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**TRANSFERABILITY AND CALIBRATION OF THE HIGHWAY SAFETY MANUAL  
PERFORMANCE FUNCTIONS AND DEVELOPMENT OF NEW MODELS FOR  
URBAN FOUR-LANE DIVIDED ROADS**

by

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A dissertation submitted in partial fulfillment of the requirements  
for the degree of Doctor of Philosophy  
in the Department of Civil, Environmental and Construction Engineering  
in the College of Engineering and Computer Science  
at the University of Central Florida  
Orlando, Florida

Fall Term  
2014

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## **ABSTRACT**

Many developing countries have witnessed fast and rapid growth in the last two decades due to the high development rate of economic activity in these countries. Many transportation projects have been constructed. In the same time both population growth and vehicle ownership rate increased; resulting in increasing levels of road crashes. Road traffic crashes in Gulf Cooperation Council (GCC) is considered a serious problem that has deep effects on GCC's population as well as on the national productivity through the loss of lives, injuries, property damage and the loss of valuable resources.

From a recent statistical study of traffic crashes in Oman, it was found that in 2013 there were 7,829 crashes occurred for a total of 1,082,996 registered vehicles. These crashes have resulted in 913, 5591, and 1481 fatal, injury and property damage only crashes, respectively (Directorate General of Traffic, 2014), which is considered high rates of fatalities and injuries compared to other more developed countries. This illustrates the seriousness and dangerousness of the safety situation in GCC countries and Oman particularly. Thus, there is an urgent need to alleviate the Severity of the traffic safety problem in GCC which in turn will set a prime example for other developing countries that face similar problems.

Two main data sources from Riyadh, the capital city of Kingdom of Saudi Arabia (KSA) and Muscat, the capital city of Sultanate of Oman have been obtained, processed, and utilized in this study. The Riyadh collision and traffic data for this study were obtained in the form of crash database and GIS maps from two main sources: the Higher Commission for the Development of Riyadh (HCDR) and Riyadh Traffic Department (RTD). The Muscat collision and traffic data

were obtained from two main sources: the Muscat Municipality (MM) and Royal Oman Police, Directorate General of Traffic (DGC). Since the ARC GIS is still not used for traffic crash geocoding in Oman, the crash data used in the analysis were extracted manually from the filing system in the DGC.

Due to the fact that not all developing countries highway agencies possess sufficient crash data that enable the development of robust models, this problem gives rise to the interest of transferability of many of the models and tools developed in the US and other developed nations. The Highway Safety Manual (HSM) is a prime and comprehensive resource recently developed in the US that would have substantial impact if researchers are able to transfer its models to other similar environment in GCC. It would save time, effort, and money. The first edition of the HSM provides a number of safety performance functions (SPFs), which can be used to predict collisions on a roadway network. This dissertation examined the Transferability of HSM SPFs and developing new local models for Riyadh and Muscat.

In this study, first, calibration of the HSM SPFs for Urban Four-lane divided roadway segments (U4D) with angle parking in Riyadh and the development of new SPFs were examined. The study calibrates the HSM SPFs using HSM default Crash Modification Factors (CMFs), then new local CMFs is proposed using cross-sectional method, which treats the estimation of calibration factors using fatal and injury data. In addition, new forms for specific SPFs are further evaluated to identify the best model using the Poisson-Gamma regression technique. To investigate how well the safety performance model fits the data set, several performance measures were examined. The performance measures summarize the differences between the

observed and predicted values from related SPFs. Results indicate that the jurisdiction-specific SPFs provided the best fit of the data used in this study, and would be the best SPFs for predicting severe collisions in the City of Riyadh. The study finds that the HSM calibration using Riyadh local CMFs outperforms the calibration method using the HSM default values.

The HSM calibration application for Riyadh crash conditions highlights the importance to address variability in reporting thresholds. One of the findings of this research is that, while the medians in this study have oversize widths ranging from 16ft-70ft, median width has insignificant effect on fatal and injury crashes. At the same time the frequent angle parking in Riyadh urban road networks seems to increase the fatal and injury collisions by 52 percent. On the other hand, this dissertation examined the calibration of the HSM SPFs for Urban intersections in Riyadh, Kingdom of Saudi Arabia (KSA) and the development of new set of models using three year of collision data (2004-2006) from the city of Riyadh. Three intersection categories were investigated: 3-leg signalized, 4-leg signalized, and 3-leg unsignalized. In addition, new forms for specific SPFs are further evaluated to identify the best model using the Poisson-Gamma regression technique. Results indicate that the new local developed SPFs provided the best fit of the data used in this study, and would be the best SPFs for predicting severe crashes at urban intersections in the City of Riyadh

Moreover, this study examined the calibration of the HSM SPFs for Fatal and Injury (FI), Property Damage Only (PDO) and total crashes for Urban Four-lane divided roadway segments (U4D) in Muscat, Sultanate of Oman and the development of new SPFs. This study first calibrates the HSM SPFs using the HSM methodology, and then new forms for specific SPFs are

further evaluated for Muscat's urban roads to identify the best model. Finally, Riyadh fatal and injury model were validated using Muscat FI dataset.

Comparisons across the models indicate that HSM calibrated models are superior with a better model fit and would be the best SPFs for predicting collisions in the City of Muscat. The best developed collision model describes the mean crash frequency as a function of natural logarithm of the annual average daily traffic, segment length, and speed limit. The study finds that the differences in road geometric design features and FI collision characteristics between Riyadh and Muscat resulted in an un-transferable Riyadh crash prediction model.

Overall, this study lays an important foundation towards the implementation of HSM methods in multiple cities (Riyadh and Muscat), and could help their transportation officials to make informed decisions regarding road safety programs. The implications of the results are extendible to other cities and countries and the region, and perhaps other developing countries as well.

**To the Souls of My Grandmother Fatima and My Uncles**



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## LIST OF ACRONYMS/ABBREVIATIONS

3 SG	3-legged signalized
3ST	3-legged unsignalized
APM	Accident Prediction Model
AIC	Akaike information criterion
AASHTO	American Association of State Highway and Transportation Officials
AADT	Annual Average Daily Traffic
ATC	Automatic Traffic Counts
BIC	Bayesian information criterion
BMA	Bayesian model averaging
Cr	Calibration Factor
CMF	Crash Modification Factor
FID	Crash Report File
CURE	Cumulative Residual plots
L	Degree of horizontal curvature
DIC	Deviance Information Criterion
DGC	Directorate General of Traffic
DD	Driveway Density
EB	Empirical Bayes
ESRI	Environmental Systems Research Institute
FI	Fatal and Injury Collisions
F	Fatal only Collisions
FARS	Fatality Analysis Reporting System



4ST	Four Legged Unsignalized Intersection
4SG	Four Legged Signalized Intersection
GLM	Generalized Linear Modeling
GIS	Geographic Information System
GPS	Global Positioning System
GOF	Goodness-Of-Fit
GCC	Gulf Cooperation Council
HCDR	High Commission for the Development of Riyadh
HSM	Highway Safety Manual
KSA	Kingdom of Saudi Arabia
LTVs	light Truck Vehicles
LLAFT	log-logistic accelerated failure time
LS	longitudinal Slope
MTC	Manual Traffic Counts
MCMC	Markov Chain Monte Carlo
MAPE	Mean Absolute Percent Prediction Error
MAD	Mean Absolute Deviation
MPB	Mean Prediction Bias
MSPE	Mean squared prediction error
MW	Median Width
MSTO	Ministry of Transportation
MLPNN	Multilayer Perception Neural Network
MNL	Multinomial logit model

MV	Multiple Vehicle
MVPLN	Multi-Variate Poisson log normal
MM	Muscat Municipality
NB	Negative Binomial
DW	Number of driveways
P-G	Poisson-Gamma
PAMs	Predictive Accident Models
PDO	Property Damage only Collisions
REGONBM	Random effect Generalized Negative Binomial model
RENB	Random effect Negative Binomial model
REGOPM	Random-Effect Generalized Ordered Probit Model
RTD	Riyadh Traffic Department
ROP	Royal Oman Police
SPF	Safety Performance Function
SMOT	Saudi Ministry of Transport
SL	Segment Length
SHW	Shoulder Width
SPC	Side Friction Coefficient
SFC	Side Friction Coefficient
P - value	Significance Level
SV	Single Vehicle
SGLMM	Spatial generalized linear mixed model
SPEED	Speed Limit

SAS	Statistical Analysis Software
SSR	Sum of Squared Residuals
K	The rate of change of curvature
TOTAL	Total Crashes
U4D	Urban Four-lane divided roadway segments
AADT <sub>maj</sub>	volume of annual average daily traffic on major roads
AADT <sub>min</sub>	volume of annual average daily traffic on minor roads
ZINB	Zero-inflated Negative Binomial
ZIP	Zero-inflated Poisson

# CHAPTER 1: INTRODUCTION

## 1.1 General Background

Road traffic crashes are recognized as a growing public health problem in the Gulf Cooperation Council countries (GCC) and other developing countries. The discovery of oil around the middle of the last century has changed many aspects of life in the GCC countries. GCC countries have expanded in terms of population, and growth of vehicles. The growth in motorization rate is accompanied by a drastic increase in the size of the road network. Such a growth has led to higher crash frequency, which resulted in loss of lives, and caused major economic and social concerns in the country.

Previous studies have highlighted the Traffic safety in GCC as a serious issue and initiated urgent need for strict and comprehensive measures (Lee, 1986; Koushki and AL anazi,1998; Koushki and Al-Ghadeer, 1992; Bener, 1991; Jadan *et al* 1992; Bener *et al* 2003; Al-Ghamdi, 1996, 1999;Koushki *et al.* 2002).

Compared to European countries and USA, GCC Countries have a very high road crashes fatality rate. In 2001, 14.8 and 7.3 persons per 10,000 vehicles were killed in Saudi, and Qatari road traffic, respectively (Bener *et al.*, 2003). The comparative rates were, for example, approximately 1.8 for Finland, 2.4 for France, 1.5 for UK, and 1.9 for USA (IRF, 2003). Thus, there is an urgent need to alleviate the traffic crash problem in GCC countries which in turn will set a prime example for other developing countries that face similar problems. However, over the past decades limited traffic safety research has been carried out for roadway networks in GCC

Countries. The majority of this research focused on a limited set of features that were of interest at the time. In the same time, the limited size of road network, limited associated data and data collection expensive cost were some of the difficulties to develop prediction models. Nowadays, there is a growing need for more robust models, similar to those developed internationally. These models uniquely partition the safety impacts of a range of road variables, allowing simultaneous assessment of a range of features. Such models provide better prediction of the expected crash risk associated with new or changed facilities, facilitate the identification of situations with abnormally high crash risk, allow more robust assessment of a range of potential solutions, and guide the development of design standards and policies. To date, there has been no research that evaluates the implementation of the highway safety manual (HSM) predictive methodology in GCC countries and the transferability and applicability of HSM models to these countries.

Therefore, this research aims to fill these research gaps by calibrating and transferring the HSM predictive models and developing new robust models and carry out a careful investigation to understand the relationship between traffic crashes and their contributing factors aiming to establish effective safety policies ready to be implemented to reduce the severity of road crashes in multiple cities (Riyadh, the capital city of Saudi Arabia and Muscat, the capital city of Oman), and could help their transportation officials to make informed decisions regarding road safety programs. The implications of the results are extendible to other cities and countries and the region, and perhaps other developing countries as well.

## 1.2 Research Objectives

This research seeks to fill some of the knowledge gap regarding the state of knowledge and state of practice in highway safety. Specifically, it focuses on urban 4-lane divided roads. The main objective of this study is to calibrate and transfer the HSM models and develop new models for urban 4-lane divided roadways in Riyadh and Muscat using crash data from 2004-2009 and 2010-2011, respectively, to evaluate the effects of several traffic and geometric design variables on traffic safety, to help understand the current safety problems and recommend solutions for improvement. For this objective, calibrated HSM models, and traditional Poisson-gamma models will be used in model development and comparisons. The specific objectives will be achieved by the following tasks:

- Develop an integrated database from three separate databases which is suitable for Safety Performance Functions (SPF) development for Riyadh and Muscat.
- To understand the limitation of current crash prediction models and the application of models to different geographic regions and different time periods.
- Identify the geometric design variables influencing the occurrence of crashes in GCC urban roadway.
- Develop crash prediction models (Safety Performance Functions) for the urban four-lane divided roadway segments with angle parking as shown in Figure1.1 using fatal and injury collisions (FI) in the City of Riyadh.
- Calibrate HSM models for the urban four-lane divided roadway segments with angle parking using fatal and injury collisions (FI) in the City of Riyadh.
- Compare HSM calibrated models with the new developed models to determine the potential for HSM model transfer.

- Evaluate the calibration and transferability of HSM predictive models for urban 4-lane divided with angle –parking both sides roadway segments.
- Use alternative local Crash Modification Factors (CMFs) instead of HSM CMFs to re-evaluate the calibration and transferability of HSM predictive models.
- Model validation of the Riyadh total FI model over time and space by using validation data different from the original data.
- Develop and estimate crash modification functions to examine the effect of angle street parking on fatal and injury accidents in Riyadh urban roads.
- Develop crash prediction models (Safety Performance Functions) for total crashes for Urban Four-lane divided roadway segments (U4D) in the City of Muscat and compare them with the calibrated HSM models.
- Develop crash prediction models (Safety Performance Functions) for fatal and injury (FI) for Urban Four-lane divided roadway segments (U4D) in the City of Muscat and compare them with the calibrated HSM models.
- Develop crash prediction models (Safety Performance Functions) for Property Damage Only (PDO) crashes for Urban Four-lane divided roadway segments (U4D) in the City of Muscat and compare them with the calibrated HSM models.
- These previous comprehensive models provide better predictions of the expected crash frequency, but since that not each GCC countries will develop its own specific models mainly due to the fact that not all highway agencies possess sufficient crash data that enable the development of robust models. This problem gives rise to interest of transferability of the previous Riyadh FI model to other similar environment in GCC.

Therefore, this research aims finally to evaluate the transferability of the Riyadh's developed model using FI crash data from Muscat urban divided roads.

- Identify and quantify the main contributing factors to the severity of highway crashes in Riyadh and Muscat.
- Identify policies and countermeasures to the major safety factor problems for urban roadways in GGC countries.



Figure 1-1: Urban roadway in Riyadh with angle parking

The original contribution of this study to the state of the art is quantification of the impact of angle parking factors on crash severity in Riyadh; the application of HSM models to the prediction of crash severity in the city of Riyadh using Riyadh local crash modification factors compared with HSM default values; and the crash severity prediction performance comparison among three statistical models, HSM models, new local NB models, and new local transferable model from neighboring GCC country.



This dissertation will develop and present a comprehensive procedure with the intent of improving the quality of research through development and transferability of predictive crash models through time and space.

### 1.3 Dissertation Organization

The dissertation organized as follows: chapter 2 following this chapter, summarizes literature review on previous works about traffic safety in Gulf Cooperation Council Countries, geometric design factors contributing to crash frequency and severity, previous research about the HSM's safety performance functions, and literature review on transferability of crash prediction models.

Chapter 3 presents the data collection methodology of collision, cross sectional, and traffic volume data in Riyadh and Muscat. Provide an information summary about Riyadh ARCGIS database, brief description about several attributes which used in this study, and the difficulties and limitations of this database.

Chapter 4 deals with the methodology used to calibrate the HSM models and the Negative Binomial model used to develop new local models, then presents the statistical performance measures used to compare between the HSM calibrated models and the new local developed models.

Chapter 5 compares between the transferability of HSM models using two approaches and the developing new local models for urban 4-lane divided roadway segments in Riyadh, Kingdom of Saudi Arabia. Chapter 6 presents the transferability of HSM models and developing new models

for urban intersections at Riyadh, Kingdom of Saudi Arabia. Chapter 7 deals with the transferring of HSM calibrated models. Developing new local models in Muscat, Sultanate of Oman, for three response variables- fatal and injury, property damage only, and total crashes. Finally, Chapter 8 concludes the research efforts, findings, and future recommendations of this work.

## CHAPTER 2: LITERATURE REVIEW

Prior to the analysis of crash data for the present work, an exhaustive search of literature was performed. The review is divided into four sections: First, this chapter reviews past limited amount of studies about Traffic Safety in the GCC Countries. Next, summarize the papers that discussed the traffic safety performance functions and geometric design factors that affect traffic safety. At the end of this chapter the literature review researches that tried to apply HSM SPFs and transfer them to different regions and the studies that dealt with the temporal and spatial transferability of different traffic prediction models.

### 2.1 Previous works about Traffic Safety in Cooperation Gulf Council Countries

Road traffic crashes in the Cooperation Gulf Council (GCC) Countries ranked the second killer or highest cause of death after cardiovascular diseases (Bener, Abu-Zidan, Bensiali, Al-Mulla, & Jadan, 2003). Previous studies have addressed the problems of traffic crashes in the Gulf Cooperation Countries (GCC). In Kingdom of Saudi Arabia (KSA), traffic crash fatality rate was 21 fatalities per 100,000 people in 2005 and this is the second highest fatality rate within the Middle East and North Africa (HCDR, 2008).

Al-Ghamdi (2002) investigated pedestrian–vehicle crashes in Riyadh using stratified contingency tables methodology. Data of 638 pedestrian–vehicle crashes reported during the period 1997–1999, were examined. The analysis showed that the pedestrian fatality rate per 100,000 people is 2.8. The rates were relatively high within the childhood (1–9 years) and young adult (10–19 years) groups, and the old-age groups (60–80 years), which indicate that young as well as the elderly people in Riyadh are more likely to be involved in fatal crashes of this type

than are those in other age groups. Nofal and Saeed (1997) investigated seasonal variation and weather effects on road traffic crashes in Riyadh City. The monthly variation of traffic crashes in Riyadh city in the period 1989–1993 has been studied with reference to time of day, lighting conditions and prevalent weather conditions. The authors found that most crashes occurred during daytime, in dry weather and specifically during the summer months of July, August and September.

Al-Ghamdi (2003) investigated traffic crashes that occurred at both intersections and non-intersection sites. A sample of 1774 reported collisions was collected in a systematic random manner for the period 1996–1998 (651 severe crashes (crashes resulting in at least one personal injury or fatality) and 1123 property-damage-only (PDO) crashes). The author performed conditional probability and contingency table analyses methodology to make inferences from the data. The study found that improper driving behavior is the primary cause of crashes at signalized urban intersections in Riyadh; running a red light and failing to yield are the primary contributing causes. The study indicates that there is an urgent need to review existing intersection geometry along with the traffic control devices installed at these sites.

Al-Ghamdi (2002) examined the effect of nine independent variables on accident severity by using logistic regression. A total of 560 subjects involved in serious crashes reported in traffic police records occurring on urban roads in Riyadh were sampled. Two variables were found to be statistically associated with the crash severity: crash location (i.e. crashes at non-intersections seem to be more severe) and crash cause (i.e. crashes as a result of travelling the wrong way and failure to yield). Both age and nationality were found to be statistically insignificant. Some of challenges encountered during research were : police reports did not describe injuries in much

detail at crash sites because of the lack of police qualifications and training, police records categorized crashes into three: property damage only (PDO), injury (no injury classification was available) and fatal crash which difficult to properly examine the factors affecting crash severity. Bendak (2005 ) investigated the impact of seat belt utilization on traffic crash injuries in Saudi Arabia by measuring seat belt use rate and its impact on the number of road crash injuries during the first few months following the law in 1998. The author used a questionnaire to investigate driver's behavior and his characteristics and their relationship with using seat belts. Results showed a significant drop in injuries due to traffic crashes after implementing the seat belt law and those personal characteristics were correlated with seat belt use rate. An average seat belt use rate of 60% for drivers and 22.7% for front seat passenger were recorded in two Riyadh suburbs in the first few months after the seat belt laws acted. These rates are considered low when compared with rates in developed countries and compared with Kuwait when the rate was almost 100% for drivers and after enforcing the use of seat belts in 1994 though this dropped to 50% for Kuwaiti drivers and 65% for non-Kuwaiti drivers.

Al-Ghamdi and Al-Gadhi (2009) investigated the effect of warning signs used as countermeasures to camel-vehicle collisions in Saudi Arabia. They examined seven camel-crossing warning signs to determine if they reduced the number of camel-vehicle collisions on rural roads. Although most of the signs showed significant reductions in mean speed the speed reductions were quite small from 3 to 7 km per hour. Statistical analysis used to rank the signs according to their effectiveness found that the influence of the warning sign on the driver starts nearly 500 m ahead of the sign and diminishes at 500 m downstream of the sign.

Al-Twajjri *et al.* (2010) investigated the factors affecting the severity of road injury crashes in Riyadh city using crash data from (2004- 2008). Injury crash severity data were classified into three categories: fatal, serious injury and slight-injury. Two nominal response models have been developed: a standard multinomial logit model (MNL) and a mixed logit model to injury-related crash data. Because of the underreporting problem on the slight injury crashes, binary and mixed binary logistic regression models were also estimated for two categories of severity: fatal and serious crashes.

The results from both multinomial and binary response models are found to be fairly consistent but the results from the random parameters model seem more reasonable. Age and nationality of the driver, excessive speed, wet road surface and dark lighting conditions and single vehicle crashes are associated with increased probability of fatal crashes. More specifically, the probability of having a fatal crash increases with the age of the driver and Saudi drivers (relative to non-Saudi drivers) are associated with the probability of fatal crashes (relative to serious injury crashes). There is no effect of age in slight injury crashes relative to the serious injury crashes. A crash involving a single vehicle is found to be more severe than a crash involving a multiple vehicles.

Al-Matawah and Jadaan (2009) used Generalized Linear Modelling (GLM) technique to investigate the impact of various contributory factors on traffic crashes in Kuwait. The study found that age, nationality, aggressive driver behavior, dangerous offences, perception of effectiveness of enforcement, marital status, speed, and experience are the main contributory factors that lead to crash involvement.

Bener *et al.* (2003) in their study about the traffic crashes in GCC countries concluded that the traffic crashes continue to be a major cause of mortality and morbidity in the GCC countries leading to substantial wastage of life and national resources. The authors investigated simple regression analysis to study the effect of several parameters on the fatality (per licensed vehicle). The parameters used were as follows: vehicle per-person; gross national product (GNP) per capita; population per physician; population per hospital bed; and percentage of the school age population attending schools.

The results of regression analysis obtained showed that the fatality rates were found: to decrease with increasing vehicle ownership; to decrease with increasing GNP per capita; decrease with increasing percentage of the school age population attending school; increase with population per physician; and increase with population per hospital bed. The authors found that the lack of reliable data is a serious problem in most of the developing countries. It is quite reasonable to assume that the incidence of crashes is much larger than actually reported.

Bener *et al.* (2009) investigated the severity of head and neck injuries in Qatar using a total of 6,709 patients during the period of 2001-2006. This study found that road traffic crashes was a major cause of head and neck injuries and that majority of the victims were non-Qataris.

## 2.2 Geometric Design Factors Contributing to Crash Frequency and Severity

The concept of modeling for collision predictions has been supported by recently carried out research, which have established the relation between collisions and geometric design features. Numerous road collision prediction models have been developed to investigate the effects of

geometric design variables on collisions. Abdel-Wahab and Abdel-Aty (2004) evaluated the effect of increased percentage of light truck vehicles (LTVs) on head-on fatal crashes. Time series models were used to forecast the future fatality trends of head-on crashes based on a crash database obtained from the Fatality Analysis Reporting System (FARS) over the period of 1975–2000. The researchers forecasted that the annual deaths in head-on crashes would have increased over a 10-year period since the year 2000, and would have reached 5324 by 2010, representing an 8% increase since the year 2000. Overall, the modeling results showed that head-on fatal crashes were affected by the increased percentage of LTVs in traffic.

Shankar *et al.* (1996) studied the effect of roadway geometrics (horizontal and vertical alignments) and environmental factors such as weather and other seasonal effects. They found that when curves are spaced further apart (i.e., fewer curves per mile) there is an increase in severe overturning crashes. They also found that highway segments that have curves with lower design speeds result in fewer crashes relative to those with higher design speeds; though the presence of snowfall tends to increase crashes on those segments with curves of lower design speeds.

Abdel-Aty *et al.* (2000) developed NB distribution model for collision frequency prediction. Collision frequency was estimated as a function of AADT; degree of horizontal curvature; segment length; width of lane, shoulders and median; and urban/rural designation. The model in this study also accounted for driver characteristics, including sex and age (young, middle aged and senior). The results showed that collision frequency increases with AADT, degree of horizontal curvature and segment length, and decreases with width of lane, shoulder and median.



Pande and Abdel-Aty (2009) investigated traffic and highway design parameters associated with severe crashes on segments of multilane arterials. A within stratum matched crash versus non crash classification approach is applied. The results indicated that severe lane-change related crashes may primarily be attributed to exposure while single-vehicle crashes and pedestrian crashes have no significant relationship with the ADT. For severe rear-end crashes speed limit, ADT, *K*-factor, time of day, day of week, median type, pavement condition, and presence of horizontal curvature were significant factors.

Hauer (2007) applied NB Statistical model to estimate collision frequencies on undivided four lane urban roads. This model evaluated the number of collisions per year as a function of the following independent variables: AADT, percentage of trucks, degree and length of horizontal curve, grade of tangents, length of vertical curve, lane width, shoulder width and type, road side hazard rating, speed limit, access points (e.g. signalized intersections, stop-controlled intersections, commercial driveways and other driveways), and the presence and nature of both parking and two-way left turn-lanes (TWLTL). The results showed that the variables that had a significant effect are: AADT, the number of commercial driveways, and speed limit. A model for injury and damage-only collisions at urban intersections in Canada was developed by Persaud *et al.* (2002), which described the relationship between collision risk and traffic attributes, including traffic volume. The time-series collision data from the study explicitly revealed temporal changes in safety conditions and enabled a comparison of the safety performance of junction types across different cities.

Zeeger *et al.* (1986) investigated the effects of lane and shoulder width on traffic crashes. The study concluded that lane width had significant effect on two-lane roadway crashes. Crash rates decreased with an increase in lane width until a width of about 12 ft., after which the rates increasing again. Fridstrom and Ingebrigsten (1991) and Karlaftis and Tarko (1998) find that network extensions increase crashes and fatalities. Milton and Mannering (1998) find similar results for increased number of lanes and that narrower lane widths reduce accident frequency. Sawalha and Sayed (2001) also find an association between the number of lanes and increased crashes on arterials.

Caliendo *et al.* (2007) developed crash-prediction models for a four-lane median-divided Italian motorway using 5-year monitoring period extending between 1999 and 2003. The authors used Poisson, Negative Binomial and Negative Multinomial regression models separately to tangents and curves. The authors found that the number of both total and severe crashes per year and carriageway increases with: length, AADT and the presence of junctions, whereas it decreases with Side friction coefficient (SFC) and longitudinal slope (LS).

Hosseinpour *et al.* (2013) examined the factors affecting the head on crash occurrence on 448 segments of five federal roads in Malaysia. Data on road characteristics and crash history were collected on the study segments during a 4-year period between 2007 and 2010. The authors developed seven count-data models including Poisson, standard negative binomial (NB), random-effect negative binomial, hurdle Poisson, hurdle negative binomial, zero-inflated Poisson, and zero-inflated negative binomial models. The author used random-effect generalized ordered probit model (REGOPM) to model crash severity. With respect to the crash frequency,

the random-effect negative binomial (RENB) model was found to outperform the other models according to goodness of fit measures. Based on the results of the model, the variables horizontal curvature, terrain type, heavy-vehicle traffic, and access points were found to be positively related to the frequency of head-on crashes, while posted speed limit and shoulder width decreased the crash frequency. With regard to the crash severity, the results of REGOPM showed that horizontal curvature, paved shoulder width, terrain type, and side friction were associated with more severe crashes, whereas land use, access points, and presence of median reduced the probability of severe crashes.

Abdul Manan *et al.* (2013) used negative binomial regression, to develop a predictive model for motorcycle fatal crashes on Malaysian primary roads. The results show that motorcycle fatalities per kilometer on primary roads are statistically significantly affected by the average daily number of motorcycles and the number of access points per kilometer. Several previous studies have indicated that access control has a positive effect on safety. Lall *et al.* (1996) showed that for two lane rural highways, driveway density was a reasonably good predictor of potential crashes within a given volume range on rural roads. Another study, also cited by Lall *et al.* (1996) indicated that an increase of access density by 10 times resulted in a doubling of the accident rate. Garber and White (1996), in a study of 30 sections in Virginia, found that ADT per lane, average speed, number of accesses, left-turn lane availability, average driveway spacing, and average difference in driveway spacing influenced the accident rate for urban principal arterials.

Brown and Tarko (1999) developed Negative binomial regression models to predict crash rates on multi-lane arterial segments based on geometric and access control characteristics. The models for total number of crashes, property-damage-only crashes, and fatal/injury crashes all have the same structure. The exposure-to-risk variables include segment length, AADT, and number of years. The significant factors include access density, proportion of signalized access points, presence of an outside shoulder, presence of a two-way left-turn lane, and presence of a median with no openings between signalized intersections. They found that the percentage of injury and fatality crashes increases with the increase in the access density. The effect of access control on crash severity is weaker than on the crash frequency.

Knuiman *et al.* (1993) examined the effect of median width of four-lane roads on crash rate using a Negative Binomial model. The findings indicated that crash rate decreases with increasing median width. Furthermore, wider medians considerably reduce “crossover crashes” involving head-on crashes between opposing vehicles. As a result, a much greater positive effect on severe crashes than on property-damage-only crashes is expected. Rodman *et al.* (1996) investigated the effect of the median width of four lane roads on collision rates using NB distribution. Their study indicated that collision rate decreases with increasing median width, while wider medians are associated with a reduction in crossover collisions that involve head-on collisions between opposing traffic.

Lyon *et al.* (2005) described the development of SPFs for urban signalized intersections based on 5-years of collision data in Toronto. Separate SPFs were developed for 3SG and 4SG intersections, several impact types (rear-end, right angle, left turn, all combined) and severity

levels, property damage only collisions (PDO), and fatal plus non-fatal injuries (F&I). They also found that the number of lanes on an approach is strongly correlated with the number of turning lanes.

Hadi *et al.* (1995) proposed several accident-prediction models with regard both to multilane roads and two-lane roads of rural or urban roads. The dependent variables were total crash rate or injury crash rate. The values of these accident indicators were estimated as a function of AADT and road environmental factors. Poisson and Negative Binomial regression models were considered. By examining the effect of traffic flow on the crash rate the conclusions reached were that crash rate increases with increasing AADT on roads having higher levels of traffic, while it decreases with AADT on roads with lower traffic volumes. This finding reflects the fact that in the presence of low traffic volumes, free-flow conditions exist so that by increasing AADT the users have more restricted freedom for maneuver with which a lesser crash risk is associated.

In recent years, there are a few studies which have started investigating injury severity from SV and MV crashes separately. For example, Persaud and Mucsi (1995) used hourly volumes derived from aggregate adjustment factors to test the effect of light conditions on these two types of crash. They found that multi-vehicle crashes mostly occurred during the daytime when the light conditions were good, whereas single-vehicle crashes were more likely to occur after sunset. Also, while single-vehicle crashes were associated with narrow lanes and shoulders, multivehicle crashes were associated with wide lanes and shoulders. Hence, they recommended that these two types of crashes be modeled separately.

Ivan *et al.* (1999) Investigated differences in causality factors for SV and MV crashes on two-lane rural highways in Connecticut. They found that contributing factors were different for each category of crashes. For example, SV crashes were negatively associated with an increase in traffic intensity (exposure), shoulder width, sight distance, and level of service (LOS). On the other hand, MV crashes were positively associated with an increase in traffic intensity, shoulder width, truck percentage, and number of traffic signals. Later on, Ivan *et al.* (2000) reported that the time-of-day differently influenced for both categories of crashes. SV crashes occurred mostly during the evening and at night, as expected, whereas MV crashes occur more frequently during daylight and evening peak periods. This was mainly attributed to the higher traffic intensity. Driveway density had a mixed effect on SV crashes. Driveways at gas stations and minor road intersections were negatively associated with SV crashes, whereas driveways located adjacent to apartment complexes seemed to be associated with an increase in SV crashes. MV crashes increased for all types of driveways.

Krull *et al.* (2000) used a logistic model to study how driver condition, vehicle type, roadway geometrics, AADT, speed limit and rollover involvement affect the probability of fatal and incapacitating injuries. They found that those variables that increase the probability of severe injury are rollover involvement, failure to use a seatbelt, alcohol use, rural roads (as opposed to urban), and higher speed limits. These variables also increase injury severity, given rollovers. There have been studies that have investigated the relation between accident severity and speed limit. For example Solomon (1964) in his study found that crash severity increases with increased speed on rural roads and the probability of fatal injury rises sharply for speeds over 70

mph. Joksch (1993) found that fatality risk was proportional to the fourth power of the change in speed of a vehicle in a crash and that the fatality risk increases with speed limit.

Ossiander and Cummings (2002) evaluated the effects of increasing the speed limit on rural freeways from 55 to 65 mph in Washington State. They analyzed data for fatal crashes, all crashes, fatalities and vehicle miles traveled on rural and urban interstate freeways in Washington State from 1970-1994. They concluded that the fatal crash rate on Washington State's rural interstate was 110 percent higher after 1987 (when the speed limit was changed to 65 mph) than it would have been if the speed limit remained the same. However, the total crash rate showed little change implying that the share of crashes resulting in fatalities increased after the speed limit increase to 65 mph.

Kweon and Kockelman (2005) estimated the total safety effects of speed limit changes on high speed roadways. Several alternative panel and non-panel models were used, where a random effects negative binomial model was selected for count data. The results indicated that the average road segment expected to show lower non-fatal crash rates up to 55mph. in contrary, fatal rates appear not affected by speed limit changes.

Malyshkina *et.al* (2010) explored the impact of design exceptions on the frequency and severity of highway crashes in Indiana. Data on crashes at carefully selected roadway sites with and without design exceptions are used to estimate appropriate statistical models of the frequency and severity of crashes at these sites using recent statistical advances with mixing distributions. The results of the modeling process show that presence of approved design exceptions has not

had a statistically significant effect on the average frequency or severity of crashes. However, the findings do suggest that the process that determines the frequency of crashes does vary between roadway sites with design exceptions and those without. The authors found that with regard to the severity of crashes, while most of the factors that affected severity were driver characteristics, urban area crashes have a lower likelihood of injury and that the posted speed limit is critical (higher speed limits result in a significantly higher probability of an injury accident). They recommended that urban/rural location and design exceptions on highways with higher speed limits need to be given careful scrutiny.

Bedard *et al.* (2002) applied a multivariate logistic regression to determine the independent contribution of driver, crash, and vehicle characteristics to drivers' fatality risk. They found that increasing seatbelt use, reducing speed, and reducing the number and severity of driver-side impacts might prevent fatalities.

Box (2002) reviewed several studies that contrasted angle parking with parallel parking. He concluded that streets with angle parking had crash rates that were 1.5 to 3 times larger than those streets with parallel parking.

In recent years, Bayesian methods have found several applications in traffic crash analysis. Ma *et al.* (2008) employed multivariate Poisson-lognormal (MVPLN) specification that simultaneously models crash counts by injury severity using Bayesian inference. The MVPLN specification allows for a more general correlation structure as well as overdispersion. The results from the MVPLN approach show statistically significant correlations between crash counts at different levels of injury severity. The non-zero diagonal elements suggest overdispersion in crash counts



at all levels of severity. The authors concluded that wide lanes and shoulders are significant factors for reducing crash frequencies as are longer vertical curves.

Chin and Quddus (2003) included Random effect negative binomial model (RENB) model to deal with the spatial and temporal effects in the traffic crash study. The authors examined the relationships between accident occurrence and different characteristics of signalized intersections in Singapore. The authors claimed that the random effect has been added to the NB model by assuming that the over-dispersion parameter is randomly distributed across groups, and this formulation is able to account for the unobserved heterogeneity across space and time.

Shively *et al.* (2010) examined a Bayesian methodology to investigate the relationships between crash occurrence and roadway features. The authors found that curvature, traffic levels, speed limit and surface width were the main contributing factors to crash occurrence. Additionally, they concluded that the key factors that affect crash counts are traffic density, presence and degree of horizontal curve and road classification.

Huang and Abdel-Aty (2010) claimed that traffic safety studies usually contains multilevel data structures, i.e. [Geographic region level-Traffic site level – Traffic crash level – Driver and vehicle unit level – Occupant level]  $\times$  Spatiotemporal level. Due to the complicated data structure, models like generalized linear regression model are incapable to handle it. Since then, the authors proposed a Bayesian hierarchical approach which explicitly specifies multilevel structures. Several case studies have been conducted using the proposed methodology and it was concluded that model fittings can be improved with the Bayesian hierarchical models handling the multilevel data.

Guo *et al.* (2010) looked into signalized intersection safety problems with corridor-level spatial correlations. The mixed effect model in which the corridor-level correlation is incorporated through a corridor specific random effect and the conditional autoregressive model were compared with normal NB and Poisson models. A full Bayesian framework was used in this study. The DIC was used to compare the performance of the alternative models and it was found out that the Poisson spatial model provides the best model fitting.

Geedipally *et al.* (2012) examined NB generalized linear model with Lindley mixed effects for analyzing traffic crash data. The purpose of introducing this method in traffic crash analysis is to address the data sets that contain large number of zeros and a long tail. The authors claimed that the NB generalized linear model provided a superior fit compared to the NB model.

Ahmed *et al.* (2011) and Yu *et al.* (2013) examined Bayesian hierarchical models to account for seasonal and spatial correlations for a mountainous freeway in Colorado. In order to consider the over-dispersion along with the spatial correlations between the homogenous segments, Poisson model, Random effect Poisson model, and Gaussian Conditionally Autoregressive prior model have been performed using Bayesian inference methodology. They concluded that the Random effect Poisson model outperformed the others.

### 2.3 Previous research about the HSM's safety performance functions

The recent release of the HSM encouraged many researchers to calibrate the safety performance functions in the HSM. This section reviews the studies that investigated the calibration and

transferability of HSM models to different jurisdictions. The first study tried to calibrate HSM carried out by Sun *et al.* (2006). The authors evaluated the calibration of the draft HSM to Louisiana state road network which consists of 13,400 miles of two-lane rural highways. Although the authors did not follow the recommended HSM procedure for calibrating the predictive model, they were able to create a database with the most important highway variables of average daily traffic (ADT), segment length, lane width, shoulder width and type, and driveway density. Generally there were small differences between the observed and predicted crash frequencies.

It was found that the highest calibration parameter was 2.28 for an AADT less than 1000 vehicles per day, and the lowest calibration parameter was 1.49 for an AADT greater than 10,000 vehicles per day. Martinelli *et al.* (2009) used HSM draft to calibrate the crash prediction model for the Italian Province of Arezzo on 1,300 kilometers of rural, two-lane highways. In this study, the calibration procedure of the HSM model has been applied to a region characterized by a different environment and different road characteristics, driver behavior, and crash reporting systems than those on which the HSM models have been developed.

The comparison between the observed crashes and four models with different calibration procedures were presented and each of the models overestimated crashes substantially. Additionally, it was found that the models overestimated crashes at low crash locations and underestimated crashes at high crash locations. The authors concluded that calibration of the model is absolutely necessary to avoid the overprediction found in the base model. The authors also note that a primary issue with calibration exists because the high segmentation of the HSM procedures leads to low or zero crash segments which are not predicted accurately by the HSM.

The primary finding was that applying a weighted average of crashes over the length of a segment performed better than using a ratio of densities or raw crashes.

Xie *et al.* (2011) focused on the application of HSM procedure on Oregon state rural road network using data from 2004-2006 in order to calibrate the model for Oregon local condition. The study found the calibration factor for rural two-way roads was 0.74 across 75 sites with 394 observed collisions and 533 HSM predicted collisions. On the other hand, the calibration factor for rural 4-legged signalized intersections (R4SG) was 0.47 across 25 sites with 142 observed collisions and 300 HSM predicted collisions. The authors explained that the calibration factor less than 1.00 due to the higher reporting system threshold in Oregon which lead to less reported property damage only crashes.

Brimley *et al.* (2012) performed the HSM calibration procedure on rural two-lane roads in Utah State using crash data from 2005-2007 on 157 selected segments and to develop new specific SPFs. The original HSM model underpredicts crashes in Utah and the calibration factor found to be 1.16. The authors incorporated new variables such as percent-single unit trucks, percent combo-unit trucks, speed limit, shoulder rumble strip, and passing ability to explore possible new relationships. Four new negative binomial models were developed using two different model types at two level of confidence. The authors found that the jurisdiction-specific model at 95 percent confidence and incorporating the natural log of AADT was determined to be best.

Zegeer *et al.* (2012) used data on two-lane rural horizontal curves in North Carolina to validate and apply the HSM to the analysis of horizontal curves. The authors used three different data sets: all segments, random selection segments and non-random selection segments. Calibration

factors for curve, tangent and the composite were calculated. The study results provided that the curve segments have a relative higher standard deviation than the tangent and composite segments. In order to save the collection data effort in the development of the calibration factors, the authors performed sensitivity analysis of each parameter's influence for the output results for curve segments. HSM predicted collisions were compared as using the minimum value and the maximum value for each parameter.

The results verified that annual average daily traffic, curve radius, and curve length were the most important factors in determining prediction accuracy. Other variables like grade, driveway density would not affect the result much if the mean value were utilized when developing the models. Finally, validation of the calibration factor was performed with an extra data set. Results indicated that the calibrated HSM prediction have no statistical significant difference with the reported collisions.

Lubliner and Schrock (2012) analyzed both the accuracy and the practicality of using the HSM rural two-lane predictive methods on Kansas rural two-lane. Ten-mile long sections were selected because they were long enough to have a variety of geometric features but short enough to provide enough geographic distribution throughout the state. Calibration sections, and their associated observed crashes, were analyzed from 2005 to 2007. From a list of 41 randomly selected sections, 19 sections were selected which resulted 239 homogenous sites and 145 crash per year which met the HSM conditions. Several methods for calibrating the rural two-lane segment safety performance function (SPF) were analyzed. The calibrated models showed significant improvements versus the uncalibrated models and were extremely accurate when

analyzed at the aggregate level. In an effort to improve the crash prediction accuracy, alternative calibration methods were considered and analyzed.

These alternatives included several linear calibration methods that addressed variables that have shown a positive correlation to highway crashes in Kansas in previous research, but are not considered in the HSM. While the linear calibration methods did not perform as well on the aggregate level, they did show improvement on the project level. Ultimately, the analysis of the HSM rural two-lane segment predictions showed a favorable accuracy and has been recommended for inclusion in KDOT's safety at the project level.

Banihashemi (2011) examined calibrating the predictive method to create two new SPFs for the state of Washington. Four new CMFs were also developed for lane width, shoulder width, curve radius, and vertical grade which were used with the new SPFs. In this study, it was found that the calibration for Washington State worked just as well as either of the new models. The newer models might be preferred if more CMFs were created specifically for the state. However, since the original SPF was created using Washington and Minnesota data, the same used to develop the model in the HSM, the fact that it worked just as well as new SPFs is not entirely surprising.

In a later study, Banihashemi (2012) conducted a sensitivity analysis for the data size issue for calculating the calibration factors. Mainly five types of highway segment and intersection crash prediction models were investigated; Rural two-lane undivided segments, rural two-lane intersections, rural multilane segments, rural multilane intersections and urban/suburban

arterials. Specifically, eight highway segment types were studied. Calibration factors were calculated with different subsets with variety percentages of the entire dataset.

Furthermore, the probability that the calibrated factors fall within 5% and 10% range of the ideal calibration factor values were counted. Based on these probabilities, recommendations for the data size issue to calibrate reliable calibration factors for the eight types of highways have been proposed. With the help of these recommendations, the HSM predictive methods can be effectively applied to the local roadway system. Sacchi *et al.* (2012) assessed the transferability of the HSM SPFs as well as CMFs. The authors used only fatal plus injury-related crashes (FI) within the HSM output to provide a consistent comparison. The study considered a sample of two-lane rural roads involving several sites characterized by high AADT.

Generally, the study observed a strong over-prediction of the HSM model and low prediction accuracy for higher AADTs. In particular, the authors found that the relative difference between HSM predictions and observed crash data increases with increasing exposure. Young and Park (2012) compare the performance of the calibrated HSM's SPFs and the jurisdiction-specific SPFs for intersections in Regina, Saskatchewan using five years of collision data (2005-2009) from the city of Regina, Saskatchewan. Four different model types were developed for each of total collisions, fatal-injury and property damage only collisions.

Three intersections categories were investigated: 3-leg unsignalized, 4-leg unsignalized, and 3 and 4-leg signalized. It was found that the jurisdiction-specific SPFs and calibrated HSM provided the best fit than the uncalibrated HSM for all types of intersections. In addition the

jurisdiction-specific SPFs were the best SPFs for predicting collisions at 3 and 4-leg intersections in the City of Regina.

Cafisco *et al.* (2013) compared the effect of choosing different segmentation methods, they examined using short vs. long roadway segment to calibrate the SPF. In addition to the segment selection criteria, new treatment types have also been identified beside those which included in the HSM.

D'Agostino (2013) examined the transferability of HSM and safety analyst SPF to Italian rural roadway by addressing the differences between two different directional segments methods, one is based on a consideration of two directional segments, and the other one is based on mono-directional segments with a correction factor that takes into account the presence of two directional traffic, as proposed by Safety Analyst. In the latter case, traffic flows are the sum of traffic flows for each direction. Both models show a good fit to the dataset.

The model calibrated on the HSM and Safety Analyst segmentation approach has calibration value of 1.26 and 0.99 respectively. The value of 0.99 suggests a better fit to the model condition than the value of 1.26. Moreover the results show how the correction factor to the intercept, suggested by Safety Analyst, can overcome the problem due to consider two separate travel direction in the statistical regression. Finally, the models both give good results in term of statistical regression, but the Safety Analyst segmentation and model approach give the best results in term of transferability.



Persaud *et al.* (2013) assessed the of HSM implementation requirements for Ministry of Transportation, Ontario (MTO). The authors investigated recalibration of the HSM algorithm for rural two-lane and multilane segments. They found that recalibration of the HSM algorithm for rural two-lane and multilane segments were successful. Goodness-of-fit measures indicated a reasonable fit to the data in general. The authors found that calibration factors for undivided segment models are 1.03 for total collisions and 0.53 for FI collisions. For the divided segment models, the calibration factors are 1.51 and 0.84 for total and FI collisions respectively. The authors found that for undivided segments, the recalibrated model for total collisions tends to under-predict for low AADT and over-predict at higher AADT. The recalibrated model for fatal and injury collisions tend to over-predict for low AADT and under-predict at higher AADTs.

## 2.4 Transferability of Crash prediction models

### 2.4.1 Introduction

The predictive accuracy of traffic crash prediction models depends on the quantity and quality of the data used to calibrate the models. The amount of data required for a good model to be calibrated is depending on researcher experience, and often on the availability of money and time. For this reason, most models calibrated with limited data in the past have proved to be inconsistent in terms of the predictive accuracy.

One of the factors that determine the suitability of statistical prediction models is the extent of the environment over which it would be valid. If a model can be easily calibrated with a small data set, then it can be fully exploited and used in many locations. But crash prediction models vary so much that it is unlikely that any one of them will fit the conditions in many places. This is partly attributable to the inconsistencies and variations in data collection and recording

systems in the different regions. Of course, one should be able to achieve higher levels of predictive accuracy if the data could be disaggregated further. But, this means that a roadway category like urban arterials may have to be represented by a multitude of models due to the varied geometric and operational conditions within the category.

With the advancement of statistical techniques and publishing of HSM the model transferability has become simpler. These techniques help the use of a prior model to predict present conditions with minimum data and funds, thus cutting the cost of data collection and time.

Transferability of prediction models is divided into two types: temporal and spatial. Temporal transferability is one in which a model calibrated at a particular site is employed at the same site at a later date to predict crashes. Spatial transferability is one in which a prediction model calibrated at a particular site is employed at a different site with similar characteristics.

The failure of models to predict precisely when they are transferred temporally may be due to differences in the behavior of influencing parameters, driver population, animal population, law enforcement, vehicle characteristics, collision nature, weather, crash reporting thresholds, and crash reporting practices since the time of model calibration.

The failure of models to predict precisely when they are transferred spatially may be attributable to the previous mentioned differences as well as socioeconomic and geometric design features differences between the prior context and the new context. Consequently, the transferability of these models over time and space presents significant problems and could result in unreliable crash estimations. This problem is well known and has been the object of several studies.

#### 2.4.2 Previous Research relevant to the Transferability of traffic Prediction models

Different researches have been conducted to evaluate the validity and transferability of collision prediction models in space and time. Sawalaha and Sayed(2005) developed negative binomial model for predicting accident frequency on the urban arterials using crash, traffic and geometric data for 283 arterial sections in Vancouver from period (1994-1996).

Later on, the transferability of the Vancouver model to Richmond city was examined using data for 102 arterial sections in Richmond. Statistical measures showed that the Vancouver model has an acceptable fit to the data. The author used two procedures for recalibrating the transferred model which are the moment method and the maximum likelihood procedures. The author emphasized that the shape parameter of the model must be recalibrated for local conditions in order to be transferable to Richmond data and also preferred to recalibrate the constant for better suit local conditions.

Persaud *et al.* (2002) examined the transferability of collision prediction models to other jurisdictions. Toronto data were used to estimate models for three- and four-legged signalized and unsignalized intersections. Then, the performances of these models were compared with those of models from Vancouver and California, which were recalibrated for Toronto. The results were mixed, which suggest that a single calibration factor may be inappropriate and disaggregation by traffic volume might be preferable. The study also noted that the transfer procedure will work best if the models being transferred to the new location resemble the functional form and have similar exponents as the locally derived SPFs.

Hadayeghi *et al.* (2006) examined the temporal transferability of zonal-level accident prediction models. It was found that the model developed using 1996 data could not be used for predicting crash frequency in 2001. The Bayesian updating approach and calibration factors were used to update the 1996 models. The updated models could produce reasonably good predictive performance on the 2001 sample. Marchionna *et al.* (2008) examined transferability of Uncalibrated SPFs from the United States, Italy, United Kingdom, and Denmark for urban intersections in Trieste, Italy. Goodness-of-fit tests were used to measure the predictive capability of the SPFs. They found that SPFs, even for SPFs developed in Italy, demonstrated poor transferability.

Chung (2010) examined log-logistic accelerated failure time (AFT) metric model based on the 2-year crash data from 2006 to 2007 in Korean Freeway Systems. In the study, the 2006 dataset was utilized to develop the prediction model and then, the 2007 dataset was employed to test the temporal transferability of the formulated 2006 model. The estimated duration model based on the year 2006 was validated for the prediction accuracy with acceptable reasonableness. Although, the duration prediction model has some limitations such as large prediction error due to the individual differences of accident treatment teams in clearing similar accidents, the computed MAPE value was 47%, which represents a reasonable prediction based on the adapted MAPE scale. Additionally, a likelihood ratio test based on a 2-year dataset (i.e., the years 2007 and 2006) results indicated that the estimated parameters in the duration model are stable over time. Although based only on a 1-year's dataset (i.e., 2007), the results showed that the developed model could be reasonably used for temporal transferability purposes

Chen *et al.* (2011) applied the Bayesian model averaging (BMA) approach to improve the transferability of aggregate accident prediction models. The results showed that the BMA approach was superior to conventional model calibration methods. Wood *et al.* (2013) investigated the temporal transferability of predictive accident models (PAMs). The models used to illustrate these issues are the models developed for rural dual and single carriageway roads in the UK and which are widely used in several software packages in spite of being fitted using data from the 1980s. The database used to test the models includes data from 2005–2009. Two principal issues are examined: the extent to which the temporal transferability of predictive accident models varies with model complexity; and the practicality and efficiency of two alternative updating strategies. It was found that increased model complexity by no means ensures better temporal transferability and that calibration of the models using a scale factor appears to be the most practical, cost-effective alternative to developing new models.

Persaud *et al.* (2012) used urban and suburban intersections collision data from 1999-2004. The study used three different models: HSM SPF, SPF –jurisdiction models (Toronto model) and validation model or transferability model used Edmonton data. It has been found that the use of calibration factors for applying HSM models to Toronto intersection data is not appropriate. When Toronto SPFs for multi vehicle and rear end collisions are used to predict collisions in Edmonton the calibration factor values for multi vehicle collisions at 3SG and 4SG intersections are 0.76 and 0.5, respectively. For rear end collisions, the calibration factor values are 1.5 and 0.75, respectively. This shows that the calibration value decreases in 4SG intersections as compared to 3SG intersections. These values also show that the Toronto SPF coefficients can be

useful for the prediction of collisions in the city of Edmonton. Overall, the CURE plot shows that the data is a good fit with some bias in the lower AADT ranges.

Several studies have focused on the transferability of real-time crash risk models. In a subsequent study, Pande *et al.* (2011) investigated the transferability for the real-time crash prediction models for the freeways in the Central Florida area. The authors utilized I-4 eastbound dataset to develop the crash prediction models and then validated these models with data from westbound of I-4, I-95 northbound and I-95 southbound. The studied freeway sections were equipped with traffic detectors collecting 30-seconds traffic flow conditions. The authors aggregated the raw data into 5-minute interval to avoid the noisy data then employed Random Forest technique to select the final model input variables for the models. Multilayer Perception Neural Network (MLPNN) were examined with the training dataset with different hidden neurons. Based on the prediction accuracy results, MLPNN models with data from 4-station and 4-hidden neurons outperformed the other models. The authors concluded that the proposed model was able to perform on both directions on I-4, while it could not provide reasonable results on I-95 both directions, in addition the authors concluded that due to differences between the two corridors in driver population and travel patterns resulted in an un-transferable crash prediction model.

Shew *et al.* (2013) developed a crash risk model based on the data collected from the US-101 freeway in California. The predictive performance of this model on the data collected from the nearby I-880 freeway was tested. The results showed that the difference in crash prediction accuracy between the US-101 dataset and the I-880 dataset was as large as 15% for the given

false alarm rate. These results suggested that the real-time crash risk models could not be directly transferred from one freeway to another due to the differences in traffic flow conditions, driver populations, and the structure of the freeway surveillance systems.

A recent study carried out by Xu *et al.* (2013) investigated the spatial and temporal transferability of the real-time crash risk prediction models by using the Bayesian updating approach. Data from California's I-880N freeway in 2002 and 2009 and the I-5N freeway in 2009 were used. The authors found that crash risk models cannot be directly transferred across time and space. The updating results indicate that the Bayesian updating approach is effective in improving both spatial and temporal transferability even when new data are limited. The predictive performance of the updated model increases with an increase in the sample size of the new data. In addition, when limited new data are available, updating an existing model is better than developing a model using the limited new data.

## 2.5 Summary

Different road collision prediction models have been developed to investigate the effects of different geometric and traffic variables on traffic collisions. The literature review found that traffic volume and roadway geometric design variables such as lane width, shoulder width, median width, driveway density, and speed limit have contribution to occurrences of traffic collisions. Through review of the literature that investigated the calibration and transferability the HSM SPF to different jurisdictions, several key points can be found that will direct this research effort to calibrate and validate the HSM SPF for urban multi-lane roadways.

- No previous studies have developed or tried to transfer Safety Performance Functions (SPFs) to GCC countries because of the limited data which pose difficulties to develop prediction models.
- Several studies preferred developing new models over the calibrated HSM models.
- Several studies observed over-prediction of the HSM model and low prediction accuracy for higher AADTs.
- Box (2002) study concluded that streets with angle parking had crash rates that were 1.5 to 3 times larger than those streets with parallel parking.
- HSM provide CMFs that quantifies the effect of on-street parking on total crashes. However, there are no CMFs that quantify the effect of angle parking on fatal and injury crashes for urban 4-lane divided roadways.
- No previous studies to the best of my knowledge have used fatal and injury collision data to develop and transfer SPF in urban area with predominant of angle parking such as Riyadh city.

The findings from previous studies and the lack of reliable models in the GCC countries inspired the effort of this study to investigate whether the SPFs in the HSM perform well in terms of predicting the number of collisions on the roadway network of Riyadh and Muscat or it would be recommended to develop new models. The implications to developing countries could be substantial as the transferability of the HSM to those countries could provide immediate benefits for safety assessment and prediction.



To date, there has been no research that evaluates the implementation and transferability of the HSM predictive methodology in the GCC countries. Therefore, this research aims to fill these gaps by calibrating and transferring the HSM predictive models and developing new local safety performance functions.

## CHAPTER 3: DATA COLLECTION

### 3.1 Introduction

The data collection part of the dissertation was the greatest effort undertaken in this study. This was certainly complicated by the fact that developing countries and GCC particularly crash databases had relatively few values that corresponded to the HSM data needs. Gulf Cooperation Council (GCC) countries are similar to other developing countries that the only crash data source is the police department. Moreover, some of the data fields were not maintained to an accuracy that was sufficient for this study.

Due to these limitations, several sources had to be consulted to provide the adequate data. This section reviews the methodology used to collect the database (i.e., Roadway characteristics Database, Collision Database and other cross-sectional characteristics) and then discusses the difficulties and limitations that were encountered while integrating the databases. The data collection step involved obtaining data on geometric and cross-sectional characteristics, traffic volumes, and crash data for each site.

### 3.2 Riyadh Data Description

The process of documentation and analysis of crash data in KSA have been improved and modernized since 2004. There are mainly three entities responsible for analyzing the crash data which are: police department, Riyadh municipality (Riyadh Traffic Department, RTD) and the Higher Commission for the Development of Riyadh (HCDR). Currently, there are four police

centers that deal with traffic crashes in Riyadh. The main center is in the Nasiriya region. The other is in the western, northern and southern regions of the city. Once a crash occurs, the traffic police attend the collision scene and fill in collision forms with relevant information using Global Positioning System (GPS). Crash report forms are passed to the crash department at the center of the traffic police. In the police crash department, crash data is entered into computers. Each police crash center has its own database of crash records.

The main Nasiriya center collects data from other centers with these data transferred using CDs to RTD. Data are collected from centers every two or three months. Riyadh Traffic Department (RTD) in turn passed the crash data to the Higher Commission for the Development of Riyadh (HCDR) for processing and analysis. The present data set covers the period of 2004-2009. The database comprises only fatal and injury collisions, Annual Average Daily Traffic (AADT), and geometric design features data for urban 4-lane divided roads (U4D) in the city of Riyadh (KSA). Non-injury data were not available since it is collected by a private company and generally not complete. The data used in this research were obtained from the Higher Commission for the Development of Riyadh (HCDR) and Riyadh Municipality (RTD).

A series of meetings were held with the HCDR and RTD directors and staff, during which several presentations regarding this research were given and relevant data were requested. Three different crash data files were supplied all in MS access file format: The first file contains the details of the crash characteristics with twenty three important attributes and contains 11,336 records, the second file contains the participants involved in the crash with eight variables and the third file contains eight variables regarding the vehicles involved in the crash.

The first file has the details of the crash characteristics with the twenty three attributes mapped on ARC GIS and each case in the file representing a collision. The detailed daily traffic volumes for road segments and intersections in Riyadh city were obtained from RTD in MS excel files and mapped also on ARC GIS. The traffic volume counts conducted during 2004-2009 by manual counts (MTC) and automatic counts (ATC).

### 3.2.1 Riyadh City ARC GIS map

The Riyadh Municipality began using GIS in 2001 following the establishment of a special unit called Geographic Information Systems, which falls under the management of the General Administration of Urban Planning. The objective of the unit at that time was to create a basic digital map of the city of Riyadh in conjunction with approved building plans (Riyadh Municipality, 2012). This objective became especially important in 2005, when the GIS center was put in charge of a three-phase plan (Riyadh Municipality, 2008).

The three-phase plan strives for maintaining an updated databases map and building applications for all municipal departments. At the same time, this GIS Centre expects to create studies that will aid the decision making process, which will be augmented through applications for an organized urban development. The Centre connects all of Riyadh's provincial departments and is responsible for providing services to the municipality departments and the public through the preparation and implementation of GIS applications. Riyadh municipality has experience of two GIS vendors. The first, Environmental Systems Research Institute (ESRI) developed the Riyadh digitized base map by using ARC/INFO applications. The project has been accomplished

successfully and the municipality is now utilizing the system with its Arabic user interface for planning, engineering, and management activities. The City of Riyadh currently uses a GIS to manage, analyze and display data. The observed crash data were obtained from the HCDR files and ARC GIS map shown in Figure 3-1, provided by the Riyadh Municipality. The crash data for road segments and intersections were collected separately.



Figure 3-1: Riyadh ARC GIS map

In the Riyadh ARC GIS map database each report file is assigned a specific crash identification number. Then the individual attributes of a specific crash are assigned to that identification number. For this study, several attributes were primarily used. The following is a list of those attributes with a brief description about how each field was used.

- FID: The Riyadh database identified each crash report by a unique case number.
- Crash date: the date crash occurred.
- Severity: The crash reports contain only two types of crash severity: fatality, and injury.
- Light condition on road: This field identifies the lighting condition where the crash occurred, and includes values for 'lighting site' and 'unlighted site'
- Weather: This field identifies the weather at the time the crash occurred and includes values for 'clear' and 'adverse weather'.
- Number of vehicles: This field identifies the number of vehicles involved in a crash.
- Cause of crash: This field identifies the cause of incident, and includes values for about 46 different crash causes such as sleeping, distraction, violation of traffic signal etc.
- Crash location: This field identifies the type of facility where the crash occurred, and includes values for 'intersection' and 'non-intersection' crashes.
- Collision point: This field identifies the type of collision and also contains a value for several different collisions: unknown, head- on, angle, rear-end, sideswipe collisions and single – vehicle collisions.
- Crash type: This field identifies the type of collision that occurred. The most common types include collision with vehicle, pedestrian, overturned, or fixed object.
- Crash time: This field identifies the time when incident occurred, and includes values for 'day' and 'night' crashes.
- Crash week day: This field identifies the week day when the crash occurred, and includes values for each weekday.
- The same attributes will be extracted for intersections, then the crash within roadway segments and within intersections and on the intersection legs (within 250 ft.) will be

obtained. In order to avoid the duplication of crash calculations some guidelines taken into consideration such as crash identity number (FID), police observations about the crash mentioned in MS file obtained from HCDR.

### 3.2.2 Collision Database

HCDR maintains a database of all crash reports filed for incidents on the Riyadh highway system. For this study, every crash report filed for the years 2004-2009 were gathered. HCDR provided the collision data in three separate tables, all in MS Access file format. The first file contains the details of the crash characteristics with twenty three important attributes and contains 11,336 records, with each record representing a single collision, the second file contain the participants involved in the crash with eight attributes and the third file contains eight attributes regarding the vehicle involved in the crash.

The HSM recommends a period of three to five years be utilized. Shorter periods than three years are subject to high variability due to the randomness of crashes. Longer periods than five years are subject to introduction of bias due changes in reporting standards or the physical changes to the roadway features. In this study a period of three years (2004-2006) will be utilized for testing the models while a three year period (2007-2009) will be used for model validation.

### 3.2.3 Segment characteristics data collection

The first task for the data collector on each segment was to confirm that it was indeed the correct facility type (urban four-lane divided roadway). Additionally, if there was an Intersection in the segment, the segment would be broken into two new segments, with the beginning or ending points of the new segments defined to exclude 250 feet on either side of the intersection. Once

each segment was confirmed and accurately defined, the necessary collision, geometric and cross-sectional characteristics were collected.

### 3.2.4 Traffic volumes data collection

The traffic volume was conducted by automatic and manual methods during the period from 2004 to 2009. The traffic count carried out on road segments and intersections. Traffic volumes (AADT) was obtained from the GIS data made available by the HCDR GIS Unit.

### 3.2.5 Crash Assignment

Observed crashes may be assigned to either roadway segments or intersections (AASHTO, 2010). Definitions of roadway segments and intersections are depicted in Figure 3-2. Observed crashes located in region A are assigned to intersections. Crashes that occur in region B could be either intersection related or roadway segment related.

The assignment of crashes in region B could be determined by analyzing the crash characteristics. Generally, crashes that occur on an intersection approach beyond 250 ft are assigned to roadway segments.

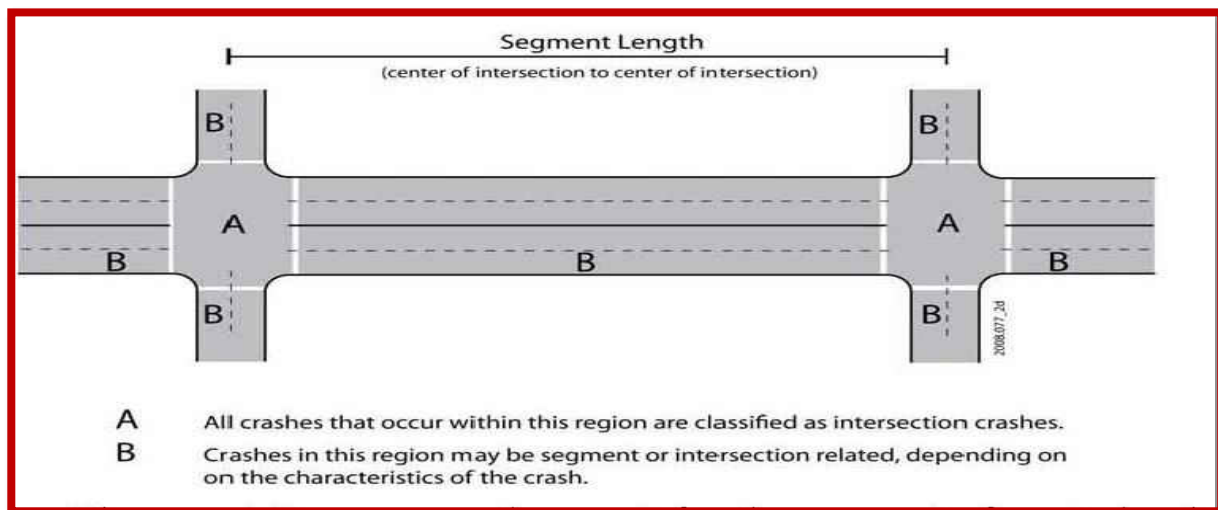


Figure 3-2 : Definition of Roadway Segments and Intersections (Source: HSM, 2010)



Since SPFs are developed using historical collision data from sites that have similar characteristics, it follows that the developed SPFs are not applicable to locations that do not exhibit similar characteristics. Where there is an interchange, the roadway characteristics no longer resemble the characteristics before or after the interchange.

The HSM states that the segment SPFs do not apply to sections within the limits of an interchange with free-flow ramp terminals. In order to properly reflect the conditions of urban roadways segments, interchange locations were not included in the analysis for SPF development.

#### 3.2.6 Other Data Sources

In the instance where roadway feature data were required but was not available through the Riyadh databases, other sources of information were consulted such as field visits, and Google earth. In Riyadh, there is currently no available database which has information pertaining to the driveway density, lane width, shoulder width, median width, and data of on –street parking.

The Google earth maps were used to determine these variables. The Riyadh databases do not carry information regarding the roadside fixed objects (RHR) and individual interpretation is needed along the entire length of segment being analyzed. Due to the relative flatness and consistent nature of Riyadh urban roads, the RHR value did not vary much either along a segment or between different segments. Therefore, it was determined that using HSM base condition for this value would be efficient.

### 3.2.7 Database Integration

In order to develop a single database that can be readily used to calibrate and develop SPFs, the three main databases mentioned above were integrated with each other. Data collected from these three sources were summarized in the Excel spread sheet. Attributes on spread sheet include the segment name, segment length, crash date, crash frequency, traffic volume, driveway density, Speed limit, shoulder width, and median width.

### 3.3 Muscat Data Description

The Sultanate of Oman has witnessed a fast and rapid growth in the last two decades due to the high development rate of economic activity in the country. Many transportation projects have been constructed. In the same time both population growth and vehicle ownership rate in Oman increase; resulting in increasing levels of road crashes. Road crashes in Oman is considered a serious problem that has deep effects on Oman's people as well as on the country's national productivity through the loss of lives, injuries, property damage and the loss of useful time.

The availability of collision data in Oman is a common problem as in the other most developing countries. The GIS tools which are important in the documentation, study and analysis of traffic safety-related issues, still not used in traffic crashes in Muscat. Therefore, this study was constrained by those data that could be extracted from traffic police files, as will be discussed shortly. The police officers responsible for completing the report usually recorded information,

such as the time, location, cause and type of accident. The traffic crashes were classified as either PDO or severe (resulting in injury or fatality or both).

It should be mentioned that there is no classification for degree of severity of traffic crashes in the official statistics. The Muscat data set covers the period of 2010-2011 and comprises fatal and injury and property damage only collisions, Annual Average Daily Traffic (AADT), and geometric design features data for urban 4-lane divided roads (U4D) in the city of Muscat. The collision and traffic data used in this study were obtained from two main sources: the Muscat Municipality (MM) and Royal Oman Police, Directorate General of Traffic (DGC).

Since the ARC GIS is still not used for traffic crash geocoding in Oman, the crash data used in the analysis were extracted manually from the filing system in the DGC. The location description in the crash report and DGC annual reports are helpful in figuring out more details about the crash characteristics and determining the location of each crash. A total of 627 police-reported crashes were collected for the period 2010–2011 on the urban four-lane divided roadway segments. The sampled crashes included two subsets. The first included 344 severe crashes. The other subset consisted of 283 PDO crashes.

The traffic volume data for road segments in Muscat city in this study were obtained from Muscat Municipality (MM) in non-electronic format (PDF files). The traffic volume counts conducted during 2011 using Manual (MTC) and Automatic Traffic Counts (ATC) and collected by private consultancy company. Since there is currently no available database which has information pertaining to the driveway density and median width, the Google Earth Maps were used to obtain these variables as shown in Figure 3.3.



Figure 3-3: Google Earth Map for Muscat Segments

The data sets contained several variables: segment length, AADT, driveway density, speed limit (mi/h), and median width (ft). Finally, the collision data, traffic volume data, and cross-section road features were merged in one file. The resulting database contained information about the collisions occurring on each segment together with the geometric and traffic characteristics of this segment. The segmentation process resulted in 104 homogeneous segments for the entire City of Muscat with the length ranging between 0.12 mi and 1.8 mi and an average of 0.48 mi.

### 3.4 Data limitations and difficulties

The process of collecting both Riyadh and Muscat crash data and taking permission from Authorities in KSA and Oman take intense efforts. A series of meeting were held with the

Authorities in Riyadh and Muscat, with the directors and staff of the related departments, during which several presentations regarding this research were given and relevant data were requested. During this period field visits were conducted to the Riyadh and Muscat urban network and the required technical notes for all the urban roads were taken.

The availability of data is a common problem in most of developing countries. In these countries the only source collecting the traffic data is the police. The police crash data are not collected with a view to provide research information but for the purposes of litigations. Therefore, such data do not have detailed information to carry out research.

The quality of data collected when crash occurs depends on the police officer who attends the crash scene. In traffic police reports, lack of accurate identification of crash locations is common; the crash location is typically identified only as an intersection or road section. Also some fields are filled with unclear text. The police officer adds a sketch illustrates how the crash happened. Location data is limited to the road name if the road were very long, sometimes, police officers write down the name of the nearest known place, building, bank etc.

The referencing location system is not used such as post markers; instead, the name of the road is written along with the type of location. In many cases the police did not take enough information for the crash to be investigated in depth to see the real cause of the crash and the report form does not help the police to take valuable information which can be used for further investigation and analysis.

Police reports at crash sites do not describe injuries in much detail because of the lack of police qualifications and training as well as facilities to perform complex examinations. Non-injury data were not available in Riyadh since it is collected by a private company and generally not complete. Consequently, it was impossible for this study to obtain details on the property damage only crashes and the degree of severity of the crashes. In the same time, collision and traffic volume data related to intersections were not available in Muscat. The current data collection process required intense time and efforts to find appropriate segments and record their attributes. The most time consuming effort to develop the models was, by far, tracking all the segments and intersections in the Arc GIS map, collecting all crash details, and double checking the excel format crashes by using FID number to avoid duplication.

Geometric design characteristics such as Lane widths, shoulder widths, parking lengths, and driveway densities were recorded for each segment using Google Earth satellite imagery. In Muscat, ARC GIS is still not used for traffic crash geocoding. Extensive work was needed to extract the collision data manually from the filing system in the DGC. The location description in the crash report and DGC annual reports were helpful in figuring out more details about the characteristics of crashes and determining the location of each crash.

### 3.5 Under-reporting problem

The effectiveness and efficiency of traffic crash models depend directly on the availability and accuracy of the related data on which the safety model is based. Hauer and Hakker (1989) pointed out that not all crashes are reportable, and not all reported crashes were reported.

Unreported data tend to produce biased estimations for prediction models which, in turn, be adversely affected by this bias.

Underreporting is more critical for crashes with slight injury severity (Koushki and Balghunaim, 1991; Ye and Lord, 2011; Al-tawijri *et al.* 2010). Koushki and Balghunaim (1991) asserted that more than 57% of traffic crashes in capital city of Riyadh remained unreported. The study revealed that more than one half of the unreported crashes were slight injury crashes and significant portion of unreported crashes occurred at intersections.

In some countries, less than half of the fatalities that happen as a result of road crashes are reported to the police. Jacobs *et al.* (2000) estimate that underreporting rates in developing countries range between 25%-50% of those crashes reported by the police. Underreporting is considered a serious limitation to traffic crashes analysis that requires urgent needs for strict and comprehensive solutions.

## CHAPTER 4: METHODOLOGY

The following section describes the methodology used to calibrate and predict the SPFs in this research. First, presents the HSM calibration methodology for urban roadways. Second, presents the traditional Poisson-Gamma model and finally, presents model performance measures used in evaluating and comparing among the calibrated and developed models.

### 4.1 HSM calibration procedure of urban four-lane divided roads

The Highway Safety Manual, released by AASHTO in July 2010, provides “analytical tools and techniques for quantifying the potential effects on crashes as a result of decisions made in planning, design, operations, and maintenance” (American Association of State Highway and Transportation Officials, 2010). The HSM safety predictive model consists of three basic parts:

- Safety Performance Function (SPF):

SPFs are regression equations used to establish the relation between crashes and exposure, generally, exposure being AADT. These SPFs are called “base SPFs” as they are used to estimate the predicted collisions at a site for a given “base condition”.

- Crash Modification Factors (CMFs):

CMFs, which have been assembled by a team of experts and documented in the HSM, are defined as the expected change in crashes which results from a given safety treatment.



- The Calibration factor (Cr):

Calibration factor is a critical component of HSM procedure used to modify the predicted number of collisions from the HSM base model to account for local differences such as collision reporting thresholds, driver behaviors, climate change, etc.

Calibration factor calculated as the ratio of total number of observed crashes to the total number of predicted crashes. A calibration factor greater than 1.0 implies that these roadways, on average, experience more crashes than the roadways used in developing the SPFs. And, a value lower than 1.0 implies that these roadways, on average, experience fewer crashes than the roadways used in developing the SPFs computed in order to adapt the model to local conditions.

SPF models are provided to estimate intersection- and non- intersection related crashes. There are separate SPFs for roadway segments and all four intersection types. The independent variables for segments are roadway segment length and AADT. The independent variables for intersection are major and minor road AADT. Due to the range of data used to develop these equations, there is an AADT range for which the equations can be used. There are also overdispersion parameters ( $k$ ) that are calculated or given with each SPF.

#### 4.1.1 Segment Models

Separate models are used to estimate the single –vehicle and multiple-vehicle collisions. The collision predictive models for roadway segments are as follows:

Multiple-vehicle crashes

$$N_{mv} = \exp(a + b \ln(AADT) + \ln(L)) \quad (4-1)$$

where

AADT= volume of annual average daily traffic on road segment

L=length of roadway segment (mi.)

a,b are the regression coefficients;

Single-vehicle crashes

$$N_{sv} = \exp(a + b \ln(AADT) + \ln(L)) \quad (4-2)$$

where

AADT= volume of annual average daily traffic on road segment

L=length of roadway segment (mi.)

a,b are the regression coefficients; and

CMFs are applied to adjust the HSM base model for local conditions. For urban four-lane, there are five CMFs for segments. The CMFs for road segments are as follows:

- On-street parking,
- Roadside fixed objects,
- Median width,
- Lighting, and
- Automated speed enforcement

#### 4.1.2 Intersection Models

The SPFs for urban intersections predict the number of total crashes at the intersection per year for base conditions. The SPF is based on the major AADT and minor AADT of the intersection.

Separate models have been developed for the following types of intersections:

3-legged unsignalized (3ST)

4-legged unsignalized (4ST)

3-legged signalized (3SG)

4-legged signalized (4SG).

Two separate models are used to estimate the multiple-vehicle and single-vehicle collisions. The collision predictive models for intersections are as follows:

Multiple-vehicle collisions

$$N_{mv} = \exp(a + b \ln(AADT_{maj}) + c \ln(AADT_{min})) \quad (4-3)$$

where

$AADT_{maj}$  = volume of annual average daily traffic on major roads

$AADT_{min}$  = volume of annual average daily traffic on minor roads

a, b, c are the regression coefficients;

Single-vehicle collisions

$$N_{sv} = \exp(a + b \ln(AADT_{maj}) + c \ln(AADT_{min})) \quad (4-4)$$

Where

$AADT_{maj}$  = volume of annual average daily traffic on major roads

$AADT_{min}$  = volume of annual average daily traffic on minor roads

a, b, c are the regression coefficients;

CMFs available for intersections include:

- Left-turn lanes
- Right-turn lanes
- Lighting
- Left-turn signal phasing
- Right-turn on red
- Red light cameras

#### 4.1.3 Calibration procedure

There are five steps listed in the HSM to correctly calibrate a model; the first step is to decide which type of roadway to perform the calibration on, the second step is to select sites to perform the calibration, using a minimum sample size of 30 to 50 sites. It also suggests randomly choosing sites to prevent choosing only sites with large number of crashes and having at least 100 crashes per year.

Once the sites are established, the next step is to collect the total crash frequency for the years chosen to observe and obtain the site characteristics. The fourth step is to use the predictive model, shown in Equation 4-5 to get the expected crash frequency for the sites for the correct number of years as:

$$N_{predicted} = N_{spf\ x} \times (CMF_{1x} \times CMF_{2x} \times \dots \times CMF_{yx}) \quad (4-5)$$

And the final step is to compute the calibration factor using the following equation:

$$Cr = \frac{\sum_{all\ sites\ observed\ crashes}}{\sum_{all\ sites\ predicted\ crashes}} \quad (4-6)$$

Where

$N_{spf\ x}$  = predicted average crash frequency determined for base conditions of the SPF developed for site type  $x$ ;

$CMF_{yx}$  = collision modification factors specific to site type  $x$  and for specific geometric design and traffic control features  $y$ ;

#### 4.2 Safety Performance Functions (SPFs)

Safety Performance Function (SPF) is a crash prediction model, which relates the frequency of crashes to traffic and the roadway characteristics (e.g., number of lanes, width of lanes, width of shoulder, etc.). There are two main types of SPFs in the literature: 1) Full SPFs and 2) Simple SPFs. Full SPF is a mathematical relationship that relates both traffic parameters and geometric parameters as explanatory variables, whereas Simple SPF includes Annual Average Daily Traffic (AADT) as the sole explanatory variable in predicting crash frequency on a roadway entity.

#### 4.3 Negative Binomial Models

Poisson-Gamma statistical model (or Negative Binomial model) belongs to the family of generalized linear models (GLMs). The Negative Binomial model is an extension of the Poisson regression model that allows the variance of the predicted coefficients to differ from the mean. The Negative Binomial arises from the Poisson model by adding an independent distributed error term  $\varepsilon$ :

$$\ln\lambda_i = \beta_{xi} + \varepsilon \quad (4-7)$$

Where,  $\ln \lambda_i$  is the expected mean number of crashes on highway section  $i$ ;  $\beta$  is the vector representing parameters to be estimated;  $x_i$  is the vector representing the explanatory variables on highway segment  $i$ ;  $\varepsilon$  is the error term, where  $\exp(\varepsilon)$  has a gamma distribution with mean 1 and variance  $\alpha$ . This gives the resulting conditional probability distribution which

$$\text{Prob}(n_i | \varepsilon) = \frac{\exp[-\lambda_i \exp(\varepsilon)] \lambda_i^{n_i}}{n_i!} \quad (4-8)$$

Where,  $n_i$  is the number of crashes on highway section  $i$  over a time period  $t$ . Integrating  $\varepsilon$  out of this expression produces the unconditional distribution of  $n_i$ . The formulation of this distribution is:

$$P(n_i) = \frac{\Gamma(\theta + n_i)}{[\Gamma(\theta) \cdot n_i!]} \cdot u_i^\theta (1 - u_i)^{n_i} \quad (4-9)$$

Where  $u_i = \theta / (\theta + \lambda_i)$  and  $\theta = 1/\alpha$ .

The Negative Binomial model can be estimated by standard maximum likelihood method. The corresponding likelihood function is:

$$L(\lambda_i) = \prod_{i=1}^N \frac{\Gamma(\theta + n_i)}{[\Gamma(\theta) \cdot n_i!]} \cdot u_i^\theta (1 - u_i)^{n_i} \quad (4-10)$$

Where  $N$  is the total number of highway sections. This function is maximized to obtain coefficient estimates for  $\beta$  and  $\alpha$ . Compared with Poisson model, Negative Binomial model has an additional parameter  $\alpha$  such that

$$\text{Var}[n_i] = E[n_i] \{1 + \alpha E[n_i]\} \quad (4-11)$$

The selection of the negative binomial over the Poisson model for crash modeling is determined by the observed statistical significance of the overdispersion parameter. If the overdispersion parameter is not significantly different than zero, then the negative binomial model simply

reduces to a Poisson regression where the variance equals the mean. If it is greater than zero, then the negative binomial is the correct choice, while the Poisson model is inappropriate.

#### 4.4 Model Validation

To examine how well a statistical model fits the data set, Goodness-of-fit (GOF) measures were examined. GOF measures summarize the differences between the observed and predicted values from related SPFs. Several GOF measures are used to assess performance; these tests include the mean absolute deviation (MAD), mean squared prediction error (MSPE), mean prediction bias (MPB) and Bayesian information criterion (BIC). The Goodness-of-fit (GOF) equations performed on the validation data include the following:

##### 4.4.1 Mean Absolute Deviation (MAD)

The MAD is suggested by Washington *et al.* (2005) as a goodness-of-fit measure for SPF. The MAD is the ratio of the sum of absolute difference between observed crash counts and predicted mean values to the number of sites  $n$ .

$$\text{MAD} = \frac{\sum_{i=1}^n |Y_i - \hat{Y}|}{n} \quad (4-12)$$

##### 4.4.2 Mean Squared Prediction Error (MSPE)

MSPE is defined as the sum of the square of the difference between observed crash counts and predicted mean values divided by the number of sites. This statistic is used to assess the error associated with a validation or external data set. A lower value for MSPE implies a better model.

$$\text{MSPE} = \frac{\sum_{i=1}^n (\hat{Y}_i - Y)^2}{n} \quad (4-13)$$

#### 4.4.3 Mean Prediction Bias (MPB)

MPB is also suggested by Washington *et al.* (2005). MPB is defined as the sum of predicted mean values minus the observed crash counts, divided by the total number of sites considered. This statistic provides a measure of the magnitude and direction of the average model bias. Unlike MAD, MPB can be positive or negative and it is given by the following equation.

$$MPB = \frac{\sum_{i=1}^n (\hat{Y}_i - Y_i)}{n} \quad (4-14)$$

A positive value of MPB indicates that the SPF is overestimating the number of crashes, whereas negative value implies concluding a site to be safer than they actually are.

Where:

$i$  = site index

$Y_i$  = observed crash frequency at site  $i$

$\hat{Y}_i$  = predicted crash frequency at site  $i$

$n$  = validation data sample size

#### 4.4.4 Bayesian information criterion (BIC)

The Bayesian information criterion (BIC) is a model selection tool and used to identify the preferred SPF. When using BIC, the model with the smallest BIC value is preferred. BIC first proposed by Gideon Schwarz (1978), is similar to the AIC, but includes a term to quantify the number of data points in the model. The BIC is calculated using Equation below.

$$BIC = k \times \ln(SSR) + k \times \ln(n) \quad (4-15)$$



Where,

$BIC$  = Bayesian information criterion,

$n$  = number of observations,

$SSR$  = sum of squared residuals, and

$k$  = number of independent variables.

# **CHAPTER 5: TRANSFERABILITY AND CALIBRATION OF HIGHWAY SAFETY MANUAL PERFORMANCE FUNCTIONS AND DEVELOPMENT OF NEW MODELS FOR URBAN FOUR-LANE DIVIDED ROADS IN RIYADH**

## **5.1 Introduction**

Riyadh, the capital city of Kingdom of Saudi Arabia (KSA), has expanded in terms of population, and growth of vehicles. The growth in motorization rate is accompanied by a drastic increase in the size of the road network. Such a growth has led to higher crash frequency level at several locations, which resulted in loss of lives, and caused major economical and social concerns in the country. Previous studies have highlighted the traffic safety in Riyadh as a serious issue that required urgent needs for strict and comprehensive measures (Koushki and Al-Ghader, 1992; Al-Ghamdi, 1999; Al-Ghamdi, 2003; Bener *et al.*, 2003; Altwaijri and Quddus, 2011).

In general, traffic crashes in the Gulf Cooperation Council (GCC) countries ranked the second killer or highest cause of death after cardiovascular diseases. Compared to European countries and USA, GCC Countries have a very high road crashes fatality rate. In 2001, 14.8 persons, and 7.3 persons per 10,000 vehicles were killed on Saudi and Qatari road traffic, respectively (Bener, *et al.*, 2003). Thus, there is an urgent need to alleviate the seriousness of the traffic safety problem in Saudi Arabia, which in turn will set a prime example for other GCC countries that face similar problems.

Therefore, this chapter aims to fill these research gaps by calibrating and transferring the Highway Safety Manual (HSM, 2010) predictive models and developing new models. The main

objectives for this chapter are: Calibrate the base SPFs provided in the HSM for urban intersections in Riyadh, develop new jurisdiction-specific SPFs using Riyadh's severe crashes' data, and traffic volume data; and Compare the performance of the these models (i.e., calibrated SPFs vs. the jurisdiction-specific SPFs). Recommendations are also provided for transforming the wealth of SPFs and safety knowledge in the HSM to GCC countries.

## 5.2 Background

Recently, several studies have been undertaken to investigate the impact of calibration of HSM's SPFs on the performance of collision prediction for local roadway networks Many recent studies have described the development of SPFs for various types of entities, such as urban arterials, rural roads, and intersections (Lyon *et al.*,2005; Martinelli, 2009;Tegge and Quyang,2010; Garber *et al.*, 2010;Young and Park, 2012 Alluri and Ogle, 2012; Sacchi *et al.*,2012; Brimley *et al.*, 2012; Bornheimer, *et al.*,2012). Lu *et al.* (2010) found that jurisdiction-specific SPFs fit their collision data better than calibrated HSM SPFs. Garber *et al.* (2011), found that jurisdiction-specific SPFs for intersections exhibited a better model fit than the HSM SPFs; however, this comparison was made to uncalibrated HSM SPFs.

Recently, several studies have been undertaken to investigate the impact of calibration of HSM's SPFs on the performance of collision prediction for local roadway networks (Persaud and Palmisano,2002; Sun *et al.*, 2006; Xie *et al.*, 2011; Howard and Steven, 2012; Mehta and Lou,2013; Cafisco *et al.*,, 2013). While these studies state in general that calibrated HSM models show better performance (measured by model fit) than uncalibrated HSM models, a common challenge encountered by researchers includes the large amount of data (e.g., roadway

characteristics, traffic volumes, and multiple years of collision information) required for the HSM's calibration procedure. This could be very challenging in most developing countries where the availability and quality of data is questionable.

Sacchi *et al.* (2012) in their investigation of the transferability of the HSM to Italy's roadways, used cumulative residual (CURE) plots to assess the validity of jurisdiction-specific models, but didn't perform a similar comparison to the HSM SPFs. Mehta and Lou (2013) found that the HSM-recommended approach for the calibration factor estimation performs well, although it is not as good as the best state specific SPF.

Young and Park (2012) compared the performance of the calibrated HSM's SPFs and the jurisdiction-specific SPFs for intersections in Regina. Four candidate models were developed for each of three categories: total collisions, fatal-injury (FI) collisions and property damage only collisions. It was found that the jurisdiction-specific SPFs and calibrated HSM provided the best fit than the uncalibrated HSM for all types of intersections. In addition the jurisdiction-specific SPFs were the best SPFs for predicting collisions at 3 and 4-leg intersections in the City of Regina.

Cafisco *et al.* (2013) compared the effect of choosing different segmentation methods, they examined using short vs. long roadway segment to calibrate the SPF. In addition to the segment selection criteria, new treatment types have also been identified beside those which had been included in the HSM.

The findings from previous studies and the lack of reliable models in the GCC countries inspired the effort of this chapter to investigate whether the SPFs in the HSM perform well in terms of predicting the number of fatal and injury collisions on the roadway network of Riyadh city or it would be recommended to develop new models. The implications to developing countries could be substantial as the transferability of the HSM to those countries could provide immediate benefits for safety assessment and prediction.

### 5.3 Data Preparation

The present data set covers the period of 2004-2009 and comprises only fatal and injury collisions, Annual Average Daily Traffic (AADT), and geometric design features data for urban 4-lane divided roads (U4D) in the city of Riyadh (KSA). Non-injury data were not available since it is collected by a private company and generally not complete. The collision and traffic data used in this study were obtained from two main sources: the Higher Commission for the Development of Riyadh (HCDR) and Riyadh Traffic Department (RTD).

Two different data files were obtained: The first file has the details of the crash characteristics with twenty three variables and contains 11,336 cases mapped on ARC GIS with each case in the file representing a collision; the second file has the detailed daily traffic volumes for road segments in Riyadh city in MS excel files. The traffic volume counts conducted during 2004-2009 by Manual (MTC) and Automatic Traffic Counts (ATC). Table 5-1 provides some basic statistics of the relevant data used to develop the prediction models.

Table 5-1: Descriptive Statistics of Variables

Variable	Description	Min.	Max.	Mean	Median
Crash frequency	The number of severe crashes occurring on the study segments during the 3-year period (2004-2006)	0	13	3.44	3
Segment(mi)	The length of segment	0.15	3.4	0.85	0.73
AADT(v/day)	Annual average daily traffic	5236	132004	38607	37575
Number of Driveways	The number of driveways	0	48	12.62	11
Driveway density	Number of driveway per mile	0	40	15.52	14
Speed limit(mi/h)	Actual posted speed limit (ranging from 31 to 55 mi/h)	31	55	42	43
Median Width(ft)	Median width(ft)	9	70	19.76	15
Shoulder Width(ft)	Shoulder width (ft)	0	22	12.40	11

Annual Average Daily Traffic (AADT) was obtained from the GIS data made available by the HCDR GIS Unit. Since there is currently no available database which has information pertaining to the driveway density, shoulder width, and median width, the Google Earth Maps were used to obtain these variables. In order to accurately collect the required data, extensive work was needed to track along the routes in both the GIS environment and Google Earth imagery to collect these data.

The first task for the data collector on each segment was to confirm that it was indeed the correct facility type (urban four-lane divided roadway segments). Additionally, if there was an Intersection in the segment, the segment would be broken into two new segments, with the beginning or ending points of the new segments defined to exclude 250 feet on either side of the

intersection. Once each segment was confirmed and accurately defined, the necessary collision, geometric and cross-sectional characteristics were collected.

The data sets contained several variables: segment length, AADT, driveway density, speed limit (mi/h), median width (ft), and shoulder width (ft). Finally, the collision data, traffic volume data, and cross-section road features were merged in one file. The resulting database contained information about the collisions occurring on each segment together with the geometric and traffic characteristics of this segment.

After the segmentation process, the 144.56 mi roadways were segregated into 172 homogeneous segments for the entire City of Riyadh with the length ranging between 0.15 mi and 3.4 mi and an average of 0.85 mi. From the segmentation process, there were 590 reported severe crashes on the 172 segments for 2004-2006 used for estimation. In order to test the calibrated and developed models, 301 reported severe crashes collected on the 172 studied segments from 2007 to 2009 were used for validation.

#### 5.4 Methodology

The current HSM calibration sampling technique is based on total crashes. Thus, there is a need for developing CMFs for fatal and injury collisions. This study involves three tasks. The first task is to calibrate the base SPF models following the HSM-recommended approach using HSM CMF default values. The second task is to calibrate the base SPF models using local Riyadh specific Crash Modification Factors (CMFs) for FI collisions. The third task is to develop

specific SPFs for Riyadh. The methods employed to achieve the three tasks are described in the following subsections.

#### 5.4.1 HSM calibration of urban four-lane divided roads

The HSM safety predictive model consists of three parts, a Safety Performance Function (SPF) developed with respect to the highway facility under given base conditions, the Crash Modification Factors (CMF's), and the Calibration Factor (Cr) computed in order to adapt the model to local conditions. There are five steps listed in the HSM to correctly calibrate a model; the first step is to decide which type of roadway to perform the calibration on, the second step is to select sites to perform the calibration, using a minimum sample size of 30 to 50 sites. It also suggests randomly choosing sites to prevent choosing only sites with large number of crashes and having at least 100 crashes per year.

Once the sites are established, the next step is to collect the total crash frequency for the years chosen to observe and obtain the site characteristics. The fourth step is to use the predictive model, shown in equation (1) to get the expected crash frequency for the sites for the correct number of years as:

$$N_{predicted} = N_{spf} \times (CMF_{1x} \times CMF_{2x} \times \dots \times CMF_{yx}) \quad (5-1)$$

And the final step is to compute the calibration factor using the following equation:

$$Cr = \frac{\sum \text{all sites observed crashes}}{\sum \text{all sites predicted crashes}} \quad (5-2)$$

Where:



$N_{spf,x}$  = predicted average crash frequency determined for base conditions of the SPF developed for site type  $x$ ;

$CMF_{yx}$  = collision modification factors specific to site type  $x$  and for specific geometric design and traffic control features  $y$ ;

This equation applies a base model and then refines the prediction of the base model by using CMFs. The base model predicts the expected number of collisions for sites that meet the base conditions. CMFs, which have been assembled by a team of experts and documented in the HSM, are then used to adjust the base model predictions to account for the effects of other variables that are different from those of the base model.

#### 5.4.2 Developed Models

Contemporary safety performance models are most often developed using a negative binomial (NB) regression. The negative binomial distribution is well suited for modeling crashes because of the naturally high variability of crash frequencies whose variance is greater than the mean. Negative binomial models are also referred to as Poisson-gamma models because crashes within a site fit a Poisson distribution, but the variation across multiple sites is Gamma distributed (Mitra and Washington, 2007; Park and Lord, 2008).

## 5.5 Results and Discussion

### 5.5.1 HSM Calibration Models

From the segmentation process, there were 590 reported severe crashes on the 172 segments for 2004-2006, the remaining crashes occurred at 6 lane roads or intersections and their approaches. HSM base models for urban/suburban arterial roadway segments have separate equations for single vehicle and multiple vehicle collisions. Equations 5-3 and 5-4 provide the HSM SPF for fatal and injury collision on urban four-lane divided segments for single vehicle (SV) and multiple vehicle (MV), respectively.

$$N = e^{(-8.71 + 0.66 \ln(AADT) + \ln(L))} \quad (5-3)$$

$$N = e^{(-12.76 + 1.28 \ln(AADT) + \ln(L))} \quad (5-4)$$

The SPFs still requires the use of CMFs as directed by the HSM. The CMFs applied for urban segments are: on-street parking, roadside fixed objects, median width, lighting, and automated speed enforcement. The crash modification factors for auto speed enforcement is unity for all segments, since during the study period speed enforcement was not applied. The crash modification factor for roadside fixed objects is assumed to be one. In this study, two approaches are used to estimate the angle parking and lighting CMFs and calibration factors. The first approach is using the HSM CMFs default values and the second approach is to estimate calibration factor using local CMFs. A brief explanation of both methods is given below.

### 5.5.1.1 HSM Default values method

The following steps were used to identify the HSM CMFs.

- Angle parking: the crash modification factor was estimated based on Research by Bonneson (2005), as

$$CMF=1+P_{pk}(f_{pk}-1) \quad (5-5)$$

Where:

$P_{pk}$  = proportion of curb length with on-street parking ( $= 0.5 L_{pk}/L$ ),  $L_{pk}$  = curb length with on-street parking (mi),  $L$ = roadway segment length (mi), and  $f_{pk}$ = factor from Table 12-19 of the HSM, 2010. The sum of curb length ( $L_{pk}$ ) was determined from Google Earth.

- Lighting : The CMF for lighting calculated based on the work of Elvik and Vaa, 2004, as

$$CMF = 1 - (P_{nr} \times (1.0 - 0.72 P_{inr} - 0.83 P_{pnr})) \quad (5-6)$$

Where:

$P_{inr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve a nonfatal injury,  $P_{pnr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve PDO crashes only, and  $P_{nr}$  = proportion of total crashes for unlighted roadway segments that occur at night.

The HSM default values of  $P_{nr}$ ,  $P_{inr}$ , and  $P_{pnr}$  for urban four-lane divided roadway segments are 0.410, 0.364 and 0.636, respectively resulted in  $CMF=0.914$ .

- Median width: The CMF was estimated based on Table 12-22 of the HSM, 2010.

### 5.5.1.2 Locally Derived values method

The following steps were used to identify the Riyadh specific CMFs.

- Angle parking: The FI crash modification factor for angle street parking was developed using cross-sectional method by developing NB SPF using 112 treated sites (sites with angle parking) and 60 untreated sites or base condition sites (sites without parking) to predict crash frequency as follows:

$$F = \exp(-4.84 + 0.507 \times \ln AADT + 0.735 \times SL + 0.422 \times PARK) \quad (5-7)$$

Where:

AAADT= Annual Average Daily Traffic.

L= Segment Length (mi), and

PARK= presence of parking (=1 if a parking exist on a segment i, =0 if a park does not exist on a segment i)

Then the crash modification factor CMF was calculated using the following equation:

$$CMF_j = \exp(\beta_j) \quad (5-8)$$

Where:

CMF<sub>j</sub>=CMF for variable *j*

*B<sub>j</sub>* =Estimated Coefficient for variable *j*

CMF for angle park =exp(0.422)=1.52

The results of SPF of angle park-related crashes are shown in Table 5-2. All the factors are statistically significant at a 95% confidence level.

Table 5-2 Riyadh-Specific SPF for including angle parking on urban four-lane roadways

Analysis Of Maximum Likelihood Parameter Estimates						
Parameter	ESTIMATE	Std Error	Wald 95% confidence Limits		Wald Chi-Square	P-value
Intercept	-4.84	1.22	-7.23	-2.45	15.74	0.0001
Ln AADT	0.507	0.111	0.289	0.726	20.71	0.0001
Segment Length	0.735	0.114	0.511	0.958	41.55	0.0001
Parking	0.422	0.139	0.078	0.624	6.37	0.0116
Dispersion	0.145	0.041	0.0836	0.252		
Deviance	185.50					
Pearson Chi-sq	172.41					
Log-Likelihood	-406.87					

- Lighting: The Riyadh Locally-Derived Values for  $P_{nr}$ ,  $P_{inr}$ , and  $P_{pnr}$  are 0.26, 0.184, and 0.735 respectively which resulted in  $CMF = 0.933$ .
- Median width:  $CMF$  not used, since the developed models show that the median width has insignificant effect on fatal and injury crashes.

Using the default HSM  $CMFs$ , the total calibration factor for urban four lane divided was estimated as 0.31. The locally derived Riyadh  $CMFs$  leads to calibration factor of 0.56. The total calibration factors - as shown in Table 5-3 - derived from both methods are lower than one, implying that HSM base  $SPFs$  are overestimating the mean crash frequencies on urban four lane divided roads in Riyadh. This indicates that the severe crashes recorded in Riyadh city appears to be very low compared with the jurisdictions from which the HSM's urban/suburban  $SPFs$  were developed.

Table 5-3: Estimated calibration factors (2004-2006)

variable	Single vehicle	Multiple vehicle	Total
Observed crashes	319	271	590
Predicted crashes using HSM default CMFs	184	1700	1884
Predicted crashes using Riyadh CMFs	98	954	1052
Calibration factor using HSM CMFs	1.73	0.16	0.31
Calibration factor using special CMFs for FI crashes	3.25	0.28	0.56

The low of fatal and injury calibration factors in Riyadh city could be attributed to the following possible reasons:

- Crashes involving both slight injury and damage to property may be recorded as "Property Damage Only" crashes. (Al-twajiri *et al.*,2011)
- Slight injury crashes may suffer from underreporting. (Koushki and Balghunaim, 1991)
- The traffic safety strategy in Riyadh is to reduce severe crashes and hence there is less focus on collecting data on "slight injury crashes".
- Differences in reporting criteria between the City of Riyadh and the jurisdictions from which the HSM SPFs were developed.
- It is possible that collisions in the City of Riyadh are simply less severe due to local roadway conditions, climatic effects, and/or driver behavior.

### 5.5.2 Local New developed Negative Binomial Models

Six SPFs were developed by the negative binomial modeling method. First, two total FI crash frequency models, followed by four specific crash models using two different model types. The first model type is simple keeps the form of HSM base SPF in view of its simplicity and its minimal requirements on data availability:

$$N = \text{EXP} [\beta_0 + \beta_1 \text{AADT} + \beta_2 L] \quad (5-9)$$

Where,

N=number of predicted crashes.

AADT= Annual Average Daily Traffic.

L= Segment Length (mi), and

$\beta_0$ ,  $\beta_1$ , and  $\beta_2$  are parameters to be estimated.

The second model type is full model takes the form of the SPF as shown in the equation below.

$$N = \text{EXP} [\beta_0 + \sum_{i=1}^p \beta_i x_i] \quad (5-10)$$

Where,

$x_i$  = independent variable, and

$p$  = number of independent variables.

#### 5.5.2.1 Total crash FI SPFs

Table 5-4 shows the parameter estimates, p-values, and the goodness-of-fit measures for the two models at 90 percent confidence level ( $p$ -value < 0.10). The two models make intuitive sense; the log likelihood (LL) value for total full model is higher compared to the simple model, indicating that full model fits the data better. Full model has slightly lower BIC value, which is consistent with the findings based on LL value. McFadden's R<sup>2</sup> value of the model (analogous to R-square test in Linear regression models), which is an indication of the additional variation in crash frequency explained by the obtained model to the constant term, is relatively low. This low value is usual for crash estimation because there are many variables (e.g. human factors) which are not measurable (Abdel-Aty and Radwan, 2000)

In view of this, it can be concluded that total full model is the best model compared to the simple model. The full model has four variables: ln (AADT), Segment length, Speed limit and driveway density.

Table 5-4: Total FI Crash models

Parameter	Total FI simple		Total FI full	
	Estimate	P-value	Estimate	P-value
Intercept	-3.90	0.0001	-4.76	0.0001
Ln AADT	0.435	0.0007	0.583	0.0001
Segment length	0.730	0.0001	0.770	0.0001
Speed Limit	-		-0.025	0.010
Driveway Density	-		0.0144	0.02
Dispersion	0.11		0.09	
Deviance/DF(Deviance)	1.04(176.49)		1.05(175.94)	
Pearson Chi-sq/DF(Pearson Chi-sq)	0.89(151.46)		0.90(150.14)	
LL	-356		-350	
McFadden's R <sup>2</sup>	0.10		0.12	
BIC	734		730	

The median width and shoulder width variables were found insignificant, so they were removed from the model. The driveway density is among the significant variables affecting the FI crash frequency. This variable has positive effect on crash frequency. This could be explained that as the number of driveways increase, there are more conflicts among vehicles, increasing the severe crash frequency.

The ln (AADT) was found to have a positive relationship with crash frequency, the reason for this is that as the number of vehicles increase through a segment, the exposure to potential crashes and the numbers of conflicts also increase. Speed limit is found to be negatively associated with the FI crash frequency, possibly indicating better designed roads, less conflicts and/or better enforcement for roads with higher speed limits.



#### 5.5.2.2 *Type specific SPFs*

Because of the differences in the characteristics associated with Single Vehicle (SV) and Multiple Vehicles (MV) crashes, many researchers (Mensah and Hauer, 1998; Ivan et al., 1999; Bonneson et al., 2007) have proposed using specific models for these two general categories of crashes when the objective of study is to estimate safety performance of roadway segments.

Table 5-5 show results of SV and MV using two model types. The positive coefficients for all the variables except speed limit indicate that the expected crash frequencies would increase as the values of these variables increase. Comparison of the Deviance, Pearson Chi, LL values indicates that both full models for SV and MV outperform simple models in predicting the expected FI crash frequencies.

Moreover, the full models also have smaller dispersion parameters compared to the simple models. However, to avoid over-fitting, the models are further compared based on the BIC value, as BIC statistic accounts for the difference in number of parameters. Again, full models have the lowest BIC value, which is consistent with the findings based on Deviance, Pearson Chi-square and LL values.

Table 5-5: Type Specific models

Parameter	SV				MV			
	Simple SV		Full SV		Simple MV		Full MV	
	Estimate	P-value value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	-1.801	0.20	-1.63	0.237	-4.431	0.005	-4.470	0.001
Ln AADT	0.210	0.09	0.310	0.056	0.426	0.004	0.540	0.0001
Segment length	0.677	0.001	0.627	0.0001	0.626	0.001	0.473	0.001
Speed Limit	-		-0.021	0.0196			-0.0167	0.0176
Driveway Density	-		0.012	0.0806				
Log DW	-		-	-	-	-	0.360	0.0867
Shoulder width	-		-	-	-	-	0.0124	0.0639
Dispersion	0.095		0.007		0.106		0.001	
Deviance/DF (Deviance)	1.04 (157.5)		0.920 (138)		0.95 (148)		0.758 (113.7)	
Pearson Chi-sq/DF (Pearson Chi-sq)	0.94 (150)		0.920 (138)		0.980 (148.2)		0.827 (124.05)	
LL	-260		-256		-251		-246	
McFadden's R <sup>2</sup>	0.11		0.130		0.120		0.140	
BIC	572		518		540		453	

As seen in Table 5-5 four variables were found to contribute significantly to the FI single - vehicle (SV) crash frequency; these variables include ln(AADT), segment length , and driveway density, which have positive effects on the SV severity collision, while speed limit was negatively associated with the outcome.

The positive effect between SV crash and driveway density was unexpected, which could be attributed to pedestrian collisions, or avoidance maneuvers. The positive effect of shoulder width on MV crashes is somewhat counterintuitive since shoulder width is expected to have a negative effect on the crash frequency.

An explanation for this result is that wider shoulders might encourage drivers to travel at higher speeds or actually use it as a lane which is illegal but common in the region. Haleem and Abdel-Aty (2010) pointed out that wider shoulders increase the risk of sideswipe crashes by encouraging inappropriate use of the shoulder for merging or lane changing maneuvers.

## 5.6 Validation and Comparisons

To examine how well a statistical model fits the data set, Goodness-of-fit (GOF) measures were examined. GOF measures summarize the differences between the observed and predicted values from related SPFs. Several GOF measures are used to assess performance; these tests include the mean absolute deviation (MAD), mean squared prediction error (MSPE), mean prediction bias (MPB) and Bayesian information criterion (BIC). Statistical GOF tests were performed on the

validation data (FI crashes for years 2007-2009). The performance of each model on the validation data set is shown in Table 5-6. These results can be compared in order to assess the transferability of the developed models – which were developed using the estimation dataset – to the validation dataset.

The values of MAD, MPB and MSPE for total full model are smaller compared to the total simple developed model, including the total calibrated models, which indicate that full model leads to lower prediction error and less bias in the prediction. Moreover the full model outperforms the other models in BIC value. Overall, the full model is better compared to the developed simple model and both total calibrated models. On the other hand, when we compare the type specific models, both the simple developed SV and MV models outperforms other full specific developed models in MAD, MSPE and MPB, while the full models performs better in terms of BIC.

Table 5-6: Goodness of fit tests for the HSM calibrated and developed models.

Developed Models						
Performance Measure	Total FI simple	Total FI full	Simple SV	Full SV	Simple MV	Full MV
MAD	2.62	1.43	1.25	1.95	1.43	2.27
MSPE	10.75	4.27	2.42	5.44	3.62	4.38
MPB	2.15	1.98	1.26	2.74	1.05	2.10
BIC	734	730	572	518	540	453
Calibrated Models						
Performance Measure	HSM default values			Riyadh local values		
	Total FI	SV	MV	Total FI	SV	MV
MAD	2.65	2.37	1.96	1.93	1.98	1.56
MSPE	12.24	7.84	6.16	7.18	3.46	3.10
MPB	2.30	2.40	1.87	1.10	1.34	1.05
BIC	1024	872	841	986	815	827

When we compare the total calibrated models, it can be observed that total Riyadh local calibrated model outperforms total HSM default in MAD, MSPE, MPB, and BIC values. Again, the Riyadh Locally derived values for SV and MV models outperform the HSM default values in MAD, MSPE, MPB and BIC. This indicates that locally derived CMFs using severe collision data perform better than HSM default CMFs.

### 5.7 Conclusion

The objective of this chapter was to calibrate the HSM SPF for urban four-lane divided roads and to develop new jurisdiction-specific SPFs. Data from 172 homogeneous segments located on approximately 144.56 miles of urban roads in City of Riyadh from a period of three years (2004-2006) were used. Calibration factors were also estimated to adjust the HSM based SPFs and new specific SPFs that quantify the relationship between the expected crash frequencies and various road and traffic characteristics were developed using Riyadh data.

Three objectives are performed in this study. The first objective is to calibrate the HSM SPFs using HSM default CMFs for Riyadh conditions. In the second objective, new locally derived CMFs are proposed, which treats the estimation of calibration factors using fatal and injury data. Finally, six different new SPFs are calibrated using the NB regression technique. The prediction capabilities of these models are evaluated using a validation data set that is different from the original estimation data set. Multiple performance measures, such as MAD, MSPE, MPB, and BIC, are considered.

The total FI calibration factors derived from both approaches is significantly lower than one, implying that the HSM base SPFs are overestimating the mean crash frequencies on urban four-lane divided roads in Riyadh. The HSM calibration method using new local CMFs seems to outperform the HSM default values for this type of facility. However, developed SPFs are found to outperform all other calibrated models. The new jurisdiction-specific models show that the relationships between crashes and roadway characteristics in Riyadh may be different from those presented in the HSM.

The new SPFs, for example, predict more crashes when the variables AADT, segment length, and driveway density were increased. The positive effect between SV crash and driveway density was unexpected, which could be attributed to pedestrian collisions, or avoidance maneuvers. The positive effect of shoulder width on MV crashes is somewhat counterintuitive since shoulder width is expected to have a negative effect on the crash frequency. An explanation for this result is that wider shoulders might encourage drivers to travel at higher speeds or actually use it as a lane which is illegal but common in the region. The locally derived CMFs for fatal and injury data showed improvement over the HSM default values, which provides a promising procedure for quantitative safety evaluations in Riyadh and GCC countries that requires additional consideration and research.

The HSM calibration application for Riyadh crash conditions highlights the importance to address variability in reporting thresholds. One of the findings of this research is that, while the medians in this study have oversize widths ranging from 16ft-70ft, median width has insignificant effect on fatal and injury crashes. In the same time the frequent angle parking in

Riyadh urban road networks seems to increase the fatal and injury collisions by 52 percent. Overall, this study lays an important foundation towards the implementation of HSM methods in the city of Riyadh, and could help the transportation officials in Riyadh to make informed decisions regarding road safety programs.

Though this study uses Riyadh data, the framework provided can be used by other GCC countries which in general have common driver behavior and design standards. The findings of this chapter indicate that road engineers in Riyadh should pay considerable attention to driveways, and angle parking management. For example, several countermeasures proposed to reduce the severe crashes in Riyadh city:

- Limiting the number of driveways.
- Using of acceleration and deceleration lanes that are of sufficient length to accommodate speed changes, and the weaving and maneuvering of traffic.
- Ensure sufficient distance/spacing between driveways to provide drivers sufficient perception time to identify locations where they expect another conflict point.
- Angle-parking needed be replaced by more effective parking designs and systems, such as replaced with parallel parking if possible or using the regulated parking instead of the free parking system.
- Median width in Riyadh urban roads can be reduced to the standard width in order to increase the lane widths.

This study is one of the first attempts to investigate the applicability of calibrating HSM models and developing new models in the GCC Countries. Since the results showed that the developed

models had more accurate performance over the HSM calibrated model, using calibrated specific CMFs with HSM SPFs should also be considered. Although this study provides thorough investigations to estimate severe collisions on multi-lane arterial segments between intersections with both data and methodology contributions, there are several limitations that exist in this study:

- (1) Due to data limitation collision severity in Riyadh was divided into two types fatal and injury. With more data available in the future, crashes would be categorized into traditional three levels (PDO, injury and fatal)
- (2) The results presented in this study were concluded based on urban arterials, future studies with different data sources and new different variables are needed to confirm the findings concluded in this study.
- (3) Unexpected positive effect of some factors such as driveway density on single vehicle crashes and shoulder width on multiple vehicle crashes, appear to be unique to the region, but needed to be addressed by future study.



## **CHAPTER 6: CALIBRATION OF HIGHWAY SAFETY MANUAL PERFORMANCE FUNCTIONS AND DEVELOPMENT OF NEW MODELS FOR URBAN INTERSECTIONS IN RIYADH**

### 6.1 Introduction

Intersection crashes play a significant role in traffic safety conditions. In safety research from the international standpoint, many researchers have shown that intersections are critical sites that require more attention. In their study of a sample of intersections in British Columbia, Sayed *et al.* (1999) reported that more than 50% of the crashes occurring in urban areas are at signalized intersections. For many intersections, especially those within urban corridors, crash frequency and severity remained relatively high despite the implementation of various geometric and traffic countermeasures.

Retting *et al.* (1999) indicated that about 40% of traffic crashes in US are at intersections or intersection-related. During their study period, they found that fatal crashes at traffic signals increased 19%, whereas the number of all other fatal crashes increased 6%. Previous studies have shown that intersection-related crashes account for about 50% of all crashes registered annually in Riyadh, the capital of the Kingdom of Saudi Arabia (KSA). More than half of these crashes are classified as severe (Al-Ghamdi, 2003).

### 6.2 Data Preparation

The present data set covers the period of 2004-2009 and comprises only fatal and injury collisions, Annual Average Daily Traffic (AADT), and geometric design features data for urban

intersections in the city of Riyadh (KSA). Non-injury data were not available since it is collected by a private company and generally not complete.

The collision and traffic data used in this study were obtained from two main sources: the Higher Commission for the Development of Riyadh (HCDR) and Riyadh Traffic Department (RTD). Two different data files were obtained: The first file has the details of the crash characteristics with twenty three variables and contains 11,336 cases mapped on ARC GIS with each case in the file representing a collision; the second file has the detailed daily traffic volumes for road segments in Riyadh city in MS excel files. The traffic volume counts conducted during 2004-2009 by Manual (MTC) and Automatic Traffic Counts (ATC). Table 6- 1 provides some basic statistics of the relevant data used to develop the prediction models.

Table 6-1: Descriptive Statistics of Variables

Variable	Number of Samples	Crash frequency			AADT major (v/day)			AADT minor (v/day)				
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean		
4 SG	129	0	11	2.95	12907	8706 0	46226	4023	63101	26369		
3 SG	33	0	7	2.4	25000	6600 0	47703	7000	61307	27547		
3-leg Unsig.	45	0	5	1.73	8510	6600 0	39096	2500	51800	24425		
Variable	Speed Limit major (mi/h)			Speed Limit minor (mi/h)			Median Width major(ft)			Median Width minor(ft)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
4 SG	37	55	45.64	31	50	42.60	11	70	19.67	10	55	19.07
3 SG	37	55	44	31	50	41	10	50	18	10	55	18
3-leg Unsig.	31	55	44	31	50	41	10	50	18	9	55	18

The HCDR file is composed of crash data derived from the Riyadh police crash report form, filled out at the scene of a crash by police officers. Crashes that occurred at or less than 250 ft from the intersection were considered to be intersection crashes in this study. Annual Average Daily Traffic (AADT) was obtained from the GIS data made available by the HCDR GIS Unit. Roads that have the highest and lowest AADTs were classified as major and minor roads, respectively.

Since currently there is no available database which has information pertaining to the traffic and geometric design characteristics, the Google Earth Maps were used to obtain these variables. In order to accurately collect the required data, extensive work was needed to track along the routes in both the GIS environment and Google Earth imagery to collect these data. A data quality analysis was also performed to ascertain that the AADTs for major and minor roads at each intersection and for each year of the study period were available. Intersections with insufficient approach AADT data, 5- and 6-leg intersections, and roundabouts were not included in the study. Therefore, the types of intersections included in this study were 3-leg signalized, 4-leg signalized, and 3-leg unsignalized. Once each intersection was confirmed and accurately defined, the necessary collision, geometric and cross-sectional characteristics were collected.

Riyadh does not maintain a comprehensive database of signal phasing. Several challenges were encountered during the collection of data for intersections. Google imagery was used to determine the number of approaches with left and right turn lanes. HCDR and RTD data, along with aerial photographs from Google, was used to determine the presence of lighting at the

intersections. Field visits and the consulting with RTD and HCDR were two important sources to determine the signal phasing type on the major and minor roads. As there was a low number of 4-leg unsignalized intersections in the study sample (13 intersections), these intersections were excluded from further analysis. After the integrated databases were examined for errors and inconsistencies, the intersections were divided into three categories: 3-leg signalized, 4-leg signalized, and 3-leg unsignalized.

Finally, the collision data, traffic volume data, and geometric road features were merged in one file. The resulting database contained information about the collisions occurring on each intersection together with the geometric and traffic characteristics of this intersection. There were 512 reported fatal and injury crashes on the 207 intersections for 2004-2006. In order to test the calibrated and developed models, 230 reported severe crashes collected on the 207 studied intersections from 2007 to 2009 were used for validation.

The purpose of this chapter was to investigate the extent to which the HSM SPFs for intersections are transferable to Riyadh, and if necessary develop Riyadh specific SPFs, using crash, geometric design and corresponding traffic data for intersection sites in Riyadh. The scope is limited to intersection types on Riyadh Municipality maintained roads for which appropriate and adequate data were available.

### 6.3 Modeling Results and Discussions

#### 6.3.1 HSM Calibration Models

There were 512 reported fatal and injury crashes on the 207 intersections for 2004-2006, the remaining crashes occurred at roadway segments, or 5- and 6-leg intersections and roundabouts. HSM base models for urban/suburban intersections have separate equations for single vehicle and multiple vehicle collisions. Tables 6-2 provide the HSM SPF coefficients used in Equations 4-3 and 4-4 for fatal and injury collision at urban intersections for multiple vehicle (MV) and single vehicle (SV), respectively.

Table 6-2: SPF Coefficients for Collisions at Intersections

Coefficients used in Equations 3 and 4				
Single Vehicle				
Intersection Type	Intercept(a)	AADTmaj(b)	AADTmin(c)	Overdispersion Parameter(k)
3ST	-	-	-	-
3SG	-9.75	0.27	0.51	0.24
4ST	-	-	-	-
4SG	-9.25	0.43	0.29	0.09
Multiple Vehicle				
Intersection Type	Intercept(a)	AADTmaj(b)	AADTmin(c)	Overdispersion Parameter(k)
3ST	-14.01	1.16	0.30	0.69
3SG	-11.58	1.02	0.17	0.30
4ST	-11.13	0.93	0.28	0.48
4SG	-13.14	1.18	0.22	0.33

The SPFs still requires the use of CMFs as directed by the HSM. The CMFs applied for urban intersections in Riyadh are: left-turn lanes, right-turn lanes, lighting, left-turn signal phasing, right-turn on red, and red light cameras. The data including intersection left turn lane, and intersection right turn lane were collected from Google Earth images. The crash modification factors for red light cameras is unity for all intersections, since during the study period red light

camera was not applied. The crash modification factors for turn right on red are unity since it is permitted in Riyadh. The crash modification factor for left turn signal phasing is 0.94 since the traffic signals phasing in Riyadh has left-turn protective. The number of left-turn lanes, right-turn lanes, and lighting crash modification factors were calculated using the following steps:

- Lighting : The CMF for lighting calculated based on the work of Elvik and Vaa(2004), as

$$CMF = 1 - 0.38 P_{ni} \quad (6-1)$$

Where:

$P_{in}$  = proportion of total crashes for unlighted intersections that occur at night.

The HSM default values of  $P_{ni}$ , for urban intersections are 0.238 and 0.0.235, for 3-legged unsignalized and signalized intersections respectively resulted in  $CMF= 0.910$  for 3ST and  $CMF= 0.911$  for both 3SG and 4SG.

- The CMFs associated with providing turn lanes are 0.93, 0.81 and 0.67 for 3SG, 4SG, and 3ST respectively.
- The CMFs associated with providing right lanes are 0.96, 0.92 and 0.86 for 3SG, 4SG and 3ST respectively.

Using the CMFs, the total calibration factors (Cr), observed crashes (O), and predicted crashes (P) for urban intersections were estimated as shown in Table 6-3. The total calibration factors produced for all intersection categories are lower than one. Unsignalized intersection category (3ST) has the lowest calibration factor at 0.25 and 3SG has the highest

calibration factor at 0.39 implying that HSM base SPFs are overestimating the mean crash frequencies at urban intersections in Riyadh. This indicates that the severe crashes recorded at urban intersections in Riyadh city are lower compared with the jurisdictions from which the HSM's urban/suburban SPFs were developed.

Table 6-3: Estimated calibration factors (2004-2006)

Intersection	Single			Multiple			Total		
	O	P	Cr	O	P	Cr	O	P	Cr
4SG	140	39	3.60	230	1323	0.17	370	1362	0.27
3SG	32	6	5.33	38	174	0.22	70	180	0.39
3ST	12	-	-	72	281	0.256	72	281	0.25

Using Riyadh-provided collision type proportions in Table 6-4, predicted crashes were computed and calibration factors (Cr) were calculated for each specific collision type. The results are summarized in Table 6-5.



Table 6-4 : Distribution of Multiple-Vehicle Collisions for Intersections by Collision Type (HSM and Riyadh Locally Derived Values)

Inters	Head- on		Rear-end		Angle		Sideswipe		Other-Multiple		Total
	HSM	Riyadh	HSM	Riyadh	HSM	Riyadh	HSM	Riyadh	HSM	Riyadh	
4SG	0.049	0.17	0.450	0.17	0.347	0.28	0.099	0.16	0.055	0.22	1.00
3SG	0.038	0.07	0.549	0.38	0.280	0.23	0.076	0.26	0.057	0.06	1.00
3ST	0.041	0.05	0.421	0.50	0.343	0.25	0.126	0.03	0.065	0.17	1.00

It is clear from Table 6-4 that angle crashes are the most severe type of crash, accounting for nearly 28% of the multiple-vehicle severe crashes at 4-leg signalized intersections, while the rear-end crashes are the most severe crashes at 3-leg signalized and 3-leg unsignalized intersections.

Table 6-5: Estimated calibration factors by Specific Collision Types (2004-2006)

Intersection	Head-on			Rear-end			Angle			Sideswipe			Others		
	O	P	Cr	O	P	Cr	O	P	Cr	O	P	Cr	O	P	Cr
4SG	38	231	0.16	66	231	0.28	68	382	0.18	30	218	0.14	28	300	0.10
3SG	4	13	0.31	14	68	0.20	12	41	0.29	13	47	0.27	4	11	0.36
3ST	9	15	0.60	27	140	0.19	24	70	0.34	7	8	0.87	5	48	0.1

The low of fatal and injury calibration factors in Riyadh city could be attributed to the following possible reasons:

- Crashes involving both slight injury and damage to property may be recorded as "Property Damage Only" crashes, Altwaijri *et.al* (2011)
- Slight injury crashes at intersections suffer from underreporting, Koushki and Balghunaim (1991).
- The traffic safety strategy in Riyadh is to reduce severe crashes and hence there is less focus on collecting data on "slight injury crashes".
- Differences in reporting criteria between the City of Riyadh and the jurisdictions from which the HSM SPFs were developed.
- It is possible that collisions in the City of Riyadh are simply less severe due to local roadway conditions, climatic effects, and/or driver behavior.

The performances of the calibration factors will be discussed in the “Validation and Comparison” subsection.

### 6.3.2 Local New developed Negative Binomial Models

SPFs were developed for the three intersection categories by the negative binomial modeling method. The model type is full model takes the form of the SPF as shown in the equation below.

$$N = \text{EXP} [\beta_0 + \sum_{i=1}^p \beta_i x_i] \quad (6-2)$$

Where,

$x_i$  = independent variable, and

$p$  = number of independent variables.

Candidate variables that may have influence on the FI crashes are:

- AADT major
- AADT minor
- Median Width major
- Median Width minor
- Posted speed limit major
- Posted speed limit minor

The variables were included into a full model. The negative binomial model for the three intersection categories indicated that the variables AADT major, AADT minor were the only significant variables. The Median Width was not included in the model, possibly due to the disproportionate distribution of Median width in the data set (most were 15ft). The posted speed limit was not significant which could be attributed to the mitigating influence of traffic signal, the posted speed limit may not have great influence on entering speeds, which likely influences the safety performance of an intersection.

As a result, the recommended model simply includes the major and minor AADT variables for the final model for the three urban intersection categories. Table 6-6 shows the parameter estimates,  $p$ -values, and the goodness-of-fit measures for the intersection categories under investigation.

Table 6-6: Total FI Crash model

Parameter	4SG		3SG		3ST	
	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	-4.30	0.0002	-13.84	0.001	-10.894	0.001
Ln AADTmaj	0.334	0.006	0.920	0.080	0.672	0.066
Ln AADTmin	0.178	0.07	0.470	0.090	0.462	0.097
Speed Limit maj	INSIG.		INSIG.		INSIG.	
Speed Limit min	INSIG.		INSIG.		INSIG.	
Median Width maj	INSIG.		INSIG.		INSIG.	
Median Width min	INSIG.		INSIG.		INSIG.	
Dispersion	0.0001		0.000		0.000	0.000
Deviance/DF(Deviance )	0.94(112)		0.71(19)		0.71(22.8)	
Pearson Chi-sq/DF(Pearson Chi-sq)	0.99(119)		0.61(16.6)		0.66(21.3)	
LL	-229		-46.68		-55.63	
McFadden's R <sup>2</sup>	0.37		0.46		0.51	
BIC	477		107		125	
AIC	466		101.40		119.26	

For the three intersection categories, as anticipated the ln(AADT )major and ln(AADT )minor affects crashes frequency positively, the reason for this is that as the number of vehicles increase through intersection approach, the exposure to potential crashes and the numbers of conflicts also increase.

#### 6.4 Intersection Model Validation

To examine how well a statistical model fits the data set, Goodness-of-fit (GOF) measures were examined. GOF measures summarize the differences between the observed and predicted values from related SPFs. Several GOF measures are used to assess performance; these tests include the

mean absolute deviation (MAD), mean squared prediction error (MSPE), mean prediction bias (MPB) and Bayesian information criterion (BIC). Statistical GOF tests were performed on the validation data (FI crashes for years 2007-2009). The performance of each model on the validation data set is shown in Table 6-7. These results can be compared in order to assess the transferability of the developed models – which were developed using the estimation dataset – to the validation dataset.

The values of MAD, MPB and MSPE for the intersection developed models are smaller compared to the calibrated models, which indicate that developed models leads to lower prediction error and less bias in the prediction. Moreover the developed models outperform the calibrated models in BIC value. Overall, the developed models are better compared to the HSM calibrated models.

Table 6-7: Goodness of fit tests for the HSM calibrated and developed models.

Total FI Developed Models			
Performance	4SG	3SG	3ST
MAD	2.54	2.37	2.06
MSPE	7.33	9.01	5.48
MPB	2.30	2.63	1.93
BIC	477	107	125
Total FI Calibrated Models			
Performance	4SG	3SG	3ST
MAD	2.87	2.48	2.10
MSPE	14.69	10.83	6.02
MPB	2.47	2.70	1.94
BIC	1010	195	198

## 6.5 Conclusion

The objective of this chapter was to calibrate the HSM SPF for urban intersections and to develop new jurisdiction-specific SPFs. Data from 207 urban intersections in City of Riyadh from a period of three years (2004-2006) were used. Calibration factors were also estimated to adjust the HSM based SPFs and new specific SPFs that quantify the relationship between the expected crash frequencies and various road and traffic characteristics were developed using Riyadh data.

Three objectives are performed in this study. The first objective is to calibrate the base SPFs provided in the HSM for urban intersections in Riyadh. In the second objective, new specific SPFs using Riyadh's severe crash data and traffic volume data are developed. Finally, the performance of these models (i.e., calibrated SPFs vs. the jurisdiction-specific SPFs) was compared and evaluated. The prediction capabilities of these models are evaluated using a validation data set that is different from the original estimation data set. Multiple performance measures, such as MAD, MSPE, MPB, and BIC, are considered.

The total FI calibration factors derived from the three intersection categories are significantly lower than one, implying that the HSM base SPFs are overestimating the mean crash frequencies at urban intersections in Riyadh. The developed SPFs are found to outperform all other HSM calibrated models. Angle crashes are the most severe type of crash, accounting for nearly 28% of the multiple-vehicle severe crashes at 4-leg signalized intersections, while the rear-end crashes are the most severe crashes at 3-leg signalized and 3-leg unsignalized intersections accounting for 38% and 50%, respectively.

While many of the geometric design features collected certainly influence the safety performance of intersections, they were not found to be significant in the model building efforts. In many cases, this is most likely due to the lack of sufficient variation and the number of intersections sampled, rather than a lack of safety influence. The locally calibrated HSM approach provides a promising procedure for quantitative safety evaluation in Riyadh and GCC countries that requires additional consideration and research.

The HSM calibration application for Riyadh crash conditions highlights the importance to address variability in reporting thresholds and the importance to include detailed information about intersection type, number of turn lanes and signal phase system in the police collision report. It was found that most of the signalized and unsignalized intersections were over-loaded with high traffic volumes. This made it difficult for these intersections to operate with acceptable level of service. Overall, this study lays an important foundation towards the implementation of HSM methods in the city of Riyadh, and could help the transportation officials in Riyadh to make informed decisions regarding road safety programs.

Though this study uses Riyadh data, the framework provided can be used by other GCC countries which in general have common driver behavior and design standards. Simple and low-cost solutions (without spatial separations) could reduce delay times to some extent but not to improve levels of service. From the findings of this chapter, several countermeasures are proposed to reduce the severe angle and rear-end crashes at urban intersections in Riyadh city:

#### Signalized Intersections

- Installation of red light cameras and detectors.

- Installation of an early alert sign for the signal.
- Decrease speed limit.
- Improve signal timing and clearance interval by adjusting yellow timing, increased all red timing, and add coordination with adjacent signals.
- Improve poor vision by installing warning signs and remove vision obstructions.
- Improve lighting at intersections.

#### Unsignalized Intersections

- Install traffic signals at high volume traffic intersections.
- Decrease speed limit.
- Installation of rumble strips.
- Improve vision of pedestrian crosswalk.

In summary, these models can be used to estimate severe collisions at urban intersections. In addition, this study is one of the first attempts to investigate the applicability of calibrating HSM models and developing new models at urban intersections in the GCC Countries. Although this study provides thorough investigation to estimate severe collisions at urban intersections, there are several limitations that exist in this study:

- (1) Due to PDO crash data limitation, collision severity in Riyadh was divided into two types fatal and injury. With more data available in the future, crashes would be categorized into traditional three levels (PDO, injury and fatal)



- (2) The results presented in this study were concluded based on urban intersections, future studies with different data sources are needed to confirm the findings concluded in this study.
- (3) Many of the geometric design features collected were not found to be significant in the model building efforts. In many cases, these is most likely due to the lack of sufficient variation and samplings, so all these possible factors need further investigation which could addressed in future studies.

## **CHAPTER 7: TRANSFERABILITY OF SAFETY PERFORMANCE FUNCTIONS: THE CASE OF URBAN FOUR-LANE DIVIDED ROADWAYS IN MUSCAT**

### 7.1 Introduction

Muscat, the capital city of Sultanate of Oman, has expanded in terms of population, and growth of vehicles. The growth in motorization rate is accompanied by a drastic increase in the size of the road network. Such a growth has led to a higher crash frequency level at several locations, which resulted in loss of lives, and caused major economical and social concerns in the country. Previous studies have highlighted the traffic safety in Muscat as a serious issue that required an urgent need for strict and comprehensive measures (Ali et al., 1994; Islam and Al-Hadharami, 2012).

In general, traffic crashes in the Gulf Cooperation Council (GCC) countries ranked the second killer or highest cause of death after cardiovascular diseases. Compared to European countries and USA, GCC Countries have a very high road crashes fatality rate. In 2001, 14.8 persons, and 7.3 persons per 10,000 vehicles were killed in Saudi and Qatari road traffic, respectively (Bener et al., 2003). Thus, there is an urgent need to alleviate the seriousness of the traffic safety problem in Saudi Arabia, which in turn will set a prime example for other GCC countries that face similar problems.

Therefore, this chapter aims to fill these research gaps by calibrating and transferring the Highway Safety Manual (HSM, 2010) predictive models and developing new models. The main objectives for this chapter are: calibrate the HSM SPFs using HSM methodology for Muscat

conditions. In the second objective, new SPFs are developed using the negative binomial (NB) regression technique. Finally, the transferability of Riyadh's developed model using FI crash data from Muscat urban divided roads are evaluated. Recommendations are also provided for transforming the wealth of SPFs and safety knowledge in the HSM to GCC countries.

## 7.2 Muscat data Preparation

This chapter involves three tasks. The first task is to calibrate the base SPF models following the HSM-recommended approach. The second task is to develop specific simple and full SPFs for three response variables (FI, PDO only and TOTAL) for Muscat city. The third task is to check the transferability of the Riyadh's model using FI crash data from Muscat urban divided roads. Finally, the performance of these models will be compared using statistical Goodness-of-fit (GOF) measures.

The present data set covers the period of 2010-2011 and comprises only fatal and injury and property damage only collisions, Annual Average Daily Traffic (AADT), and geometric design features data for urban 4-lane divided roads (U4D) in the city of Muscat. The collision and traffic data used in this study were obtained from two main sources: the Muscat Municipality (MM) and Royal Oman Police, Directorate General of Traffic (DGC).

Since the ARC GIS is still not used for traffic crash geocoding in Oman, the crash data used in the analysis were extracted manually from the filing system in the DGC. The location description in the crash report and DGC annual reports are helpful in figuring out more details about the

characteristics and determining the location of each crash. A total of 627 police-reported crashes were collected for the period 2010–2011 on the urban four-lane divided roadway segments.

The sampled crashes included two subsets. The first included 344 severe crashes. The other subset consisted of 283 PDO crashes.

The traffic volume data for road segments in Muscat city in this study were obtained from Muscat Municipality (MM) in non-electronic format (PDF files). The traffic volume counts conducted during 2011 using Manual (MTC) and Automatic Traffic Counts (ATC) and collected by private consultancy company. Table 7- 1 provides some basic statistics of the relevant data used to develop the prediction models.

Table 7-1 : Descriptive Statistics of Variables

Variable	Description	Min.	Max.	Mean	Media
FI	The number of fatal and injury crashes	0	19	3.27	2.5
PDO	The number of property damage only	0	18	2.69	2
TOTAL	The number of FI and PDO crashes	0	33	5.97	5
Segment(mi)	The length of segment	0.12	1.8	0.48	0.4
AADT(v/day)	Annual average daily traffic	5198	66028	30640	31064
Number of driveways	The number of driveways	0	10	2.5	2
Driveway density	Number of driveway per mile	0	26.7	6.56	4.91
Speed limit(mi/h)	Actual posted speed limit	37	50	46	47
Median Width(ft)	Median width(ft)	10	25	16.70	15

Since there is currently no available database which has information pertaining to the driveway density and median width, the Google Earth Maps were used to obtain these variables. In order to accurately collect the required data, extensive work was needed to track along the routes in both the GIS environment and Google Earth imagery to collect these data.

The first task for the data collector on each segment was to confirm that it was indeed the correct facility type (urban four-lane divided roadway segments). Additionally, if there was an Intersection in the segment, the segment would be broken into two new segments, with the beginning or ending points of the new segments defined to exclude 250 feet on either side of the intersection. Once each segment was confirmed and accurately defined, the necessary collision, geometric and cross-sectional characteristics were collected.

The data sets contained several variables: segment length, AADT, driveway density, speed limit (mi/h), and median width (ft). Finally, the collision data, traffic volume data, and cross-section road features were merged in one file. The resulting database contained information about the collisions occurring on each segment together with the geometric and traffic characteristics of this segment. The segmentation process resulted in 104 homogeneous segments for the entire City of Muscat with the length ranging between 0.12 mi and 1.8 mi and an average of 0.48 mi. From the segmentation process, there were 627 reported crashes on the 104 segments for 2010-2011.

The crash data was divided into the estimation and validation portions. Seventy percent of the segments (73 segments) was selected randomly and used as the estimation data to develop the SPFs while the remaining thirty percent (31 segments) was used as the validation data.

### 7.3 Modeling Results and Discussion

#### 7.3.1 HSM Calibration Models

In the estimation data set, there were 249, 208 and 457 reported FI, PDO and total crashes, respectively on the 73 segments for 2010-2011. HSM base models for urban/suburban arterial roadway segments have separate equations for single vehicle and multiple vehicle collisions.

Table 7-2 provides the HSM SPF coefficients on urban four-lane divided segments for single vehicle (SV) and multiple vehicles (MV), respectively.

Table 7-2: SPF Coefficients for Single and Multiple Collisions on Urban Roadway Divided Segments

Collision Type	SV		MV	
	Intercept(a)	AADT(b)	Intercept(a)	AADT(b)
Fatal and injury	-8.71	0.66	-12.76	1.28
Property Damage Only Damage	-5.04	0.45	-12.81	1.38
Total	-5.05	0.47	-12.34	1.36

The SPFs still requires the use of CMFs as directed by the HSM. The CMFs applied for urban segments are: on-street parking, roadside fixed objects, median width, lighting, and automated speed enforcement. The crash modification factor for auto speed enforcement is unity for all segments, since speed enforcement was not applied on urban arterial segments. The crash modification factor for roadside fixed objects is assumed to be one. In this study, HSM approach

was used to estimate the CMFs for parking, lighting and median width. A brief explanation of the method is given below. The following steps were used to identify the HSM CMFs.

- Parking: the crash modification factor was estimated based on research by Bonneson (2005), as

$$CMF=1+P_{pk}(f_{pk}-1) \quad (7-1)$$

Where:

$P_{pk}$  = proportion of curb length with on-street parking ( $= 0.5 L_{pk}/L$ ),  $L_{pk}$  = curb length with on-street parking (mi),  $L$ = roadway segment length (mi), and  $f_{pk}$ = factor from Table 12-19 of the HSM,( 2010). The sum of curb length ( $L_{pk}$  ) was determined from Google Earth.

- Lighting : The CMF for lighting calculated based on the work of Elvik and Vaa (2004) as

$$CMF = 1 - (P_{nr} \times (1.0 - 0.72 P_{inr} - 0.83 P_{pnr} )) \quad (7-2)$$

Where:

$P_{inr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve a nonfatal injury,  $P_{pnr}$  = proportion of total nighttime crashes for unlighted roadway segments that involve PDO crashes only, and  $P_{nr}$  = proportion of total crashes for unlighted roadway segments that occur at night.

The HSM default values of  $P_{nr}$ ,  $P_{inr}$  , and  $P_{pnr}$  for urban four- lane divided roadway segments are 0.410,0.364 and 0.636, respectively resulting in a  $CMF=0.914$ .

- Median width: The CMF was estimated based on Table 12-22 of the HSM (2010).

Using the HSM CMFs, the total calibration factor for urban four lane divided was estimated as shown in Table 7-3. The local Muscat calibration factors for the PDO and TOTAL collision categories are higher than one, implying that HSM base SPFs are underestimating the mean crash frequencies for these collision types on urban four lane divided roads in Muscat. On the other hand, the FI crashes has lower calibration factor which indicates that the severe crashes recorded in Muscat city are lower compared with the jurisdictions from which the HSM’s urban/suburban SPFs were developed.

Table 7-3: Estimated calibration factors (2010-2011)

Variable	Single vehicle	Multiple vehicle	Total
FI Observed Crashes	138	105	243
PDO Observed Crashes	111	93	204
Total Observed Crashes	249	198	447
FI Predicted Crashes	31.55	240.70	272.25
PDO Predicted Crashes	17.75	135.40	153.15
Total Predicted Crashes	49.3	376	422.3
Calibration Factor (FI)	4.37	0.43	0.89
Calibration Factor (PDO)	6.25	0.69	1.33
Calibration Factor (TOTAL)	5.05	0.53	1.06

The low fatal and injury calibration factors in Muscat city could be attributed to the following possible reasons:

- Crashes involving both slight injury and damage to property may be recorded as “Property Damage Only” crashes.



- Slight injury crashes may suffer from underreporting.
- Differences in reporting criteria between the City of Muscat and the jurisdictions from which the HSM SPFs were developed.
- It is possible that collisions in the City of Muscat are simply less severe due to local roadway conditions, climatic effects, and/or driver behavior.

The performances of the calibration factors will be discussed in the “Validation and Comparison” subsection.

### 7.3.2 Local New developed Negative Binomial Models

Six SPFs were developed by the negative binomial modeling method using two different model types. The first model type is simple keeps the form of HSM base SPF in view of its simplicity and its minimal requirements on data availability:

$$N = \text{EXP} [\beta_0 + \beta_1 \text{AADT} + \beta_2 L] \quad (7-3)$$

Where,

N=number of predicted crashes.

AADT= Annual Average Daily Traffic.

L= Segment Length (mi), and

$\beta_0$ ,  $\beta_1$ , and  $\beta_2$  are parameters to be estimated.

The second model type is full a model that takes the form of the equation shown below.

$$N = \text{EXP} [\beta_0 + \sum_{i=1}^p \beta_i x_i] \quad (7-4)$$

Where,

$x_i$  = independent variable, and

$p$  = number of independent variables.

Table 7-4 shows the parameter estimates,  $p$ -values, and the goodness-of-fit measures for the six collision severity models. The two model forms make intuitive sense; the full models perform better in term of deviance, dispersion, and log likelihood (LL) values. Both simple and full models have comparable goodness-of-fit measures. In view of this, it can be concluded that the total full model is the best model compared to the simple model. The full models for PDO and TOTAL crashes have three variables:  $\ln(\text{AADT})$ , Segment length, and Speed limit. While the FI full model has four variables:  $\ln(\text{AADT})$ , Segment length, Speed limit and median width.

Table 7-4: Crash Severity models

Parameter	FI				PDO			
	FI Simple		FI Full		PDO Simple		PDO Full	
	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	-8.042	0.002	-8.945	0.0011	-10.966	0.0001	-12.15	0.0001
Ln AADT	0.854	0.0007	0.7027	0.0059	1.126	0.0001	1.079	0.0001
Segment length	0.774	0.0019	0.6744	0.0060	0.599	0.0076	0.525	0.0197
Speed Limit			0.0684	0.030			0.0367	0.098
Median Width			-	0.141			INSIG.	
Driveway Density			INSIG.				INSIG.	
Dispersion	0.367		0.318		0.192		0.179	
Deviance/DF(Deviance)	1.10(111.40)		1.10(11)		1.030(10)		1.038(1)	
PearsonChi-/DF(PearsonChi)	1.066(107.70)		1.04(10)		0.98(99.7)		0.951(9)	
LL	-227.52		-225.20		-202.02		-200.64	
McFadden's R <sup>2</sup>	0.19		0.21		0.20		0.23	
BIC	437.62		473.62		422.64		424.51	
TOTAL(FI+PDO)								
	TOTAL simple			TOTAL Full				
Parameter	Estimate	P-value	Estimate	P-value				
Intercept	-8.40	0.0001	-9.77	0.0001				
Ln AADT	0.94	0.0001	0.897	0.0001				
Segment length	0.89	0.0001	0.806	0.0005				
Speed Limit			0.040	0.048				
Median Width			INSIG.					
Driveway Density			INSIG.					
Dispersion	0.324		0.305					
Deviance/DF(Deviance)	1.14(108.88)		1.15(108.46)					
Pearson Chi-sq/DF(Pearson Chi-	1.08(102.85)		1.047(98.50)					
LL	-259.25		-257.35					
McFadden's R <sup>2</sup>	0.18		0.20					
BIC	536.84		537.63					

The median width and driveway density variables were found insignificant for the three collision categories, except FI, the median width has marginally significant negative effect on the FI crashes. The  $\ln(\text{AADT})$  was found to have a positive relationship with crash frequency, the reason for this is that as the number of vehicles increase through a segment, the exposure for potential crashes and the numbers of conflicts also increase. Speed limit is found to be positively associated with the crash frequency.

#### 7.4 Transferability of Riyadh Model to Muscat Data

The fatal and injury (FI) crash data from the city of Muscat is used to check the transferability of Riyadh's FI developed model to Muscat urban roads. The following section explains the data used to develop Riyadh FI model and the developed negative binomial model equation.

##### 7.4.1 Riyadh Data Description

The Riyadh data set covers the period of 2009-2010 and comprises only fatal and injury collisions, Annual Average Daily Traffic (AADT), and geometric design features data for urban 4-lane divided roads (U4D) in the city of Riyadh (KSA). Non-injury data were not available since it is collected by a private company and generally not complete. The collision and traffic data used were obtained from two main sources: the Higher Commission for the Development of Riyadh (HCDR) and Riyadh Traffic Department (RTD).

Two different data files were obtained: The first file has the details of the crash characteristics with twenty three variables and contains 2597 cases mapped on ARC GIS with each case in the file representing a collision; the second file has the detailed daily and hourly traffic volumes for road segments in Riyadh city in MS excel files. The traffic volume counts were conducted by Manual (MTC) and Automatic Traffic Counts (ATC). Table 7-5 provides some basic statistics of the relevant data used to develop the prediction models.

Table 7-5: Descriptive Statistics of Variables

Variable	Description	Min.	Max.	Mean	Median
Crash frequency	The number of severity crashes occurring on the study segments during the 2-year period (2009-2010)	0	9	2	3
Segment(mi)	The length of segment	0.15	3.4	0.85	0.73
AADT(v/day)	Annual average daily traffic	5236	132004	38607	37575
Number of driveways	The number of driveways on the study segments	0	48	12.62	11
Driveway density	Number of driveway per mile	0	40	15.52	14
Speed limit(mi/h)	Actual posted speed limit (rangfrom 31 to 55 mi/h)	31	55	42	43
Median Width(ft)	Median width(ft)	9	70	19.76	15
Shoulder Width(ft)	Shoulder width (ft)	0	39	12.65	11

Annual Average Daily Traffic (AADT) was obtained from the GIS data made available by the HCDR GIS Unit. Since there is currently no available database which has information pertaining to the driveway density, shoulder width, and median width, the Google Earth Maps were used to obtain these variables. In order to accurately collect the required data, extensive work was needed to track along the routes in both the GIS environment and Google Earth imagery to collect these data.

The data sets contained several variables: segment length, AADT, driveway density, speed limit (mi/h), median width (ft), and shoulder width (ft). Finally, the collision data, traffic volume data, and cross-section road features were merged in one file. The resulting database contained information about the collisions occurring on each segment together with the geometric and traffic characteristics of this segment.

After the segmentation process, the 144.56 mi roadways were segregated into 172 homogeneous segments for the entire City of Riyadh with the length ranging between 0.15 mi and 3.4 mi and an average of 0.85 mi. From the segmentation process, there were 420 reported severe crashes on the 172 segments for 2009-2010 used for estimation. The Total FI Riyadh model, which developed using negative binomial (NB) regression has four variables:  $\ln(\text{AADT})$ , Segment length, Speed limit and driveway density as shown in Table7-6.

Table 7-6: Riyadh Models Coefficients

Parameter	Riyadh TOTAL FI Model Coefficients		Riyadh Specific FI Models			
			SV FI Model Coefficients		MV FI Model Coefficients	
	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	-6.78	0.0016	-4.168	0.0809	-4.86	0.0434
Ln AADT	0.688	0.0043	0.384	0.087	0.414	0.091
Segment length	0.48	0.016	0.198	0.089	0.408	0.056
Speed Limit	-0.0268	0.15	-0.0167	0.20	-0.0147	0.20
Driveway Density	0.0302	0.0072	0.0115	INSIG.	0.0336	0.008-
Dispersion	0.40		0.51		0.216	
Deviance/DF (Deviance)	1.11 (185.11)		1.047 (154)		1.08 (164.04) (113.7)	
Pearson Chq/DF (Pearson Chi-sq)	0.98 (164.32)		1.01 (149.24)		0.956 (144.44)	
LL	-255.21		-208.46		-183.64	
McFadden's R <sup>2</sup>	0.11					
BIC	541		437		397.54	

### 7.5 Validation and Comparisons

To examine how well a statistical model fits the data set, Goodness-of-fit (GOF) measures were examined. GOF measures summarize the differences between the observed and predicted values from related SPFs. Several GOF measures are used to assess performance; these tests include the mean absolute deviation (MAD), mean squared prediction error (MSPE), mean prediction bias (MPB) and Bayesian information criterion (BIC). Statistical GOF tests were performed on the 30% validation data. In the validation data set, there were 95, 75 and 170 reported FI, PDO and total crashes respectively on the 31 segments for 2010-2011. The performance of each model is

shown in Table 7-7. The values of MAD, MPB and MSPE for simple models are smaller compared to the full developed models for the severity collisions except for the FI model, which indicate that the simple model leads to lower prediction error and less bias in the prediction. However the full models outperform the simple models in BIC value. Overall, the simple model is better compared to the full developed model.

On the other hand, when we compare the HSM calibrated models, it is clear that HSM calibrated models outperforms the new local developed models in MAD, MSPE, and MPB while the new models performs better in terms of BIC measure. This indicates that locally calibrated HSM models perform better than new developed models in terms of mean-related measures. Based on the performance measures results, Riyadh model transferred to Muscat fatal and injury (FI) data does not perform better compared to both local FI HSM calibrated and new developed models.

Table 7-7: Goodness of fit measures for the HSM calibrated and developed models

Developed Models						
Performance	FI simple	FI full	PDO	PDO full	TOTAL	TOTAL
MAD	2.18	2.02	1.48	1.55	3.33	3.41
MSPE	7.15	7.08	3.71	4.08	21.14	22.28
MPB	0.086	0.180	0.102	0.153	0.283	0.430
BIC	437.62	473.62	422.64	424	537	538
Calibrated Models						
Performance	HSM Calibrated Models			Riyadh TOTAL FI		
	FI	PDO	TOTAL	FI		
MAD	1.62	0.03	3.30	2.87		
MSPE	5.10	3.39	20.89	19.00		
MPB	0.04	0.4	0.073	-2.76		
BIC	754.82	712.03	873.24	783.57		

As shown in Table 7-8, the mean of driveway density and median width on Riyadh urban networks are 15.52 ft and 19.76 ft, while for Muscat urban networks are 6.56 ft and 16.70 ft,



respectively. At the same time, unlike Muscat, there is frequent angle parking in Riyadh urban road network. These differences in road geometric design features and FI collision characteristics between Riyadh and Muscat resulted in an un-transferable Riyadh crash prediction model. It can be observed that unlike other models, the MPB for Riyadh model is negative indicating that this model has negative bias.

Table 7-8: Comparison of Geometric design and collision characteristics between Riyadh and Muscat

variable	Min.		Max.		Mean		Median	
	Riyadh	Muscat	Riyadh	Muscat	Riyadh	Muscat	Riyadh	Muscat
FI	0	0	9	19	2	3.27	3	2.5
Segment (mi)	0.15	0.12	3.4	1.8	0.85	0.48	0.73	0.4
AADT (v/day)	5236	5198	132004	66028	38607	30640	37575	31064
Number of driveways	0	0	48	10	12.62	2.5	11	2
Driveway density	0	0	40	26.7	15.52	6.56	14	4.91
Speed limit (mi/h)	31	37	55	50	42	46	43	47
Median Width(ft)	9	10	70	25	19.76	16.70	15	15

## 7.6 Conclusion

The objective of this chapter was to calibrate the HSM SPF for urban four-lane divided roads and to develop new jurisdiction-specific SPFs. Data from 73 homogeneous segments located on urban roads in the City of Muscat from a period of two years (2010-2011) was selected randomly

and used as the estimation data to develop the SPFs while the remaining 31 segments was used as the validation data. Calibration factors were also estimated to adjust the HSM based SPFs and new specific SPFs that quantify the relationship between the expected crash frequencies and various road and traffic characteristics were developed using Muscat data.

Three objectives are performed in this study. The first objective is to calibrate the HSM SPFs using HSM methodology for Muscat conditions. In the second objective, new SPFs are developed using the NB regression technique. Finally, Riyadh total fatal and injury model was evaluated using Muscat data to check the transferability of this model to other different geographic region in GCC countries. The prediction capabilities of these models are evaluated using a validation data set that is different from the original estimation data set.

Multiple performance measures, such as MAD, MSPE, MPB, and BIC, are considered. The calibration factors derived for PDO and TOTAL are larger than one, implying that the HSM base SPFs are underestimating the mean crash frequencies on urban four-lane divided roads in Muscat for these two collision severity. On the other hand the FI calibration factor is lower than one. Based on the performance measure comparisons and the calibration factors, the HSM calibrated models seem to outperform the new developed SPFs. However, developed SPFs are found to outperform all other calibrated models in BIC value. The new jurisdiction-specific models show that the relationships between crashes and roadway characteristics in Muscat seem not different from those presented in the HSM.

The new SPFs, for example, predict more crashes when the variables AADT, segment length, and speed limit were increased. The HSM SPFs data showed lower improvement over the developed models, which provides a promising procedure for quantitative safety evaluations in Muscat and GCC countries that requires additional consideration and research.

The medians in Riyadh have oversize widths ranging from 16ft-70ft. The mean of driveway density and median width on Riyadh urban networks are 15.52 ft and 19.76 ft, while for Muscat urban networks are 6.56 ft and 16.70 ft, respectively. Unlike Muscat, there is frequent angle parking in Riyadh urban road networks, these differences in road geometric design features and FI collision characteristics between Riyadh and Muscat resulted in a non-transferable Riyadh crash prediction model.

The HSM calibration application for Muscat crash conditions highlights the importance to address variability in reporting thresholds. One of the findings of this research is that the median width and driveway density have insignificant effect on the TOTAL and PDO traffic crashes in Muscat. While the median width has slight negative effect on FI crashes. The study also indicates that reducing the maximum speed can reduce fatal and injury, PDO and total crashes.

Though this study uses Muscat data, the framework provided can be used by other GCC countries which in general have common driver behavior and design standards. Overall, this study lays an important foundation towards the implementation of HSM methods in the city of Muscat, and could help the transportation officials in Muscat to make informed decisions

regarding road safety program. The following policies and countermeasures could be suggested based on the analysis results:

- The road engineers in Muscat should pay considerable attention to urban road median width.
- Automated enforcement needs to be implemented to ensure speed compliance.
- Reinforce driver education and provide effective driver training programs.

This study is one of the first attempts to investigate the applicability of calibrating HSM models and developing new models in the GCC Countries. The results are important as it points to the potential adaptation of the HSM to other countries, and that not necessarily models from adjacent countries could be easily transferable.

## CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

This dissertation incorporated the analysis of traffic safety data for urban roadway segments and intersections. Various data sources (e.g. Riyadh traffic data, Riyadh crash data, Muscat traffic data and Muscat crash data) have been obtained, analyzed, and utilized in this study. This chapter discusses the critical findings, conclusions, research implications and recommendations of the three major research aspects: (1) transferability of HSM SPFs and development of new local models for Riyadh urban segments using FI crashes, (2) transferability of HSM SPFs and development of new local models for Riyadh urban intersections using FI crashes, and (3) transferability of HSM SPFs and development of new local models for Muscat urban segments using FI, PDO, and TOTAL crashes.

### 8.1 Summary

#### 8.1.1 Riyadh urban roadway segments

In this study the HSM SPFs were calibrated using HSM default CMFs for Riyadh conditions. Furthermore, new methodological contribution of this dissertation is the introduction of locally derived crash modification factors (CMFs) for Riyadh angle parking using fatal and injury collision data. The total FI calibration factors derived from both approaches is significantly lower than one, implying that the HSM base SPFs are overestimating the mean crash frequencies on urban four-lane divided roads in Riyadh.

The HSM calibration method using new local CMFs seems to outperform the HSM default values for this type of facility. However, developed SPFs are found to outperform all other calibrated models. The new jurisdiction-specific models show that the relationships between

crashes and roadway characteristics in Riyadh may be different from those presented in the HSM. The new SPFs, for example, predict more crashes when the variables AADT, segment length, and driveway density were increased. The positive effect between SV crash and driveway density was unexpected, which could be attributed to pedestrian collisions, or avoidance maneuvers. The positive effect of shoulder width on MV crashes is somewhat counterintuitive since shoulder width is expected to have a negative effect on the crash frequency.

An explanation for this result is that wider shoulders might encourage drivers to travel at higher speeds or actually use it as a lane which is illegal but common in the region. The locally derived CMFs for fatal and injury data showed improvement over the HSM default values, which provides a promising procedure for quantitative safety evaluations in Riyadh and GCC countries that requires additional consideration and research.

The HSM calibration application for Riyadh crash conditions highlights the importance to address variability in reporting thresholds. One of the findings of this research is that, while the medians in this study have oversize widths ranging from 16ft-70ft, median width has insignificant effect on fatal and injury crashes. In the same time the frequent angle parking in Riyadh urban road networks seems to increase the fatal and injury collisions by 52 percent. Though this study uses Riyadh data, the framework provided can be used by other GCC countries which in general have common driver behavior and design standards. The findings of this chapter indicate that road engineers in Riyadh should pay considerable attention to driveways, and angle parking management. For example, several countermeasures proposed to reduce the severe crashes in Riyadh city:

- Limiting the number of driveways.
- Using acceleration and deceleration lanes that are of sufficient length to accommodate speed changes, and the weaving and maneuvering of traffic.
- Ensure sufficient distance/spacing between driveways to provide drivers sufficient perception time to identify locations where they expect another conflict point.
- Angle-parking needed be replaced by more effective parking designs and systems, such as replaced with parallel parking in possible places or using the regulated parking instead of the free parking system.
- Median width in Riyadh urban roads can be reduced to the standard width in order to increase the lane widths.

In addition, this study is one of the first attempts to investigate the applicability of calibrating HSM models and developing new models in the GCC Countries. Since the results showed that the developed models had more accurate performance over the HSM calibrated model, using calibrated specific CMFs with HSM SPFs should also be considered.

#### 8.1.2 Riyadh urban intersections

Furthermore, this study calibrated HSM SPFs for urban intersections and developed new jurisdiction-specific SPFs. Data from 207 urban intersections in City of Riyadh from a period of three years (2004-2006) were used. Calibration factors were also estimated to adjust the HSM based SPFs and new specific SPFs that quantify the relationship between the expected crash frequencies and various road and traffic characteristics were developed using Riyadh data.

The prediction capabilities of these models are evaluated using a validation data set that is different from the original estimation data set. Multiple performance measures, such as MAD, MSPE, MPB, and BIC, are considered.

The total FI calibration factors derived from the three intersection categories are significantly lower than one, implying that the HSM base SPFs are overestimating the mean crash frequencies at urban intersections in Riyadh. The developed SPFs are found to outperform all other HSM calibrated models. Angle crashes are the most severe type of crash, accounting for nearly 28% of the multiple-vehicle severe crashes at 4-leg signalized intersections, while the rear-end crashes are the most severe crashes at 3-leg signalized and 3-leg unsignalized intersections accounting for 38% and 50% respectively.

While many of the geometric design features collected certainly influence the safety performance of intersections, they were not found to be significant in the model building efforts. In many cases, these is most likely due to the lack of sufficient variation and the number of intersections sampled, rather than a lack of safety influence. The locally calibrated HSM approach provides a promising procedure for quantitative safety evaluations in Riyadh and GCC countries that requires additional consideration and research.

The HSM calibration application for Riyadh crash conditions highlights the importance to address variability in reporting thresholds and the importance to include detailed information about intersection type, number of turn lanes and signal phase system in the police collision report. It was found that most of the signalized and unsignalized intersections were over-loaded



with high traffic volumes. This made it difficult for these intersections to operate with acceptable levels of service. From the findings of this chapter, several countermeasures proposed to reduce the severe angle and rear-end crashes at urban intersections in Riyadh city:

#### Signalized Intersections

- Installation of red light cameras and detectors.
- Installation of an early alert sign for the signal.
- Decrease speed limit.
- Improve signal timing and clearance interval by adjust yellow timing, increased all red timing, and add coordination with adjacent signals.
- Improve poor vision by installing warning signs and remove vision obstructions.
- Improve lighting at intersections.

#### Unsignalized Intersections

- Install traffic signals at high volume traffic intersections..
- Installation of rumble.
- Improve vision of pedestrian crosswalk.

### 8.1.3 Muscat urban roadway segments

Moreover, HSM SPFs were calibrated using HSM methodology for Muscat conditions and new local models are developed for three response variables- i) FI, ii)PDO, and iii) TOTAL crashes. In addition, Riyadh total fatal and injury model was evaluated using Muscat data to check the transferability of this model to other different geographic region in GCC countries. The prediction capabilities of these models are evaluated using a validation data set that is different from the original estimation data set.

The calibration factors derived for PDO and TOTAL are larger than one, implying that the HSM base SPFs are underestimating the mean crash frequencies on urban four-lane divided roads in Muscat for these two collision severity. On the other hand the FI calibration factor is lower than one. With the consideration of model performance results and the calibration factors, it can be concluded that the HSM calibrated models provided the best goodness-of-fit. While the developed SPFs are found to outperform all other calibrated models in BIC value, the new jurisdiction-specific models show that the relationships between crashes and roadway characteristics in Muscat seem not significantly different from those presented in the HSM. The new SPFs, for example, predict more crashes when the variables AADT, segment length, and speed limit were increased. The HSM SPFs data showed lower improvement over the developed models, which provides a promising procedure for quantitative safety evaluations in Muscat and GCC countries that requires additional consideration and research.

The medians in Riyadh have oversize widths ranging from 16ft-70ft. The mean of driveway density and median width on Riyadh urban networks are 15.52 ft and 19.76 ft, while for Muscat urban networks are 6.56 ft and 16.70 ft, respectively. Unlike Muscat, there is frequent angle parking in Riyadh urban road networks, these differences in road geometric design features and FI collision characteristics between Riyadh and Muscat resulted in a non-transferable Riyadh crash prediction model.

The HSM calibration application for Muscat crash conditions highlights the importance to address variability in reporting thresholds. One of the findings of this research is that the median

width and driveway density have insignificant effect on the PDO and TOTAL traffic crashes in Muscat.

Though this study uses Muscat data, the framework provided can be used by other GCC countries which in general have common driver behavior and design standards.

## 8.2 Research implications

### 8.2.1 Crash Developed Models

The findings from the Chapters 5, 6, and 7 provide some implications to traffic safety agencies in GCC countries. The traffic safety studies in GCC countries have not explored the relationship between the crash frequency and physical roadway characteristics of segments and intersections. On the contrary, this study is the first that explored the roadway characteristics such as traffic volume, segment length, median width, speed limit, driveway density, and shoulder width which are believed to significantly influence traffic crashes.

For practitioners, Highway engineers, transportation planners and policy makers in these countries, the results and findings can provide meaningful guidance for designing and adapting specific education, operational, engineering, and awareness campaigns and stricter enforcement to reduce traffic collisions.

Thus the safety performance models developed in this study will assist decision makers to forecast the magnitude of the traffic crash problem in GCC countries in the future. Crash prediction models are considered invaluable tools that have many applications in road safety

analyses. These mathematical models have the capability to describe, explain and predict the variations in crashes. Consequently, these models are considered extremely important for the GCC countries for the following reasons:

1. Investigate the safety problem in GCC countries from the perspective of forecasting the effect of geometric and roadway physical characteristics on the traffic crash problem in the future.
2. The safety prediction models developed in this study normally have important utility including:
  - Forecasting the size of the crash problem in the future and identifying its future implications.
  - The design and selection of safety measures to alleviate traffic crashes and/or reduce their effects.
  - Assist legislators with the appropriate laws and regulations to address the traffic safety problem.
  - Assist national planners address the traffic safety problem through the educational system, the planning of public transportation facilities, the police enforcement programs, etc.
  - Assist economists evaluate and forecast the economic burden of traffic crashes on the level of the whole economy.

### 8.2.2 HSM Calibrated Models

With respect to HSM calibration part, this study lays an important foundation towards the implementation of HSM methods in Muscat and Riyadh, and could help the transportation officials to make informed decisions regarding road safety programs. Using HSM calibration factors developed in this study, the Muscat Municipality (Directorate General of Roads) and Riyadh Municipality can confidently use the HSM predictive methods to evaluate the safety of urban roads in Muscat and Riyadh. Besides the HSM default CMFs, local HSM CMFs could allow local agencies in Riyadh to use the HSM predictive methods by generating the SPF models for local conditions. Although the HSM recommends agencies to develop locally derived values, this study proved that both Riyadh and Muscat cities can directly use the HSM default proportions. In spite that this study uses Riyadh Muscat data, the framework provided can be used by other GCC countries which in general have common driver behavior and design standards.

### 8.3 Future Research

Data is crucial for the crash analysis. The quality of the research is highly dependent on the availability and quality of data. Lack of information on PDO data in Riyadh makes it impossible to investigate and analyze the factors associated with PDO crashes. Obtaining more valuable data about PDO crashes in Riyadh will be very helpful in improving future research. The intersection results presented in this study were concluded based on urban intersections, future studies with different data sources are needed to confirm the findings concluded in this study.

Many of the geometric design features collected were not found to be significant in the model building efforts. In many cases, these is most likely due to the lack of sufficient variation and sampling, thus all these possible factors need further investigation which could addressed in future studies.

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