NS)	430	49	Parallel	Down	5.2	2	4	70
Terry Fox Drive (W-NS)	446	124	Parallel	Down	4.6	2	6	60

Appendix 2: Matlab Script Estimating Deceleration Point

```

function [adjusted_data] = decpoint(filename, sheetid, mindistance,
maxdistance, pvalue)

% Function to determine the point at which vehicles start to decelerate
% on deceleration SCL

% Estimating beginning point of deceleration is based on finding the
% overall deceleration rate from each point in the speed profile to the
end
% point. Confidence interval is established based on the mean and
standard
% deviation of overall deceleration rate for all points starting from
the
% beginning of the speed profile to a point specific distance from the
% gore (this distance and the level of significance are variables). If
the
% deceleration rate at the first point is outof the confidence
interval,
% deceleration is assumed not to have started. Check is repeated
starting
% with the following point until the first point where overall
deceleration
% rate is within the confidence bounds is found.

% First, reading data from an Excel file
% For extended lanes:
% Sheet 1: Greenbank
% For limited lanes:
% Sheet 1: Bronson
% Sheet 2: Carp
% Sheet 3: Moodie
% Sheet 4: Parkdale
filename = 'Speed data_Limited.xlsx';
sheetid = 6;

mindistance = 50; % Minimum distance in calculating overall
deceleration
maxdistance = 100; % Maximum distance to use for calculating overall
deceleration
% to establish the confidence interval

pvalue = 0.05; % p-value to screen overall acceleration rates
alldata = xlsread(filename,sheetid);
[n,m] = size(alldata);

% Drivers' ID in column 1 of the data is not in sequence

```

```

% Need to create new drivers ID in sequence starting at 1
% Also, determine the number of drivers
driverid = ones(n,1);
i2 = 1;
orig_driver_vehicle(i2,1) = alldata(1,1);
orig_driver_vehicle(i2,2) = alldata(1,5); % 0 = PC & 1 = Truck
for i = 2:n
    if alldata(i,1) == alldata(i-1,1)
        driverid(i) = driverid(i-1);
    else
        driverid(i) = driverid(i-1) + 1;
        i2 = i2 + 1;
        orig_driver_vehicle(i2,1) = alldata(i,1);
        orig_driver_vehicle(i2,2) = alldata(i,5);
    end
end

ndrivers = max(driverid);

% Initialize site data
initialspeed = zeros(ndrivers,2);
finalspeed   = zeros(ndrivers,1);
decrate      = zeros(ndrivers,2);
decdistance  = zeros(ndrivers,2);
dectime      = zeros(ndrivers,1);

% For each driver, determine the start point of deceleration: decpt
for i = 1:ndrivers

    % Extract the speed profile for each driver into 3 vectors:
    % distance, time & speed
    % and determine the number of points in the speed profile: npts
        distance = alldata(driverid==i,2);
        time     = alldata(driverid==i,3);
        speed    = alldata(driverid==i,4);
        npts     = length(distance);
    % distance and time are normalized to end at zero
        distance = abs(distance - distance(npts));
        time     = abs(time - time(npts));

        overalldec_t = zeros(npts,1); overalldec_d = zeros(npts,1);
    if distance(1) <= mindistance
        % Deceleration lane is too short; estimate deceleration rate for
        % all points and use it as the distribution
            decpt = 1;
        for j = 1:npts-1
            % overalldec_t(j) = (speed(j) - speed(npts))/(time(j) - time(npts))
            % but time(npts) = 0
                overalldec_t(j) = (speed(j) - speed(npts))/time(j);

            % overalldec_d(j) = (speed(j)^2 - speed(npts)^2)/(2*(distance(j) -
            distance(npts)))
            % but distance(npts) = 0

```



```

        overalldec_d(j) = (speed(j)^2 -
speed(npts)^2)/(2*distance(j));
end
        overalldec = (overalldec_t(1:npts) + overalldec_d(1:npts))/2;

        range1 = 1;
if npts > 20
        range2 = npts - 10;
else
        range2 = npts - 1;
end
        meandec = mean(overalldec(range1:range2));

else
% Deceleration lane may be too long
% Determine the overall deceleration rate between each point and the
% last point in the speed profile based on time and distance

        npts2 = npts -1; % max number of deceleration estimates
for j = 1:npts-1
if distance(j)<mindistance,
        npts2 = j-1; % number of deceleration estimates
break
end

% overalldec_t(j) = (speed(j) - speed(npts))/(time(j) - time(npts))
% but time(npts) = 0
        overalldec_t(j) = (speed(j) - speed(npts))/time(j);

% overalldec_d(j) = (speed(j)^2 - speed(npts)^2)/(2*(distance(j) -
distance(npts)))
% but distance(npts) = 0
        overalldec_d(j) = (speed(j)^2 -
speed(npts)^2)/(2*distance(j));
end

        overalldec = (overalldec_t(1:npts2) + overalldec_d(1:npts2))/2;

% Confidence interval can be determined using all points as one
% sample or using only points in a specific range to avoid bias
% by the deceleration rate calculated at the early points of the
% speed profile

% First, find the point corresponding to maxdistance
        ptmax = 1;

while distance(ptmax+1)> maxdistance
        ptmax = ptmax + 1;
end

        mindegf = npts2 - ptmax;
if mindegf > 9, mindegf = 9; end
        decpt = 1; maxdegf = npts2 - 1;

```

```

while maxdegf>mindegf % terminate check if only 10 points are left
if decpt < ptmax
    range1 = ptmax;
else
    range1 = decpt;
end

    range2 = npts2;
    degf = range2 - range1;

    meandec = mean(overalldec(range1:range2));
    stddec = std(overalldec(range1:range2));

% Establish confidence interval assuming t-distribution
    tvalue = tinv(1-pvalue/2,degf);
    maxdec = meandec + stddec*tvalue;
    mindec = meandec - stddec*tvalue;

if overalldec(decpt)<mindec || overalldec(decpt)>maxdec
    decpt = decpt + 1; maxdegf = maxdegf - 1;
else
break
end
end
end

    initialspeak(i,1) = speed(decpt);
    initialspeak(i,2) = speed(1); % speed at diverge point
    finalspeak(i) = speed(npts);
    decrate(i,1) = meandec;
    decrate(i,2) = overalldec(decpt); % overall deceleration
adjustment but no mean
    decrate(i,3) = overalldec(1); % overall deceleration rate with
no adjustment
    decdistance(i,1)= distance(decpt);
    decdistance(i,2)= distance(1);
    dectime(i) = time(1) - time(decpt);

end

adjusted_data = [orig_driver_vehicle, decrate, initialspeak,
finalspeak, decdistance, dectime];

```

Appendix 3: Final Database After Reprocessing the Data

Table 2: Island Park Drive (E-N).

Trucks	Adjusted Overall Deceleration	Original Overall Deceleration	Initial Speed	Diverge Speed	Final Speed	Deceleration Distance	Deceleration Length	Deceleration Time	Distance to Decelerate	SCL Length	Utilization Rate
0	1.46	1.46	22.31	22.31	20.07	31.51	31.51	0.00	0.00	58	0.54
0	0.28	0.28	23.95	23.95	23.38	47.07	47.07	0.00	0.00	58	0.81
0	0.39	0.39	21.78	21.78	21.30	26.59	26.59	0.00	0.00	58	0.46
0	0.76	0.76	22.59	22.59	21.16	40.86	40.86	0.00	0.00	58	0.70
0	0.24	0.24	19.18	19.18	18.90	22.49	22.49	0.00	0.00	58	0.39
0	0.43	0.43	20.58	20.58	20.04	25.26	25.26	0.00	0.00	58	0.44
0	0.49	0.49	20.72	20.72	19.63	44.91	44.91	0.00	0.00	58	0.77
0	0.40	0.40	19.49	19.49	18.79	33.72	33.72	0.00	0.00	58	0.58
0	0.78	0.78	22.95	22.95	21.52	39.96	39.96	0.00	0.00	58	0.69
0	0.64	0.64	22.02	22.02	21.50	17.64	17.64	0.00	0.00	58	0.30
0	0.20	0.20	21.69	21.69	21.35	36.98	36.98	0.00	0.00	58	0.64
0	0.46	0.46	25.70	25.70	25.14	31.04	31.04	0.00	0.00	58	0.54
0	0.28	0.28	23.11	23.11	22.72	33.39	33.39	0.00	0.00	58	0.58
0	0.44	0.44	21.13	21.13	20.63	23.52	23.52	0.00	0.00	58	0.41
0	0.94	0.94	21.77	21.77	21.02	17.14	17.14	0.00	0.00	58	0.30
0	0.26	0.26	24.42	24.42	24.16	24.00	24.00	0.00	0.00	58	0.41
0	0.43	0.43	20.80	20.80	20.18	29.38	29.38	0.00	0.00	58	0.51
0	0.43	0.43	20.30	20.30	19.43	39.83	39.83	0.00	0.00	58	0.69
0	0.21	0.21	21.64	21.64	21.32	32.94	32.94	0.00	0.00	58	0.57
0	0.27	0.27	21.30	21.30	20.88	33.54	33.54	0.00	0.00	58	0.58
0	0.44	0.44	20.69	20.69	20.07	28.86	28.86	0.00	0.00	58	0.50
0	0.43	0.43	25.01	25.01	24.27	41.71	41.71	0.00	0.00	58	0.72
0	0.85	0.85	24.74	24.74	22.77	54.45	54.45	0.00	0.00	58	0.94
0	0.35	0.35	22.33	22.33	21.85	29.61	29.61	0.00	0.00	58	0.51

0	0.44	0.44	18.69	18.69	17.76	38.41	38.41	0.00	0.00	58	0.66
0	0.51	0.51	18.19	18.19	17.04	39.03	39.03	0.00	0.00	58	0.67
0	0.57	0.57	17.68	17.68	16.34	39.28	39.28	0.00	0.00	58	0.68
0	0.64	0.64	20.69	20.69	19.88	25.21	25.21	0.00	0.00	58	0.43
0	0.18	0.18	20.02	20.02	19.65	39.66	39.66	0.00	0.00	58	0.68
0	0.53	0.53	20.00	20.00	18.93	38.73	38.73	0.00	0.00	58	0.67
0	0.58	0.58	19.99	19.99	19.24	25.11	25.11	0.00	0.00	58	0.43
0	0.32	0.32	18.38	18.38	17.76	35.45	35.45	0.00	0.00	58	0.61
0	0.56	0.56	20.41	20.41	20.02	13.81	13.81	0.00	0.00	58	0.24
0	0.62	0.62	19.16	19.16	18.18	29.35	29.35	0.00	0.00	58	0.51
0	0.47	0.47	18.02	18.02	17.04	36.30	36.30	0.00	0.00	58	0.63
0	0.57	0.57	20.05	20.05	19.60	15.42	15.42	0.00	0.00	58	0.27
0	0.73	0.73	15.18	15.18	13.36	34.64	34.64	0.00	0.00	58	0.60
0	0.19	0.19	17.27	17.27	16.90	33.48	33.48	0.00	0.00	58	0.58
0	0.69	0.69	19.02	19.02	18.15	23.02	23.02	0.00	0.00	58	0.40
0	0.54	0.54	21.56	21.56	20.52	40.08	40.08	0.00	0.00	58	0.69
0	0.71	0.71	17.51	17.51	16.48	24.67	24.67	0.00	0.00	58	0.43
0	0.42	0.42	19.91	19.91	18.93	44.96	44.96	0.00	0.00	58	0.78
0	0.49	0.49	16.29	16.29	15.14	36.94	36.94	0.00	0.00	58	0.64
0	0.95	0.95	22.37	22.37	20.38	44.39	44.39	0.00	0.00	58	0.77
0	0.81	0.81	19.55	19.55	18.15	32.56	32.56	0.00	0.00	58	0.56
0	0.48	0.48	20.60	20.60	20.07	22.30	22.30	0.00	0.00	58	0.38
0	0.27	0.27	19.19	19.19	18.73	31.01	31.01	0.00	0.00	58	0.53
0	0.37	0.37	19.22	19.22	18.26	48.40	48.40	0.00	0.00	58	0.83
0	0.27	0.27	20.66	20.66	20.25	30.56	30.56	0.00	0.00	58	0.53
0	0.26	0.26	19.99	19.99	19.63	27.69	27.69	0.00	0.00	58	0.48
0	0.95	0.95	19.69	19.69	18.40	25.79	25.79	0.00	0.00	58	0.44

0	0.28	0.28	21.28	21.28	20.88	29.81	29.81	0.00	0.00	58	0.51
0	0.46	0.46	21.41	21.41	20.77	29.59	29.59	0.00	0.00	58	0.51
0	0.52	0.52	17.65	17.65	17.29	12.07	12.07	0.00	0.00	58	0.21
0	0.51	0.51	19.30	19.30	18.48	30.00	30.00	0.00	0.00	58	0.52
0	0.29	0.29	17.32	17.32	17.09	13.05	13.05	0.00	0.00	58	0.22
0	1.42	1.42	23.14	23.14	20.41	40.94	40.94	0.00	0.00	58	0.71
0	0.59	0.59	19.86	19.86	18.85	32.87	32.87	0.00	0.00	58	0.57
0	0.44	0.44	21.97	21.97	21.24	36.20	36.20	0.00	0.00	58	0.62
0	0.56	0.56	20.33	20.33	19.43	31.85	31.85	0.00	0.00	58	0.55
0	0.42	0.42	21.11	21.11	20.32	38.84	38.84	0.00	0.00	58	0.67
0	1.22	1.22	19.83	19.83	17.62	34.45	34.45	0.00	0.00	58	0.59
0	1.35	1.35	20.44	20.44	17.18	44.39	44.39	0.00	0.00	58	0.77
0	0.97	0.97	22.20	22.20	20.46	37.86	37.86	0.00	0.00	58	0.65
0	0.71	0.71	21.08	21.08	19.88	34.32	34.32	0.00	0.00	58	0.59
0	0.08	0.08	19.52	19.52	19.38	38.26	38.26	0.00	0.00	58	0.66
0	0.60	0.60	21.47	21.47	20.54	32.20	32.20	0.00	0.00	58	0.56
0	0.43	0.43	21.89	21.89	21.24	32.81	32.81	0.00	0.00	58	0.57
0	0.61	0.61	17.27	17.27	15.12	56.23	56.23	0.00	0.00	58	0.97
0	0.50	0.50	19.69	19.69	19.01	25.55	25.55	0.00	0.00	58	0.44
0	0.29	0.29	19.71	19.71	19.43	18.75	18.75	0.00	0.00	58	0.32
0	0.52	0.52	21.19	21.19	20.46	29.50	29.50	0.00	0.00	58	0.51
0	0.57	0.57	24.54	24.54	23.61	39.34	39.34	0.00	0.00	58	0.68
0	0.64	0.64	19.86	19.86	18.57	37.99	37.99	0.00	0.00	58	0.65
0	1.22	1.22	21.50	21.50	20.35	19.19	19.19	0.00	0.00	58	0.33
0	0.39	0.39	21.11	21.11	20.54	30.35	30.35	0.00	0.00	58	0.52
0	0.23	0.23	14.73	14.73	14.23	31.00	31.00	0.00	0.00	58	0.53
0	0.23	0.23	20.69	20.69	20.21	42.63	42.63	0.00	0.00	58	0.74

0	0.56	0.56	19.25	19.25	17.90	44.52	44.52	0.00	0.00	58	0.77
0	0.34	0.34	24.79	24.79	24.25	38.21	38.21	0.00	0.00	58	0.66
0	0.54	0.54	23.56	23.56	22.66	39.16	39.16	0.00	0.00	58	0.68
0	0.22	0.22	17.15	17.15	16.76	29.67	29.67	0.00	0.00	58	0.51
0	1.17	1.17	22.75	22.75	20.49	41.44	41.44	0.00	0.00	58	0.71
0	0.46	0.46	18.88	18.88	17.96	36.84	36.84	0.00	0.00	58	0.64
0	0.62	0.62	23.00	23.00	21.91	39.11	39.11	0.00	0.00	58	0.67
Mean	0.54	0.54	20.58	20.58	19.66	33.08	33.08	0.00	0.00	58	0.57
Std	0.29	0.29	2.16	2.16	2.21	8.86	8.86	0.00	0.00	0	0.15

Table 3: Parkdale Ave. (W-NS).

Trucks	Mean Deceleration	Adjusted Overall Deceleration	Original Overall Deceleration	Initial Speed	Diverge Speed	Final Speed	Deceleration Distance	Deceleration Length	Deceleration Time	Distance to Decelerate	SCL Length	Utilization Rate
0	0.84	0.80	0.80	22.21	22.21	19.18	77.49	77.49	0.00	0.00	179	0.43
0	0.76	0.79	0.79	22.53	22.53	19.40	82.08	82.08	0.00	0.00	179	0.46
0	0.89	0.96	0.96	23.04	23.04	21.07	44.45	44.45	0.00	0.00	179	0.25
0	0.44	0.40	0.29	21.15	20.82	19.62	78.36	83.78	0.26	5.42	179	0.44
0	1.27	1.05	1.05	22.51	22.51	17.14	101.85	101.85	0.00	0.00	179	0.57
0	1.85	1.65	1.65	27.34	27.34	21.94	79.81	79.81	0.00	0.00	179	0.45
0	0.46	0.48	0.48	25.25	25.25	24.40	43.62	43.62	0.00	0.00	179	0.24
0	1.44	1.37	1.22	24.62	24.50	19.79	77.10	84.58	0.30	7.47	179	0.43
0	1.44	1.68	1.68	28.39	28.39	23.78	70.28	70.28	0.00	0.00	179	0.39
0	1.44	1.35	1.35	23.36	23.36	19.65	58.41	58.41	0.00	0.00	179	0.33
0	1.12	1.01	1.01	23.07	23.07	18.93	85.93	85.93	0.00	0.00	179	0.48
0	1.12	1.17	1.17	24.96	24.96	21.91	60.11	60.11	0.00	0.00	179	0.34
0	1.12	0.50	0.50	22.82	22.82	21.30	67.15	67.15	0.00	0.00	179	0.38
0	1.12	1.49	1.49	22.89	22.89	18.48	59.80	59.80	0.00	0.00	179	0.33
0	1.12	1.59	1.59	25.52	25.52	19.85	79.34	79.34	0.00	0.00	179	0.44
0	0.88	0.80	0.55	28.08	27.62	26.07	67.99	75.14	0.25	7.16	179	0.38
0	1.80	1.51	1.51	24.00	24.00	18.79	72.90	72.90	0.00	0.00	179	0.41
0	0.62	0.57	0.57	23.21	23.21	21.35	72.34	72.34	0.00	0.00	179	0.40
0	1.48	1.25	1.25	25.38	25.38	21.21	77.64	77.64	0.00	0.00	179	0.43
0	0.54	0.53	0.62	20.91	21.90	19.09	67.44	91.63	1.15	24.19	179	0.38
0	1.07	1.13	1.13	23.69	23.69	22.39	26.30	26.30	0.00	0.00	179	0.15
0	1.07	1.61	1.61	23.85	23.85	18.59	68.46	68.46	0.00	0.00	179	0.38
0	1.07	1.10	1.10	23.88	23.88	20.63	65.01	65.01	0.00	0.00	179	0.36
0	0.85	0.78	0.71	27.96	28.01	25.62	79.50	89.36	0.35	9.86	179	0.44
0	0.29	0.34	0.34	21.78	21.78	21.10	43.17	43.17	0.00	0.00	179	0.24
0	0.29	1.46	1.46	25.54	25.54	22.00	56.67	56.67	0.00	0.00	179	0.32
0	0.70	0.55	0.55	21.03	21.03	19.01	73.80	73.80	0.00	0.00	179	0.41
0	0.97	0.92	0.92	19.63	19.63	14.54	93.09	93.09	0.00	0.00	179	0.52
0	0.63	0.62	0.58	20.83	20.78	18.67	68.20	71.35	0.16	3.15	179	0.38
0	0.63	0.92	0.92	26.11	26.11	23.92	59.13	59.13	0.00	0.00	179	0.33
0	0.72	0.68	0.55	23.76	23.47	21.24	82.27	90.74	0.36	8.47	179	0.46
0	0.37	0.39	0.39	20.64	20.64	18.76	94.36	94.36	0.00	0.00	179	0.53
0	0.37	0.89	0.89	21.82	21.82	19.40	55.12	55.12	0.00	0.00	179	0.31
0	0.99	0.84	0.84	22.58	22.58	19.46	76.96	76.96	0.00	0.00	179	0.43
0	0.99	1.00	1.00	19.50	19.50	16.47	53.18	53.18	0.00	0.00	179	0.30

0	1.28	1.17	1.17	23.80	23.80	19.01	86.87	86.87	0.00	0.00	179	0.49
0	0.62	0.61	0.61	21.46	21.46	19.15	76.85	76.85	0.00	0.00	179	0.43
0	0.67	0.60	0.60	23.63	23.63	21.80	69.70	69.70	0.00	0.00	179	0.39
0	1.21	1.15	1.15	21.90	21.90	16.33	90.64	90.64	0.00	0.00	179	0.51
0	1.25	1.06	1.06	24.07	24.07	20.13	82.09	82.09	0.00	0.00	179	0.46
0	0.80	0.69	0.69	20.80	20.80	18.56	64.14	64.14	0.00	0.00	179	0.36
0	0.97	1.14	1.14	23.09	23.09	20.88	42.23	42.23	0.00	0.00	179	0.24
0	0.49	0.39	0.39	21.96	21.96	20.52	78.35	78.35	0.00	0.00	179	0.44
0	0.70	0.53	0.53	20.97	20.97	19.06	72.88	72.88	0.00	0.00	179	0.41
0	1.75	1.16	1.16	25.67	25.67	23.34	49.00	49.00	0.00	0.00	179	0.27
0	0.81	0.77	0.77	20.77	20.77	17.28	85.65	85.65	0.00	0.00	179	0.48
0	1.14	0.97	0.97	25.94	25.94	22.89	76.37	76.37	0.00	0.00	179	0.43
0	0.76	0.78	0.78	20.67	20.67	17.67	72.14	72.14	0.00	0.00	179	0.40
0	0.62	0.61	0.61	18.54	18.54	14.99	96.52	96.52	0.00	0.00	179	0.54
0	0.89	0.82	0.67	22.64	22.29	19.48	79.91	86.85	0.31	6.93	179	0.45
0	0.66	0.65	0.65	18.48	18.48	14.82	92.37	92.37	0.00	0.00	179	0.52
0	0.60	0.59	0.59	20.26	20.26	18.31	63.45	63.45	0.00	0.00	179	0.35
0	0.53	0.50	0.50	23.21	23.21	21.66	68.88	68.88	0.00	0.00	179	0.38
0	1.01	0.77	0.77	21.81	21.81	20.26	41.74	41.74	0.00	0.00	179	0.23
0	1.13	1.17	1.01	28.78	28.86	25.88	66.89	80.13	0.46	13.24	179	0.37
0	0.93	0.87	0.75	28.46	28.48	26.04	75.22	88.32	0.45	13.10	179	0.42
0	0.61	0.50	0.50	23.26	23.26	21.77	66.03	66.03	0.00	0.00	179	0.37
0	1.42	1.35	1.35	25.70	25.70	21.91	65.95	65.95	0.00	0.00	179	0.37
0	0.89	0.89	0.89	22.90	22.90	19.12	87.80	87.80	0.00	0.00	179	0.49
0	0.38	0.44	0.44	20.70	20.70	18.59	93.77	93.77	0.00	0.00	179	0.52
0	1.17	0.91	0.91	24.00	24.00	20.46	87.12	87.12	0.00	0.00	179	0.49
0	0.82	0.70	0.66	20.05	19.94	16.55	91.62	94.71	0.16	3.09	179	0.51
0	0.78	0.75	0.62	27.60	27.47	25.76	64.96	73.33	0.31	8.37	179	0.36
0	1.33	1.31	1.13	21.61	21.60	17.03	66.69	77.57	0.51	10.89	179	0.37
0	1.24	1.07	1.07	23.09	23.09	18.09	96.04	96.04	0.00	0.00	179	0.54
0	1.38	1.10	1.10	23.53	23.53	18.84	90.56	90.56	0.00	0.00	179	0.51
0	0.80	0.79	0.79	25.19	25.19	22.39	83.81	83.81	0.00	0.00	179	0.47
0	0.85	0.75	0.75	24.84	24.84	22.05	87.01	87.01	0.00	0.00	179	0.49
0	0.84	0.78	0.78	23.02	23.02	20.46	70.36	70.36	0.00	0.00	179	0.39
0	0.39	0.32	0.32	21.41	21.41	20.40	66.44	66.44	0.00	0.00	179	0.37
0	0.38	0.36	0.27	24.02	23.78	22.72	84.44	90.57	0.25	6.13	179	0.47
0	1.43	1.36	1.36	26.11	26.11	20.57	93.35	93.35	0.00	0.00	179	0.52
0	1.46	1.25	1.25	26.86	26.86	23.00	76.31	76.31	0.00	0.00	179	0.43
0	0.95	0.78	0.78	21.56	21.56	18.67	74.23	74.23	0.00	0.00	179	0.41
0	0.71	0.64	0.64	21.25	21.25	18.45	86.42	86.42	0.00	0.00	179	0.48

0	0.84	0.70	0.70	22.83	22.83	20.24	80.43	80.43	0.00	0.00	179	0.45
0	0.66	0.63	0.63	22.29	22.29	19.51	91.50	91.50	0.00	0.00	179	0.51
0	1.29	1.24	1.24	22.78	22.78	19.01	62.98	62.98	0.00	0.00	179	0.35
0	1.06	0.84	0.84	24.95	24.95	21.77	88.22	88.22	0.00	0.00	179	0.49
0	1.16	1.11	1.01	21.17	21.07	16.86	73.59	78.96	0.26	5.36	179	0.41
0	2.32	2.14	2.14	26.79	26.79	20.52	68.37	68.37	0.00	0.00	179	0.38
0	0.68	0.63	0.53	20.43	20.33	18.28	65.88	75.14	0.46	9.26	179	0.37
0	0.89	0.86	0.86	24.14	24.14	21.24	75.60	75.60	0.00	0.00	179	0.42
0	1.18	1.17	1.17	25.82	25.82	21.38	87.70	87.70	0.00	0.00	179	0.49
0	0.90	0.86	0.86	22.39	22.39	18.34	95.53	95.53	0.00	0.00	179	0.53
0	1.24	1.03	1.03	27.33	27.33	23.39	97.82	97.82	0.00	0.00	179	0.55
0	1.23	1.14	1.14	23.45	23.45	18.12	96.83	96.83	0.00	0.00	179	0.54
0	1.00	0.94	0.81	21.56	21.35	18.14	71.15	77.73	0.30	6.57	179	0.40
0	0.76	0.76	0.76	21.11	21.11	17.67	87.15	87.15	0.00	0.00	179	0.49
0	0.41	0.37	0.37	21.78	21.78	20.54	69.68	69.68	0.00	0.00	179	0.39
Me an	0.94	0.91	0.89	23.29	23.28	20.16	74.41	76.06	0.07	1.65	179	0.42
Std	0.38	0.36	0.36	2.35	2.34	2.46	14.82	15.15	0.17	4.03	0	0.08

Table 4: Bronson Ave. (W-NS).

Trucks	Mean Deceleration	Adjusted Overall Deceleration	Original Overall Deceleration	Initial Speed	Diverge Speed	Final Speed	Deceleration Distance	Deceleration Length	Deceleration Time	Distance to Decelerate	SCL Length	Utilization Rate
0	1.15	1.07	1.07	23.05	23.05	19.37	72.64	72.64	0.00	0.00	212	0.34
0	0.43	0.49	0.49	24.58	24.58	22.68	89.65	89.65	0.00	0.00	212	0.42
0	0.43	1.89	1.89	23.05	23.05	18.31	50.86	50.86	0.00	0.00	212	0.24
0	0.78	0.94	0.94	26.02	26.02	22.04	99.63	99.63	0.00	0.00	212	0.47
0	1.41	1.30	1.30	22.63	22.63	14.13	119.16	119.16	0.00	0.00	212	0.56
0	1.49	1.41	1.41	25.52	25.52	20.43	81.70	81.70	0.00	0.00	212	0.39
0	1.13	1.10	0.69	25.53	25.80	22.43	66.31	117.95	2.03	51.64	212	0.31
0	0.44	0.45	0.45	20.93	20.93	18.59	102.57	102.57	0.00	0.00	212	0.48
0	0.44	1.19	1.19	24.05	24.05	19.40	83.70	83.70	0.00	0.00	212	0.39
0	1.13	0.87	0.87	24.91	24.91	20.16	123.76	123.76	0.00	0.00	212	0.58
0	1.13	1.43	1.43	23.88	23.88	18.65	76.05	76.05	0.00	0.00	212	0.36
0	0.87	0.82	0.81	24.27	24.27	21.09	87.31	88.54	0.05	1.23	212	0.41
0	1.46	1.16	1.16	24.80	24.80	20.54	83.25	83.25	0.00	0.00	212	0.39
0	1.21	1.07	0.84	23.77	24.85	19.48	86.49	142.11	2.32	55.62	212	0.41
0	1.46	1.24	1.24	25.71	25.71	19.70	109.22	109.22	0.00	0.00	212	0.52
0	0.99	1.08	1.08	23.10	23.10	18.67	83.57	83.57	0.00	0.00	212	0.39
0	0.99	1.08	1.08	25.47	25.47	21.21	90.74	90.74	0.00	0.00	212	0.43
0	1.35	1.32	1.32	25.16	25.16	20.04	87.03	87.03	0.00	0.00	212	0.41
0	1.35	1.38	1.38	26.03	26.03	21.51	76.87	76.87	0.00	0.00	212	0.36
0	1.46	1.35	1.23	26.02	26.24	19.32	111.71	128.09	0.66	16.38	212	0.53
0	1.26	0.83	0.83	23.38	23.38	20.04	89.15	89.15	0.00	0.00	212	0.42
0	0.82	0.80	0.72	22.46	22.32	18.32	104.57	113.66	0.41	9.09	212	0.49
0	1.39	1.28	1.28	24.39	24.39	20.09	74.34	74.34	0.00	0.00	212	0.35
0	1.48	1.21	1.21	27.36	27.36	22.71	95.92	95.92	0.00	0.00	212	0.45
0	0.80	0.73	0.67	23.35	23.43	19.59	110.70	123.61	0.56	12.91	212	0.52
0	1.33	1.26	1.26	26.41	26.41	21.82	86.32	86.32	0.00	0.00	212	0.41
0	0.75	0.69	0.65	22.93	22.99	19.40	108.44	116.20	0.31	7.77	212	0.51
0	0.75	0.91	0.91	21.91	21.91	17.23	99.21	99.21	0.00	0.00	212	0.47
0	1.33	0.80	0.80	25.71	25.71	21.82	117.65	117.65	0.00	0.00	212	0.55
0	1.51	1.36	1.36	25.66	25.66	20.90	80.77	80.77	0.00	0.00	212	0.38
0	1.91	1.79	1.79	30.50	30.50	24.38	92.50	92.50	0.00	0.00	212	0.44
0	1.91	0.55	0.55	23.94	23.94	21.90	85.66	85.66	0.00	0.00	212	0.40
0	0.77	0.79	0.79	20.82	20.82	14.61	137.57	137.57	0.00	0.00	212	0.65
0	1.40	1.08	0.95	24.74	25.10	19.30	111.96	137.83	1.06	25.87	212	0.53
0	1.37	1.12	0.98	26.05	26.41	20.29	118.16	145.45	1.06	27.30	212	0.56

0	1.25	1.07	0.95	24.46	24.19	19.29	106.36	113.82	0.30	7.46	212	0.50
0	1.28	0.95	0.74	23.88	23.35	19.38	103.07	116.40	0.56	13.33	212	0.49
0	1.40	1.33	1.33	24.10	24.10	16.53	114.55	114.55	0.00	0.00	212	0.54
0	1.60	1.39	1.39	26.66	26.66	20.90	98.51	98.51	0.00	0.00	212	0.46
0	1.14	1.07	1.07	25.32	25.32	19.65	119.32	119.32	0.00	0.00	212	0.56
0	1.76	1.76	1.26	24.83	26.35	17.95	83.68	150.43	2.63	66.74	212	0.39
0	1.39	0.83	0.83	21.63	21.63	16.09	132.12	132.12	0.00	0.00	212	0.62
0	0.59	0.58	0.58	22.66	22.66	19.65	109.31	109.31	0.00	0.00	212	0.52
0	1.06	1.10	1.10	25.02	25.02	19.12	116.85	116.85	0.00	0.00	212	0.55
0	0.82	0.72	0.62	22.32	22.57	18.21	116.78	144.53	1.26	27.74	212	0.55
0	1.12	0.95	0.95	27.02	27.02	22.40	120.52	120.52	0.00	0.00	212	0.57
0	1.17	1.13	1.01	23.66	25.13	19.59	76.82	121.46	1.86	44.64	212	0.36
0	1.17	0.50	0.50	21.79	21.79	18.37	138.60	138.60	0.00	0.00	212	0.65
0	1.01	0.89	0.89	25.55	25.55	22.76	75.24	75.24	0.00	0.00	212	0.35
0	0.90	0.80	0.80	21.80	21.80	17.01	117.06	117.06	0.00	0.00	212	0.55
0	2.20	1.88	1.88	28.47	28.47	21.02	99.47	99.47	0.00	0.00	212	0.47
0	1.80	1.76	1.76	27.60	27.60	19.15	109.90	109.90	0.00	0.00	212	0.52
0	1.52	1.38	1.38	28.13	28.13	21.07	125.21	125.21	0.00	0.00	212	0.59
0	0.89	0.84	0.84	23.13	23.13	16.90	148.13	148.13	0.00	0.00	212	0.70
0	0.84	0.80	0.80	22.77	22.77	18.32	113.62	113.62	0.00	0.00	212	0.54
0	0.92	0.63	0.63	18.57	18.57	15.28	89.16	89.16	0.00	0.00	212	0.42
0	0.77	0.63	0.54	26.30	26.13	23.04	127.67	140.98	0.51	13.31	212	0.60
0	0.88	0.89	0.89	21.94	21.94	18.12	85.03	85.03	0.00	0.00	212	0.40
0	0.68	0.65	0.65	22.91	22.91	19.95	96.72	96.72	0.00	0.00	212	0.46
0	1.30	1.24	1.24	24.77	24.77	17.96	115.62	115.62	0.00	0.00	212	0.55
0	2.38	2.16	2.16	27.05	27.05	18.12	93.13	93.13	0.00	0.00	212	0.44
0	1.45	1.24	1.03	19.18	18.71	12.61	84.25	94.13	0.50	9.88	212	0.40
0	0.67	0.66	0.70	22.58	24.49	19.87	85.96	143.42	2.46	57.45	212	0.41
0	1.03	1.06	1.06	21.52	21.52	17.67	70.61	70.61	0.00	0.00	212	0.33
0	1.64	1.20	1.17	24.27	24.27	17.70	115.98	119.65	0.15	3.67	212	0.55
0	1.64	0.82	0.82	25.60	25.60	20.49	144.44	144.44	0.00	0.00	212	0.68
0	1.61	1.35	1.35	28.66	28.66	23.40	100.94	100.94	0.00	0.00	212	0.48
0	1.03	0.86	0.86	26.10	26.10	22.29	106.58	106.58	0.00	0.00	212	0.50
0	1.11	1.04	1.04	22.63	22.63	14.45	145.59	145.59	0.00	0.00	212	0.69
0	0.81	0.74	0.05	23.08	20.99	20.73	68.84	110.13	1.72	41.29	212	0.32
0	1.66	1.48	1.48	27.50	27.50	22.63	81.79	81.79	0.00	0.00	212	0.39
0	1.66	2.14	2.14	29.61	29.61	23.04	79.36	79.36	0.00	0.00	212	0.37
0	1.66	0.66	0.66	22.24	22.24	19.23	99.12	99.12	0.00	0.00	212	0.47
0	1.66	0.67	0.67	23.10	23.10	20.04	97.94	97.94	0.00	0.00	212	0.46
0	0.75	0.60	0.60	19.99	19.99	15.25	138.80	138.80	0.00	0.00	212	0.65

0	0.45	0.40	0.40	22.74	22.74	20.84	104.39	104.39	0.00	0.00	212	0.49
0	0.77	0.76	0.64	23.44	24.41	20.65	80.77	132.17	2.18	51.40	212	0.38
0	0.77	0.58	0.58	20.46	20.46	17.73	91.89	91.89	0.00	0.00	212	0.43
0	0.67	0.64	0.20	23.49	21.99	21.09	82.58	98.05	0.65	15.47	212	0.39
0	0.93	1.01	1.01	25.43	25.43	19.87	123.25	123.25	0.00	0.00	212	0.58
0	0.95	0.83	0.69	21.80	22.18	18.48	80.85	109.49	1.26	28.64	212	0.38
0	0.60	0.53	0.53	23.68	23.68	20.73	122.79	122.79	0.00	0.00	212	0.58
0	1.68	1.42	1.42	27.16	27.16	20.54	110.69	110.69	0.00	0.00	212	0.52
0	1.51	1.41	1.25	22.97	23.55	15.59	100.40	125.83	1.11	25.43	212	0.47
0	1.51	1.64	1.64	24.10	24.10	15.11	106.12	106.12	0.00	0.00	212	0.50
1	1.20	1.14	0.79	25.91	25.30	22.29	75.96	90.47	0.57	14.50	212	0.36
1	1.06	1.02	1.02	21.21	21.21	14.08	122.06	122.06	0.00	0.00	212	0.58
1	1.76	1.75	1.28	24.38	24.88	16.67	89.62	135.51	1.87	45.89	212	0.42
1	1.10	1.03	0.92	22.43	22.38	16.86	105.13	117.55	0.56	12.42	212	0.50
1	1.93	1.86	1.69	21.18	22.93	6.73	105.96	142.32	1.71	36.36	212	0.50
Me an	1.19	1.07	1.01	24.19	24.25	19.25	100.56	108.60	0.34	8.04	212	0.47
Std	0.42	0.39	0.40	2.25	2.28	2.72	19.96	22.11	0.67	16.01	0	0.09

Table 5: Moodie Drive (W-NS).

Trucks	Mean Deceleration	Adjusted Overall Deceleration	Original Overall Deceleration	Initial Speed	Diverge Speed	Final Speed	Deceleration Distance	Deceleration Length	Deceleration Time	Distance to Decelerate	SCL Length	Utilization Rate
0	0.58	0.52	0.27	28.59	28.67	27.06	81.87	167.09	2.97	85.23	292	0.28
0	0.38	0.36	0.36	31.20	31.20	29.72	126.04	126.04	0.00	0.00	292	0.43
0	0.33	0.16	0.16	27.72	27.72	26.92	135.30	135.30	0.00	0.00	292	0.46
0	0.17	0.23	0.23	28.56	28.56	27.59	119.25	119.25	0.00	0.00	292	0.41
0	0.62	0.58	0.58	26.72	26.72	23.36	147.09	147.09	0.00	0.00	292	0.50
0	0.44	0.39	0.39	28.39	28.39	26.53	129.89	129.89	0.00	0.00	292	0.44
0	0.46	0.46	0.46	29.59	29.59	26.86	165.65	165.65	0.00	0.00	292	0.57
0	0.63	0.54	0.32	28.97	28.95	27.39	82.04	137.57	1.91	55.53	292	0.28
0	0.15	0.10	0.10	27.03	27.03	26.53	138.81	138.81	0.00	0.00	292	0.48
0	0.47	0.44	0.28	28.14	28.45	26.34	111.90	207.43	3.37	95.53	292	0.38
0	0.45	0.46	0.46	31.06	31.06	29.36	111.05	111.05	0.00	0.00	292	0.38
0	0.25	0.18	0.10	21.72	21.42	20.67	121.60	153.07	1.40	31.47	292	0.42
0	0.34	0.34	0.22	29.17	28.92	27.59	130.11	170.98	1.42	40.87	292	0.45
0	0.08	0.07	0.07	24.20	24.20	23.58	225.57	225.57	0.00	0.00	292	0.77
0	0.52	0.50	0.36	28.61	28.61	26.78	101.77	142.81	1.45	41.04	292	0.35
0	0.58	0.56	0.31	31.03	30.78	29.53	80.86	121.41	1.31	40.55	292	0.28
0	0.68	0.51	0.40	27.72	28.20	25.39	121.82	187.50	2.37	65.68	292	0.42
0	0.40	0.27	-0.12	31.00	29.08	29.89	123.90	199.07	2.47	75.16	292	0.42
0	0.06	0.03	0.03	27.78	27.78	27.59	200.65	200.65	0.00	0.00	292	0.69
0	0.27	0.27	0.27	29.89	29.89	28.39	162.15	162.15	0.00	0.00	292	0.56
0	0.56	0.48	0.35	31.61	31.64	29.71	121.62	168.79	1.42	47.17	292	0.42
0	0.39	0.39	0.22	28.34	28.31	27.00	93.42	164.64	2.52	71.22	292	0.32
0	0.50	0.32	0.26	29.84	29.64	28.00	165.87	182.26	0.50	16.39	292	0.57
0	0.67	0.65	0.50	28.03	29.22	25.53	102.14	204.41	3.53	102.27	292	0.35
0	0.17	0.09	0.09	30.89	30.89	30.38	166.53	166.53	0.00	0.00	292	0.57
0	0.17	0.08	0.08	22.95	22.95	22.39	151.96	151.96	0.00	0.00	292	0.52
0	0.54	0.48	0.48	28.86	28.86	26.01	162.02	162.02	0.00	0.00	292	0.55
0	0.85	0.78	0.71	33.11	33.17	30.33	112.91	126.24	0.41	13.33	292	0.39
0	0.33	0.32	0.32	25.36	25.36	22.86	188.16	188.16	0.00	0.00	292	0.64
0	0.61	0.57	0.46	33.31	33.28	31.25	117.11	142.25	0.76	25.14	292	0.40
0	0.57	0.52	0.46	27.59	27.64	25.13	124.06	143.27	0.71	19.21	292	0.42
0	0.47	0.48	0.36	27.86	28.56	26.27	89.38	175.83	3.02	86.46	292	0.31
0	0.22	0.21	0.21	28.89	28.89	27.67	162.37	162.37	0.00	0.00	292	0.56
0	0.16	0.14	0.14	26.08	26.08	25.17	173.81	173.81	0.00	0.00	292	0.60
0	0.16	0.56	0.56	27.28	27.28	26.13	54.53	54.53	0.00	0.00	292	0.19

0	0.49	0.34	0.15	28.70	28.20	27.21	123.31	182.00	2.07	58.69	292	0.42
0	0.59	0.55	0.44	25.50	26.58	23.14	102.75	195.33	3.58	92.58	292	0.35
0	0.25	0.17	0.17	30.84	30.84	30.00	145.21	145.21	0.00	0.00	292	0.50
0	0.30	0.22	0.22	27.11	27.11	25.75	161.18	161.18	0.00	0.00	292	0.55
0	0.30	0.45	0.45	27.09	27.09	24.61	140.45	140.45	0.00	0.00	292	0.48
0	0.28	0.26	0.26	22.45	22.45	21.45	82.50	82.50	0.00	0.00	292	0.28
0	0.44	0.40	0.36	24.64	25.39	22.22	142.08	209.67	2.73	67.58	292	0.49
0	0.26	0.23	0.08	25.78	25.47	24.81	106.17	207.24	3.93	101.07	292	0.36
0	0.43	0.55	-0.31	33.39	30.03	31.98	84.29	194.43	3.48	110.14	292	0.29
0	0.33	0.26	0.20	28.92	28.78	27.56	147.22	174.88	0.97	27.66	292	0.50
0	0.17	0.12	0.12	30.34	30.34	29.70	153.10	153.10	0.00	0.00	292	0.52
0	0.40	0.28	0.28	29.61	29.61	28.13	153.13	153.13	0.00	0.00	292	0.52
0	0.46	0.24	0.24	26.50	26.50	24.64	198.49	198.49	0.00	0.00	292	0.68
0	0.23	0.16	0.16	31.09	31.09	30.31	152.94	152.94	0.00	0.00	292	0.52
0	0.44	0.36	0.36	31.06	31.06	28.84	185.33	185.33	0.00	0.00	292	0.63
0	0.61	0.49	0.40	28.22	28.20	25.40	155.26	188.01	1.17	32.75	292	0.53
0	0.25	0.26	0.26	26.89	26.89	25.31	157.71	157.71	0.00	0.00	292	0.54
0	0.46	0.46	0.46	29.75	29.75	26.73	183.98	183.98	0.00	0.00	292	0.63
0	0.72	0.66	0.40	28.25	28.67	25.95	94.38	185.89	3.23	91.52	292	0.32
0	0.43	0.38	0.20	30.56	30.25	29.25	101.53	146.04	1.47	44.51	292	0.35
0	0.39	0.37	0.22	25.36	25.50	23.78	105.35	189.22	3.32	83.87	292	0.36
0	0.30	0.23	0.23	27.03	27.03	26.03	116.16	116.16	0.00	0.00	292	0.40
0	0.36	0.33	0.33	26.78	26.78	26.23	43.75	43.75	0.00	0.00	292	0.15
0	0.36	0.23	0.23	30.42	30.42	29.92	66.40	66.40	0.00	0.00	292	0.23
0	0.51	0.45	0.38	30.95	31.20	29.14	119.04	161.36	1.37	42.32	292	0.41
0	0.01	0.06	0.06	27.70	27.70	27.23	207.45	207.45	0.00	0.00	292	0.71
0	0.17	0.23	0.23	28.28	28.28	26.50	213.80	213.80	0.00	0.00	292	0.73
0	0.84	0.56	0.55	31.70	31.81	28.34	180.62	192.08	0.31	11.45	292	0.62
0	0.42	0.35	0.35	30.39	30.39	28.42	163.96	163.96	0.00	0.00	292	0.56
0	0.70	0.68	0.33	29.31	28.92	26.78	104.64	183.13	2.67	78.50	292	0.36
0	0.58	0.53	0.44	30.00	30.36	27.60	128.67	183.12	1.81	54.45	292	0.44
0	0.45	0.50	0.30	28.34	28.25	26.45	103.15	163.83	2.07	60.68	292	0.35
0	0.31	0.28	0.28	25.47	25.47	23.81	148.30	148.30	0.00	0.00	292	0.51
0	0.16	0.08	0.08	27.20	27.20	26.84	120.84	120.84	0.00	0.00	292	0.41
0	0.38	0.35	0.35	27.08	27.08	24.43	197.59	197.59	0.00	0.00	292	0.68
0	0.49	0.45	0.45	26.42	26.42	22.75	198.76	198.76	0.00	0.00	292	0.68
0	0.60	0.59	0.59	32.56	32.56	29.60	155.12	155.12	0.00	0.00	292	0.53
0	0.68	0.64	0.57	26.03	26.78	23.17	109.08	159.30	1.91	50.22	292	0.37
0	0.52	0.37	0.37	30.61	30.61	28.70	152.30	152.30	0.00	0.00	292	0.52
0	0.96	0.76	0.68	33.47	33.67	29.17	176.62	211.06	0.96	34.43	292	0.60

0	0.41	0.28	0.24	30.67	30.84	29.28	147.74	195.36	1.56	47.61	292	0.51
0	0.56	0.36	0.13	30.50	29.75	28.89	134.66	194.93	2.02	60.26	292	0.46
0	0.31	0.40	0.40	31.61	31.61	29.56	156.56	156.56	0.00	0.00	292	0.54
1	0.30	0.20	0.07	27.75	27.11	26.49	168.14	243.59	2.76	75.44	292	0.58
1	0.61	0.55	0.55	24.03	24.03	21.45	106.28	106.28	0.00	0.00	292	0.36
1	0.55	0.49	0.49	25.20	25.20	22.17	145.32	145.32	0.00	0.00	292	0.50
1	0.29	0.21	0.21	22.20	22.20	21.22	100.35	100.35	0.00	0.00	292	0.34
1	0.46	0.25	0.25	25.95	25.95	23.86	214.93	214.93	0.00	0.00	292	0.74
1	0.66	0.55	0.55	29.56	29.56	25.86	184.81	184.81	0.00	0.00	292	0.63
1	0.20	0.14	0.14	26.33	26.33	25.19	217.95	217.95	0.00	0.00	292	0.75
Me an	0.42	0.37	0.30	28.38	28.36	26.62	138.38	163.54	0.88	25.15	292	0.47
Std	0.19	0.17	0.17	2.57	2.49	2.56	39.26	37.44	1.21	33.90	0	0.13

Table 6: Terry Fox Drive (E-NS).

Trucks	Mean Deceleration	Adjusted Overall Deceleration	Original Overall Deceleration	Initial Speed	Diverge Speed	Final Speed	Deceleration Distance	Deceleration Length	Deceleration Time	Distance to Decelerate	SCL Length	Utilization Rate
0	0.16	0.19	0.19	28.42	28.42	26.64	260.93	260.93	0.00	0.00	388	0.67
0	0.59	0.60	0.60	32.99	32.99	29.03	202.87	202.87	0.00	0.00	388	0.52
0	0.27	0.32	0.32	27.38	27.38	23.84	279.55	279.55	0.00	0.00	388	0.72
0	0.57	0.53	0.53	31.01	31.01	28.17	159.09	159.09	0.00	0.00	388	0.41
0	0.54	0.50	0.50	28.86	28.86	24.48	226.86	226.86	0.00	0.00	388	0.58
0	0.27	0.30	0.30	29.84	29.84	27.25	250.18	250.18	0.00	0.00	388	0.64
0	0.48	0.38	0.38	28.66	28.66	25.73	209.47	209.47	0.00	0.00	388	0.54
0	0.45	0.25	0.12	27.59	27.62	26.39	131.09	270.40	5.04	139.30	388	0.34
0	0.33	0.24	0.18	29.76	29.60	28.56	144.54	170.04	0.87	25.50	388	0.37
0	0.36	0.31	0.31	28.58	28.58	25.20	290.08	290.08	0.00	0.00	388	0.75
0	0.43	0.45	0.45	25.38	25.38	19.67	285.99	285.99	0.00	0.00	388	0.74
0	0.30	0.19	0.18	29.90	30.20	28.74	174.35	239.40	2.17	65.05	388	0.45
0	0.39	0.27	0.21	31.41	31.38	29.53	212.19	272.70	1.92	60.51	388	0.55
0	0.18	0.21	0.21	23.67	23.67	20.50	324.75	324.75	0.00	0.00	388	0.84
0	0.14	0.23	0.23	30.22	30.22	28.01	282.52	282.52	0.00	0.00	388	0.73
0	0.61	0.60	0.60	29.66	29.66	24.62	225.46	225.46	0.00	0.00	388	0.58
0	0.41	0.36	0.36	30.26	30.26	26.92	261.36	261.36	0.00	0.00	388	0.67
0	0.45	0.51	0.51	28.35	28.35	25.34	158.18	158.18	0.00	0.00	388	0.41
0	0.57	0.31	0.31	28.75	28.75	26.12	234.87	234.87	0.00	0.00	388	0.61
0	0.64	0.60	0.03	30.34	28.67	28.33	98.01	317.98	7.41	219.96	388	0.25
0	0.22	0.36	0.36	29.13	29.13	26.75	180.71	180.71	0.00	0.00	388	0.47
0	0.85	0.74	0.43	30.51	31.77	27.78	107.08	281.10	5.60	174.03	388	0.28
0	0.15	0.11	0.01	27.74	27.02	26.94	192.62	220.64	1.00	28.02	388	0.50
0	0.17	0.27	0.57	25.17	27.71	23.94	109.18	166.52	2.16	57.34	388	0.28
0	0.20	0.25	0.32	25.29	27.43	23.95	132.12	279.28	5.59	147.16	388	0.34
0	0.20	0.26	0.26	29.52	29.52	27.50	222.81	222.81	0.00	0.00	388	0.57
0	0.54	0.51	0.22	33.71	32.80	30.76	188.11	305.02	3.48	116.91	388	0.48
0	0.18	0.28	0.28	26.22	26.22	23.50	244.19	244.19	0.00	0.00	388	0.63
0	0.91	0.72	0.51	31.12	31.72	27.75	136.66	235.28	3.12	98.62	388	0.35
0	0.61	0.59	0.59	23.93	23.93	19.78	152.50	152.50	0.00	0.00	388	0.39
0	0.59	0.60	0.24	29.21	28.20	25.62	162.94	297.23	4.66	134.29	388	0.42
0	0.84	0.82	0.34	30.56	30.97	27.78	98.73	281.15	5.95	182.42	388	0.25
0	0.51	0.54	0.54	30.24	30.24	26.95	172.07	172.07	0.00	0.00	388	0.44
0	0.18	0.13	0.13	28.11	28.11	27.00	237.13	237.13	0.00	0.00	388	0.61
0	-0.07	0.01	0.01	29.20	29.20	29.12	262.08	262.08	0.00	0.00	388	0.68

0	0.32	0.35	0.53	20.76	24.83	19.11	92.31	233.36	6.19	141.05	388	0.24
0	0.55	0.49	0.14	30.59	29.81	28.62	120.42	257.65	4.54	137.23	388	0.31
0	0.22	0.25	0.25	24.36	24.36	21.03	299.09	299.09	0.00	0.00	388	0.77
0	0.55	0.53	0.53	29.57	29.57	24.20	273.72	273.72	0.00	0.00	388	0.71
0	0.54	0.50	0.22	28.84	28.69	26.39	133.42	289.88	5.44	156.46	388	0.34
0	0.48	0.37	0.10	33.15	32.42	31.64	133.56	244.49	3.37	110.93	388	0.34
0	0.91	0.85	0.72	28.73	30.35	24.95	119.27	207.68	3.03	88.41	388	0.31
0	0.23	0.33	0.33	25.31	25.31	21.59	260.13	260.13	0.00	0.00	388	0.67
0	0.90	0.83	0.46	32.38	32.42	28.06	156.50	288.43	4.09	131.92	388	0.40
0	0.24	0.27	0.27	26.72	26.72	24.31	224.21	224.21	0.00	0.00	388	0.58
0	0.49	0.45	0.45	28.19	28.19	23.08	292.84	292.84	0.00	0.00	388	0.75
0	0.20	0.18	0.18	31.70	31.70	29.98	295.99	295.99	0.00	0.00	388	0.76
0	0.43	0.44	0.30	25.99	26.27	22.78	178.26	281.44	3.99	103.19	388	0.46
0	0.43	0.38	0.31	28.88	29.16	26.00	208.88	280.59	2.48	71.71	388	0.54
0	0.50	0.41	0.31	29.79	30.89	28.37	100.11	243.98	4.74	143.87	388	0.26
0	0.42	0.39	0.25	26.51	27.63	24.97	100.15	285.68	6.91	185.53	388	0.26
0	0.84	0.81	0.49	33.29	34.60	30.58	105.76	267.88	4.79	162.13	388	0.27
0	0.42	0.40	0.39	31.10	31.86	29.09	151.43	213.93	2.02	62.50	388	0.39
0	0.38	0.49	0.49	28.92	28.92	24.42	240.77	240.77	0.00	0.00	388	0.62
0	0.15	0.22	0.22	29.46	29.46	27.37	270.98	270.98	0.00	0.00	388	0.70
0	0.24	0.24	0.16	27.25	26.88	25.10	236.06	290.82	2.02	54.76	388	0.61
0	0.11	0.15	0.15	29.91	29.91	28.27	310.77	310.77	0.00	0.00	388	0.80
0	0.54	0.48	0.25	28.23	28.61	25.98	126.35	291.68	5.80	165.33	388	0.33
0	0.19	0.17	0.17	33.82	33.82	32.42	268.49	268.49	0.00	0.00	388	0.69
0	0.07	0.11	0.12	24.52	24.97	23.42	241.26	300.85	2.42	59.59	388	0.62
0	0.63	0.62	0.36	28.93	30.04	26.31	116.67	297.09	6.15	180.42	388	0.30
0	0.36	0.42	0.42	28.38	28.38	23.95	277.03	277.03	0.00	0.00	388	0.71
0	0.06	0.02	0.01	24.35	24.29	24.20	191.84	194.33	0.11	2.48	388	0.49
0	0.27	0.49	0.49	26.63	26.63	20.40	292.12	292.12	0.00	0.00	388	0.75
0	0.18	0.20	0.53	24.03	28.56	23.29	88.56	256.60	6.40	168.04	388	0.23
0	0.23	0.17	0.10	24.79	25.11	24.09	98.30	251.90	6.25	153.60	388	0.25
0	0.19	0.17	0.13	28.37	28.87	27.64	119.48	269.87	5.29	150.39	388	0.31
0	0.25	0.24	0.24	32.81	32.81	30.64	288.16	288.16	0.00	0.00	388	0.74
0	1.08	0.96	0.70	30.15	31.60	25.20	141.34	262.16	3.93	120.82	388	0.36
0	0.00	0.07	0.07	27.73	27.73	26.95	297.80	297.80	0.00	0.00	388	0.77
0	0.18	0.15	-0.02	31.90	31.21	31.39	103.85	271.84	5.35	167.98	388	0.27
0	0.39	0.27	0.27	28.48	28.48	25.89	261.93	261.93	0.00	0.00	388	0.68
0	0.30	0.25	0.25	29.82	29.82	27.17	305.89	305.89	0.00	0.00	388	0.79
0	0.38	0.43	0.43	28.96	28.96	24.45	274.93	274.93	0.00	0.00	388	0.71
0	0.62	0.57	0.57	27.88	27.88	23.12	210.57	210.57	0.00	0.00	388	0.54

0	0.72	0.62	0.44	30.15	30.68	26.59	162.77	264.95	3.38	102.18	388	0.42
0	0.46	0.38	0.28	25.96	26.37	23.42	163.58	265.38	3.94	101.80	388	0.42
0	0.42	0.32	0.29	27.26	28.09	25.37	156.98	249.61	3.38	92.64	388	0.40
0	0.68	0.70	0.52	30.62	32.82	28.33	95.61	260.00	5.49	164.39	388	0.25
0	0.56	0.62	0.62	32.24	32.24	26.75	261.35	261.35	0.00	0.00	388	0.67
0	0.40	0.35	0.28	29.04	29.48	26.82	178.12	266.17	3.03	88.06	388	0.46
0	0.82	0.96	0.99	30.76	32.43	27.39	100.70	149.66	1.56	48.96	388	0.26
0	0.44	0.30	0.30	29.52	29.52	27.27	212.64	212.64	0.00	0.00	388	0.55
0	0.06	0.19	0.19	28.53	28.53	26.78	254.75	254.75	0.00	0.00	388	0.66
0	0.41	0.34	0.34	27.19	27.19	24.20	231.14	231.14	0.00	0.00	388	0.60
0	0.75	0.67	0.40	29.31	30.85	27.10	90.78	268.66	5.93	177.88	388	0.23
0	0.23	0.17	0.17	28.13	28.13	26.34	286.59	286.59	0.00	0.00	388	0.74
0	0.26	0.35	0.35	27.16	27.27	23.23	285.81	289.91	0.16	4.10	388	0.74
0	0.30	0.21	0.18	28.35	28.05	26.18	281.64	290.48	0.31	8.84	388	0.73
0	0.46	0.28	0.28	30.60	30.60	28.09	265.65	265.65	0.00	0.00	388	0.68
0	0.39	0.30	0.25	29.63	29.91	27.55	196.93	273.35	2.58	76.42	388	0.51
0	0.62	0.54	0.40	29.58	29.21	25.34	214.61	266.88	1.77	52.27	388	0.55
0	0.52	0.53	0.53	30.25	30.25	24.70	287.59	287.59	0.00	0.00	388	0.74
0	0.21	0.18	0.05	28.40	27.86	27.31	173.69	287.12	4.04	113.43	388	0.45
0	0.24	0.27	0.27	30.95	30.95	28.31	294.46	294.46	0.00	0.00	388	0.76
0	0.59	0.56	0.47	27.84	29.96	25.42	115.17	265.28	5.25	150.11	388	0.30
0	0.65	0.54	0.37	29.27	29.29	25.17	205.45	302.65	3.33	97.20	388	0.53
0	0.43	0.39	0.39	26.91	26.91	24.03	189.90	189.90	0.00	0.00	388	0.49
0	0.45	0.36	0.14	29.85	29.46	28.17	136.05	264.30	4.34	128.25	388	0.35
0	0.48	0.44	0.40	25.91	27.14	22.31	194.86	300.93	4.03	106.08	388	0.50
0	0.78	0.74	0.54	29.84	30.43	27.37	94.70	163.04	2.27	68.34	388	0.24
0	0.92	0.83	0.63	29.46	30.55	25.67	124.12	217.99	3.18	93.87	388	0.32
0	0.64	0.53	0.53	31.74	31.74	26.23	302.58	302.58	0.00	0.00	388	0.78
0	0.39	0.21	0.16	31.60	31.49	30.45	171.44	198.35	0.86	26.91	388	0.44
1	0.04	0.18	0.33	23.76	26.39	22.53	160.09	281.42	4.89	121.33	388	0.41
1	0.42	0.38	0.37	27.54	27.85	24.78	187.77	218.26	1.11	30.50	388	0.48
1	0.36	0.22	0.22	25.68	25.68	23.64	233.41	233.41	0.00	0.00	388	0.60
1	0.33	0.27	0.19	27.12	27.49	25.42	164.66	293.60	4.74	128.95	388	0.42
1	0.42	0.32	0.32	29.80	29.80	26.28	304.49	304.49	0.00	0.00	388	0.78
1	0.12	0.20	0.22	26.50	26.75	24.42	264.70	271.31	0.26	6.61	388	0.68
1	0.40	0.35	0.26	27.57	27.56	24.73	212.60	282.02	2.53	69.42	388	0.55
1	0.58	0.53	0.33	28.76	28.91	26.06	138.27	235.62	3.38	97.36	388	0.36
1	0.59	0.50	0.28	27.26	27.55	24.89	123.68	248.42	4.54	124.74	388	0.32
1	0.38	0.24	0.24	25.39	25.39	22.28	312.69	312.69	0.00	0.00	388	0.81
Me an	0.42	0.39	0.33	28.66	28.96	25.98	200.46	257.02	1.97	56.56	388	0.52

Std	0.23	0.20	0.17	2.39	2.23	2.58	68.86	40.21	2.29	65.42	0	0.18
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Table 7: Carp Road (E-NS).

Trucks	Mean Deceleration	Adjusted Overall Deceleration	Original Overall Deceleration	Initial Speed	Diverge Speed	Final Speed	Deceleration Distance	Deceleration Length	Deceleration Time	Distance to Decelerate	SCL Length	Utilization Rate
0	0.19	0.13	0.13	31.58	31.58	30.15	344.26	344.26	0.00	0.00	430	0.80
0	0.25	0.21	0.19	29.61	29.50	27.47	289.49	298.40	0.30	8.90	430	0.67
0	0.59	0.49	0.22	31.00	31.58	29.01	120.42	352.41	7.36	231.98	430	0.28
0	0.30	0.27	0.16	27.81	27.86	26.00	179.12	310.16	4.68	131.04	430	0.42
0	0.51	0.39	0.39	30.25	30.25	26.17	295.80	295.80	0.00	0.00	430	0.69
0	0.30	0.37	0.06	29.28	28.89	28.24	80.06	302.30	7.68	222.24	430	0.19
0	0.79	0.32	0.15	32.92	32.03	30.12	277.43	392.83	3.50	115.40	430	0.65
0	0.64	0.55	0.37	33.39	33.50	28.95	252.67	382.52	3.90	129.85	430	0.59
0	0.53	0.35	0.32	29.14	29.81	26.44	213.95	297.03	2.83	83.07	430	0.50
0	0.45	0.48	0.29	26.89	28.97	24.82	113.10	380.27	9.72	267.17	430	0.26
0	0.43	0.30	0.27	25.72	26.42	24.25	121.05	204.17	3.23	83.12	430	0.28
0	0.69	0.63	0.24	30.47	30.22	27.14	151.81	381.94	7.50	230.13	430	0.35
0	0.77	0.61	0.35	32.36	31.39	27.86	220.67	303.33	2.52	82.65	430	0.51
0	0.75	0.75	0.28	30.03	31.22	27.75	86.80	368.02	9.11	281.22	430	0.20
0	0.63	0.57	0.33	28.75	29.92	26.23	122.36	315.85	6.50	193.48	430	0.28
0	0.67	0.66	0.33	31.11	32.22	28.40	122.14	353.13	7.30	230.98	430	0.28
0	0.37	0.35	0.15	29.47	29.97	28.11	113.49	370.43	8.53	256.94	430	0.26
0	0.37	0.28	0.16	31.00	30.78	28.83	235.42	358.30	3.90	122.88	430	0.55
0	-0.03	0.21	0.21	29.25	29.25	26.40	369.20	369.20	0.00	0.00	430	0.86
0	0.42	0.37	0.18	27.28	27.75	25.63	116.80	324.62	7.57	207.81	430	0.27
0	0.67	0.57	0.34	32.22	31.89	28.01	222.72	348.64	3.96	125.92	430	0.52
0	0.54	0.26	0.26	31.31	31.31	28.61	313.68	313.68	0.00	0.00	430	0.73
0	0.30	0.21	0.21	27.75	27.75	25.05	348.14	348.14	0.00	0.00	430	0.81
0	0.84	0.77	0.39	29.09	30.14	25.98	110.29	299.45	6.37	189.15	430	0.26
0	0.43	0.36	0.36	31.22	31.22	26.97	344.10	344.10	0.00	0.00	430	0.80
0	0.34	0.35	0.19	27.72	28.33	26.04	130.23	326.71	7.09	196.47	430	0.30
0	0.42	0.48	0.10	28.20	27.95	26.79	79.95	320.93	8.56	240.98	430	0.19
0	0.39	0.35	0.35	33.39	33.39	29.39	357.97	357.97	0.00	0.00	430	0.83
0	0.23	0.16	0.05	32.75	32.22	31.70	213.01	336.29	3.81	123.28	430	0.50
0	0.86	0.76	0.29	29.92	30.03	26.50	126.89	348.85	7.37	221.95	430	0.30
0	0.33	0.26	0.26	27.47	27.47	24.11	333.48	333.48	0.00	0.00	430	0.78
0	0.18	0.15	0.15	31.03	31.03	29.29	343.24	343.24	0.00	0.00	430	0.80
0	0.49	0.32	0.14	33.09	33.47	32.02	107.18	354.44	7.42	247.26	430	0.25
0	0.64	0.32	0.32	28.97	28.97	24.63	367.45	367.45	0.00	0.00	430	0.85
0	0.56	0.34	0.21	30.78	30.14	28.11	232.14	285.53	1.75	53.39	430	0.54

0	0.67	0.51	0.33	31.11	32.58	28.64	145.68	369.18	7.05	223.50	430	0.34
0	0.61	0.24	0.24	31.20	31.20	28.87	301.12	301.12	0.00	0.00	430	0.70
0	0.39	0.11	0.11	28.47	28.47	27.11	363.72	363.72	0.00	0.00	430	0.85
0	0.28	0.23	0.14	29.56	29.61	28.00	198.99	332.97	4.55	133.98	430	0.46
0	0.46	0.39	0.39	34.97	34.97	32.63	203.88	203.88	0.00	0.00	430	0.47
0	0.15	0.09	0.09	29.25	29.25	28.00	390.00	390.00	0.00	0.00	430	0.91
0	0.36	0.45	0.45	32.25	32.25	26.89	350.16	350.16	0.00	0.00	430	0.81
0	0.36	0.16	0.16	26.86	26.86	25.08	297.26	297.26	0.00	0.00	430	0.69
0	0.54	0.52	0.32	28.53	29.97	25.77	143.11	366.33	7.59	223.22	430	0.33
0	0.24	0.24	0.24	30.08	30.08	26.70	397.68	397.68	0.00	0.00	430	0.92
0	0.05	0.29	0.31	34.34	34.56	31.90	271.32	278.16	0.21	6.84	430	0.63
0	0.43	0.32	0.28	28.92	29.22	25.25	312.31	383.16	2.44	70.85	430	0.73
0	0.28	0.21	0.21	26.45	26.45	23.78	319.92	319.92	0.00	0.00	430	0.74
0	0.92	0.43	0.43	33.72	33.72	29.48	315.10	315.10	0.00	0.00	430	0.73
0	0.71	0.70	0.21	29.61	30.61	27.70	78.02	401.09	10.64	323.07	430	0.18
0	0.22	0.33	0.33	28.97	28.97	25.43	297.65	297.65	0.00	0.00	430	0.69
0	0.46	0.43	0.43	30.83	30.83	26.09	315.97	315.97	0.00	0.00	430	0.73
0	0.33	0.24	0.23	26.31	27.53	24.86	152.31	309.99	5.90	157.68	430	0.35
0	0.18	0.09	0.09	25.81	25.81	24.57	341.98	341.98	0.00	0.00	430	0.80
0	0.22	0.18	0.14	26.97	26.58	24.89	298.94	305.85	0.25	6.91	430	0.70
0	0.45	0.31	0.31	30.31	30.31	26.83	322.87	322.87	0.00	0.00	430	0.75
0	0.42	0.34	0.34	29.14	29.14	26.50	217.88	217.88	0.00	0.00	430	0.51
0	1.02	0.95	0.81	32.36	33.50	24.45	234.26	325.79	2.72	91.52	430	0.54
0	0.29	0.23	-0.01	31.28	30.28	30.43	112.05	347.50	7.62	235.44	430	0.26
0	0.44	0.30	0.15	23.56	24.03	22.12	109.14	293.85	7.69	184.71	430	0.25
0	0.22	0.19	0.19	29.06	29.06	26.67	357.75	357.75	0.00	0.00	430	0.83
0	0.38	0.22	0.19	31.75	31.89	29.78	281.36	344.06	1.98	62.69	430	0.65
0	0.23	0.22	0.18	29.78	29.56	27.61	287.08	304.15	0.51	17.06	430	0.67
0	0.48	0.43	0.27	30.86	32.33	28.99	131.89	387.56	8.10	255.66	430	0.31
0	0.64	0.43	0.23	27.78	28.08	25.11	165.54	342.72	6.29	177.18	430	0.38
0	0.22	0.15	0.06	27.89	27.58	26.83	199.23	363.40	5.97	164.17	430	0.46
0	0.49	0.44	0.29	28.64	29.64	26.51	132.18	305.22	5.90	173.03	430	0.31
0	0.69	0.73	0.34	30.31	31.42	27.17	123.21	371.03	8.08	247.81	430	0.29
0	0.52	0.44	0.18	30.31	30.97	28.74	105.97	378.21	8.81	272.24	430	0.25
0	0.44	0.40	0.36	27.06	29.36	24.86	141.17	334.59	6.92	193.42	430	0.33
0	0.48	0.46	0.25	30.72	31.31	28.70	130.82	309.76	5.74	178.93	430	0.30
0	0.94	0.85	0.53	33.28	34.31	28.55	170.86	343.06	5.08	172.20	430	0.40
0	0.65	0.50	0.29	29.45	29.92	26.29	174.27	357.06	6.16	182.79	430	0.41
0	0.50	0.47	0.26	26.78	27.50	24.54	120.46	300.85	6.61	180.38	430	0.28
0	0.36	0.30	0.25	27.83	27.86	24.70	277.78	326.83	1.77	49.04	430	0.65

0	0.45	0.39	0.21	27.06	28.28	25.56	101.87	356.17	9.18	254.30	430	0.24
0	0.63	0.60	0.38	31.03	32.14	28.49	126.37	289.63	5.20	163.26	430	0.29
0	0.66	0.53	0.32	28.95	30.11	26.61	123.49	316.11	6.51	192.61	430	0.29
0	0.63	0.53	0.29	29.89	31.08	27.74	117.32	336.61	7.17	219.28	430	0.27
0	0.34	0.15	0.15	30.56	30.56	29.00	318.05	318.05	0.00	0.00	430	0.74
0	0.29	0.23	0.18	28.00	28.58	26.55	175.38	312.28	4.84	136.90	430	0.41
0	0.07	0.08	0.30	23.53	27.39	23.16	106.51	356.66	9.90	250.15	430	0.25
0	0.39	0.31	0.21	31.75	31.58	29.33	235.78	326.99	2.88	91.20	430	0.55
0	0.19	0.14	0.04	27.45	26.83	26.39	205.38	312.31	3.94	106.93	430	0.48
1	0.24	0.22	0.06	28.09	28.00	27.28	102.30	356.48	9.01	254.18	430	0.24
1	0.18	0.12	0.04	27.34	27.42	26.88	103.58	349.54	8.98	245.96	430	0.24
1	0.15	0.05	0.05	27.86	27.86	27.38	288.98	288.98	0.00	0.00	430	0.67
1	0.41	0.33	0.10	28.72	28.64	27.42	111.46	330.38	7.67	218.92	430	0.26
1	0.58	0.40	0.32	25.78	27.20	23.03	167.23	331.87	6.28	164.64	430	0.39
1	0.68	0.45	0.26	26.86	27.00	23.88	170.31	312.20	5.26	141.90	430	0.40
1	0.08	0.07	0.11	25.78	26.42	24.76	345.39	390.66	1.70	45.26	430	0.80
1	-0.01	0.03	0.03	26.14	26.14	25.86	271.34	271.34	0.00	0.00	430	0.63
1	0.43	0.03	0.03	29.31	29.31	28.98	341.18	341.18	0.00	0.00	430	0.79
1	0.32	0.17	0.17	22.61	22.61	20.08	327.13	327.13	0.00	0.00	430	0.76
1	0.79	0.70	0.31	26.28	26.86	22.33	136.16	374.51	8.86	238.35	430	0.32
1	0.34	0.25	0.25	26.61	26.61	23.78	272.23	272.23	0.00	0.00	430	0.63
1	0.61	0.52	0.21	26.09	26.17	23.45	125.54	326.87	7.74	201.33	430	0.29
1	0.46	0.33	0.18	26.83	26.58	24.44	186.78	307.57	4.53	120.80	430	0.43
Me an	0.44	0.36	0.24	29.26	29.59	26.84	216.40	331.78	3.95	115.38	430	0.50
Std	0.22	0.19	0.12	2.42	2.34	2.25	94.62	37.74	3.46	100.74	0	0.22

Table 8: Terry Fox Drive (W-NS).

Trucks	Mean Deceleration	Adjusted Overall Deceleration	Original Overall Deceleration	Initial Speed	Diverge Speed	Final Speed	Deceleration Distance	Deceleration Length	Deceleration Time	Distance to Decelerate	SCL Length	Utilization Rate
0	0.39	0.37	0.18	31.00	31.64	29.67	108.32	346.20	7.53	237.87	446	0.24
0	0.43	0.36	0.36	30.92	30.92	28.86	169.59	171.16	0.05	1.57	446	0.38
0	0.32	0.27	-0.01	29.81	28.81	28.86	101.51	324.89	7.56	223.38	446	0.23
0	0.74	0.70	0.43	28.89	29.42	25.59	126.86	245.40	4.08	118.54	446	0.28
0	0.78	0.57	0.43	30.67	31.06	26.84	195.40	291.57	3.03	96.18	446	0.44
0	0.70	0.62	0.24	26.84	27.03	23.89	119.71	337.50	8.06	217.78	446	0.27
0	0.17	0.14	0.14	29.81	29.81	28.39	284.61	284.61	0.00	0.00	446	0.64
0	0.26	0.20	0.19	31.92	31.92	30.09	291.36	292.97	0.05	1.61	446	0.65
0	0.61	0.62	0.62	35.92	35.92	31.09	261.12	261.12	0.00	0.00	446	0.59
0	0.50	0.20	0.20	31.58	31.58	29.42	329.85	329.85	0.00	0.00	446	0.74
0	0.33	0.17	0.17	23.95	23.95	22.03	261.67	261.67	0.00	0.00	446	0.59
0	0.35	0.26	0.26	26.47	26.47	22.92	340.40	340.40	0.00	0.00	446	0.76
0	0.18	0.13	0.13	26.61	26.61	25.53	221.65	221.65	0.00	0.00	446	0.50
0	0.83	0.74	0.36	32.48	33.75	29.81	112.62	349.20	7.13	236.58	446	0.25
0	0.18	0.07	0.00	27.31	26.81	26.81	185.49	323.43	5.07	137.95	446	0.42
0	0.27	0.24	0.24	30.67	30.67	28.70	247.66	247.66	0.00	0.00	446	0.56
0	0.25	0.17	0.17	27.53	27.53	25.34	333.34	333.34	0.00	0.00	446	0.75
0	0.29	0.25	0.25	30.81	30.81	28.03	326.12	326.12	0.00	0.00	446	0.73
0	0.78	0.72	0.37	29.47	30.75	26.81	104.15	314.38	6.91	210.22	446	0.23
0	0.15	0.10	0.04	27.97	27.45	27.06	251.20	275.54	0.86	24.34	446	0.56
0	0.33	0.32	0.11	29.61	29.47	28.14	131.26	350.75	7.38	219.48	446	0.29
0	0.76	0.62	0.38	35.34	35.09	31.81	190.57	288.96	2.78	98.40	446	0.43
0	0.73	0.65	0.30	34.11	34.39	31.81	117.81	285.64	4.87	167.83	446	0.26
0	0.52	0.54	0.26	28.61	29.28	26.42	110.26	310.31	6.86	200.05	446	0.25
0	0.57	0.45	0.30	25.84	26.06	23.17	145.06	238.99	3.63	93.94	446	0.33
0	0.57	0.64	0.64	28.70	28.70	25.34	141.35	141.35	0.00	0.00	446	0.32
0	0.21	0.15	0.15	27.28	27.28	25.48	325.35	325.35	0.00	0.00	446	0.73
0	0.12	0.18	0.20	28.00	28.45	27.39	95.14	149.08	1.91	53.94	446	0.21
0	0.37	0.22	0.06	28.09	27.22	26.53	189.96	333.98	5.15	144.02	446	0.43
0	0.57	0.54	0.38	25.20	25.64	20.53	197.98	314.68	4.58	116.71	446	0.44
0	0.23	0.20	0.16	32.45	32.17	30.64	277.24	301.84	0.76	24.60	446	0.62
0	-0.06	0.13	0.13	30.09	30.09	29.20	207.71	207.71	0.00	0.00	446	0.47
0	0.41	0.42	0.27	28.75	29.95	27.23	101.51	292.07	6.51	190.55	446	0.23
0	0.41	0.11	0.11	29.17	29.17	28.89	72.60	72.60	0.00	0.00	446	0.16
0	0.77	0.36	0.36	32.42	32.42	28.95	300.91	300.91	0.00	0.00	446	0.67

0	0.21	0.19	0.19	29.86	29.86	27.81	316.14	316.14	0.00	0.00	446	0.71
0	0.48	0.47	0.54	27.95	30.92	24.70	182.26	317.37	4.58	135.11	446	0.41
0	0.43	0.43	0.32	27.47	29.64	25.42	127.32	362.22	8.40	234.89	446	0.29
0	0.64	0.52	0.44	32.75	32.81	28.78	235.25	283.88	1.47	48.63	446	0.53
0	0.47	0.36	0.36	29.11	29.11	24.61	334.44	334.44	0.00	0.00	446	0.75
0	0.42	0.37	0.12	28.34	28.31	26.92	104.78	312.46	7.36	207.68	446	0.23
0	0.05	0.12	0.12	31.58	31.58	30.37	304.33	304.33	0.00	0.00	446	0.68
0	0.40	0.33	0.33	26.95	26.95	23.11	289.91	289.91	0.00	0.00	446	0.65
0	0.05	0.01	-0.10	27.64	26.47	27.56	160.85	307.69	5.41	146.85	446	0.36
0	0.36	0.17	0.17	31.14	31.14	29.34	329.79	329.79	0.00	0.00	446	0.74
0	0.33	0.20	0.17	28.42	28.47	26.34	281.91	345.40	2.27	63.48	446	0.63
0	0.38	0.20	0.20	30.58	30.58	28.64	293.79	293.79	0.00	0.00	446	0.66
0	0.65	0.64	0.43	26.92	29.14	24.17	109.52	312.23	7.16	202.70	446	0.25
0	0.44	0.45	0.45	31.47	31.47	26.36	330.14	330.14	0.00	0.00	446	0.74
0	0.13	0.16	0.16	25.86	25.86	23.78	326.45	326.45	0.00	0.00	446	0.73
0	0.38	0.29	0.27	27.08	26.95	23.86	281.07	291.96	0.35	10.89	446	0.63
0	1.68	1.46	1.33	39.67	39.56	35.17	115.04	123.16	0.21	8.12	446	0.26
0	0.24	0.22	0.10	26.89	27.22	25.98	110.95	321.01	7.76	210.06	446	0.25
0	0.17	0.15	0.07	29.72	29.31	28.61	210.23	307.79	3.32	97.57	446	0.47
0	0.13	0.11	0.11	27.11	27.11	25.70	327.67	327.67	0.00	0.00	446	0.73
0	0.51	0.50	0.27	28.25	27.78	24.53	196.08	317.58	4.44	121.51	446	0.44
0	0.07	0.03	0.03	25.39	25.39	24.95	346.78	346.78	0.00	0.00	446	0.78
0	0.59	0.61	0.30	28.25	29.03	25.98	101.81	286.76	6.45	184.95	446	0.23
0	0.46	0.33	0.33	29.86	29.86	27.03	243.28	243.28	0.00	0.00	446	0.55
0	0.42	0.31	0.31	31.73	31.73	30.84	90.92	90.92	0.00	0.00	446	0.20
0	0.48	0.37	0.37	33.89	33.89	30.75	273.29	273.29	0.00	0.00	446	0.61
0	0.32	0.16	0.13	27.86	27.92	26.34	266.16	319.48	1.92	53.31	446	0.60
0	0.27	0.25	0.25	28.17	28.17	26.03	230.49	230.49	0.00	0.00	446	0.52
0	0.46	0.51	0.51	32.31	32.31	26.48	336.12	336.12	0.00	0.00	446	0.75
0	0.00	0.09	0.12	29.72	30.36	29.00	231.75	342.66	3.68	110.91	446	0.52
0	0.41	0.60	0.60	30.25	30.25	23.36	305.50	305.50	0.00	0.00	446	0.68
0	1.09	0.92	0.45	33.53	34.72	30.42	109.21	316.46	6.09	207.25	446	0.24
0	0.43	0.41	0.41	26.70	26.70	26.34	23.39	23.39	0.00	0.00	446	0.05
0	0.27	0.21	0.11	29.28	29.45	28.25	138.80	300.84	5.50	162.04	446	0.31
0	0.19	0.17	0.16	30.70	30.70	29.06	285.30	308.00	0.75	22.70	446	0.64
0	0.89	0.99	0.99	37.73	37.73	33.87	139.16	139.16	0.00	0.00	446	0.31
0	0.96	0.91	0.77	25.47	26.86	21.14	109.44	178.71	2.67	69.27	446	0.25
1	0.51	0.39	0.15	27.61	27.75	26.09	105.45	300.23	7.01	194.78	446	0.24
1	0.49	0.36	0.35	29.89	29.86	25.53	334.56	349.66	0.51	15.10	446	0.75
1	0.59	0.61	0.14	25.95	25.81	23.92	82.33	346.50	10.18	264.18	446	0.18

1	0.04	0.15	0.15	28.56	28.56	26.61	360.39	360.39	0.00	0.00	446	0.81
	0.43	0.37	0.28	29.50	29.68	27.12	211.31	284.83	2.53	73.52	446	0.47
	0.28	0.26	0.22	2.87	2.88	2.77	91.41	70.38	3.04	88.04	0	0.20

Table 9: Right Lane Average Speeds at Study Sites.

Island Park Drive (E-N)	Parkdale Ave. (W-NS)	Bronson Ave. (W-NS)	Moodie Drive (W-NS)	Terry Fox Drive (E-NS)	Carp Road (E-NS)	Terry Fox Drive (W-NS)
22.93	26.81	21.20	29.28	30.58	28.12	28.89
24.53	29.71	27.96	20.97	26.83	28.04	28.27
27.59	26.65	27.78	27.26	27.76	29.47	28.38
24.92	27.71	21.55	24.82	28.42	27.87	27.58
27.16	26.98	21.65	29.15	26.89	29.90	27.28
28.42	25.95	25.69	29.05	28.81	26.47	27.21
27.54	26.46	23.62	28.50	27.58	28.91	29.65
23.24	22.60	26.98	28.35	25.60	27.14	29.46
23.92	24.52	20.24	25.06	27.88	28.75	29.66
28.53	25.28	19.70	26.60	25.20	28.57	31.85
27.05	20.85	26.43	26.81	28.29	27.35	26.08
27.58	23.58	30.50	26.90	28.33	26.31	34.23
23.41	25.29	26.71	28.58	27.94	28.22	27.46
25.52	28.53	26.27	25.86	31.40	29.22	33.92
21.81	26.38	26.21	29.57	33.15	25.95	33.41
19.55	24.16	28.99	26.83	32.43	26.26	32.18
24.48	28.97	24.99	28.23	28.94	28.76	31.72
25.80	26.81	31.80	27.55	32.54	24.20	27.74
22.76	24.13	25.92	29.68	31.19	29.12	31.03
22.11	20.65	26.00	33.56	27.89	27.21	30.90
17.24	33.13	24.68	29.89	28.46	29.31	31.87
22.05	27.77	23.45	28.32	28.71	24.88	30.99
24.09	22.22	25.12	29.41	31.44	29.24	36.33
21.96	24.13	27.92	28.80	30.34	27.72	29.23
21.20	24.62	26.30	26.75	33.22	30.90	23.92
20.99	31.64	28.48	26.65	28.57	25.95	31.70
27.02	25.02	26.13	28.85	28.82	28.34	28.30
20.77	30.63	24.09	34.83	26.29	32.54	32.09
20.19	30.94	27.15	28.24	26.13	32.60	29.33
21.14	22.52	26.08	29.75	27.34	32.20	30.71
21.04	22.43	20.21	31.25	22.65	29.42	30.44
22.25	29.41	31.17	26.06	26.56	32.64	32.85
26.58	24.07	25.76	28.64	31.85	26.41	34.45
21.65	30.15	26.23	28.81	23.66	32.94	29.83
25.29	22.20	26.23	31.15	29.68	30.96	26.93

19.45	25.68	26.57	22.65	25.15	33.50	29.56
21.76	23.13	27.30	24.75	32.66	31.60	32.49
22.90	31.22	25.55	32.30	30.89	29.45	26.38
23.07	29.47	29.23	28.41	32.14	31.79	29.27
20.78	24.25	25.72	28.87	29.09	27.66	30.99
20.76	28.22	29.46	28.96	28.92	29.20	27.72
22.80	30.73	23.17	29.90	26.57	28.93	26.13
21.93	28.21	29.52	28.45	28.34	28.43	30.70
23.51	24.91	26.69	28.76	31.03	26.93	26.43
23.11	27.53	25.53	27.73	28.17	32.09	29.52
21.89	27.69	30.46	28.27	29.07	31.70	31.33
20.93	27.66	24.48	29.70	29.45	27.22	34.55
23.66	30.31	24.61	28.87	27.55	24.78	28.36
23.34	26.98	26.71	26.71	30.14	29.50	30.85
21.59	32.56	27.93	28.22	28.24	28.04	29.15
21.57	27.07	29.72	29.59	28.25	31.77	32.32
25.22	28.16	25.34	30.94	33.04	27.92	30.00
18.80	27.15	25.56	28.40	29.67	26.98	29.71
23.56	26.28	26.42	28.32	27.16	29.47	27.82
21.24	27.05	24.80	30.62	29.78	29.17	28.98
20.41	23.73	27.49	31.70	33.85	33.63	30.38
22.45	28.66	25.61	29.07	28.80	33.41	26.24
22.26	29.29	27.72	29.35	27.75	32.15	27.95
24.16	29.39	24.91	32.10	32.82	33.96	31.83
26.91	27.90	23.55	32.32	27.30	31.14	34.47
27.13	24.67	26.31	29.20	28.30	32.06	26.76
25.32	26.60	27.49	28.88	30.94	28.69	34.20
23.33	24.40	22.98	29.43	29.04	31.13	29.26
18.92	25.00	24.06	25.47	30.02	30.29	29.34
24.81	23.35	29.01	29.14	26.17	29.59	30.15
23.73	31.68	30.38	32.79	24.77	30.75	29.49
24.73	21.27	26.02	30.27	30.25	32.42	31.13
24.70	24.85	29.01	30.66	26.96	32.23	30.49
27.11	27.94	30.20	31.39	29.58	29.86	28.10
24.34	29.03	27.41	29.97	27.91	29.43	27.19
23.55	31.68	25.85	32.93	26.61	26.78	31.15
22.96	29.78	29.26	26.45	29.51	32.55	29.06
22.85	32.06	31.79	26.22	29.55	30.40	30.79
27.93	24.90	26.27	28.09	23.97	31.75	26.04

28.10	28.90	27.92	30.43	32.33	28.67	33.07
27.65	27.31	26.13	30.67	30.31	31.09	28.24
21.74	25.20	30.85	26.69	27.63	32.24	32.05
20.85	26.52	23.83	29.49	27.75	27.54	27.92
25.44	25.14	34.52	29.14	29.20	27.73	30.76
24.35	25.38	26.08	30.30	25.02	31.87	34.23
26.67	28.35	24.54	28.96	30.03	25.68	27.59
21.72	26.45	27.30	28.84	30.20	32.04	26.64
22.43	31.42	26.81	32.04	27.42	32.53	28.36
30.15	28.14	26.28	28.68	28.05	30.24	31.25
26.58	24.89	27.63	28.48	27.27	29.75	29.23
26.98	24.73	29.75	28.53	27.93	30.95	29.20
26.35	25.19	28.11	29.29	26.98	27.96	29.98
28.87	26.21	34.97	29.41	28.48	26.32	29.83
28.00	28.35	28.56	32.17	30.53	29.35	34.32
27.25	25.50	22.98	25.26	29.11	33.02	30.12
27.61	26.31	29.32	26.60	28.00	30.24	31.74
24.48	29.88	31.34	33.03	27.23	27.73	27.54
24.97	22.99	27.41	26.12	29.08	30.19	29.76
27.30	23.73	28.60	29.71	31.26	28.68	29.65
25.75	28.85	31.29	26.35	29.51	32.42	27.56
24.48	25.24	27.62	28.67	29.15	32.94	32.59
24.38	27.45	26.46	30.55	34.70	28.32	27.63
25.02	22.71	22.79	31.05	29.08	32.63	30.11
29.41	23.82	34.01	30.26	26.02	24.57	28.17
25.42	27.52	26.85	28.39	27.04	30.76	27.04
22.44	28.40	23.51	28.66	26.77	30.44	31.97
24.66	29.40	32.05	33.06	29.96	33.12	30.47
24.44	28.03	24.18	28.96	28.17	32.75	28.20
30.98	29.12	26.44	27.49	34.06	30.61	32.54
26.41	26.26	29.45	35.24	25.86	34.12	23.94
27.24	23.75	27.81	30.44	27.85	29.87	31.57
24.57	30.14	31.02	27.36	27.99	32.58	28.39
30.22	29.29	22.67	31.41	31.87	34.01	
26.48	26.48	25.45	27.53	28.19	34.28	
29.87	36.48	20.54		28.39	33.40	
27.51	30.92	30.78		41.87	31.40	
26.40	25.57	29.57		32.27	26.65	
24.72	30.86	26.61		31.00	28.08	

26.20	24.60	28.16		29.62	33.75	
28.20	27.83	27.13		29.46	29.07	
26.55	21.33	27.81		29.55	33.56	
24.68	24.13	23.44		27.77	26.50	
21.19	20.18	25.16		31.79	29.87	
24.41	27.10	30.97		32.84	31.75	
26.88	26.97			29.73	26.01	
24.82	24.40			26.86	28.08	
25.87	27.86			33.39	31.03	
28.57	31.47			30.79	32.15	
27.61	29.77			33.89	28.93	
26.35	26.65				35.38	
29.24	26.15					
26.16	28.23					
27.92	26.01					
30.98						
28.05						
24.58						
28.16						
20.69						
25.54						
21.70						
25.27						
21.63						
24.85						
26.44						
23.85						
25.77						
24.35						
24.78						
28.04						
26.17						
23.81						
27.94						
25.13						
28.65						
25.12						
26.60						
22.42						
24.08						

21.01						
Average						
24.67	26.85	26.84	28.95	29.11	29.86	29.85

Table 10: P-value of Correlation Coefficients at Island Park Drive E-N

	Initial Speed	Final Speed	Utilization Rate	Deceleration rate
Initial Speed	NA	< 0.001	< 0.001	< 0.001
Final Speed	< 0.001	NA	0.2067	0.0518
Utilization Rate	< 0.001	0.2067	NA	0.0143
Deceleration Rate	< 0.001	0.0518	0.0143	NA

Table 11: P-value of Correlation Coefficients at Parkdale Avenue W-NS

	Initial Speed	Final Speed	Utilization Rate	Deceleration rate
Initial Speed	NA	< 0.001	0.0086	< 0.001
Final Speed	< 0.001	NA	< 0.001	0.1000
Utilization Rate	0.0086	< 0.001	NA	0.0359
Deceleration Rate	< 0.001	0.1000	0.0359	NA

Table 12: P-value of Correlation Coefficients at Bronson Avenue W-NS

	Initial Speed	Final Speed	Utilization Rate	Deceleration rate
Initial Speed	NA	< 0.001	0.0251	< 0.001
Final Speed	< 0.001	NA	< 0.001	0.0137
Utilization Rate	0.0251	< 0.001	NA	< 0.001
Deceleration Rate	< 0.001	0.0137	< 0.001	NA

Table 13: P-value of Correlation Coefficients at Moodie Drive W-NS

	Initial Speed	Final Speed	Utilization Rate	Deceleration rate
Initial Speed	NA	< 0.001	0.3137	< 0.001
Final Speed	< 0.001	NA	0.0213	0.0316
Utilization Rate	0.3137	0.0213	NA	< 0.001
Deceleration Rate	< 0.001	0.0316	< 0.001	NA

Table 14: P-value of Correlation Coefficients at Terry Fox Drive E-NS

	Initial Speed	Final Speed	Utilization Rate	Deceleration rate
Initial Speed	NA	< 0.001	0.3490	< 0.001
Final Speed	< 0.001	NA	< 0.001	0.4741
Utilization Rate	0.3490	< 0.001	NA	< 0.001
Deceleration Rate	< 0.001	0.4741	< 0.001	NA

Table 15: P-value of Correlation Coefficients at Carp Road E-NS

	Initial Speed	Final Speed	Utilization Rate	Deceleration rate
Initial Speed	NA	< 0.001	< 0.001	< 0.001
Final Speed	< 0.001	NA	0.3366	0.4791
Utilization Rate	< 0.001	0.3366	NA	< 0.001
Deceleration Rate	< 0.001	0.4791	< 0.001	NA

Table 16: P-value of Correlation Coefficients at Terry Fox Drive W-NS

	Initial Speed	Final Speed	Utilization Rate	Deceleration rate
Initial Speed	NA	< 0.001	0.3371	< 0.001
Final Speed	< 0.001	NA	0.0039	< 0.001
Utilization Rate	0.3371	0.0039	NA	< 0.001
Deceleration Rate	< 0.001	< 0.001	< 0.001	NA

Table 17: P-value of Correlation Coefficients of All Sites Combined Dataset W-

	Initial Speed	Final Speed	Utilization Rate	Deceleration rate
Initial Speed	NA	< 0.001	0.4287	< 0.001
Final Speed	< 0.001	NA	0.1116	< 0.001
Utilization Rate	0.4287	0.1116	NA	< 0.001
Deceleration Rate	< 0.001	< 0.001	< 0.001	NA

Appendix 4: Initial Speeds ANOVA Test at Study Sites.

Anova: Single Factor

ALL SCLs

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Island Park Drive (E-N)	85.000	1748.977	20.576	4.675
Parkdale Ave. (W-NS)	90.000	2096.289	23.292	5.504
Bronson Ave. (W-NS)	90.000	2176.938	24.188	5.067
Moodie Drive (W-NS)	85.000	2412.660	28.384	6.630
Terry Fox Drive (E-NS)	114.000	3267.331	28.661	5.716
Carp Road (E-NS)	98.000	2867.162	29.257	5.862
Terry Fox Drive (W-NS)	76.000	2241.900	29.499	8.264

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	6637.774	6.000	1106.296	187.414	< 0.001	2.113
Within Groups	3724.757	631.000	5.903			
Total	10362.531	637.000				

Anova: Single Factor

Remove Island Park Drive (E-N)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Parkdale Ave. (W-NS)	90.000	2096.289	23.292	5.504
Bronson Ave. (W-NS)	90.000	2176.938	24.188	5.067
Moodie Drive (W-NS)	85.000	2412.660	28.384	6.630
Terry Fox Drive (E-NS)	114.000	3267.331	28.661	5.716
Carp Road (E-NS)	98.000	2867.162	29.257	5.862
Terry Fox Drive (W-NS)	76.000	2241.900	29.499	8.264

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	3368.676	5.000	673.735	110.602	< 0.001	2.230
Within Groups	3332.066	547.000	6.092			
Total	6700.742	552.000				

Anova: Single Factor

**Remove Parkdale Ave.
(W-NS)**

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Bronson Ave. (W-NS)	90.000	2176.938	24.188	5.067
Moodie Drive (W-NS)	85.000	2412.660	28.384	6.630
Terry Fox Drive (E-NS)	114.000	3267.331	28.661	5.716
Carp Road (E-NS)	98.000	2867.162	29.257	5.862
Terry Fox Drive (W-NS)	76.000	2241.900	29.499	8.264

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	1695.489	4.000	423.872	68.304	< 0.001	2.391
Within Groups	2842.190	458.000	6.206			
Total	4537.679	462.000				

Anova: Single Factor

**Remove Bronson
Ave. (W-NS)**

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Moodie Drive (W-NS)	85.000	2412.660	28.384	6.630
Terry Fox Drive (E-NS)	114.000	3267.331	28.661	5.716
Carp Road (E-NS)	98.000	2867.162	29.257	5.862
Terry Fox Drive (W-NS)	76.000	2241.900	29.499	8.264

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	68.612	3.000	22.871	3.529	0.015	2.629
Within Groups	2391.265	369.000	6.480			
Total	2459.877	372.000				

Anova: Single Factor

**Remove Moodie
Drive (W-NS)**

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Terry Fox Drive (E-NS)	114	3267.331	28.661	5.716
Carp Road (E-NS)	98	2867.162	29.2568	5.862
Terry Fox Drive (W-NS)	76	2241.9	29.499	8.264

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	36.411	2	18.205	2.828557	0.061	3.027
Within Groups	1834.347	285	6.436			
Total	1870.758	287				

Appendix 5: FRL and Diverge Speeds ANOVA Test at Each Site.

Anova: Single
Factor

Island Park Drive (E-N)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Diverge Speed	85.00	1748.98	20.58	4.67
RL Speed	154.00	3799.92	24.67	7.52

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	920.06	1.00	920.06	141.35	< 0.001	3.88
Within Groups	1542.66	237.00	6.51			
Total	2462.72	238.00				

Anova: Single
Factor

**Parkdale Ave.
(W-NS)**

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Diverge Speed	90.00	2094.91	23.28	5.47
RL Speed	128.00	3436.87	26.85	8.51

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	674.89	1.00	674.89	93.04	< 0.001	3.88
Within Groups	1566.84	216.00	7.25			
Total	2241.73	217.00				

Anova: Single
Factor

**Bronson Ave.
(W-NS)**

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Diverge Speed	90.00	2182.82	24.25	5.20
RL Speed	119.00	3194.01	26.84	8.63

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	342.91	1.00	342.91	47.92	< 0.001	3.89
Within Groups	1481.17	207.00	7.16			
Total	1824.07	208.00				

Anova: Single
Factor

**Moodie Drive
(W-NS)**

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Diverge Speed	85.00	2410.26	28.36	6.20
RL Speed	109.00	3155.14	28.95	5.25

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	16.64	1.00	16.64	2.93	0.09	3.89
Within Groups	1088.53	192.00	5.67			
Total	1105.17	193.00				

Anova: Single Factor

Terry Fox Drive (E-NS)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Diverge Speed	114.00	3301.99	28.96	4.98
RL Speed	124.00	3610.00	29.11	6.75

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	1.30	1.00	1.30	0.22	0.64	3.88
Within Groups	1392.10	236.00	5.90			
Total	1393.40	237.00				

Anova: Single Factor

Carp Road (E-NS)

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Diverge Speed	98.00	2899.47	29.59	5.46
RL Speed	125.00	3733.07	29.86	6.17

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	4.25	1.00	4.25	0.73	0.40	3.88
Within Groups	1294.51	221.00	5.86			
Total	1298.76	222.00				

Anova: Single
Factor

**Terry Fox
Drive (W-NS)**

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Diverge Speed	76.00	2255.54	29.68	8.31
RL Speed	107.00	3193.81	29.85	5.78

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit</i>
Between Groups	1.29	1.00	1.29	0.19	0.66	3.89
Within Groups	1236.50	181.00	6.83			
Total	1237.80	182.00				

Appendix 6: Multiple Linear Regression of Deceleration Used in MCS.

Table 18: Deceleration Regression at Island Park Drive (E-N).

<i>Regression Statistics</i>	
Multiple R	0.970
R Square	0.940
Adjusted R Square	0.938
Standard Error	0.071
Observations	85.000

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3.000	6.478	2.159	423.390	0.000
Residual	81.000	0.413	0.005		
Total	84.000	6.891			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	0.040	0.076	0.527	0.599	-0.112	0.192	-0.112	0.192
Initial Speed	0.557	0.016	35.410	<0.001	0.525	0.588	0.525	0.588
Final Speed Utilization	-0.530	0.015	-35.014	<0.001	-0.560	-0.499	-0.560	-0.499
Rate	-0.944	0.060	-15.764	<0.001	-1.063	-0.825	-1.063	-0.825

Table 19: Deceleration Regression at Parkdale Ave. (W-NS).

<i>Regression Statistics</i>	
Multiple R	0.981
R Square	0.963
Adjusted R Square	0.961
Standard Error	0.070
Observations	90.000

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3.000	10.977	3.659	736.389	0.000
Residual	86.000	0.427	0.005		
Total	89.000	11.404			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	0.046	0.089	0.510	0.611	-0.132	0.223	-0.132	0.223
Initial Speed	0.313	0.007	46.858	<0.001	0.299	0.326	0.299	0.326
Final Speed Utilization	-0.273	0.007	-40.472	<0.001	-0.286	-0.259	-0.286	-0.259
Rate	-2.215	0.105	-21.185	<0.001	-2.423	-2.007	-2.423	-2.007

Table 20: Deceleration Regression atBronson Ave. (W-NS).

<i>Regression Statistics</i>	
Multiple R	0.963
R Square	0.927
Adjusted R Square	0.924
Standard Error	0.108
Observations	90.000

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3.000	12.709	4.236	362.307	0.000
Residual	86.000	1.006	0.012		
Total	89.000	13.715			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	-0.289	0.142	-2.040	0.044	-0.571	-0.007	-0.571	-0.007
Initial Speed	0.225	0.007	31.127	< 0.001	0.211	0.240	0.211	0.240
Final Speed	-0.162	0.006	-26.147	< 0.001	-0.175	-0.150	-0.175	-0.150
Utilization Rate	-2.024	0.129	-15.709	< 0.001	-2.280	-1.768	-2.280	-1.768

Table 21: Deceleration Regression at Moodie Drive (W-NS).

<i>Regression Statistics</i>	
Multiple R	0.964
R Square	0.929
Adjusted R Square	0.926
Standard Error	0.048
Observations	85.000

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3.000	2.385	0.795	351.897	0.000
Residual	81.000	0.183	0.002		
Total	84.000	2.568			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	0.060	0.061	0.984	0.328	-0.061	0.180	-0.061	0.180
Initial Speed	0.184	0.006	29.793	< 0.001	0.172	0.197	0.172	0.197
Final Speed	-0.173	0.006	-27.695	< 0.001	-0.185	-0.160	-0.185	-0.160
Utilization Rate	-0.693	0.039	-17.651	< 0.001	-0.772	-0.615	-0.772	-0.615

Table 22: Deceleration Regression at Terry Fox Drive (E-NS).

<i>Regression Statistics</i>	
Multiple R	0.939
R Square	0.882
Adjusted R Square	0.878
Standard Error	0.071
Observations	114.000

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3.000	4.090	1.363	273.165	0.000
Residual	110.000	0.549	0.005		
Total	113.000	4.639			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	-0.090	0.083	-1.089	0.279	-0.254	0.074	-0.254	0.074
Initial Speed	0.146	0.006	25.156	< 0.001	0.135	0.158	0.135	0.158
Final Speed	-0.127	0.005	-23.198	< 0.001	-0.137	-0.116	-0.137	-0.116
Utilization Rate	-0.798	0.040	-20.148	< 0.001	-0.877	-0.720	-0.877	-0.720

Table 23: Deceleration Regression at Carp Road (E-NS).

<i>Regression Statistics</i>	
Multiple R	0.937
R Square	0.878
Adjusted R Square	0.874
Standard Error	0.069
Observations	98.000

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3.000	3.164	1.055	224.718	0.000
Residual	94.000	0.441	0.005		
Total	97.000	3.605			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	0.104	0.087	1.196	0.235	-0.069	0.278	-0.069	0.278
Initial Speed	0.128	0.006	21.692	< 0.001	0.116	0.140	0.116	0.140
Final Speed	-0.118	0.006	-18.800	< 0.001	-0.131	-0.106	-0.131	-0.106
Utilization Rate	-0.639	0.033	-19.486	< 0.001	-0.704	-0.574	-0.704	-0.574

Table 24: Deceleration Regression at Terry Fox Drive (W-NS)

<i>Regression Statistics</i>	
Multiple R	0.918
R Square	0.843
Adjusted R Square	0.837
Standard Error	0.103
Observations	76.000

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	3.000	4.141	1.380	128.994	0.000
Residual	72.000	0.770	0.011		
Total	75.000	4.911			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	-0.180	0.128	-1.398	0.166	-0.436	0.076	-0.436	0.076
Initial Speed	0.152	0.009	16.843	< 0.001	0.134	0.170	0.134	0.170
Final Speed	-0.131	0.009	-13.938	< 0.001	-0.150	-0.112	-0.150	-0.112
Utilization Rate	-0.801	0.060	-13.288	< 0.001	-0.921	-0.681	-0.921	-0.681

Table 25: Deceleration Regression Using All Sites Combined Data

SUMMARY OUTPUT

<i>Regression Statistics</i>	
Multiple R	0.922
R Square	0.849
Adjusted R Square	0.848
Standard Error	0.150
Observations	638.000

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	4.000	80.690	20.173	891.270	0.000
Residual	633.000	14.327	0.023		
Total	637.000	95.017			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	0.547	0.051	10.773	< 0.001	0.447	0.646	0.447	0.646
Initial Speed	0.189	0.004	46.760	< 0.001	0.181	0.197	0.181	0.197
Final Speed	-0.169	0.003	-48.542	< 0.001	-0.176	-0.163	-0.176	-0.163
Utilization Rate	-0.835	0.036	-23.070	< 0.001	-0.906	-0.764	-0.906	-0.764
SCL Length	-0.002	0.000	-25.622	< 0.001	-0.002	-0.002	-0.002	-0.002

Appendix 7: Diagnostics of the Regression

Deceleration Rates Used in MCS.

Island Park Drive (E-N)

Figure 1: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10.

Figure 2: Residuals Plot for Each Predicted Deceleration Rate Using Equation 5.10.

Figure 3: Residuals Histogram.

Parkdale Ave. (W-NS)

Figure 4: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10.

Figure 5: Residuals Plot for Each Predicted Deceleration Rate Using Equation 5.10.

Figure 6: Residuals Histogram.

Bronson Ave. (W-NS)

Figure 7: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10.

Figure 8: Residuals Plot for Each Each Predicted Deceleration Rate Using Equation 5.10.

Figure 9: Residuals Histogram.

Moodie Drive (W-NS)

Figure 10: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10.

Figure 11: Residuals Plot for Each Predicted Deceleration Rate Using Equation 5.10.

Figure 12: Residuals Histogram.

Terry Fox Drive (E-NS)

Figure 13: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10.

Figure 14: Residuals Plot for Each Predicted Deceleration Rate Using Equation 5.10.

Figure 15: Residuals Histogram.

Carp Road (E-NS)

Figure 16: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10.

Figure 17: Residuals Plot for Each Predicted Deceleration Rate Using Equation 5.10.

Figure 18: Residuals Histogram.

Terry Fox Drive (W-NS)

Figure 19: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10.

Figure 20: Residuals Plot for Each Predicted Deceleration Rate Using Equation 5.10.

Figure 21: Residuals Histogram.

All Sites Data Combined

Figure 22: Line of Equality between Reprocessed Deceleration Rate and Predicted Deceleration Rate Using Equation 5.10.

Figure 23: Residuals Plot for Each Predicted Deceleration Rate Using Equation 5.10.

Figure 24: Residuals Histogram.

Appendix 8: Multiple Linear Regression between Mean of the Parameters and Standard Deviation.

Table 26: Mean and Standard Deviations of Parameters at Each Site

v_i	Available L (SL)	v_{f85}	U	v_f	d	$Std(v_i)$	$Std(v_f)$	$Std(U)$	$Std(d)$
20.576	58.000	21.410	0.570	19.663	0.540	2.162	2.214	0.153	0.286
23.292	179.000	22.386	0.416	20.163	0.907	2.346	2.457	0.083	0.358
24.188	212.000	21.872	0.474	19.251	1.070	2.251	2.724	0.094	0.393
28.384	292.000	29.542	0.474	26.621	0.369	2.575	2.564	0.134	0.175
28.661	388.000	28.330	0.517	25.979	0.392	2.391	2.582	0.177	0.203
29.257	430.000	28.985	0.503	26.843	0.358	2.421	2.249	0.220	0.193
29.499	446.000	29.775	0.474	27.119	0.371	2.875	2.773	0.205	0.256

Table 27: Modeling Mean v_i

<i>Regression Statistics</i>	
Multiple R	0.990
R Square	0.980
Adjusted R Square	0.970
Standard Error	0.613
Observations	7.000

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression					
n	2.000	73.651	36.826	98.143	0.000
Residual	4.000	1.501	0.375		
Total	6.000	75.152			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	11.584	2.731	4.241	0.013	4.000	19.167	4.000	19.167
Available L	0.014	0.004	3.615	0.022	0.003	0.024	0.003	0.024
Vf85	0.413	0.140	2.953	0.042	0.025	0.801	0.025	0.801

Table 28: Modeling Mean v_f

<i>Regression Statistics</i>	
Multiple R	0.999
R Square	0.997
Adjusted R Square	0.996
Standard Error	0.235
Observations	7.000

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2.000	83.662	41.831	755.930	0.000
Residual	4.000	0.221	0.055		
Total	6.000	83.883			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	1.762	1.179	1.495	0.209	-1.511	5.036	-1.511	5.036
Vf85	0.967	0.025	38.306	0.000	0.897	1.037	0.897	1.037
StdVf	-1.310	0.457	-2.864	0.046	-2.580	-0.040	-2.580	-0.040

- *Mean U was found to have no relation with any of the parameters*

Table 29: Modeling Std (v_i) Using Mean v_f

<i>Regression Statistics</i>	
Multiple R	0.759
R Square	0.576
Adjusted R Square	0.492
Standard Error	0.167
Observations	7.000

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1.000	0.191	0.191	6.805	0.048
Residual	5.000	0.140	0.028		
Total	6.000	0.331			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>p-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	1.303	0.437	2.979	0.031	0.178	2.427	0.178	2.427
Vf	0.048	0.018	2.609	0.048	0.001	0.095	0.001	0.095

Table 30: Modeling Std (vi) Using Mean v85thf

<i>Regression Statistics</i>	
Multiple R	0.786
R Square	0.618
Adjusted R Square	0.541
Standard Error	0.159
Observations	7.000

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1.000	0.205	0.205	8.085	0.036
Residual	5.000	0.127	0.025		
Total	6.000	0.331			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	1.205	0.435	2.768	0.039	0.086	2.325	0.086	2.325
Vf85	0.047	0.017	2.843	0.036	0.005	0.090	0.005	0.090

- *Std(v_p) was found to have no relation with any of the parameters*
- *Std(U) was found to have no relation with any of the parameters*

Appendix 9: MCS Script.

Using Each Site's Data

```
function [adjusted_data] = InputPositive(filename, sheet, xlRange)

filename = '2013-09-16_Adjusted Data - Only positive Deceleration';
sheet = 7;
xlRange = 'R:U';
Lrange = 'M2';

%sheet: 1- Island Park, 2-Parkdale, 3-Bronson, 4-Moodie, 5-Terrfox E-
NS,
%6- Carp, 7- Terryfox W-NS

Data = xlsread(filename, sheet, xlRange); %data input
Limit = xlsread(filename, sheet, Lrange) %SCL length

X = [Data(:,2) Data(:,3) Data(:,4) Data(:,1)]; %Arranged data

Dec = mean(X(:,4)); % mean deceleration rate
Sd_Dec = std(X(:,4)); %std deceleration rate
IS = mean(X(:,1)); % mean Initial Speed
Sd_IS = std(X(:,1)); %std Initial Speed
FS = mean(X(:,2)); % Mean Final Speed
Sd_FS = std(X(:,2)); %Std Final Speed
Ut = mean(X(:,3)); %Mean Utilization Rate
Sd_Ut = std(X(:,3)); % Std Utilization Rate

Mean_X = [mean(X(:,2)) mean(X(:,3)) mean(X(:,4)) mean(X(:,1))]; %mean
values of variables

corr = corrcoef(X); %Correlation Ceof between all variables

V = [ones(size(X(:,2))) Data(:,2) Data(:,3) Data(:,4)]; %arranged data
for regression

V1= [Data(:,2) Data(:,3) Data(:,4)]; %arranged data to get correlation
matrix without deceleration rate values

corrV1 = corrcoef(V1); % correlation ceof. without deceleration rate

b = regress(Data(:,1),V);

runs = 150000; % number of simulation runs

% Monte Carlo Simulation of Diverge and Deceleration
```

```

% Input Data

% Random Number Generation
R_DS = rand(1,runs); % Random Numbers for DS
R_EOS = rand(1,runs); % Random Numbers for EOS
R_Ut = rand(1,runs); % Random Numbers for Utilization rate
All_Data=[R_DS' R_EOS' R_Ut']; % All data

% Convert random numbers to correlated random numbers
% Cholesky Decomposition
% upper_corr is an upper triangular matrix
U = All_Data * chol(corrV1); % Correlated random numbers
%U_start = U;
U(U(:,1) > 1,:) = [];
U(U(:,2) > 1,:) = [];
U(U(:,3) > 1,:) = [];
U(U(:,1) < 0,:) = [];
U(U(:,2) < 0,:) = [];
U(U(:,3) < 0,:) = [];
U(:,1) = norminv(U(:,1),IS,Sd_IS);
U(:,2) =norminv(U(:,2),FS,Sd_FS) ;
U(:,3) =norminv(U(:,3),Ut,Sd_Ut) ;
U(U(:,1) < 0,:) = []; % remove negative diverge speed
U(U(:,2) < 0,:) = []; % remove negative final speed
U(U(:,3) < 0,:) = []; % remove Negative Utilization
U(:,4) = b(1,:) + b(2,:)*U(:,1)+b(3,:)*U(:,2)+b(4,:)*U(:,3);
U(:,5) = ((U(:,1).^2)-(U(:,2).^2))./(2*U(:,4)); % Length
U(:,8) = U(:,5)./U(:,3);
U(U(:,5) < 0,:) = []; %removing negative lengths
U(:,6) = U(:,1)-U(:,2);
U(U(:,6) < 0,:) = []; % remove any negative speed difference
U(U(:,4) > mean(U(:,4))+ 1.96*std(U(:,4)),:) = [];
U(U(:,4) < mean(U(:,4))- 1.96*std(U(:,4)),:) = [];
U(U(:,3) > mean(U(:,3))+ 1.96*std(U(:,3)),:) = [];
U(U(:,3) < mean(U(:,3))- 1.96*std(U(:,3)),:) = [];
U(U(:,6) > mean(U(:,6))+ 1.96*std(U(:,6)),:) = [];
U(U(:,6) < mean(U(:,6))- 1.96*std(U(:,6)),:) = [];
U(U(:,3) < min(X(:,3)) ,:) = []; %remove any utilization rate less than
the minimum at every site
U(U(:,4) < min (X(:,4)),:) = []; %remove any deceleration rate less
than the minimum at every site
X = U(:,8) > Limit; %identify failures, Demand length exceeding actual
length of the SCL
X(X(:,1) < 1,:)= []; % Remove successions
length(X)/length(U) % Probability of Noncompliance

end

```


Using All Sites Combined Data

```
function [adjusted_data] = InputAllSCLs_LongDecl(filename, sheet,
xlRange)

filename = '2013-09-16_Adjusted Data - Only positive Deceleration';
sheet = 8;
xlRange = 'AC:AG';

%sheet: 1- Island Park, 2-Parkdale, 3-Bronson, 4-Moodie, 5-Terrfox E-
NS,
%6- Carp, 7- Terryfox W-NS

Data = xlsread(filename, sheet, xlRange); %data input

X = [Data(:,2) Data(:,3) Data(:,4) Data(:,5) Data(:,1)]; %Arranged data

L = --; % Available SCL Length (Input that depends on the site)

FS = -- ; % Mean Final Speed at site (Input that depends on the Site)
Sd_FS = --; %Std Final Speed at site (Input that depends on the Site)
IS = 29.0847; % mean Initial Speed @ long lanes;
Sd_IS = 2.472; %std Initial Speed @ long lanes
Ut = mean(X(:,3)); %Mean Utilization Rate
Sd_Ut = std(X(:,3)); % Std Utilization Rate

corr = corrcoef(X); %Correlation Ceof between all variables

V = [ones(size(X(:,2))) X(:,2) X(:,3) X(:,4)]; %arranged data for
regression

V1= [X(:,1) X(:,2) X(:,3)]; %arranged data to get correlation matrix
without deceleration rate values

corrV1 = corrcoef(V1); % correlation ceof. without deceleration rate

b = regress(X(:,5),V);

runs = 150000; % number of simulation runs

% Monte Carlo Simulation of Diverge and Deceleration
```

```

% Input Data

% Random Number Generation
R_DS = rand(1,runs);    % Random Numbers for DS
R_EOS = rand(1,runs);   % Random Numbers for EOS
R_Ut = rand(1,runs);    % Random Numbers for Utilization rate

All_Data=[R_DS' R_EOS' R_Ut']; % All data

% Convert random numbers to correlated random numbers
% Cholesky Decomposition
% upper_corr is an upper triangular matrix
U = All_Data * chol(corrV1); % Correlated random numbers
%U_start = U;
U(U(:,1) > 1,:) = [];
U(U(:,2) > 1,:) = [];
U(U(:,3) > 1,:) = [];

U(U(:,1) < 0,:) = [];
U(U(:,2) < 0,:) = [];
U(U(:,3) < 0,:) = [];

U(:,1) = norminv(U(:,1),IS,Sd_IS);
U(:,2) =norminv(U(:,2),FS,Sd_FS) ;
U(:,3) =norminv(U(:,3),Ut,Sd_Ut) ;

U(U(:,1) < 0,:) = []; % remove negative diverge speed
U(U(:,2) < 0,:) = []; % remove negative final speed
U(U(:,3) < 0,:) = []; % remove Negative Utilization

U(:,5) = b(1,:)+ b(2,:)*U(:,2)+b(3,:)*U(:,3)+b(4,:)*L;
U(:,6) = ((U(:,1).^2)-(U(:,2).^2))./(2*U(:,5)); % Length
U(U(:,6) < 0,:) = []; %removing negative lengths
U(:,7) = U(:,1)-U(:,2);
U(U(:,7) < 0,:) = []; % remove any negative speed difference
U(U(:,5) > mean(U(:,5))+ 1.96*std(U(:,5)),:) = [];
U(U(:,5) < mean(U(:,5))- 1.96*std(U(:,5)),:) = [];
U(U(:,3) > mean(U(:,3))+ 1.96*std(U(:,3)),:) = [];
U(U(:,3) < mean(U(:,3))- 1.96*std(U(:,3)),:) = [];
U(U(:,7) > mean(U(:,7))+ 1.96*std(U(:,7)),:) = [];
U(U(:,7) < mean(U(:,7))- 1.96*std(U(:,7)),:) = [];
U(U(:,3) < min(X(:,3)) ,:) = []; %remove any utilization rate less than
the minimum at all site
U(U(:,5) < min (X(:,5)),:) = []; %remove any deceleration rate less
than the minimum at all site
U(:,8) = U(:,6)./U(:,3);
M = U(:,8) > L; %identify failures, Demand length exceeding actual
length of the SCL
M(M(:,1) < 1,:)= []; % Remove successions
length(M)/length(U) % Probability of Noncompliance

end

```

Appendix 10: FORM Script.

Using Each Site's Data

```
function b = ell(x,MS,C_inv)

A = x - MS;

b = sqrt(A'*C_inv*A);


function [LS,c] = limit_state(L,x)

c = [];

LS = L - ((x(1)^2-x(2)^2)/(2*x(3)*x(4)));


%ellipsoid approach on all limited SCLs

% x(1) = initial or diverge speed at the SCL
% x(2) = final or end speed at the SCL
% x(3) = Deceleration rate
%M_x(1) = mean initial or diverge speed at the SCL
%M_x(2) = mean final or end speed at the SCL
%M_x(3) = mean deceleration rate at the SCL
%M_x(4) = mean Utilization rate at the SCL
%Sd_x(1) = std of initial or diverge speed at the SCL
%Sd_x(2) = std of final or end speed at the SCL
%Sd_x(3) = std of deceleration rate at the SCL
%Sd_x(4) = std of Utilization rate at the SCL
function [adjusted_data] = InputAll(filename, sheet, xlRange)

filename = '2013-09-16_Adjusted Data - Only positive Deceleration';
sheet = 7;
xlRange = 'R:U';
Lrange = 'M2';

%sheet: 1- Island Park, 2-Parkdale, 3-Bronson, 4-Moodie, 5-Terrfox E-
NS,
%6- Carp, 7- Terryfox W-NS

Data = xlsread(filename, sheet, xlRange) %data input
Limit = xlsread(filename, sheet, Lrange) %SCL length

X = [Data(:,2) Data(:,3) Data(:,1) Data(:,4)]; %Arranged data
```

```

M_x(1) = mean(X(:,1)); % mean Initial Speed
Sd_x(1) = std(X(:,1)); %std Initial Speed
M_x(2) = mean(X(:,2)); % Mean Final Speed
Sd_x(2) = std(X(:,2)); %Std Final Speed
M_x(3) = mean(X(:,3)); % mean deceleration rate
Sd_x(3) = std(X(:,3)); %std deceleration rate
M_x(4) = mean(X(:,4)); %Mean Utilization Rate
Sd_x(4) = std(X(:,4)); % Std Utilization Rate

%matrix of mean is MS
MV = [M_x(1) M_x(2) M_x(3) mean(X(:,4))]' ;
%Matrix of Std
Sd_MS = diag([Sd_x(1) Sd_x(2) Sd_x(3) Sd_x(4)]);
%Lower bound = LB, Upper Bound = UB

Ub = MV + 2*diag(Sd_MS);
Lb = MV - 2*diag(Sd_MS);

% Length of SCL
L=Limit

% correlation matrix

Cor = corrcoef(X); %Correlation Ceof between all variables

% Covariance matrix and inverse
C = Sd_MS*Cor*Sd_MS;
Cinv = inv(C);

C_inv = inv(C);

[x, b] = fmincon(@(x) ell(x,MV,C_inv),MV,[],[],[],[],[],Lb,Ub,@(x)
limit_state(L,x))

PNC = 1-normcdf(b)
end

```

Using All Sites Combined Data

```
function b = ell(x,MS,C_inv)

A = x - MS;

b = sqrt(A'*C_inv*A);


function [LS,c] = limit_state(L,x)

c = [];

LS = L - ((x(1)^2-x(2)^2)/(2*x(3)*x(4)));


%ellipsoid approach on all limited SCLs

% x(1) = initial or diverge speed at the SCL
% x(2) = final or end speed at the SCL
% x(3) = Deceleration rate
%M_x(1) = mean initial or diverge speed at the SCL
%M_x(2) = mean final or end speed at the SCL
%M_x(3) = mean deceleration rate at the SCL
%M_x(4) = mean Utilization rate at the SCL
%Sd_x(1) = std of initial or diverge speed at the SCL
%Sd_x(2) = std of final or end speed at the SCL
%Sd_x(3) = std of deceleration rate at the SCL
%Sd_x(4) = std of Utilization rate at the SCL
function [adjusted_data] = InputAll(filename, sheet, xlRange)

filename = '2013-09-16_Adjusted Data - Only positive Deceleration';
sheet = 8;
xlRange = 'AC:AG';


%sheet: 1- Island Park, 2-Parkdale, 3-Bronson, 4-Moodie, 5-Terrfox E-
NS,
%6- Carp, 7- Terryfox W-NS
```

```

Data = xlsread(filename, sheet, xlRange) %data input

X = [Data(:,2) Data(:,3) Data(:,1) Data(:,4)]; %Arranged data

M_x(1) = mean(X(:,1)); % mean Initial Speed
Sd_x(1) = std(X(:,1)); %std Initial Speed
M_x(2) = mean(X(:,2)); % Mean Final Speed
Sd_x(2) = std(X(:,2)); %Std Final Speed
M_x(3) = mean(X(:,3)); % mean deceleration rate
Sd_x(3) = std(X(:,3)); %std deceleration rate
M_x(4) = mean(X(:,4)); %Mean Utilization Rate
Sd_x(4) = std(X(:,4)); % Std Utilization Rate

%matrix of mean is MS
MV = [M_x(1) M_x(2) M_x(3) M_x(4)]';
%Matrix of Std
Sd_MS = diag([Sd_x(1) Sd_x(2) Sd_x(3) Sd_x(4)]);
%Lower bound = LB, Upper Bound = UB

Ub = MV + 2*diag(Sd_MS);
Lb = MV - 2*diag(Sd_MS);

% Length of SCL
L=446

% correlation matrix

Cor = corrcoef(X); %Correlation Ceof between all variables

% Covariance matrix and inverse
C = Sd_MS*Cor*Sd_MS;
Cinv = inv(C);

C_inv = inv(C);

[x, b] = fmincon(@(x) ell(x,MV,C_inv),MV,[],[],[],[],[],Lb,Ub,@(x)
limit_state(L,x))

PNC = 1-normcdf(b)
end

```

Appendix 11: MCS Design Application Script.

Using All Sites Combined Data

```
function [adjusted_data] = InputAllSCLs(filename, sheet, xlRange)

filename = '2013-09-16_Adjusted Data - Only positive Deceleration';
sheet = 8;
xlRange = 'AC:AG';

%sheet: 1- Island Park, 2-Parkdale, 3-Bronson, 4-Moodie, 5-Terrfox E-
NS,
%6- Carp, 7- Terryfox W-NS

Data = xlsread(filename, sheet, xlRange); %data input

X = [Data(:,2) Data(:,3) Data(:,4) Data(:,5) Data(:,1)]; %Arranged data

Vf = 31; %85th design gore/final speed (Input by Designer)
L = 400; %Design Length (Input by Designer)

Ut = mean(X(:,3)); %Mean Utilization Rate
Sd_Ut = std(X(:,3)); % Std Utilization Rate
IS = 29.0847; % mean Initial Speed @ long SCL lanes;
Sd_IS = 2.472; %std Initial Speed
Sd_FS = std(X(:,2)); %Std Final Speed
FS = 1.762404+0.967134*Vf-1.30991*Sd_FS % Mean Final Speed

corr = corrcoef(X); %Correlation Ceof between all variables

V = [ones(size(X(:,2))) X(:,1) X(:,2) X(:,3) X(:,4)]; %arranged data
for regression

V1= [X(:,1) X(:,2) X(:,3)]; %arranged data to get correlation matrix
without deceleration rate values

corrV1 = corrcoef(V1); % correlation ceof. without deceleration rate

b = regress(Data(:,1),V);

runs = 150000; % number of simulation runs

% Monte Carlo Simulation of Diverge and Deceleration

% Input Data
```

```

% Random Number Generation
R_DS = rand(1,runs);      % Random Numbers for DS
R_EOS = rand(1,runs);     % Random Numbers for EOS
R_Ut = rand(1,runs);      % Random Numbers for Utilization rate

All_Data=[R_DS' R_EOS' R_Ut']; % All data

% Convert random numbers to correlated random numbers
% Cholesky Decomposition
% upper_corr is an upper triangular matrix
U = All_Data * chol(corrV1); % Correlated random numbers
%U_start = U;
U(U(:,1) > 1,:) = [];
U(U(:,2) > 1,:) = [];
U(U(:,3) > 1,:) = [];

U(U(:,1) < 0,:) = [];
U(U(:,2) < 0,:) = [];
U(U(:,3) < 0,:) = [];

U(:,1) = norminv(U(:,1),IS,Sd_IS);
U(:,2) =norminv(U(:,2),FS,Sd_FS) ;
U(:,3) =norminv(U(:,3),Ut,Sd_Ut) ;

U(U(:,1) < 0,:) = []; % remove negative diverge speed
U(U(:,2) < 0,:) = []; % remove negative final speed
U(U(:,3) < 0,:) = []; % remove Negative Utilization

U(:,5) = b(1,:)+ b(2,:)*U(:,1)+b(3,:)*U(:,2)+b(4,:)*U(:,3)+b(5,:)*L;
U(:,6) = ((U(:,1).^2)-(U(:,2).^2))./(2*U(:,5)); % Length
U(U(:,6) < 0,:) = []; %removing negative lengths
U(:,7) = U(:,1)-U(:,2);
U(U(:,7) < 0,:)= []; % remove any negative speed difference
U(U(:,5) > mean(U(:,5))+ 1.96*std(U(:,5)),:) = [];
U(U(:,5) < mean(U(:,5))- 1.96*std(U(:,5)),:) = [];
U(U(:,3) > mean(U(:,3))+ 1.96*std(U(:,3)),:) = [];
U(U(:,3) < mean(U(:,3))- 1.96*std(U(:,3)),:) = [];

U(U(:,3) < min(X(:,3)) ,:) = []; %remove any utilization rate less than
the minimum at all site
U(U(:,5) < min (X(:,5)),:) = []; %remove any deceleration rate less
than the minimum at all site

U(:,8) = U(:,6)./U(:,3);

X = U(:,8) > L; %identify failures, Demand length exceeding actual
length of the SCL
X(X(:,1) < 1,:)= []; % Remove successions
length(X)/length(U) % Probability of Noncompliance

end

```

Appendix 12: Speed Profiles

Figure 25: Speed Profiles of Vehicles at Island Park Drive E-N

Figure 26: Speed Profiles of Vehicles at Parkdale Avenue W-NS.

Figure 27: Speed Profiles of Vehicles at Bronson Avenue W-NS.

Figure 28: Speed Profiles of Vehicles at Moodie Drive W-NS.

Figure 29: Speed Profiles of Vehicles at Terry Fox Drive E-NS.

Figure 30: Speed Profiles of Vehicles at Carp Road E-NS.

Figure 31: Speed Profiles of Vehicles at Terry Fox Drive W-NS.

Appendix 13: Frequency of Demand Length Output for MCS using the Dataset of Each Site.

Figure 32: Demand Length Histogram for Island Park Drive E-N.

Figure 33: Demand Length Histogram for Parkdale Avenue W-NS.

Figure 34: Demand Length Histogram for Bronson Avenue W-NS.

Figure 35: Demand Length Histogram for Moodie Drive W-NS.

Figure 36: Demand Length Histogram for Terry Fox Drive E-NS.

Figure 37: Demand Length Histogram for Carp Road E-NS.

Figure 38: Demand Length Histogram for Terry Fox Drive W-NS.