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Evaluation of Geometric Design Needs of Freeway Systems Based on Safety and Geometric Data

Eneliko Mujuni Mulokozi
University of Nevada, Las Vegas, mulokozi@unlv.nevada.edu

EVALUATION OF GEOMETRIC DESIGN NEEDS OF FREEWAY SYSTEMS BASED ON TRAFFIC AND GEOMETRIC DATA

By

Eneliko Mulokozi

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Hualiang Teng, Ph.D., Committee Chair

Moses Karakouzian, Ph.D., Committee Member

Alexander Paz, Ph.D., Committee Member

Mohamed Kaseko, Ph.D., Committee Member

Kaushik Ghosh, Ph.D., Graduate College Representative

Thomas Piechota, Ph.D., Interim Vice President for Research &
Dean of the Graduate College

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ABSTRACT

Evaluation of geometric design needs of freeway systems based on safety and Geometric data

By

Eneliko Mulokozi

Dr. Hualiang Teng, Advisory Committee Chair
Associate Professor of Civil Engineering
University of Nevada, Las Vegas

Freeways are arterial highways characterized by high levels of safety and high speed vehicular traffic. Access to and from the freeways is provided through ramps. Geometric elements making up freeway facilities include the roadway, median shoulders, grades, and ramps to and from the traveled way at selected locations, shoulders, radius of curvature, lane width, and speed-change lanes. With the increase of traffic using the freeway systems, there arises more traffic weaving movements within the elements making up the freeway systems. This causes traffic flow to compete at the limited spaces available and reduces safety performance of freeway system.

In studies on safety issues of freeway systems, geometric elements of freeways have been evaluated for their safety effects on crashes occurring on the freeways. These studies have included interchange spacing, number of through lanes, median shoulder width and type, ramp spacing, length of segment, speed change lanes, and lengths for limited and extended lanes. Their findings revealed that freeway safety issues are associated with freeway geometric characteristics. However, the previous studies did not consider the safety impact of all segment types on the crash frequency on freeways. This study observed four types of segments when a freeway is divided into segments with Exit

and Entry terminals. These segments were defined as EN-EN, EX-EX, EN-EX, EX-EN segments where "EX" stands for Exit from the freeway and "EN" stands for Entrance to the freeway. The study also extends types of weaving movements taking place in weaving segments.

Crash rate and severity models were developed in this study based on the data collected for every freeway segment type. A complete set of geometric data was included in the data for each freeway segment type. Models for individual freeway segment type (EN-EN, EX-EX, EN-EX, and EX-EN) were developed. The results indicated that for EN-EN segment type; only two freeway characteristics had an impact: median width and segment length. Wider median and long segments both reduced crash while they were insignificant for severity model.

For EX-EX segment type, the number of through lanes, median width, and AADT had an impact on average crash rate while for a severity model, only the number of through lanes had an impact. Specifically, it was found that, the number of through lanes reduced both average crash rate and high severity crashes when all through lanes were combined together. However, on individual segment type in a specific freeway, it was found that, the number of through lanes on I-15 increased average crash rate while they reduced average crash rate on I-215. Wider median reduced average crash rate while it increased high severity crashes. Traffic volume increased average crash rate while it was found insignificant on severity model. At a freeway level, EX-EX segment type reduced average crash rate compared to both I-215 and US95 while it reduced average crash rate for I-215 compared to I-15 and US95.

For EN-EX segment type, shoulder width had a significant impact on average crash rates while the number of through lanes, median width, length of segment, and curve radius indicated significant impact on severity crashes. Wider shoulders on I-15 reduced average crash rate. The number of through lanes increased high severity crashes when all number of lanes were combined together. However, on individual freeways, the number of through lanes on reduced high severity crashes while they were insignificant on I-215 and US95. Wider median increased high severity crashes when all freeways were combined together while they reduced high severity crashes on I-15. Long segment increased high severity crashes when all EN-EX segment type from all freeways was combined together. Segments with large radius of curvature reduced high severity crashes when all for combined freeways while they increased high severity crashes for I-15. At a freeway level, I-15 increased both average crash rate and high severity crashes compared to I-215 and US95.

For EX-EN segments, shoulder and AADT had a significant impact on average crash rate while the number of through lanes, median width, radius curvature and lane changes from ramp-to-freeway had a significant impact on severity crashes. Wider shoulder reduced average crash rate for combined data from all freeways but increased crash rate on I-215.Wider median increased high severity crashes for combined data from all freeways while they were insignificant on average crash rate models. Segments with large radius of curvature increased high severity crashes while it was insignificant on average crash rate model. Lane changes from ramp-to-freeway increased high severity crashes. AADT increased average crash rate while it was found insignificant on severity crashes.

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DEDICATION

To my wife Beatrice K. Mulokozi, My children Irene and Moses, and my mother Judith K. Mulokozi.

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CHAPTER 1 INTRODUCTION

1.1. Background

The Nevada traffic crash reports published by safety engineering division indicated that for year 2006 to 2010, a total of 287,359 crashes occurred. In year 2012, there were 51,664 crashes lower than the average of five year crashes. Detailing these crashes by severity level, the report indicated that, 235 fatal crashes, 18,675 injury crashes and 32,754 property damage crashes were recorded with respective percentages as 0.45% fatal, 36.15% injury, and 63.40% property damage, *NDOT*, (2010).

With respect to freeways, crash data obtained from NDOT indicated that a total of 1,661 crashes occurred on the freeway systems during the year 2010. Among these 12 (0.72%) crashes were fatal, 735 (44.25%) injury crashes and 914 (55.03%) property damage crashes. These data indicate that more severe crashes happened on freeways than on arterials, which need further investigation to improve safety performance. Different alternatives can be implemented to improve safety performance on freeways including increasing capacity at bottleneck locations, altering the geometrics to eliminate safety hazards, enhancing various attributes of the freeway environment (e.g., signing, pavement markings, illumination) to increase safety and driver convenience, *FHWA*, (2011). Among these alternatives, those on geometric design are fundamental. Different research activities have investigated the relationship of crashes on freeways to its geometric characteristics (Pilko *et al.*, 2007; Ray *et al.*, 2011; Fitzpatrick *et al.*, 2010; Abdel-Aty, 2009; Sarhan *et al.*, 2008; Golob *et al.*, 2004; Chen *et al.*, 2010; Qi *et al.*, 2007). Table 1 shows every reference with freeway characteristics studied.

Table 1: Previous studies with freeway characteristics

	Reference							
Freeway characteristics	Sarhan, *et al.*, 2008	Chen, *et al.*, 2009	Chen, *et al.*, 2010	Qi, *et al.*, 2007	Pilko, *et al.*, 2007	Golob *et al.*, 2004	Ray *et al.*, 2011	Fitzpatrick *et al.*, 2010
Length of segment	×			×				×
Acceleration lane	×							
Deceleration lane	×							
Number of lanes	×			×	×			
Traffic volume	×	×		×		×	×	
Type of weaving segments	×							
Speed limit		×						×
Length of deceleration lane		×						
Number of lanes on exit ramps		×						
Left-side off-ramp			×					
Right-side off-ramp			×					
Horizontal curvature				×				
Interchange spacing					×		×	
Shoulder width					×			
Lane change geometry						×		

Results from these studies lead to different recommendations to improve safety performance of freeways. For instance, Fitzapatrick *et al*., (2010) proposed updates to current Texas Department of Transportation guidelines on recommended distances between ramps. The same task was also conducted by Ray *et al*., (2011). In their study relationship between ramp spacing and safety was discussed for three ramp combinations: EN–EX, EN–EN and EX–EN where EX implies that a terminal is an exit (off-ramp) and EN implies an entry (on-ramp).

Instead of focusing on freeway segments between ramps or interchanges, weaving sections within the system were also investigated. Sarhan *et al.,* (2008) found that for two acceleration lane with the same length, extended acceleration lanes increases collision frequency compared to limited acceleration lanes. Deceleration lanes were also found to have the same trend. The study also incorporated risk factors defining two types of weaving movements (Types A and B). In Type A, a vehicle makes one lane change to reach the desired terminal and in Type B one of the two weaving maneuvers could be accomplished without any lane change. The results indicated that Type B had the highest crash frequency.

Review of literature indicated that some of the studies did not consider more freeway characteristics. For instance, Qi (2007) considered horizontal curve, length of roadway section and number of through lanes. Chang (2005) used the number of lanes, lane width, horizontal curvature, and vertical grades. Sarhan (2008) used length of segment, lengths of acceleration and deceleration lanes, number of lanes, and weaving section types: type A where each weaving vehicle makes one lane change to either enter or leave the facility, type B where one of the weaving vehicles accomplishes its movement without any lane change. In this study, more freeway characteristics are considered to evaluate geometric elements of the freeways leading to crash occurrence and provide appropriate recommendations. Four types of segments are considered in this study:

EN-EN, EX-EX, EN-EX, and EX-EN. In every segment two types of models are develop to explain the two types of crashes: crash rate and severity crashes. The study also covered types of weaving movements taking place in weaving sections.

1.2 Statement of the problem

A freeway is considered as a major highway infrastructure designed to achieve high mobility and transitioning on and off urban streets through ramps. Currently, high frequency of crashes occurred on the freeway systems in Las Vegas, Nevada caused by more traffic weaving movements as a result of increased traffic. This is attributed to traffic flows competing at the limited spaces of the weaving sections on freeways. Drivers using these systems require more spaces available for appropriate decision making to avoid crashes. In the event that spaces between segment terminals is not sufficient, the likelihood of crash occurrence increases because drivers do not have time to observe and make decisions of avoiding crashes.

So far, models that were developed to quantify safety issues of geometric risk factors use only general factors such as total number of lanes and traffic flows. Little attention is given to detailed investigation of the effect of detailed freeway geometric elements to crash frequency and severity. For instance, Highway Capacity Manual 2010 uses three geometric variables which indicate how many lane changes must be made by weaving vehicles to successfully complete their weaving maneuver: (1) minimum number of lane changes for vehicles moving from the ramp to the main facility, (2) minimum lane changes for vehicles moving from the main facility to the ramp, and (3) the minimum number of lanes from which a weaving maneuver may be completed with one lane change, or no lane change. These variables are related to safety issues; however they have not been investigated on their effect to freeway safety. This proposed study will identify geometric design issues on freeway systems in Las Vegas, Nevada, based on available safety data.

1.3 Research hypothesis

This study assumes that safety problems on freeway systems can be appropriately investigated by focusing on freeway segments between ramps. These segments are taken to be those located between the entry and exit to the terminals. Investigating geometrical elements on these segments will help understand the likely cause of crashes on freeways. One of the geometric elements assumed to cause crashes is the short length of segments defined by the space between entry and exit terminals. If the length on these segments is sufficient to allow drivers to observe and make decisions to avoid safety hazards, the likelihood of crash frequency occurring on the systems will be minimized.

Because of short lengths within these segments, it is further assumed that there are safety problems caused by vehicular traffic crossing each other for the purpose of either avoiding weaving vehicles or entering or exiting the facility. Segments involved in weaving movements are assumed to have geometric components which influence how movements are taking place and are likely to cause safety problems experienced within these segments. Specifically, three geometrical components related to weaving movements will be investigated and these are lane change from ramp-to-freeway, lane change from freeway-to-ramp and number of lanes involved in weaving movements.

The geometrical configurations of entry to and exit from the main facility are likely to result in safety issues. Freeway segments which have auxiliary lanes to allow drivers to plan ahead and make decision to enter the facility are assumed to have better safety performance compared to those segments which do not have auxiliary lanes. Finally, it is also assumed that there is insufficient number of lanes to accommodate growing number of traffic on freeways and such a condition may likely cause crashes.

1.4 Objectives

Since safety issues are associated with geometric elements of freeway systems, the aim of the study is to investigate geometric design leading to safety problems. This will be done by calibrating regression models to identify the geometric design factors that influence safety in the freeway systems in Las Vegas, Nevada. Different sets of regression models will be developed for different types of segments (EN-EN, EX-EX, EN-EX, and EX-EN). The developed models (crash rate models and crash severity models) will be compared to identify the geometric problems. Solutions to mitigate the geometric design problems will be proposed.

1.5 Study contributions

This study deals with the geometric design of freeways in Las Vegas, Nevada. Geometric design of freeways fundamentally influences the safety and mobility that the system can provide. Previous safety studies have used number of through lanes, length of segments, lane width, grades, horizontal curvature, lengths of acceleration and deceleration lanes, median and shoulder widths, and weaving types. These studies did not consider other important freeway characteristics. For instance, Highway Capacity Manual, 2010 uses three geometric variables which indicate how many lane changes must be made by weaving vehicles to successfully complete their weaving maneuver. These variables are minimum number of lane changes for vehicles moving from the ramp to the main facility, minimum lane changes for vehicles moving from the main facility to the ramp, and the minimum number of lanes from which a weaving maneuver may be completed with one lane change, or no lane change. They are related to safety issues; however they have not been investigated on their effect to freeway safety. Second, the observed segments in this study were categorized into four types of segments defined by terminal configurations (EN-EN, EX-EX, EN-EX, and EX-EN). The previous studies did not consider these types of segments. In this study, more freeway characteristics are considered to evaluate geometric elements of the freeways leading to crash occurrence and provide appropriate recommendations. The study also extends types of weaving movements taking place in weaving sections by including a variable defining the total number of lanes involved in weaving maneuvers and the number of lane changes for vehicles moving from ramp to freeways.

1.6 Organization of the report

There are six chapters included in this study. Problem statement, research hypothesis, study objectives and benefits are explained in Chapter 1. Chapter 2 reviews previous research activities specifically conducted on freeway systems including safety performance modeling approaches. Chapter 3 discusses study methodology where crash frequency and severity model specifications are detailed. Data collection is described in Chapter 4 whereas Chapter 5 discusses descriptive statistics and results of analysis. Finally, conclusions and recommendations are given in Chapter 6.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Freeways are controlled-access highways which are characterized by the highest safety level, absence of traffic signals and at-grade intersections, and no driveway access Roess, *et al*., (2011); AASHTO (2004). All entries to and exit from the freeways are provided by ramps. Generally, freeway geometric elements have been designed to facilitate efficient mobility while maintaining the required safety performance along the freeways. However, the increase in traffic leads to the decrease in safety performance of freeways geometric elements. It is therefore imperative that safety issues along freeways be investigated to maintain highest safety performance of the freeways. Safety performance along the freeways is the function of geometric elements of freeways, operation and traffic flow characteristics as well as roadway and environmental characteristics. This section reviews these characteristics with the main focus placed on safety performance of freeway geometric elements and statistical safety modeling approaches used in safety studies. The review is anticipated to provide a base in identifying safety problems specifically related to freeway systems, development of safety performance functions and recommends countermeasures to solve the identified problems.

2.2 Freeway safety performance and modeling

Freeways are designed exclusively for high-speed vehicular traffic with expected high level of traffic safety. Interaction between vehicles is mainly expected at the entrance to and from the main facility as well as within the segments defined by the spacing between the ramps. Vehicles entering the facility are required to accelerate and negotiate for sufficient gaps to merge with the vehicles on the main facility while exiting vehicles decelerate and enter the off-ramp to leave the main facility. To facilitate such operations, freeways are comprised of standard geometric elements to allow movements of traffic while maintaining safety. However, due to operation nature of vehicular traffic on freeways, safety performance on freeways is not always at the highest level and different research activities have been undertaken to investigate the effect on crashes of freeway geometrics, operation and roadway characteristics.

Sarhan, *et al*., (2008), conducted a study to evaluate the safety performance of freeways as influenced by the characteristics of speed-change lanes at the entrance and exit areas. Using data collected from 26 interchanges along highway 417 within the City of Ottawa, Ontario, Canada, the research group investigated the effects on collision frequencies occurred on the segments and on speed-change lanes of freeway geometric and operation features. Freeway geometric features included lengths of segments, acceleration and deceleration lanes as limited or extended lanes, number of lanes on the main facility, number of lanes of the two ramps bounding each segments and the type of weaving segments. Traffic volumes for main facility and at the entrance and exit ramps were also included. Using negative binomial modeling approach, the results indicated that increasing the lengths of both acceleration and deceleration lanes reduce crash frequencies as more time is available to motorists for correct decisions on merging and diverging tasks. Reduction in crash frequency was also true at locations were limited length of speed-change lanes was used compared to extended length. This implies that extended lanes are likely to be used as both acceleration and deceleration lanes which may increase the collision. It is also true that unfamiliar drivers may have impression that the number of lanes spans to both terminals, a situation which may subject them to risk factors.

They further investigated the effect on collision frequencies resulting from the type of weaving movements experienced on the weaving segments. Weaving movements were classified as Type A, where each weaving vehicle makes one lane change for successful completion of maneuver and Type B in which one of the two weaving maneuvers could be accomplished without making any lane change while a maximum of one lane – change is required by the other weaving vehicle. Modeling results indicated that weaving type A was safer compared to weaving type B.

The number and arrangement of lanes on freeway exit ramps also associated with safety performance of freeway diverge areas. For instance, Chen, *et al*., (2009) used data collected on 343 freeway segments in the state of Florida to conduct an investigation on how the configurations of freeway exit ramps could affect their safety performance. In this case an observation unit was interpreted as a diverge area segments which contained a deceleration lane and an exit ramp which span distances of 1500ft and 100ft upstream and downstream of painted nose respectively. Exit ramps were classified as single lane with tapered design (Type 1), single lane with outer lane of main facility dropped at the exit gore (Type 2), two-lane exit ramp with an optional lane to either exit or continue on the main facility (Type 3), and two-lane exit with an outer lane of the main facility dropped at the exit gore including a taper (Type 4). Crash frequency and rate as well as crash severity were investigated using t-test, proportionality test and regression analysis were used as statistical tools.

Results of proportionality test indicated that the number and arrangement of lanes on freeway exit ramps does not affect crash severity in a significant way. Furthermore, the t-test indicated that Type 2 exit ramps (not lane-balanced) had significantly higher frequency and crash rates as compared to Type 1 exit ramps (lane-balanced). Also Type 4 exit ramps (not lane-balanced) had significantly higher crash frequency and crash rates as compared to Type 3 exit ramps (lane-balanced). This implied that using lane-balanced exit ramps improved safety performance at these areas. Using regression analysis, it was shown that an increase in freeway AADT and ramp AADT, deceleration lane length increased number of crashes while increase in posted speed limit decreased crash counts. Using the same approach it was further shown that lane-balanced exit ramps had lower crash frequency compared to none lane-balanced exit ramps.

Chen, *et al*., (2010) continued to investigate safety of freeway diverge areas by evaluating safety performance of left-side off-ramps. Specifically, the study examined the impacts of left-side off-ramps at the freeway diverging areas by using traffic conflict approach and evaluated the safety performance of the same areas by comparing with the right-side off-ramps. Further, the study identified the contributing factors to crashes at selected freeway segments. Using the same statistical approach, conflict study results showed that conflict rates at the locations with two exclusive off-ramps are slightly higher than the location with the optional lane. Cross-sectional comparisons results showed that the left-side off-ramps have higher average crash counts, crash rates and percentage of severe crashes. At t-test indicated that only crash severity for left side exit ramps is significantly different with the right side diverge areas at selected freeway segments. A crash prediction model indicated that increasing freeway AADT, ramp

AADT and length of deceleration lane would increase crash counts while increasing ramp length would reduce the potential crash counts for both left-side and right-side diverge areas.

Gore area is another location in freeway systems known to affect safety and operational performance of freeways especially when a driver is in its vicinity. It is described as a triangular piece of land found where roads merge or split and they are intended to help organize and protect traffic when cars are entering or exiting the highway, Wikipedia (2013). When a driver approaches these areas, a large amount of directional information must be processed for a short period of time to avoid unpredictable maneuvers resulting from driver indecisiveness, FHWA-RD-97-095, (1997); Lunenfeld (1993) showed that drivers increase the chance of making errors when they are to maneuver in the vicinity of the gore areas. Hakkert, *et al*., (1998), showed that the use of bollard devices help to reduce erratic vehicle maneuvers at highway exits by 60% in daytime and up to 65% at night time.

Qi, *et al.*, (2007) further conducted an investigation on geometric variables mainly located of the main facility. These included horizontal curvature, number of lanes, and length of roadway section. The study also included traffic flow defined as the hourly volume per lane and weather characteristics variables. Using data collected from Hampton roads, southeast Virginia and random effects ordered probit models were developed, their results of which indicated that crash rates are very high at low levels of congestion, and decreases rapidly with increasing V/C ratio which then gradually increase at peak levels of congestion. The number of lanes was found significant and in the case of horizontal curve, the percentage of horizontal curve in a road section will affect the traffic accident likelihood with respect to unfamiliar drivers.

Chang (2005) considered numbers of lanes, lane width, horizontal curvature, vertical grade and AADT and developed Negative binomial and artificial neural network models. The results indicated that an increase in the number of lanes increases accident likelihood because the total amount of lane changing as well as conflicts between traffic will increase. Freeway sections with grade equal to 3% or greater were found to increase the accident likelihood when compared to level sections. The results of horizontal curve showed that there is a reduction in accident likelihood with degree of curvature greater than six degrees. It was further revealed that the more closely interchanges are, the more crash frequency is experienced. Lastly it was also indicated that as AADT increases, crash frequency is more likely to occur.

O'Cinneide (1998) is a study that reviewed the literature from different countries that dealt with the impacts of geometric design on roadway safety. The review included all types of roads and different geometric features. For example, it reviewed the study that investigated the impact of passing lane on two or three lane roads. It also reviewed the study on the impact of the number of lane on safety on two lane highways. It indicates that significant difference would result from modification of road alignments.

Realizing the tradeoff between access and safety by building an interchange between two interchanges, Pilko, *et al*., (2007) investigated the characteristics of freeway segment, interchange to interchange, that influence safety. The characteristics considered in this study include interchange spacing, shoulder widths and number of lanes in the freeway segment. Measures for safety are total crashes and fatal and injury crashes happened in a freeway segment. The data for these characteristics and safety were collected from the states of California and Washington. Linear regression models were developed to correlate the safety and the characteristics of freeway segments. Sensitivity of the model was analyzed, and it was found that their models show a high sensitivity to freeway length and ramp AADT when predicting fatal and injury crashes.

The study in Park *et al*., (2009) focuses on the freeway segments that have curve and ramps. The freeway segments were not defined from interchange to interchange, or from ramp to ramp. They were selected only for those that have a curve with tangent before and after the curve. There may be ramps on some of the identified curves. These curves were on either rural or urban freeways. The geometric features identified for each curve includes number of lanes, median type, and density of ramps. The measure for safety is crash frequency. Negative binomial regress models were developed to relate the safety and the geometric features.

Golob *et al*., (2004) conducted a study on the safety implication of weaving sections on freeways. In their study, weaving sections were categorized into three types. Type A are weaving section where every merging or diverging vehicles must execute one lane change, Type B are those merging or diverging can be done without changing lanes, and Type C are those where one maneuver requires at least two lane changes. They used the data from Southern California. A multivariate Probit model was developed that relates the type of weaving section where an accident occurred and the characteristics of accident, the features of weaving section type, and traffic flow. It was found that there was no difference among these three types in terms of overall accident rates. However, there were significant differences in terms of the types of accidents that occur within these types in terms of severity, and location of the primary collision, the factors causing the accident, and the time period in which the accident is most likely to occur. We realized that Highway Capacity Manual has adopted a new categorization of weaving sections, which will be used in this study.

Ray *et al*., (2011) developed guidelines for ramp and interchange spacing, with emphasis given to ramp spacing. Safety is measured by number of crashes, crash types, and severity. Based on previous research, this study discusses the relationship between ramp spacing for the following three ramp combinations: EN-EX, EX-EN and EN-EN. Equations like Equation (1) to calculate crash frequency are provided for the ramp spacing combinations EN-EX and EN-EN.

$$Total = 9.7 * 10^{-6} L^{1.0} (DADT)^{1.12} (ADT_{EN})^{0.18} (ADT_{EN})^{0.02}$$

$$exp\left(\frac{450}{s} - 0.23 * AuxLn\right) \qquad (1)$$

"***L***" is segment length (in miles) defined from the physical gore of the first (upstream) entrance ramp to the end of the acceleration lane taper of the second (downstream) entrance ramp; "**S**" is ramp spacing (in feet) defined from the painted tip of the first entrance ramp to the painted tip of the second entrance ramp; "***DADT***" is the average daily traffic (in vehicles per day) on the freeway mainline upstream of the first entrance gore in the analysis direction; "(ADT_{EN})" – the first term is the average daily entering traffic (in vehicles per day) from the first entrance ramp; "(ADT_{EN})" – the second term is the average daily entering traffic (in vehicles per day) from the second entrance ramp; and "***Total***" is the number of crashes (of all types and severities) (crashes per year) expected to occur between the physical gore of the first (upstream) entrance ramp to the end of the acceleration lane taper of the second (downstream) entrance ramp. The variables in Equation (1) are specifically referred to in the ramp spacing in Figure 1

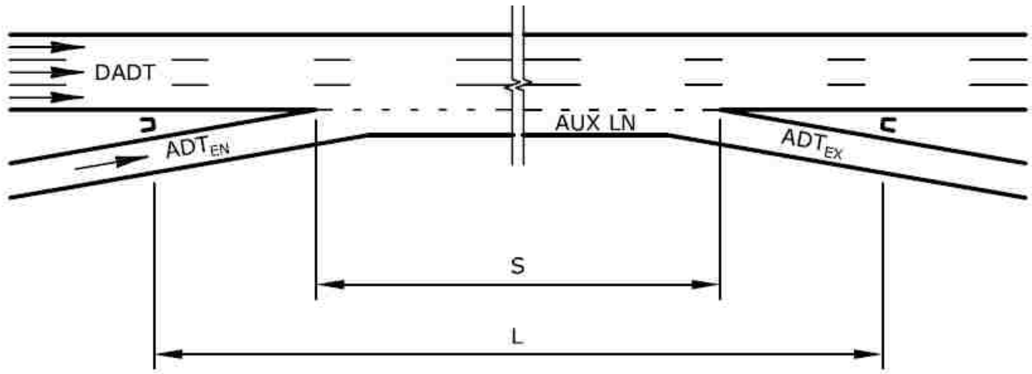

Figure 1: Typical Layout and Variables for the EN-EX Ramp Spacing Combination

Fitzpatrick *et al*., (2010) conducted a study to: (1) investigate relationships between weaving length, speed, and overall vehicle operations on Texas freeways; and (2) propose updates to current Texas Department of Transportation guidance on recommended distances between ramps. Microscopic traffic simulation models were calibrated for seven freeway locations. With the calibrated models, traffic volumes and length of weaving section were varied as inputs to the models. The data on weaving section length and traffic volumes from simulation models were then used to develop regression models to express weaving section length as a function of traffic volumes. The results from the regression models were used to develop guidelines on weaving section length in Texas.

Based on the literature review it can be summarized that different geometric features of freeway have been considered in different studies. Equations for safety in relation to different geometric features have been developed for adoption for planning, design and operations of freeway interchanges. These equations were not developed for individual states. To identify the geometric problems in Las Vegas, such equations should be developed based on the data from Las Vegas. Even though geometric features of freeways have been considered in these studies, they usually covered a few of them, not quite comprehensive. This study will consider all the major geometric features that describe the characteristics of freeways.

CHAPTER THREE METHODOLOGY

3.1 Introduction

In this study, the geometric design issues on freeways in Las Vegas were investigated by following this process: literature review, methodology development, data collection, and data analysis. In literature review, the relevant studies conducted in the past were obtained different sources and compiled with the identification of their study objectives, methods employed and the findings. The gap in identifying geometric design issues in the past was then revealed. Given the inputs from literature review, the methods to identify the geometric design needs are determined. The needed safety, geometric, operation and traffic data are then collected. These data were screened for quality control. They were analyzed based on descriptive statistics. They were used to develop crash rate and severity models. The results of the models were interpreted from which the geometric design needs of freeway were identified. This process is presented in figure 2.

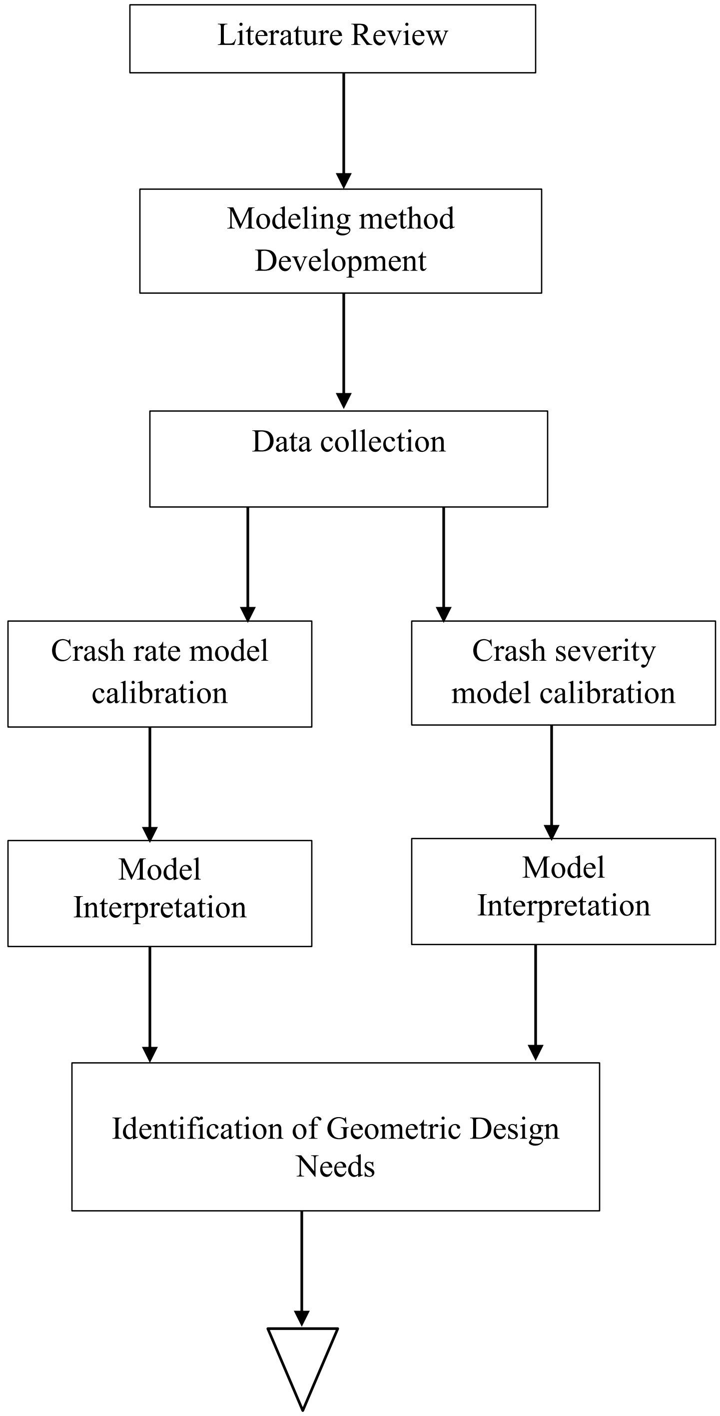

Figure 2: Flow chart of activities

3.2 Data collection

Every freeway was divided into segments bounded by entry and exit ramps. Four segment types were obtained as EN-EN, EX-EX, EN-EX, and EX-EN where EX implies that a terminal is an exit (off-ramp) and EN implies an entry (on-ramp). In every segment type, data on freeway characteristics assumed to associate with the occurrence of crashes was collected. Crashes falling in every segment were obtained using GIS tools and were of two types: (1) severity crashes which included property damage, injury crashes and fatal crashes. (2) Crash rate as a function of traffic volume exposure and crash frequency. Freeway characteristics in every segment included length of segment, median and shoulder widths, number of through lanes, curve radius, grades, auxiliary lanes, number of lanes involved in weaving movements, AADT, and number of lane changes both from ramp-to-freeway and from freeway-to-ramp. All of these characteristics were collected through visual aids and measurement tools from Google earth and Google map.

3.3 Data analysis

Data analysis involves the quantitative description of data collected and the actual modeling of the data to quantify the relationship between freeway characteristics and crashes. Main features of data are described using descriptive statistics using graphs and summary statistics. To quantify the effects of freeway characteristics on crashes, statistical models are used. The following sections explain the statistical theory of the models for the type of crashes obtained.

3.3.1 Crash rate model specification

Crash rate analysis can be considered as a tool used to measure the relative safety of a segment by combining crash frequency and vehicle exposure, FWHA (2013) and massDOT (2013). This method helps engineers and planners to prioritize safety activities when encountered with limited resources. For the case of a road segment, crash rate can be calculated as:

$$R = \frac{100{,}000{,}000 * C}{365 * N * V * L} \quad (1)$$

where,

R = crash rate for the road segment expressed as crashes per 100 million vehicle-miles of travel (VMT)

C = Total number of crashes in the study period

N = Number of years of data

V = Number of vehicles per day

L = Length of roadway segment in miles.

The crash rate computed by equation (1) can be considered as a continuous outcome which is caused by freeway characteristics including (1) geometric elements of the freeway, (2) operation and traffic elements, and (3) whether related roadway travel pavement conditions. The relationship between a continuous outcome and freeway characteristics can be explained using multiple linear regression technique. Data are modeled using a linear function of freeway characteristics, whose values are used to predict the crash rate. The basic form of a linear function, y_i for data point y_i, and p freeway characteristics is given as:

$$y_i = \beta_0 + \beta_1 x_{i1} + \cdots \ldots \ldots \ldots \ldots + \beta_p x_{ip} + \varepsilon_i \quad (2)$$

where,

$\beta_0 \ldots\ldots\ldots\ldots.., \beta_p$ are the unknown partial regression coefficients which indicate the relative effect of a particular freeway characteristic on the crash rate.

y_i is the crash rate

x_i are freeway characteristics

ε_i is the error term which captures all other factors which influence the crash rate, other than the controlled freeway characteristics and it is assumed to be normally distributed.

The partial regression coefficients in equation (2) are estimated using ordinary least squares technique. The goodness of fit of the fitted regression model can be measured by using the sample coefficient of determination which gives the proportional or percentage of the total variation in the crash rate explained jointly by the freeway characteristics and it is given as:

$$R^2 = \frac{SST-SSE}{SST} \quad (3)$$

where,

SST is the total sum of squares given as:

$$SST = \sum_i^n (y_i - \bar{y})^2 \quad (4)$$

SSE is the error sum of squares given as:

$$SSE = \sum_{i=1}^n (y_i - \widehat{y_i})^2 \quad (5)$$

The overall significant of the regression can be tested based on the assumption that none of the freeway characteristics has any linear relationship with the crash rate and it uses an F-statistic given as:

$$F = \frac{R^2/p}{(1-R^2)/(n-P-1)} \quad (6)$$

where,

R^2 = the coefficient of determination given by equation (3)

n = number of observations, and

p = number of freeway characteristics in the model.

Testing hypotheses about the insignificance of a population parameter at a given significant level uses a t test, Wooldridge (2009). The test about the influence of any population parameter uses individual partial regression coefficient and can be conducted by using a t statistic based on the regression coefficients and their standard errors as:

$$t_{\hat{\beta}_j} = \hat{\beta}_j / se(\hat{\beta}_j) \qquad (7)$$

The coefficient is considered significant if the value in equation (7) is greater than the critical value determined from the level of significant and the number of degrees of freedom. For this study, 5% level of significant is used.

3.3.2 Crash Severity Model specification

The analysis of crash severity examines the likelihood of injuries and fatalities. In the crash database, the crash severity is classified into one of the following three ordered categories: (1) property damage crash only, (2) Injury crashes, (3) Fatal crashes. An ordered probit model extends the probit model to multiple ordered categories where the numerical values of the categories do not matter, but categories must be in logical ascending or descending order. Different researchers have used the model to analyze crash severity in different areas of transportation and other fields (Gray, *et al*., 2008, Zhu, *et al*., 2011, Kockelman, *et al*., 2002, Dykin, *et al*., 2002, and Abdel-Aty, 2003, Yamamoto, *et al*., 2008, and Shimamura, *et al*., 2005). In additional to the nature of ordered crash severities which motivates the selection of the model, the observed data points to be analyzed equals 1661. This is more than 1000 data points and unlike the multinomial model, 95% confident intervals of parameters are expected to be narrower and stable around the true value for each parameter, Ye *et al*., (2013)

The model is based on the assumption that the predicted crash severity y_i^* depends linearly on the freeway characteristics according to the following equation:

$$y_i^* = x_i'\beta + \varepsilon_i \tag{8}$$

where y_i^* is the predicted crash severity by driver *i*, *β,* is a row vector of unknown parameters, *xi* a vector of explanatory variables, and ε_i is the random error term that follows normal distribution. The severity level is classified based on the predicted severity using the following criteria (μ1, μ2 and μ3 are the thresholds estimated by the model):

$$y_i = \begin{cases} 0 & \text{if } y_i^* \leq 0 \text{ (Property damage only)} \\ 1 & \text{if } 0 < y_i^* \leq \mu_1 \text{ (Injury crash)} \\ 2 & \text{if } \mu_1 < y_i^* \leq \mu_2 \text{ (Fatal crash)} \end{cases} \tag{9}$$

y_i in equation (9) represents observed severity levels (“0” for property damage, “1” for injury crash, and “2” for fatal crash).

The estimated coefficients on the explanatory variables capture the marginal effect of the corresponding factor on the injury severity of the crash. In this case, a positive value of a coefficient indicates that the corresponding explanatory factor is associated with more severe crashes Zhu, *et al*., (2011).

The probability that the i^{th} severity is equal to y_i is written as:

$$P(y_i = 0|x_i) = \Phi(\mu_1 - \beta x_i) \quad (10)$$

$$P(y_i = 1|x_i) = \Phi(\mu_2 - \beta x_i) - \Phi(\mu_1 - \beta x_i) \quad (11)$$

$$P(y_i = 2|x_i) = 1 - \Phi(\mu_2 - \beta x_i) \quad (12)$$

From equations (10), (11), and (12), $\Phi(.)$ is the standard normal cumulative distribution function. The log-likelihood function is given as:

$$\log L = \textstyle\sum_i \ln[P(y_i)] \quad (13)$$

Values of the maximum likelihood estimates β_j are computed in such a way they maximize the log-likelihood function indicated by equation (13). The overall significance of the explanatory variables is tested by comparing the restricted log-likelihood $(Log\ L_R)$ to the maximized log-likelihood $(Log\ L_U)$ to produce the likelihood ratio test statistic given as:

$$LR = -2(Log\ L_R) - Log\ L_U) \quad (14)$$

The statistic is distributed as χ^2 with degrees of freedom equal to the number of explanatory variables. The test is based on the null hypothesis that none of the explanatory variables have an effect.

For the analysis of data with ordered probit model, an equivalent statistic to R^2 does not exist because the model are maximum likelihood estimates arrived at through an iterative process UCLA (2013). In this study, the goodness-of-fit of the model is evaluated using McFadden's Pseudo statistic given as:

$$Pseudo - R^2 = 1 - \frac{Log\ L_U}{Log\ L_R} \qquad (15)$$

where $Log\ L_R$ is the log-likelihood of the intercept model treated as a total sum of squares, and $Log\ L_U$ is the log-likelihood of the model treated as the sum of squared errors. A small ratio of the log-likelihoods indicates that the full model is as far better fit than the intercept model.

CHAPTER 4 DATA COLLECTION

Data used were collected from three freeways located in Las Vegas, Nevada (see Figure 3) which included: I-15, I-215, and US95. These freeways were divided into contiguous segments of freeways bounded by entry and exit. Table 2 shows that the numbers of segments for US95 and I-215 considered in this study are more than that for I-15. For each segment, four groups of data were collected for analysis: (1) geometric, (2) operation (3) traffic data and (4) environmental. Geometric data included length of segments, shoulder and median widths, number of through lanes, auxiliary lanes, segment terminal configurations, curve radius, and grades. The segment terminal configurations were defined based on entry and exits to the freeway and these included: EN-EX,

EX-EN, EN-EN, and EX-EX. Operation data are for weaving movements which were also collected as a function of geometric characteristics affecting these movements and these included: number of lanes involved in weaving movements, number of lane changes from ramp-to-freeway, and number of lane changes from freeway-to-ramp. Environmental data included pavement surface denoted whether a pavement was wet or dry at the time a crash occurred.

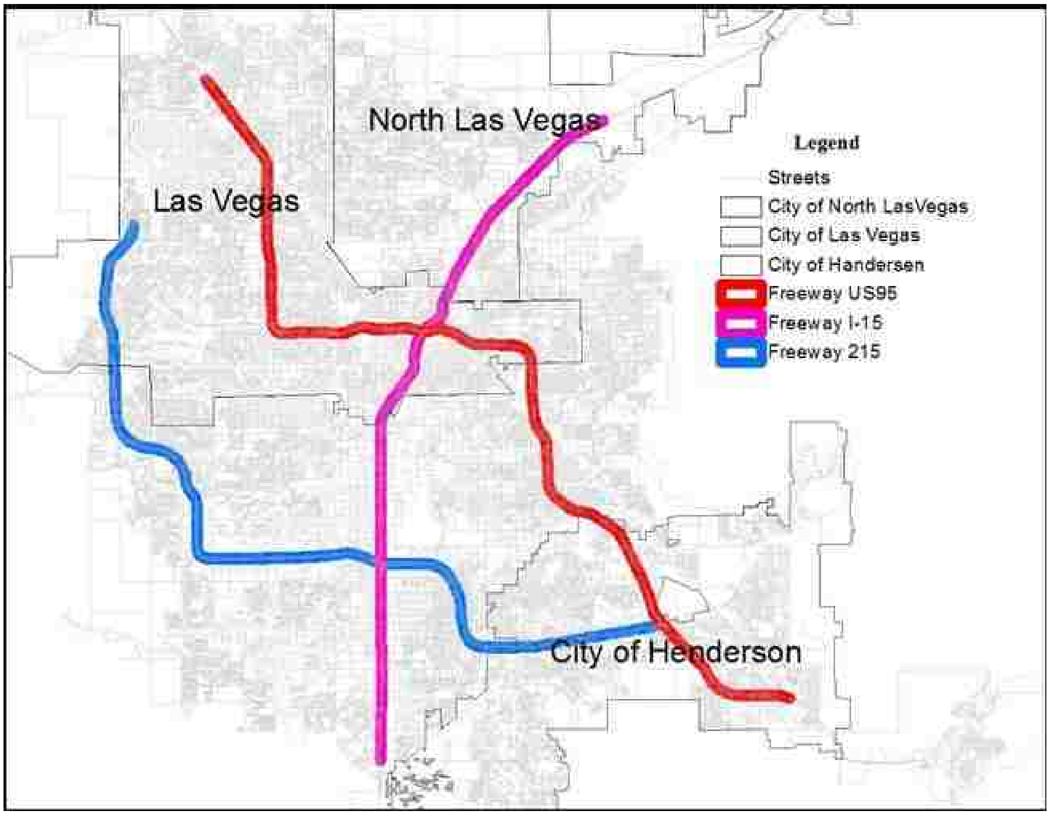

Figure 3: Study location

Table 2: Total segments in each freeway

Freeway	Number of segments
I-15	73
I-215	104
US-95	116

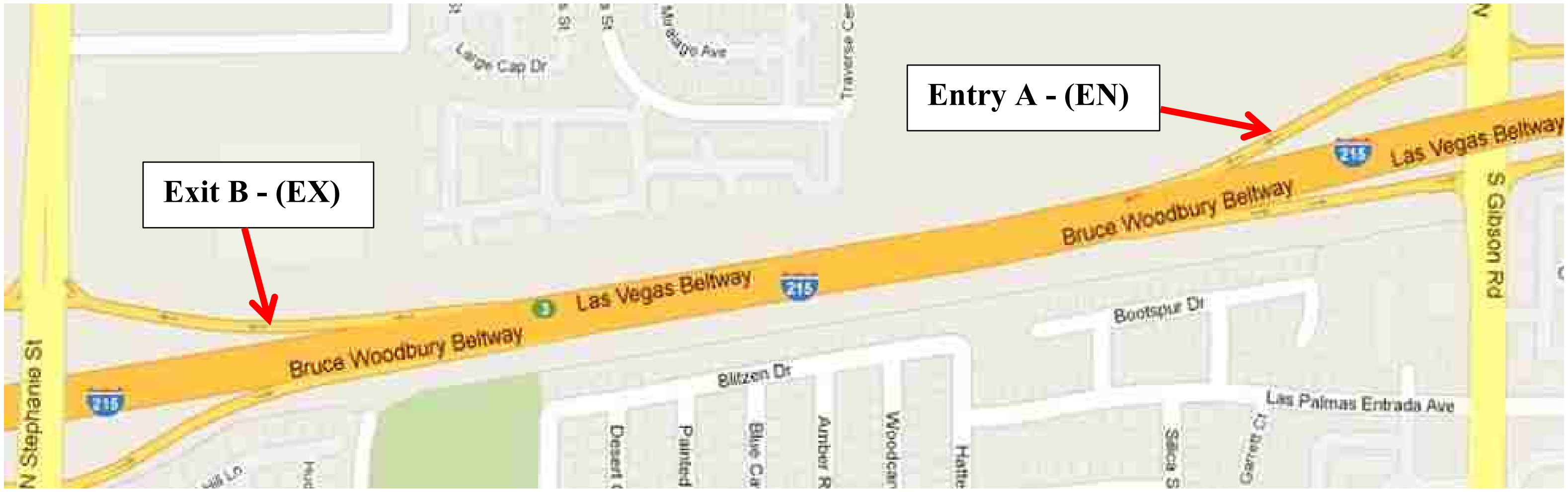

Figure 4: EN-EX Segment (bounded by entry A and exit B)

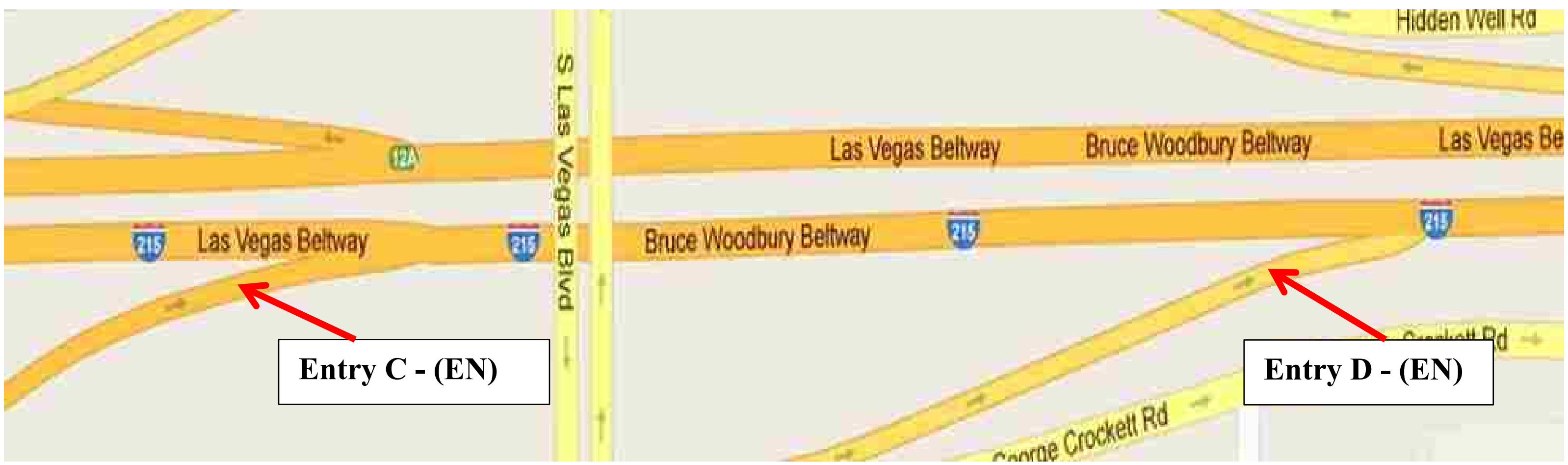

Figure 5: EN-EN Segment (bounded by entries C and D)

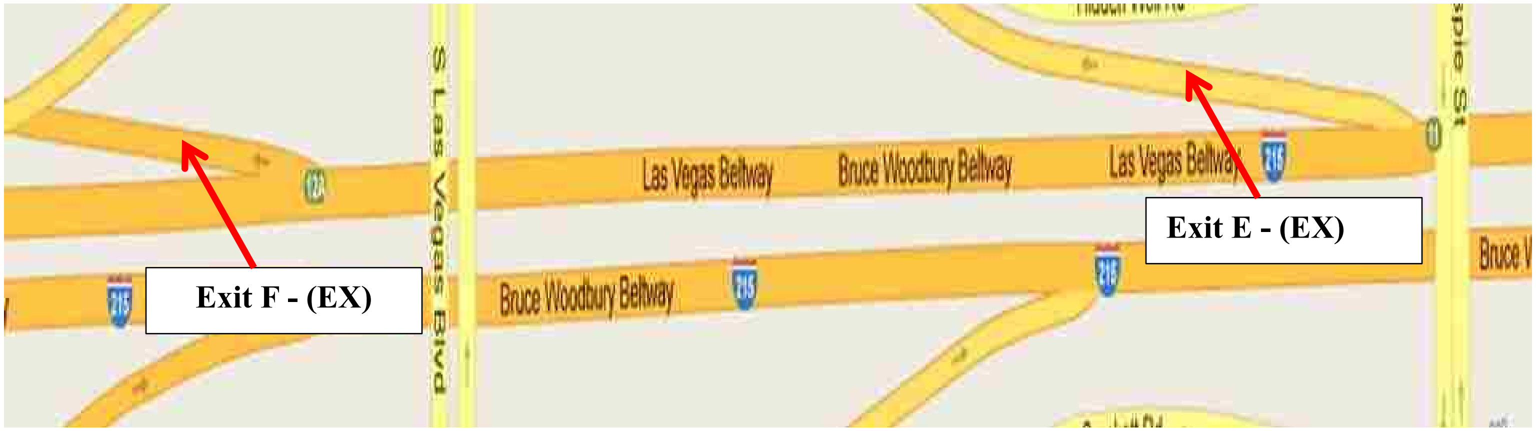

Figure 6: EX-EX Segment (bounded by exits E and F)

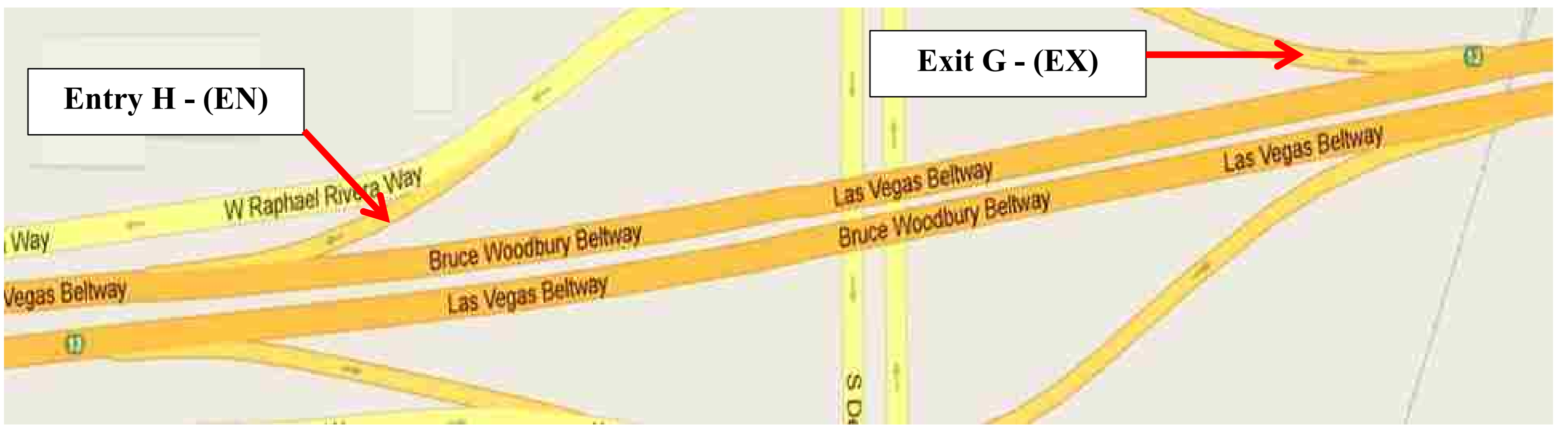

Figure 7: EX-EX Segment (bounded by exit G and entry H)

Segmentation

Figure 10 to Figure 13 show four types of segments observed as defined by their terminal configurations. These constituted observation unit. Geometric elements of freeways were observed and recorded from each segment. Crash data, posted speed limit and pavement surface environmental conditions were obtained as an Excel file from Nevada Department of Transportation. Using latitude and longitude of the crash data, the file were converted to a point shapefile and overlaid with the created segment polygon. However, Crash data file provided by NDOT contains crash location that seems to follow shapefile from 2007. Coordinates given might not be projected at the exact location where crashes had occurred. The point features created from spreadsheet show crash data points in a straight line that follow Clark County street center lines shapefile. The similarities can be seen in screen shots below (Figure 14) in which the Google Earth image dated 2007 has same freeway (95 and Decatur) diverging construction area which matches the ArcGIS crash points along street centerline.

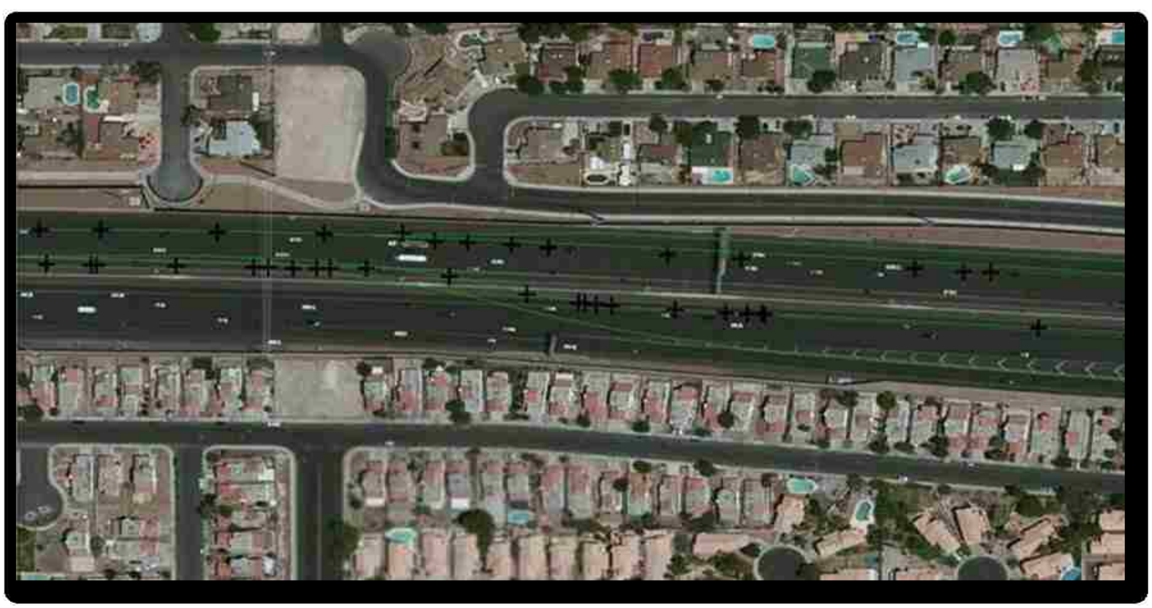

Figure 8: Overlay problems of crashes and segments

The projected crashes where not overlaid exactly on the segment polygons created and spatial adjustment was applied Gorr, *et al*., (2011). Figure 15 shows segment polygons with crashes overlaid. Crash frequency was obtained by joining the point and polygon shapefiles. Using appropriate tools in GIS, crashes happened in the polygon are counted and the results exported to Excel files which were then cleaned to obtain the final required crash frequency. Cleaning involved removing all variables created under the process of counting for instance crash number, vehicle and street directions.

Crash severity data were also obtained by overlaying the crashes with polygon shapefiles. Crashes falling in an individual segment were visualized and recorded in the same way as for the frequency data, and the resulting data were exported to the Excel file for data cleaning. The data exported to the Excel file include many data items. Not all the data items were needed in the modeling process, for instance codes indicating street directions, driver actions, crash number, and city towns. This information was removed as a process to clean the dataset. The speed limit and travel way surface conditions were also extracted from the crash data file obtained from Nevada Department of Transportation.

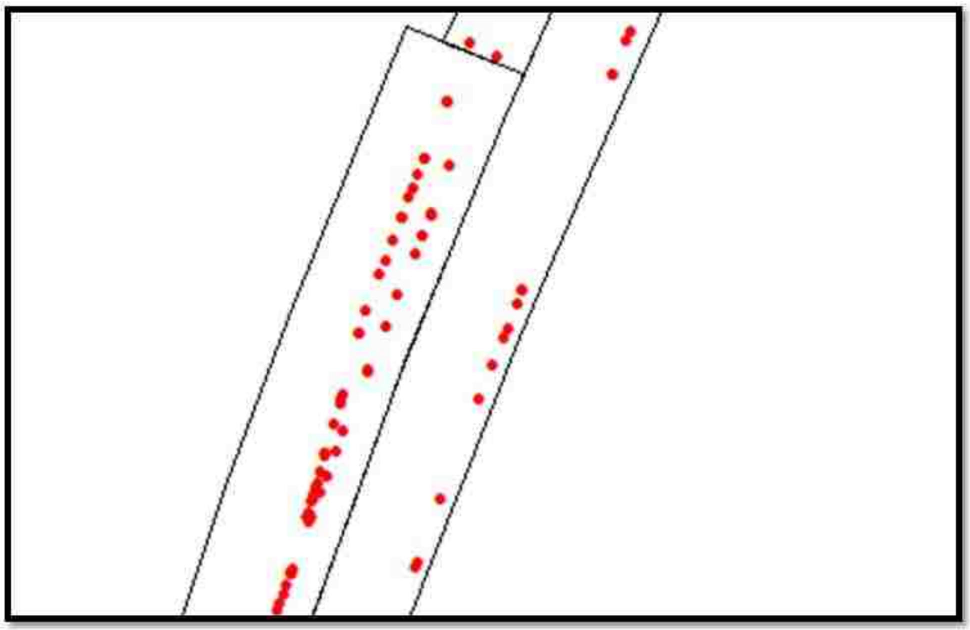

Figure 9: Crashes overlaid with digitized segments

Geometric data

Length of each segment was defined as the base length (L_B) between its terminals as defined in 2010 Highway Capacity Manual and Roess *et al.*, (2011) which is shown in Figure 4. The width of each segment was taken as equal to the width of a freeway define by the number of through lanes plus the inside median and outside shoulder widths (Figure 5). This helped include all crashes occurred on the main facility, speed-change lanes, and those found on median and shoulders.

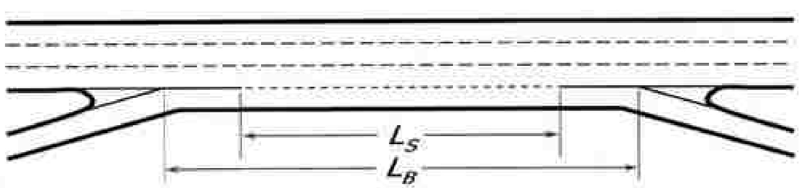

Figure 10: Definition of length of segment
Source: HCM2010

Figure 11: Sample segment digitized showing the measurements of segment width

It is shown in Figure 6 that shoulder width was taken as the ground length measured from the point where edges of the external lanes touch the shoulder to the point where it ends at pavement edge. The median width was taken as the ground length from the point where the extreme inside lane touches the median to the center of the median on each direction of the freeway. This width included the inside shoulder. Both median and shoulders were measured using available tools in the Google Earth Pro Imagery of 2010 Figure 6 illustrates the measurement of these variables.

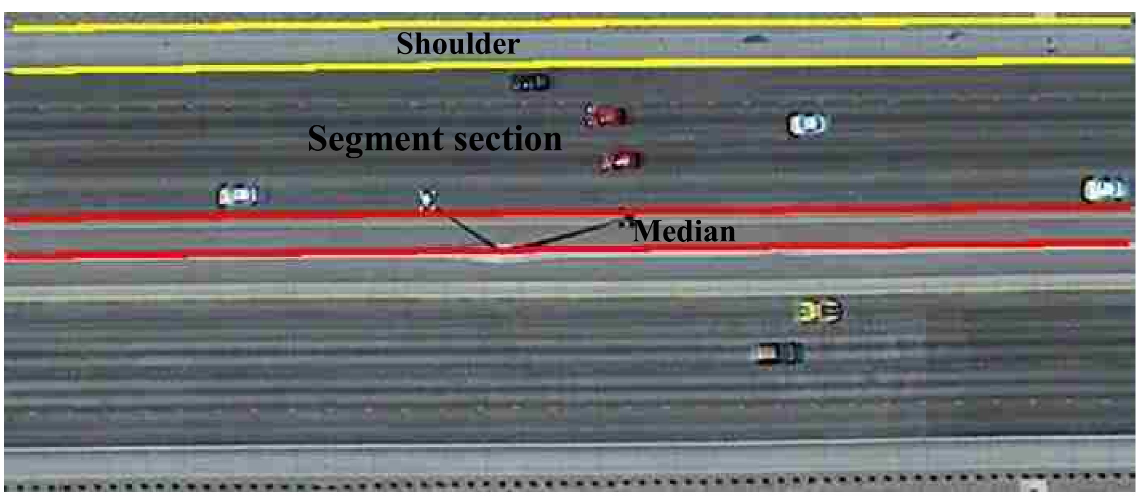

Figure 12: Median and shoulder width – ground distance between the two red lines

The number of through lanes were visualized and counted using Google earth as the number of marked mainline on the freeway which delineate lanes of travel. For segments where the auxiliary lane extends from entrance to exit, the auxiliary lane was included in the total number of through lanes, Sarhan *et al*., (2008).

Figure 13: Part of a segment indicating through lanes

The types of auxiliary lanes included are continuous auxiliary lanes. These are portion of the roadway adjoining the traveled way for speed change, turning, weaving, truck climbing, maneuvering of entering and leaving traffic. Their purpose is to supplement through-traffic movement and improve operational efficiency AASHTO (2001)

Vertical and horizontal alignments are not reported in any database for the state of Nevada. Grade for freeway segments was recorded from Google Earth pro using the average grade technique Roess (2011). This approach is acceptable for freeway segments containing composite grades with segment lengths less than 4,000 feet and grades less than 5%. Freeway segment elevations were recorded from Google Earth at the painted gore nose of each terminal on either side of the segment. The difference of the two elevations was divide by the segment length resulting in the calculated average grade and used as a variable in the modeling as the average grade for that segment. Google Earth provides the ability to produce alignment grade by creating a path in order to generate a profile. However, most freeway segments have multiple grade changes which cause uncertainty with collecting either the maximum grade of the freeway segment or to record the average. One study suggests the use of global positioning systems (GPS) to collect roadway alignment (Awuah-Baffour, Sarasua, Dixon, Bachman, & Guensler, 1997). We did not take this GPS approach because the fore mentioned study was not concerned with the use of the data but just the accuracy of the data collection.

In this study, each curve observed on each segment from Google Earth was treated as a simple curve, and the radii were determined using ArcGIS Curve Calculator under the COGO toolbar. The arc length was measured in ArcGIS, along with the chord length. With those two measurements, the freeway segment radii were determined with the use of the calculator. Some segments shared the same curve radius due to curve length surpassing the designated segmentation of painted gore to painted gore. When a segment contained more than one curve, the shorter radius was taken having the most extreme effect on vehicle maneuvering. An example can be seen in Figure 18. Such was the case for freeway segments containing part of a curve and no curve for the reminder.

Figure 14: Reverse curve located on US 95 and Russell Rd interchange,
curve with smaller radius circled

More complicated curves such as spiral and combination curves, similar to the reverse curve seen in Figure 18, could not be determined based on visual inspection. There are a few methods exist for recording curve radius. According to one method, researchers suggest using ArcGIS to dissolve polyline vertices into those segment vertices with drastic changes in order to analyze less coordinates Hans, *et al*., (2012). Then the resulting coordinates are used to iterate chord lengths which are then analyzed through regression. This method was proven to be the most accurate but may be too time consuming. Thus it was not adopted for this study.

Operation data

On EN-EX segments where merging movements are closely followed by diverging segments, there is insufficient distance for merge and diverge segments to operate independently. This situation necessitate traffic streams to cross each other because drivers entering and exiting the facility need to locate themselves to their desired lanes for either continuing travel along the facility or exiting the facility. Segments of the facility from which an additional weaving movements are taking place by lane–changing activity are called weaving segments. These segments have geometric components which influence how movements are taking place and are likely to cause safety problems experienced within these segments. To present the traffic situations on these segments, three data items were collected: lane change from ramp-to-freeway, lane change from freeway-to-ramp, and number of lanes involved in weaving movements (see figures 8 and 9). These data items are defined in the 2010 Highway Capacity Manual. From a segment like the one on figure 8, it is assumed that every weaving vehicle enters the segment in the lane closest to its desired exit and leaves the segment in the lane closest to its entry. The number of lane change in figure 8 is one. The second data item involved the minimum number of lanes involved for successively completing the lane changes. Since a vehicle moves from the auxiliary lane to the lane closest to the next exit terminal, only two lanes are involved to successively complete the movement.

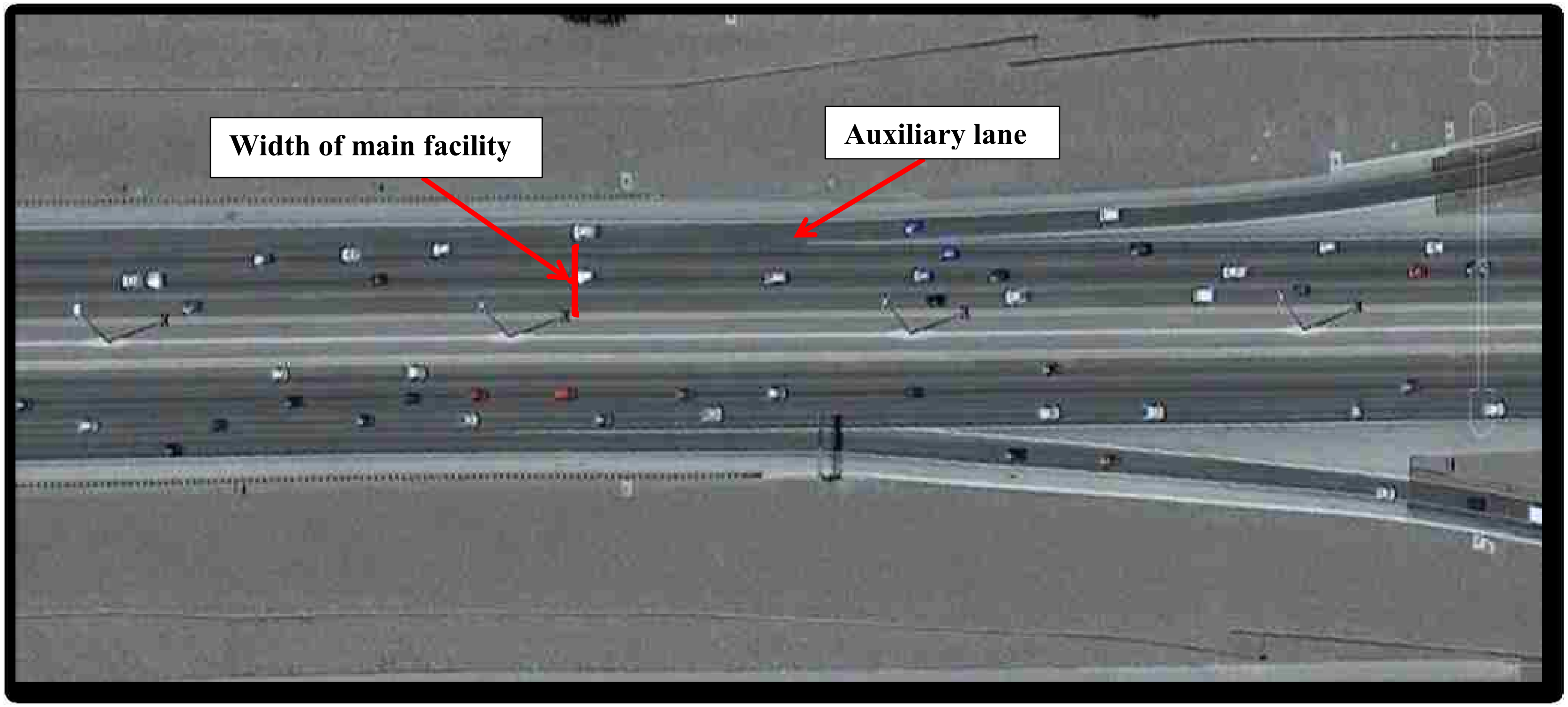

Figure 15: Weaving movement variables - lane change from ramp-to-freeway and weaving movement lanes

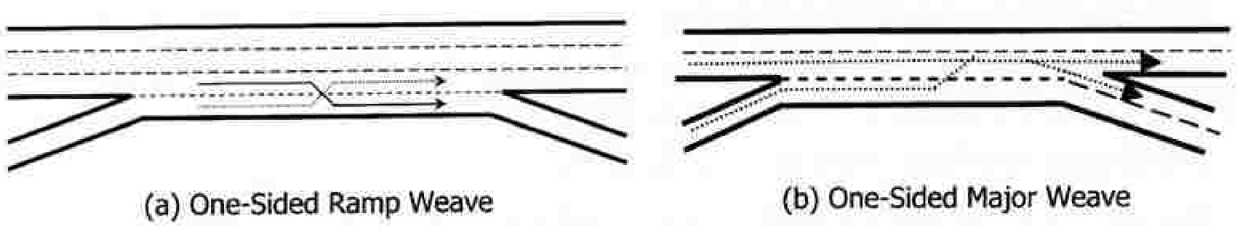

Figure 16: One-sided weaving segments (Source: HCM2010)

Traffic volume and speed limit data

Traffic and control data involved speed limit and average annual daily traffic data (AADT). Average annual daily traffic data were provided by the Nevada Department of Transportation (NDOT), given in their recent report for Clark County NDOT (2012). NDOT reported actual vehicle counts and estimated values for 2010. Although counts were not provided for each segment location, further evaluation for missing segment volumes was needed. For the segments requiring additional analysis, a balanced approach was taken to determine traffic volumes for each location using ramp volumes and nearby count locations provided. This approach is demonstrated in figure 15 where the sum of the given volumes, 126,000 vehicles per day for mainline flow with 15,000 and 12,000 for on-ramp and off-ramp, respectively. The resulting AADT of 153,000 vehicles per was taken for the segment of US 95 south of Craig Road.

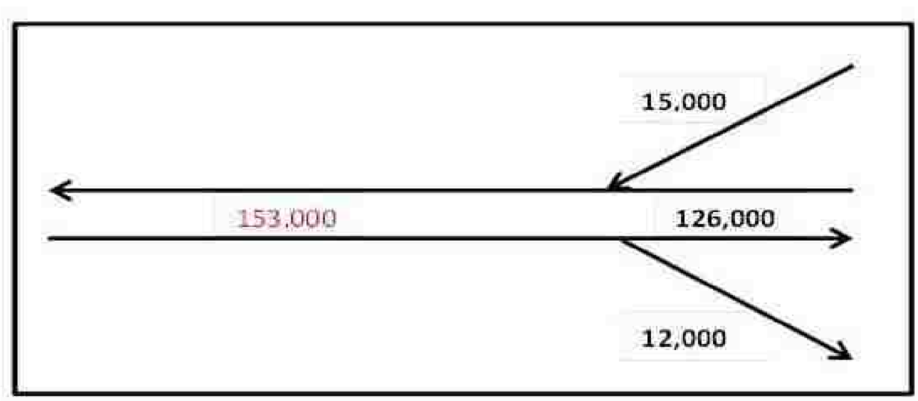

Figure 17: Balanced approach example, calculated output value in red

For segment volumes that could not be determined through this approach due to vague location description in the traffic report, the AADT value of the nearest location was assigned. Only a few segments were handled in this manner which can be seen in figure 17.

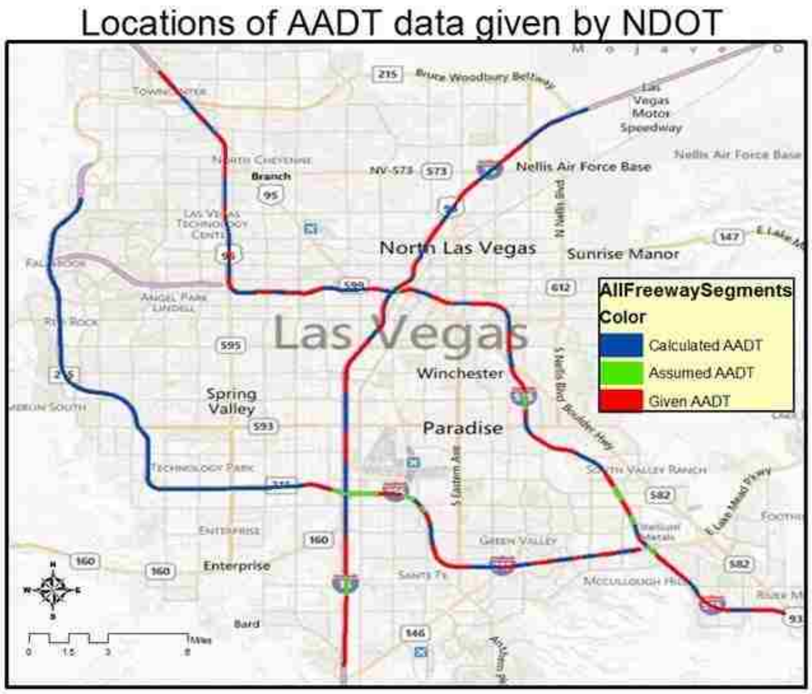

Figure 18: Comparative map of given AADT locations calculated

CHAPTER 5: MODELING RESULTS

5.1. Descriptive statistics

This study uses data collected on 293 digitized segments from freeways I-15, I-215 and US95 to investigate possible risk factors contributing to crashes. In this section data is summarized using descriptive statistics supplemented by graphical displays to explain important main features of the variables in a sample dataset. Descriptive measures of sample are statistics which include measures of central tendency and variability. Since variables include both categorical and quantitative variables, boxplots and scatter plots are also displayed to visually indicate the relationships between crashes and explanatory variables. All categorical variables were coded with definitions indicated on table 3.

Table 3: Definitions of categorical variables

Variable	Definition
Auxiliary lanes	"0" if present; "1" otherwise
EN-EN segments	"1" for EN-EN segments; "0" otherwise
EX-EX segments	"1" for EX-EX segments; "0" otherwise
EN-EX segments	"1" for EN-EX segments; "0" otherwise
EX-EN segments	"1" for EX-EN segments; "0" otherwise
Wet/dry pavement surface	"0" for dry condition; "1" otherwise
Weather condition	"0" for clear weather; "1" otherwise

Table 4 and Table 5 display summary statistics for EN-EN, EX-EX, EN-EX, and EX-EN segments. Following these tables are figure indicating distribution of crash rates within different freeway characteristics.

Table 4: Descriptive statistics for EN-EN and EX-EX segments

	EN-EN Segments				EX-EX Segments			
Variables	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Crash rate	21.876	67.37	0	353.04	23.20	25.96	0	109.98
Number of through lanes	3.59	1.12	2	6	3.64	1.00	2	6
Length of segment	2836.59	1909.56	520	8648	3163.93	1462.61	1011	5999.99
Shoulder width	12.45	3.38	6.3	21.62	11.98	4.13	3.8	23.06
Median width	15.22	10.55	1.8	47.89	15.75	7.32	3.4	27.5
Curve radius	2377.06	2807.04	0	10088	2066	2981	0	7300
Grades	-0.12	0.77	-3.4	1.5	0.20	0.70	-0.8	2.4
Lane changes: ramp-to-facility	0.26	0.45	0	1	0.36	0.49	0	1
Lane changes: facility-ramp	0.19	0.40	0	1	0.36	0.49	0	1
Lanes involved in weaving	0.81	1.11	0	3	0.91	1.15	0	3
AADT	145833	50657	56000	257000	162940	80933	44500	298100
Number of segments	27				22			

Table 5: Descriptive statistics for EN-EX and EX-EN segments

	EN-EX Segments				**EX-EN Segments**			
Variables	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Crash rate	33.78	70.87	0	515.80	43.60	75.41	0	485.69
Number of through lanes	3.68	0.91	2	6	3.22	0.89	2	7
Length of segment	3087.74	1961.14	767.295	14118.93	3237.40	1443.57	781	7671
Shoulder width	13.23	4.82	2.2	34.72	12.80	3.83	3.2	27.69
Median width	19.82	13.71	2.6	95.3	19.58	12.71	3.4	79.81
Curve radius	1981	2666	0	9994	1700	2736	0	11088
Grades	-0.10	0.62	-3.5	1.8	0.05	0.69	-2.5	3.7
Lane changes: ramp-to-facility	0.39	0.49	0	1	0.26	0.44	0	1
Lane changes: facility-ramp	0.36	0.48	0	1	0.25	0.43	0	1
Lanes involved in weaving	0.88	1.01	0	3	0.66	0.95	0	3
AADT	138550	66962	25500	298100	137523	65657	25500	298100
Number of segments	124				120			

From table 4 and 5, it can be seen that EX-EN segments had the highest mean crash rate compared to other segment types. However, statistics tests shown in table 6 indicate that no conclusion can be made on EX-EN segment had the highest mean crash rate because p-values are higher than 5% level of significance.

Table 6: Comparison tests for difference between mean crash rates across segments

Test	**EN-EN Vs EX-EN**	**EX-EX Vs EX-EN**	**EN-EX Vs EX-EN**
t statistic	-1.378	-1.252	-1.049
p-value	0.085	0.106	0.148

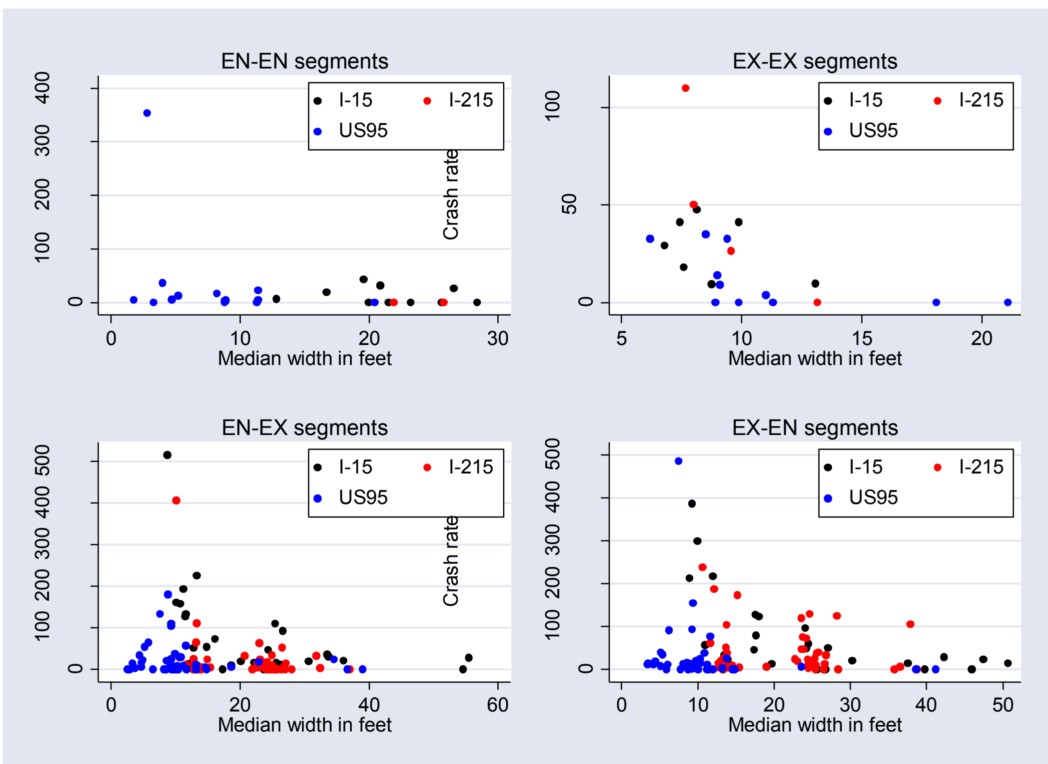

Figure 19: Distribution of crash rate against median width across segment types

Figure 19 shows the relationship of crash rate with median width across segment types. As the figure indicates, for segment types, there are high crash rates with narrower median width. After reaching the top crash rate, they decreases as median width increases.

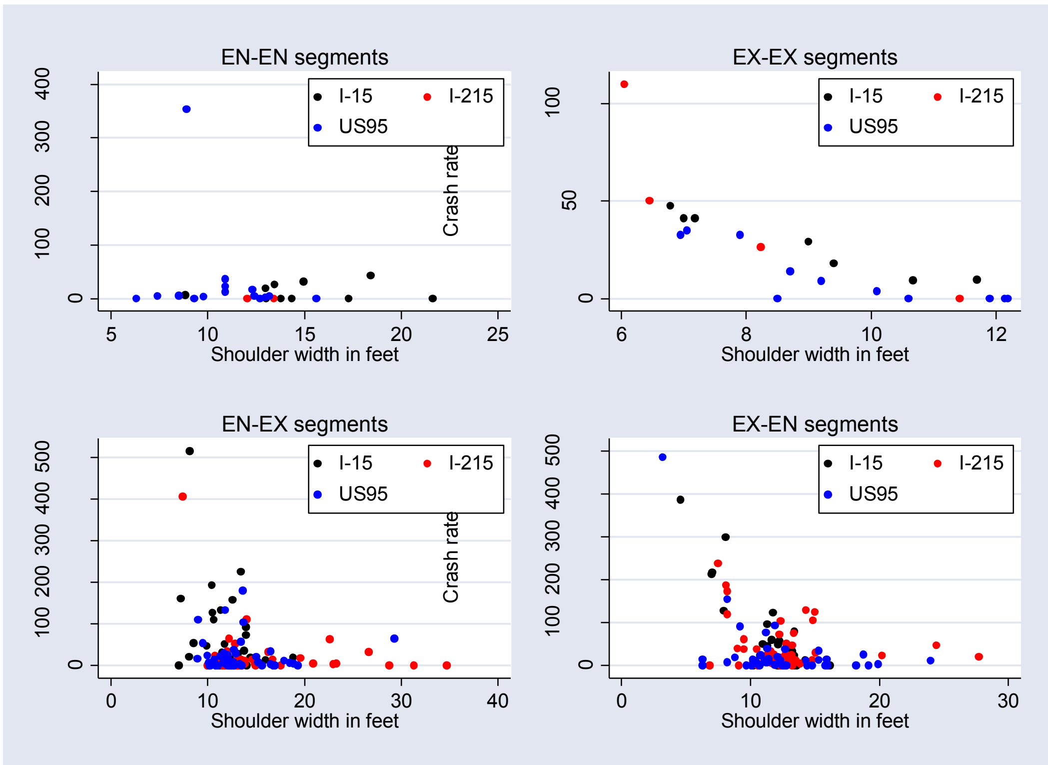

Figure 20: Distribution of crash rate against shoulder width

Figure 20 shows crash rate distribution across shoulder width for segment types. EN-EN segments had one peak with higher crash rates compared to other segments.

EX-EX segments had a decreasing trend in crash rate for segments with shoulder width below 10ft at which point the crash rate drops. The same trend was also seen from segments with shoulder width greater than 15ft. EN-EX segment type showed high crash rate for narrower width between 6ft to 8ft and between 10ft to 15ft. There was approximately low crash rate for shoulder width greater than 5ft. EX-EN segments displayed the same trend of crash rate which also decreases for higher shoulder width.

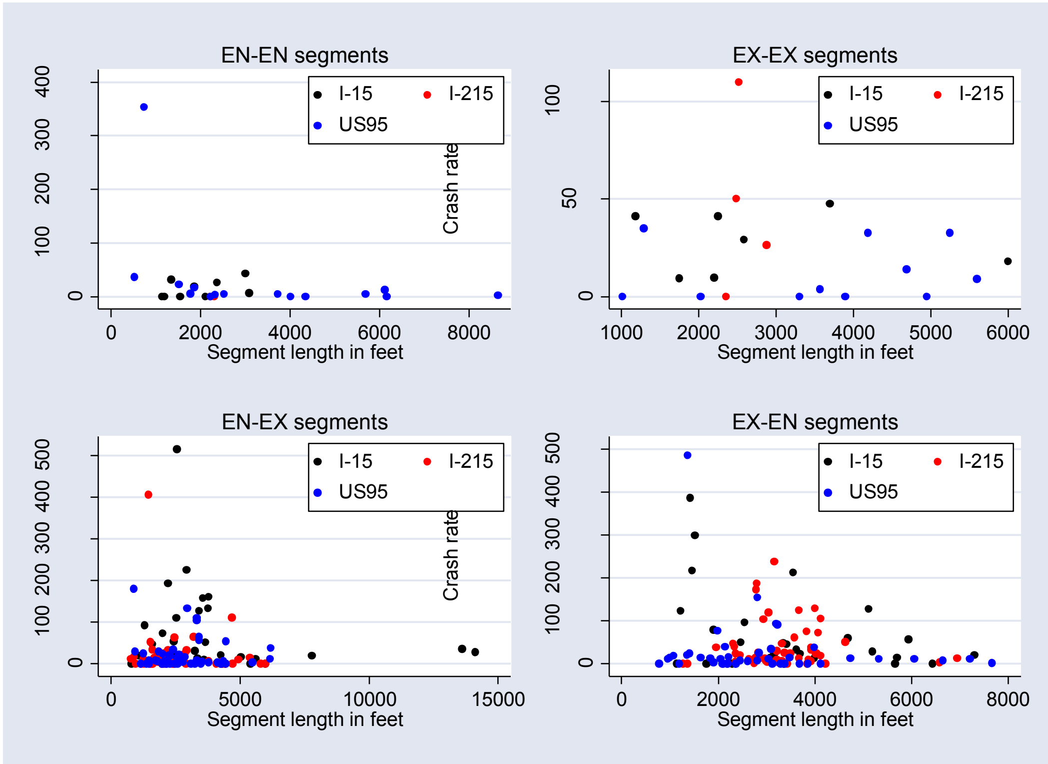

Figure 21: Distribution of crash rate against segment length

The relationship between crash rate and the length of segment is displayed in figure 21. It can be seen that for EN-EN segments the highest crash rate occurred at one short segments and the rate decreases with long segments. EX-EX segments had different trend than EN-EN segments. The crash rate did not vary with the length of segment. There are many EN-EX segments which are short and had more crash rate. Also the same segments indicated high crash rate compared to long segments.

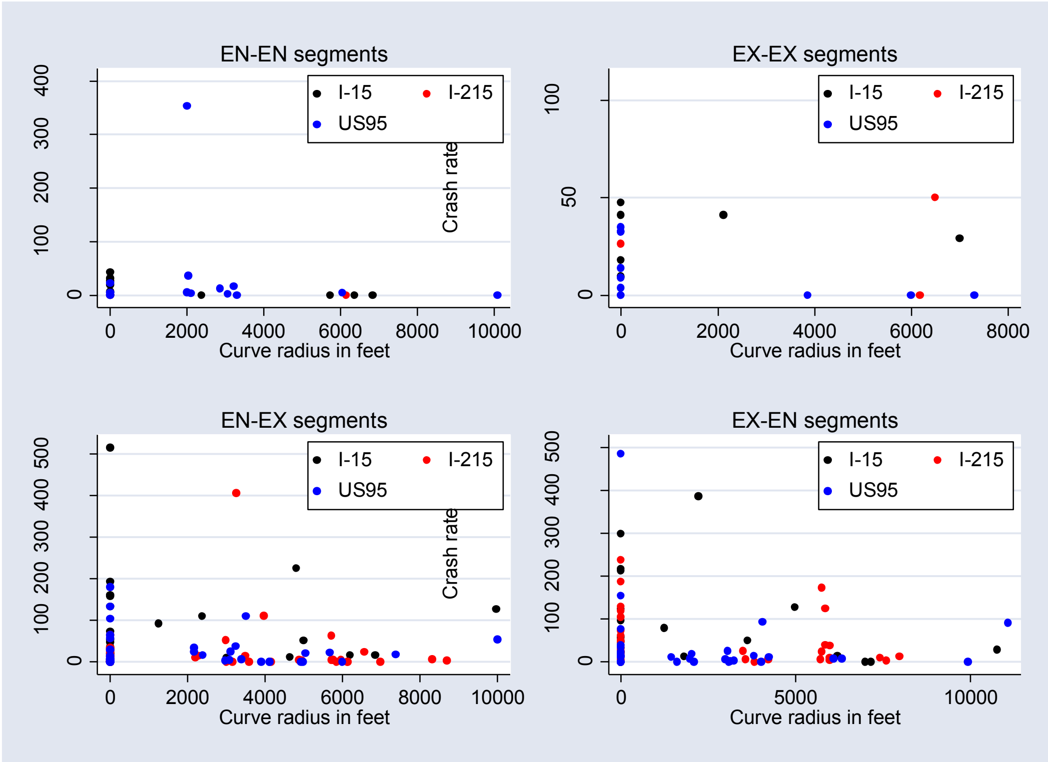

Figure 22: Distribution of crash rate against Curve radius.

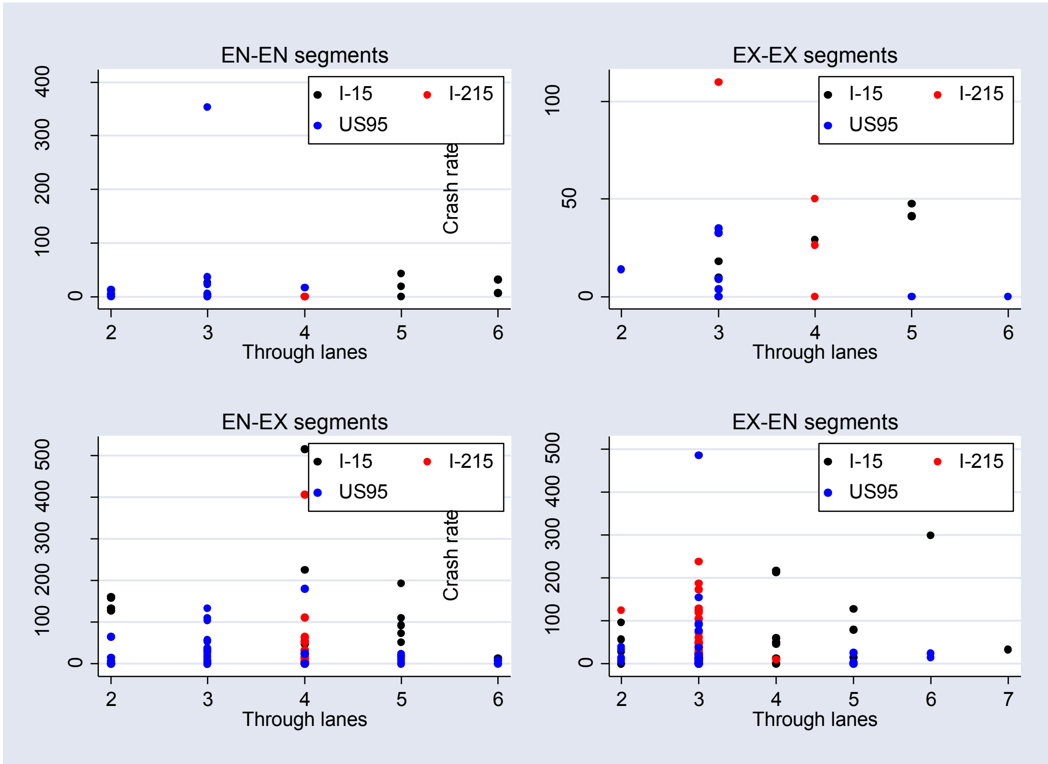

Figure 23: Distribution of crash rate against number of through lanes.

As indicated in figure 23, the highest crash rates did not happen on the segments having few numbers of lanes. The number of lanes having highest crash rates varies among these four types of segments.

Figure 24 shows the distribution of crash rate versus annual average daily traffic (AADT). The trend of crash rate with AADT is the mix of decreasing and increasing trend. Some segments with small traffic volume indicated high crash rate while for some segments, high traffic volumes showed low crash rate.

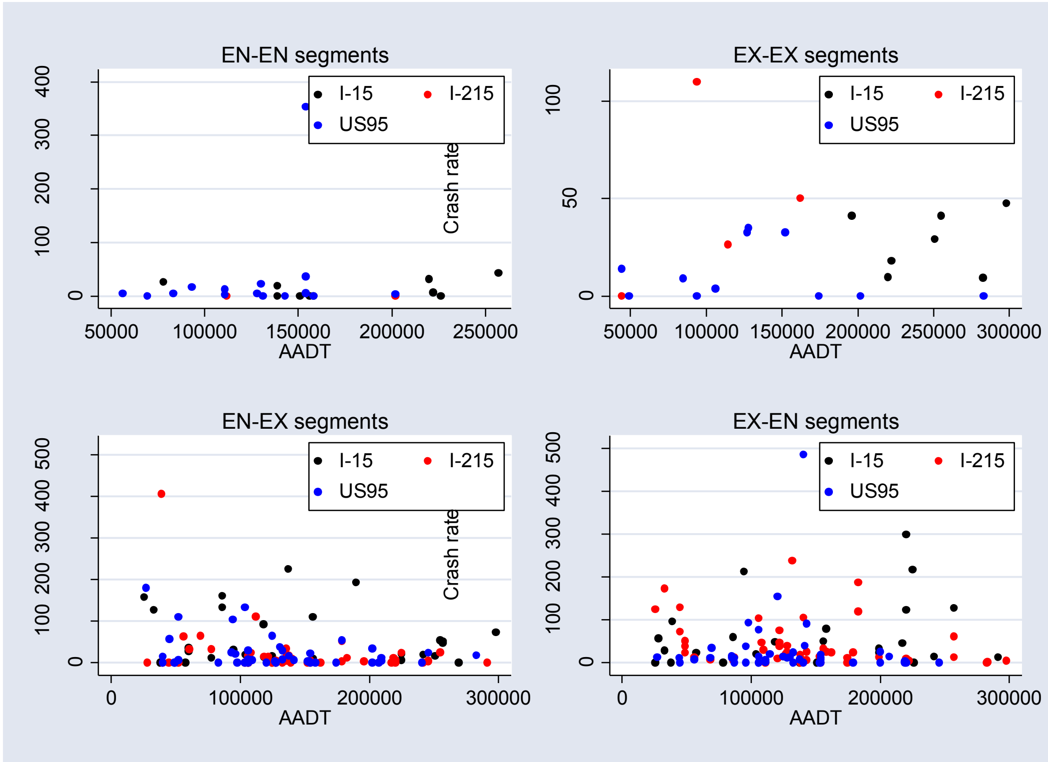

Figure 24: Distribution of crash rate against AADT for segment type

Figure 25 displays the denseness and sparseness of the samples across segments with and without auxiliary lanes. As indicated by the graphs, segments with auxiliary lanes tend to have more crash rate than segments without auxiliary lanes. Also there are outliers in EN-EX and EX-EN segments without auxiliary lanes than those with auxiliary lanes. The spread and mean in crash rate values for EX-EX segments with auxiliary lanes are higher than those of EX-EX segments without auxiliary lanes.

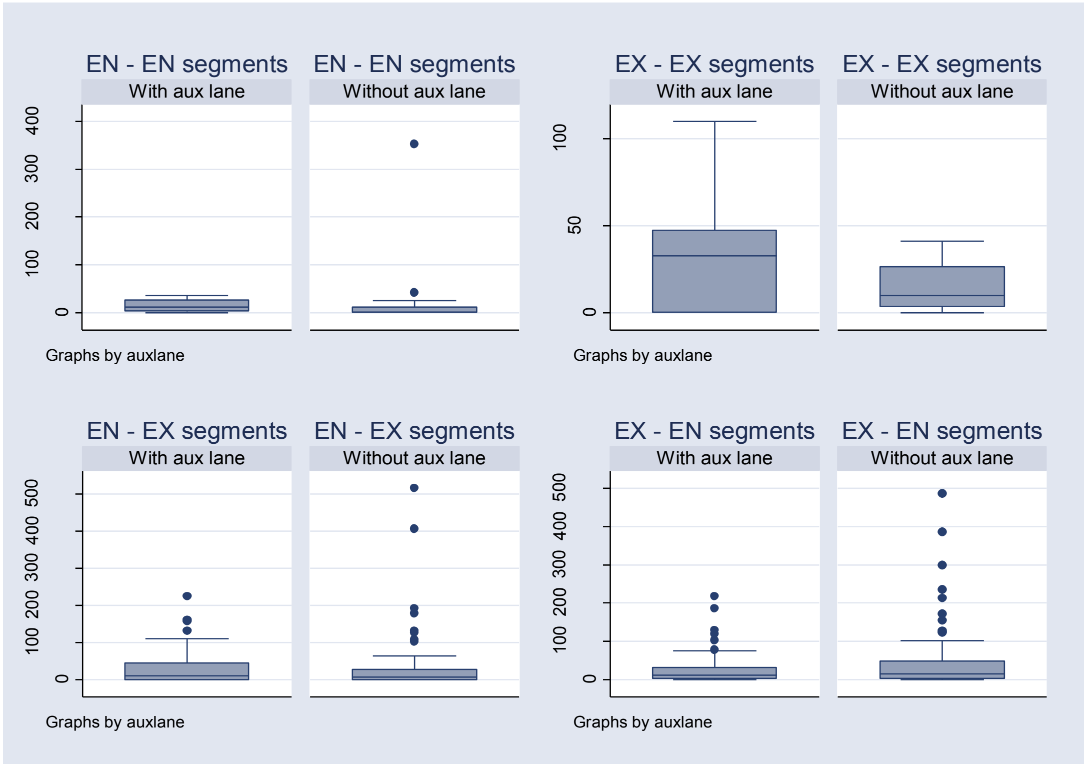

Figure 25: Distribution of crash rate against segments with or without auxiliary lanes.

5.2. Crash rate model Calibration

This section discusses results of four multiple linear regression models developed for crash rate One model was developed for each segment type. Three dummy variables for freeways were included in the dataset and interacted with other variables to indicate the effects of variables in a given segment type located in a specific freeway. Two of the three dummy variables: I-15, I-215 was included in the model and US95 was used as the base group for comparison. Explanatory variables included were (1) geometric elements, (2) operation (3) environmental and (4) traffic flow variables. The following subsection discusses the findings of this model with interpretation of significant predictors.

5.2.1. Model results

The results indicated in table shows only significant variables and the blanks indicate that a variable was not significant. As indicated on Table 6 below, two variables were found significant for EN-EN segment type model. However, the F-statistic of the model resulted in a p-value of 0.05422 which indicates that overall, the model is marginally significant. On individual bases, only the median width and length of segment were significant at 5% level of significance. For the purpose of this study all models are interpreted at the 5% level of significant. The coefficient on median width is negative which implies that wider median reduced the crash rate. This trend can also be seen on the upper graph of Figure 26 which combines data from all three freeways.

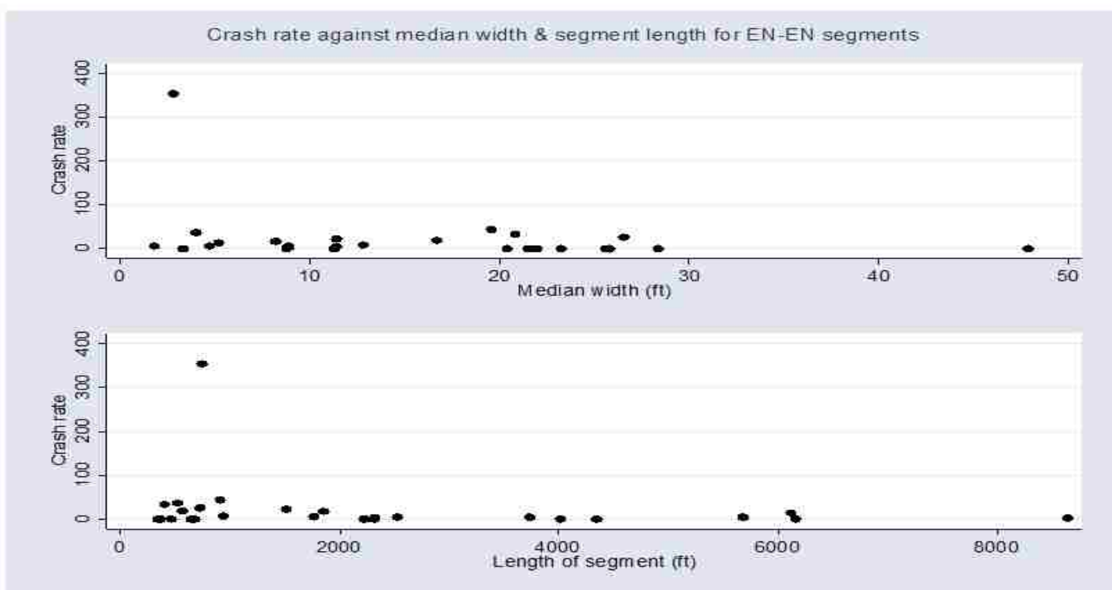

Figure 26: Variation of crash rate Vs median width & segment length for EN-EN segments

The coefficient on length of segment is negative which implies that the crash rates for long segments are higher than those for short segments. This is true because with long segments there are more spaces for drivers to maneuver for the purpose of avoiding crashes.

The model for EX-EX segment types was significant. As indicated from the table, the coefficient on I-15 is negative which implies that there was low average crash rate on I-15 compared to average crash rate experienced on US95. The coefficient on I-215 is positive, which implies that there was high average crash rate on I-215 compared to average crash rate experienced on US95. The coefficient on the number of through lanes is negative which implies that segments with more lanes had lower average crash rate. This is reasonable because more lanes provide more spaces for drivers to maneuver and avoid crashes. The coefficient on the variable for the number of through lanes on I-15 is positive, which implies that segments with more lanes on I-15 had higher average crash rate compared to segments with the same number of lanes on US95 and I-215. This might be due to the fact that there is more visitor population on I-15 who are not familiar with the road in Las Vegas. The coefficient on the number of through lanes on I-215 is negative, which implies that segments with more lanes on I-215 tended to have lower average crash rate than other freeways. This might be due to the reason that the travelers on I-215 are more familiar to the roads in Las Vegas than on other roads. The coefficient on median width is negative, which implies that segments with wider median had lower average crash rate. This is consistent with our intuitive. The coefficient on the number of average annual daily traffic (AADT) is positive which implies that EX-EX segments with high traffic volume had higher average crash rate. This is reasonably true because with more traffic on the freeways collisions are more likely to occur due to drivers competing over a limited space.

Table 7: Crash rate model calibration results for types of segments.

Independent variable	CRASH RATE MODEL							
	EN - EN SEGMENTS		EX - EX SEGMENTS		EN - EX SEGMENTS		EX - EN SEGMENTS	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
I-15			-110.6502	0.0003	206.3900	0.0006	-424.0700	0.0483
I-215			359.4776	0.0000			-141.1580	0.0030
Through lanes			-11.8804	0.0055				
Through lanes * I-15			32.2534	0.0001				
Through lanes * I-215			-80.2516	0.0000				
Median width	-3.1130	0.0300	-1.4447	0.0242				
Length of segment	-31.4500	0.0409						
Shoulder							-7.2130	0.0051
Shoulder * I-15					-13.0160	0.0074		
Shoulder * I-215							11.9580	0.0007
AADT			28.4133	0.0011				
AADT * I-15							39.9310	0.0295
Constant	299.2660	0.0190	-264.1417	0.0026	21.4830	0.0019	117.2130	0.0005
Auxiliary statistics								
R-sq	0.216		0.8987		0.1514		0.1781	
Adj. R-Sq	0.150		0.8481		0.1374		0.142	
F-statistics (p-value)	3.299 (0.05422)		17.75 (0.000)		10.8 (0.000)		4.94 (0.000)	
Observations	27		22		124		120	

The model for EN-EX segments was statistically significant. Two variables from this model were found significant. The coefficient on I-15 is positive, which implies that the EN-EX segments on I-15 had high average crash rate compared to average crash rate experienced on US95 and I-215. The EN-EX segments on I-215 and US95 had the same crash rate statistically. The coefficient on the variable representing the shoulder on I-15 is negative, which implies that en-ex segments with wider shoulders located on I-15 had lower average crash rate. This is reasonable because wider shoulder would give enough recovery area for drivers who have left the travel lane.

The model for the EX-EN segment type was also found statistically significant at the 5% level of significant. The coefficient on I-15 is negative, which implies that I-15 had lower average crash rate compared to average crash rate experienced I-15 and US95.

The coefficient on I-215 is negative, which implies that the EX-EN segment on I-215 had lower average crash rate than that of US95 as well. The coefficient on the shoulder is negative, which indicates that wider shoulder on the EN-EX segments that usually run under interchange bridges reduced the average crash rate. Wider shoulder might be more important under bridges than in other locations. The coefficient for the variable of shoulder on I-215 is positive which implies that wider shoulders on the EX-EN segments on I-215 caused higher crash rate. This is counter-intuitive and need more investigation.

5.3. Ordered Probit model calibration

5.3.1 Model results

Table 8: Severity model calibration results for types of segments

ORDERED PROBIT MODEL FOR VEHICULAR CRASH SEVERITY						
	EX-EX SEGMENTS		**EN-EX SEGMENTS**		**EX-EN SEGMENTS**	
Variable	**Coef.**	**Stat.**	**Coef.**	**Stat.**	**Coef.**	**Stat.**
I-15			9.5162	0.0000	1.6323	0.0000
I-215					4.7632	0.0000
Through lanes	-0.4964	0.0030	2.2466	0.0000	-0.7002	0.0000
Through lanes * I-15			-2.6705	0.0000		
Median width	0.0713	0.0000	0.1632	0.0000	0.0302	0.0010
Median width * I-15			-0.1488	0.0000		
Segment length			0.5842	0.0040		
Curve radius			-0.0001	0.0210	-0.0001	0.0050
Curve radius * I-15			0.0004	0.0000		
Lane change: ramp-to-freeway					0.4278	0.0200
Auxiliary parameters						
μ_1	-0.2881741		14.68992		0.6850804	
μ_1					5.352499	
Likelihood ratio test						
LR χ^2(9)	27.28		451.1400		1127.14	
Prob > χ^2 (9)	0.0000		0.0000		0.0000	
Pseudo R2	0.1915		0.6699		0.8093	
Observations	107		557		938	

Table 8 presents results obtained for severity models. Only three segments are included in the table: EX-EX, EN-EX, and EX-EN since all variables for EN-EN were not significant. The likelihood ratio tests for all these three models indicate that all models are significant. The model for EX-EX segment had only two variables found significant: number of through lanes and median width. The coefficient on the number of through lanes is negative, which shows that EX-EX segments with more through lanes had fewer high severity crashes happened. This is because with more lanes drivers might have more spaces available to maneuver to avoid crashes. Among the three freeways: I-15, I-215 and US 95, none of them had more high severity crashes than other freeways. The coefficient on the median width is positive which indicates that wider median increased the likelihood of more severity crashes. This is counter-intuitive and need more investigation.

For EN-EX segments, the coefficient on I-15 is positive, which indicates that there was higher severity crashes on I-15 compared to US95 and I-215. It is known that there are more visitors on I-15 than on other freeway, and they are less familiar with the roads in Las Vegas. Their behaviors like sudden slowing down and speeding up may cause more severe crashes. This implies that some of these risk factors on I-15 might have contributed to the occurrence of high severity crashes. The coefficient on the number of through lanes is positive, which implies that more lanes on freeways increased high severity crashes. This result is counter-intuitive because it is expected that more lanes provides spaces for drivers to avoid crashes due to less traffic congestion. Therefore more investigation is needed. The coefficient on through lanes on EN-EX segment on

I-15 is negative, which indicates that segments with more through lanes on I-15 had lower severity crashes. This might be due to the fact that vehicles on I-15 tended to travel slower than on I-215 and US95.

The coefficient on the median width is positive which indicates that EN-EX segments with wider median had higher severity crashes. This is counter-intuitive because wider medians are expected to provide more spaces for drivers to avoid collisions. The coefficient on the variable representing median width of EN-EX segments on I-15 is negative, which implies that EN-EX segment with wider medians on I-15 had fewer high severity crashes and this is consistent with intuitive.

The coefficient on the EN-EX segment length is positive which indicates that the long segments had more high severity crashes. This is counter-intuitive because in long segments drivers are expected to have more time for avoiding crashes. In this case more investigation is needed. The coefficient on the curve radius is negative, which indicates that EN-EX segments with large radii had fewer high severity crashes. This is true because with large radius on segments visibility is better. Also with large radius, drivers can easily negotiate the curve. The coefficient on the variable representing radius on I-15 is positive, which shows that curvature with large radius increased the chance of high severity crashes. This is counter-intuitive and needs more investigation.

The model for EX-EN segment type also was statistically significant. The coefficient on I-15 is positive which implies that by comparison, that were more high severity crashes on I-15 than on the EX-EN segments on I-215 and US95. This might be caused by more complicated geometric conditions and traveler population on I-15. The coefficient on I-215 EX-EN segments is also positive which indicates that I-215 had higher likelihood of high severity crashes when compared to US95. The results shows that I-15 and I-215 both had higher likelihood of high severity crashes compared to US95 with I-15 being more sensitive than I-15. As far as individual geometric elements are concern, the coefficient on the number of through lanes is negative, which shows that these segments with more through lanes had lower likelihood of high severity crashes. This is expected because with more lanes, drivers increase driving confidence and can easily maneuver to avoid any risk factors encountered on the freeways. This situation applies to all the three freeway with equal amount of influence. The coefficient on the median width is positive indicating that wider medians increased the likelihood of high severity crashes. This is counter-intuitive and needs more investigation. The coefficient on the curve radius is negative, which implies that segments with large radius had lower risk of high severity crashes. This is consistent with intuitive because curves with large radius had better visibility and easy to drive on.

The coefficient on the variable "lane change: ramp-to-freeway" is positive, which implies that segments with more lane changing for emerging had higher likelihood of high severity crashes. This is intuitively reasonable because with more lanes involving in merging there would be more vehicle interactions and this may likely increase collisions.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

This study studied the effect of primary geometric factors to the occurrence of crashes on freeways in the Las Vegas metropolitan area in Southern Nevada. Multiple linear and ordered probit regression models were calibrated for crash rate and severity for four segment types: EN-EX, EX-EN, EN-EN, and EX-EX. GIS and Google map tools were used in collecting crash, geometric and other relevant data.

Geometric variables used in this study included number of through lanes on the main facility, presence/absence of auxiliary lanes, length of segments, curve radius within the segments, and grade. Other geometric variables were used concerned geometrical elements defining weaving movements occurring on weaving segments and they were: minimum number of lane changes that a ramp-to-facility weaving vehicle must make to successfully complete a ramp-to-facility movement, and the number of lanes involved in weaving maneuver. Traffic variables included average annual daily traffic (AADT). Furthermore, variables which indicated whether pavement surface was wet or dry were included in the analysis in this study.

Based on analyzing the results, it can be seen that the characteristics of these four segment types determine the factors influencing crash rate and severity. In general, as shown in table 9 below, the following observations can be summarized below.

1. The factors that influenced crash rate and severity on EN-EX are different. Narrower shoulder width, particularly that on I-15, caused lower crash rate, but did not have any impact on crash severity. In other words, the shoulder, primarily on the outer lane, provides space for avoid crashes; when a crash occurred, its severity would has nothing

to do with shoulder. The crashes could be either on other lanes or cannot be avoided regardless of shoulder width. Such crashes should be rear-end collision on the outer –lane next to the shoulder. On the other hand, number of through lane, median width, and curve radius had no impact on crash rate, but influenced the severity of crashes. Speaking differently, having more through lane, wider median, or bigger curve radius did not cause more or fewer crashes, but would make the crash more or less severe.

I-15 presented a different influencing pattern for factors of the number of through lanes, median width, and radius. In addition, there are unique but non-identified factors that made I-15 different both on crash rate and severity. This observation implies that futher study is needed to identify such factors so that corresponding countermeasures can be proposed. Segment length did influence the crash severity, but no crash rate on the EN-EX segments.

2. The influencing pattern on EX-EN segments is different from that on EN-EX segments, even though some factors influenced their crash rate and severity commonly. Particularly, segment length did not impact on crash rate and severity. Traffic weaving, that may cause crash on EN-EX segment, apparently not a problem on this type of segments anymore. One operational factor, the change changes from on-ramp appeared significantly increasing the likelihood of occurring high severity crash, probably due to the backup of congestion from the contiguous EN-EX segment downstream. Traffic volume influenced crash rate, but not severity. The combination of operation and traffic

flow needs further investigation. In addition, there are identified factors on I-215 that contributed to the lower crash rate and higher severity on their EX-EN segments.

3. As far as the EX-EX segments, those factors like shoulder width, radius and lane change character did not influence crash rate and severity. Number of through lane, median and traffic volume influenced the crash rate or crash severity. This might be determined by the characteristics of this type of segment, where congestion would be incurred on freeway if traffic cannot get off from the second off ramp smoothly.
4. No factors were identified influencing crash rate and severity on EN-EN segments. Regardless of how traffic is congested on these two on-ramps, traffic on the main line would not be influenced significantly, particularly when ramp metering is implemented. The occurrence of crashes on these segments would not be influenced by the geometric characteristics of these segments such as segment length, number of through lane, etc.

Table 9: Crash Rate and Crash Severity for Three Segment Types

Independent variable	EX-EX Segments				EN-EX Segments				EX-EN Segments			
	Crash Rate		Crash Severity		Crash Rate		Crash Severity		Crash Rate		Crash Severity	
	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
I-15	-110.6502	0.0003			206.39	0.0006	9.5162	0	-424.07	0.0483	1.6323	0
I-215	359.4776	0							-141.158	0.003	4.7632	0
Through lanes	-11.8804	0.0055	-0.4964	0.003			2.2466	0			-0.7002	0
Through lanes * I-15	32.2534	0.0001					-2.6705	0				
Through lanes * I-215	-80.2516	0										
Median width	-1.4447	0.0242					0.1632	0			0.0302	0.001
Median width * I-15			0.0713	0			-0.1488	0				
Length of segment							0.5842	0.004				
Shoulder									-7.213	0.0051		
Shoulder * I-15					-13.016	0.0074						
Shoulder * I-215									11.958	0.0007		
Curve radius							-0.0001	0.021			-0.0001	0.005
Curve radius * I-15							0.0004	0				
Lane change: ramp-to-freeway											0.4278	0.02
AADT	28.4133	0.0011										
AADT * I-15									39.931	0.0295		
Constant	-264.1417	0.0026			21.483	0.0019			117.213	0.0005		

There are many areas that need further investigation. First, some variables including segment length, number of lane change, shoulder width, median width, and curve have counterintuitive results and thus the causes for such counterintuitive result need further investigations. Second, some variables like shoulder and median widths have nonlinear relation with frequency. It should be investigated for the appropriate forms of variables in regression models.

Key to Variables:

1. tlanes: Through lanes
2. nwv: Number of lanes involved in weaving
3. lcrf: Lane changes from ramp to freeway
4. lcfr: Lane changes from freeway to ramp
5. EN-EN segment
6. EX-EX segment
7. EN-EX segment
8. EX-EN segment
9. seglength: Base length of segments
10. shoulder: shoulder width
11. median: median width
12. grade: grade
13. radius: curve radius
14. aux: indicator variable for presence of auxiliary lanes
15. aadt: Annual average daily traffic
16. splimit: Speed limit

Appendix B: Correlation matrices for crash rate model

Table 10: EN-EN segment type for crash rate model

Correlation matrix for EN-EN segment types											
	tlanes	lcrf	lcfr	nwv	length	shoulder	median	grade	radius	aux	AADT
tlanes	1.000										
lcrf	0.143	1.000									
lcfr	0.264	0.588	1.000								
nwv	0.370	0.721	0.693	1.000							
length	-0.386	-0.241	-0.274	-0.338	1.000						
shoulder	0.374	-0.140	-0.137	-0.210	-0.131	1.000					
median	0.532	-0.060	-0.069	-0.096	-0.338	0.680	1.000				
grade	-0.151	-0.082	-0.151	-0.078	0.076	-0.012	-0.202	1.000			
radius	-0.034	-0.050	0.178	-0.200	0.161	0.147	-0.049	0.101	1.000		
aux	-0.167	-0.542	-0.317	-0.780	0.370	0.058	0.124	0.000	0.240	1.000	
AADT	0.667	0.230	0.439	0.346	-0.393	0.347	0.290	-0.149	0.057	-0.128	1.000

Table 11: EN-EN segment type for crash rate model

Correlation matrix for data of crash rate model											
	tlanes	lcrf	lcfr	nwv	length	shoulder	median	grade	radius	aux	AADT
tlanes	1.000										
lcrf	0.184	1.000									
lcfr	0.184	0.804	1.000								
nwv	0.383	0.817	0.817	1.000							
length	-0.564	-0.213	-0.117	-0.163	1.000						
shoulder	-0.199	0.037	0.018	-0.146	0.104	1.000					
median	0.129	0.333	0.352	0.185	-0.209	0.703	1.000				
grade	0.048	-0.262	-0.179	-0.259	-0.094	0.063	0.112	1.000			
radius	0.337	0.340	0.340	0.176	-0.304	0.089	0.231	-0.100	1.000		
aux	-0.309	-0.716	-0.716	-0.807	0.199	0.153	-0.232	0.255	-0.474	1.000	
AADT	0.538	0.048	0.099	0.295	-0.358	-0.037	0.086	0.129	-0.031	-0.260	1.000

Table 12: EN-EX segment type for crash rate model

Correlation matrix for data of crash rate model											
	tlanes	lcrf	lcfr	nwv	length	shoulder	median	grade	radius	aux	AADT
tlanes	1.000										
lcrf	0.266	1.000									
lcfr	0.344	0.846	1.000								
nwv	0.357	0.903	0.859	1.000							
length	-0.180	0.006	0.001	0.001	1.000						
shoulder	0.048	0.053	0.098	0.035	-0.086	1.000					
median	0.186	0.234	0.170	0.171	0.253	0.150	1.000				
grade	-0.119	0.060	0.176	-0.025	0.083	0.055	0.025	1.000			
radius	0.177	-0.004	0.072	0.042	-0.020	-0.033	-0.064	0.034	1.000		
aux	-0.206	-0.504	-0.453	-0.575	-0.094	-0.081	-0.184	-0.082	-0.072	1.000	
AADT	0.349	-0.005	0.071	0.049	-0.167	-0.046	0.085	-0.136	0.105	-0.073	1.000

Table 13: EX-EN segment type for crash rate model

Correlation matrix for data of crash rate model											
	tlanes	lcrf	lcfr	nwv	length	shoulder	median	grade	radius	aux	AADT
tlanes	1.000										
lcrf	0.028	1.000									
lcfr	-0.011	0.890	1.000								
nwv	0.288	0.798	0.780	1.000							
length	-0.230	0.057	0.071	-0.019	1.000						
shoulder	-0.074	0.098	-0.011	-0.005	-0.001	1.000					
median	-0.126	0.181	0.120	0.135	0.285	0.086	1.000				
grade	-0.043	-0.072	-0.088	-0.212	-0.042	0.069	0.167	1.000			
radius	-0.037	0.105	0.131	0.113	0.263	-0.109	0.229	-0.017	1.000		
aux	-0.122	-0.348	-0.323	-0.414	0.107	0.075	-0.112	0.136	-0.038	1.000	
AADT	0.493	-0.025	-0.030	0.089	-0.349	-0.119	-0.048	0.176	-0.004	-0.272	1.000

Appendix C: Correlation matrices for ordered probit model

Table 14: EN-EN segment type for severity model

Correlation matrix for data of severity model											
	tlanes	lcrf	lcfr	nwv	length	shoulder	median	grade	radius	aux	AADT
tlanes	1.000										
lcrf	0.295	1.000									
lcfr	0.295	1.000	1.000								
nwv	0.541	0.648	0.648	1.000							
length	-0.426	-0.157	-0.157	-0.423	1.000						
shoulder	-0.181	-0.168	-0.168	-0.102	-0.597	1.000					
median	0.531	0.018	0.018	0.290	-0.360	0.045	1.000				
grade	-0.508	-0.930	-0.930	-0.737	0.391	0.034	-0.324	1.000			
radius	-0.432	-0.048	-0.048	-0.096	-0.414	0.629	-0.503	0.110	1.000		
aux	-0.109	0.091	0.091	-0.195	0.384	-0.247	0.283	-0.109	-0.527	1.000	
AADT	0.683	0.174	0.174	0.249	-0.599	0.322	0.453	-0.399	-0.010	-0.186	1.000

Table 15: EX-EX segment type for severity model

Correlation matrix for data of severity model											
	tlanes	lcrf	lcfr	nwv	length	shoulder	median	grade	radius	aux	AADT
tlanes	1.000										
lcrf	0.241	1.000									
lcfr	0.654	0.134	1.000								
nwv	0.732	0.459	0.808	1.000							
length	-0.198	-0.371	-0.221	-0.377	1.000						
shoulder	0.141	-0.272	0.097	-0.111	0.598	1.000					
median	0.185	0.248	0.127	0.209	0.324	0.430	1.000				
grade	-0.294	-0.209	-0.182	-0.274	0.224	-0.062	0.363	1.000			
radius	-0.131	0.216	0.314	0.036	-0.066	0.018	0.021	0.287	1.000		
aux	-0.761	-0.370	-0.709	-0.760	0.144	0.049	-0.385	0.128	-0.009	1.000	
AADT	0.561	0.380	0.674	0.809	-0.470	-0.069	0.376	-0.050	-0.049	-0.590	1.000

Table 16: EN-EX segment type for severity model

Correlation matrix for data of severity model											
	tlanes	lcrf	lcfr	nwv	length	shoulder	median	grade	radius	aux	AADT
tlanes	1.000										
lcrf	0.091	1.000									
lcfr	0.060	0.648	1.000								
nwv	0.001	0.766	0.774	1.000							
length	-0.416	-0.170	0.007	-0.193	1.000						
shoulder	0.085	0.182	0.140	0.079	0.264	1.000					
median	-0.154	0.224	-0.175	0.098	-0.347	-0.045	1.000				
grade	-0.347	0.193	0.275	0.242	0.316	0.219	0.046	1.000			
radius	-0.034	0.095	0.140	0.087	0.307	0.195	-0.250	0.090	1.000		
aux	-0.154	-0.339	0.016	-0.201	0.271	-0.105	-0.399	-0.193	-0.010	1.000	
AADT	0.479	0.079	0.152	0.088	-0.328	-0.459	-0.123	-0.353	-0.207	-0.065	1.000

Table 17: EX-EN segment type for severity model

Correlation matrix for data of severity model											
	tlanes	lcrf	lcfr	nwv	length	shoulder	median	grade	radius	aux	AADT
tlanes	1.000										
lcrf	-0.158	1.000									
lcfr	0.018	0.904	1.000								
nwv	0.411	0.764	0.835	1.000							
length	-0.610	0.275	0.177	-0.146	1.000						
shoulder	-0.285	0.353	0.230	0.082	0.298	1.000					
median	0.234	0.278	0.242	0.372	-0.023	0.049	1.000				
grade	-0.100	0.058	0.021	-0.015	0.182	-0.240	0.361	1.000			
radius	0.097	0.017	0.124	0.101	0.108	-0.083	-0.053	-0.190	1.000		
aux	0.122	-0.257	-0.186	-0.107	-0.316	-0.387	-0.309	-0.204	0.123	1.000	
AADT	0.613	-0.491	-0.325	-0.051	-0.704	-0.550	-0.230	-0.085	0.099	0.432	1.000

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VITA

Eneliko Mulokozi
Graduate Assistant
Department of Civil and Environmental Engineering
Howard R. Hughes College of Engineering
University of Nevada, Las Vegas
4505 Maryland Parkway, Box 454015
Las Vegas, NV 89154-4015
Phone: 702-403-2517
Email: mulokozi@unlv.nevada.edu

EDUCATION

University of Dar es salaam, Tanzania: B.SC., Civil & Structural Engineering, 2003.

Major Area: Structural / Transportation Engineering

Areas of Study: Engineering management; computer applications in civil engineering, Highway and transportation engineering; Transportation economics; Traffic engineering; Geometric design; Construction techniques and maintenance, Engineering Mechanics, Surveying, Soil Mechanics and Foundation Engineering, Hydraulic and Water Resources Engineering, Behavior and Analysis of Structures, Introduction to Building design and construction, Building Materials, Construction Management and Site organization, Design of Timber Structures, Design of Steel Structures.

MS – Training Center for Development co – operation, Arusha – Tanzania

Major Area: Management

Areas of Study: Communication and Managing Conflicts, Delegation and Motivation, Building and Managing Teams, Principles of Management and Leadership, Personnel Management Systems and Principles and Organization Structure and Controls

Institute of Fundraising and Direct Marketing – Nairobi

Major Area:	Management
Areas of Study:	Project Proposal Writing, Project Cycle Management, Monitoring and Evaluation, Principles of Fundraising, Strategic Planning for Fundraising, Maintaining good donor relations

University of Nevada, Las Vegas: M.SC., Transportation Engineering, 2011 - Present.

Major Area:	Transportation Engineering
Areas of Study:	Traffic Engineering, GIS Applications in Civil Engineering, Public Transit Systems and Technology, Applied Statistics for Engineers, Statistical Modeling, Regression Analysis II, Travel Demand analysis, Transportation planning, Geometric design of highways, Operations research applications in Civil engineering, Intelligent Transportation Systems.

EXPERIENCE

17/11-present	University of Nevada, Las Vegas, Graduate Assistant, Department of Civil and Environmental Engineering
03/10-12/10	Serviceplan Limited, Tanzania, Civil Engineer / Deputy Managing Director
03/07-02/10	Dar es Salaam Water and Sewerage System – Dawasco, Tanzania, Area Manager
06/04-12/05	Evangelical Lutheran Church – Karagwe Diocese, Civil Engineer
06/03-12/03	LOMO Consult, Tanzania, Civil / Structural Engineer
07/02-12/02	BCEOM (French Consulting Company), Tanzania, Material Engineer

PROFESSIONAL AFFILIATIONS

Institute of Transportation Engineering (ITE) (2011 - Present)

Academic Honors, Offices Held in Student /Professional Organizations.

1. President – American Railway Engineering and Maintenance – of - the Way Association Student Chapter at University of Nevada, Las Vegas

2. Golden Key International Honor Society

Research

1. Developing modules for civil engineering focused Science, Technology, Engineering, and Mathematics (STEM) curriculum for high schools.

2. Investigating the effect of Non – random samples for modeling crash occurrence at signalized intersections.

Research Interests

Road safety engineering, Intelligent Transportation Systems, Transportation Planning and Demand Modeling, Systems analysis in civil engineering, Application of GIS in Transportation engineering.