Transferability and Calibration of Highway Safety Manual Performance Functions and Development of New Models for Urban Four-Lane Divided Roads in Riyadh

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ABSTRACT
The first edition of the Highway Safety Manual (HSM) provides a number of safety performance functions (SPFs), which can be used to predict severe collisions on a roadway network. This paper examined the calibration of the HSM SPFs for Urban Four-lane divided roadway segments (U4D) with angle parking in Riyadh, Kingdom of Saudi Arabia (KSA) and the development of new SPFs. This study first calibrates the HSM SPFs using HSM default Crash Modification Factors (CMFs), then new local CMFs are proposed, which adjust the estimation of calibration factors using fatal and injury crash data. In addition, new forms for specific SPFs are further evaluated to identify the best model using the Poisson-Gamma regression technique.

It was found 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 best fatal and injury model describes the mean crash frequency as a function of natural logarithm of the annual average daily traffic, segment length, speed limit, and driveway density. The study finds that the HSM calibration using Riyadh local CMFs outperforms the calibration method using HSM default values. Based on these results, potential countermeasures were proposed to reduce severe crashes on Riyadh urban roads, and the potential for HSM application in KSA are addressed.

Keywords: Model transferability, developing countries, Urban roadway segments, Safety Performance Functions, Calibration factors, Negative Binomial model, Highway Safety Manual.
**INTRODUCTION:**

Riyadh, the capital city of the 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 economic and social concerns in the country. Previous studies have highlighted the traffic safety situation in Riyadh as a serious issue that required urgent needs for strict and comprehensive measures (1-7).

In general, traffic crashes in the Gulf Cooperation Council (GCC) countries ranked the second killer or highest cause of death after cardiovascular disease. Compared to European countries and USA, GCC Countries have a very high road crash fatality rate. In 2001, 14.8 persons, and 7.3 persons per 10,000 vehicles were killed in Saudi and Qatari road traffic, respectively (1). 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 paper aims to fill these research gaps by calibrating and transferring the Highway Safety Manual (HSM) (8) predictive models and developing new models. The main objectives of this paper are: Calibrate the base SPFs provided in the HSM for urban four lane divided roadway segments in Riyadh using HSM CMFs default values, estimate new calibration factors using proposed local CMFs, and develop new jurisdiction-specific SPFs using Riyadh’s severe crash data, traffic volume, and roadway geometric design features; 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.

**BACKGROUND**

Many recent studies have described the development of SPFs for various types of entities, such as urban arterials, rural roads, and intersections (9-18). Lu et al. (10) found that jurisdiction-specific SPFs fit their collision data better than the calibrated HSM SPFs. Garber et al. (16), 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 (19-24). 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. (11) 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 (23) 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 (18) 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. (24) compared the effect of choosing different segmentation methods, they examined using short vs. long roadway segments 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 paper to investigate whether the given SPFs in 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. Other proposal is using the HSM SPF but CMFs calibrated from local conditions are also investigated.

DATA DESCRIPTION
The present data set covers the period of 2004-2009 and comprises 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. In the KSA the police have the legal responsibility to report crashes. The crash reporting thresholds in Riyadh are for crashes that exceeds $120 in damage.

The traffic police department provides annual reports and databases of road traffic crashes to the Higher Commission for the Development of Riyadh (HCDR) and Riyadh Traffic Department (RTD). The traffic crash proportions in Riyadh (2004-2009) are 0.32, 1.37 and 98.31, percent for fatal, injury, and property damage only, respectively (4). 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 and hourly 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 1 provides basic statistics of the relevant data used to develop the prediction models.

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). All non-intersection crashes were used in the study. The crashes that were identified as at intersection or in the immediate vicinity of the intersection (within 250 ft) were excluded. Once each segment was confirmed and accurately defined, the necessary collision, geometric and cross-sectional characteristics were collected.
Table 1. Descriptive Statistics of Variables

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

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 and were 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.

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 developed Riyadh specific Crash Modification Factors (CMFs) for FI collisions. The third task is to develop specific full SPFs for Riyadh. The methods employed to achieve the three tasks are described in the following subsections.

HSM calibration of urban four-lane divided roads

The HSM 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.

The collision predictive models for roadway segments are (8):

\[ N_{predicted} = N_{spfx} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) \]  

(1)
Where:

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

\[ CMF_{yx} = \text{crash modification factors specific to site type } x \text{ and for specific geometric design and traffic control features } y; \]

HSM base models for urban/suburban arterial roadway segments have separate equations for single and multiple vehicle collisions. Equations 2 and 3 provide the HSM SPF for fatal and injury collision on urban four-lane divided segments for single vehicle (SV) and multiple vehicle (MV), respectively.

\[ N = e^{-8.71 + 0.66 \ln(AADT) + \ln(L)} \] (2)

\[ N = e^{-12.76 + 1.28 \ln(AADT) + \ln(L)} \] (3)

The base conditions for urban four lane divided roadway segments models as described in the HSM are:

- On-street parking: None
- Roadside fixed objects: None
- Median width: 15 ft.
- Lighting: None
- Automated speed: None

The calibration factor allows the adjustment of the estimate to local conditions and is calculated using the following equation:

\[ Cr = \frac{\sum \text{all sites observed crashes}}{\sum \text{all sites predicted crashes}} \] (4)

The HSM calibration procedure suggests that at least 30 to 50 sites with at least 100 crashes per year should be included for each facility for this calibration analysis. To avoid a site selection bias, the sites should be randomly selected and then the number of crashes should be determined. As a result, the data set may include sites with no crashes as well as high-crash locations.

**Developed Models**

Contemporary safety performance models are most often developed using a negative binomial (NB) regression. 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 (25,26).

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:

\[ \ln \lambda_i = \beta_{xi} + \varepsilon \] (5)
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

$$\text{Prob}(n_i \mid \varepsilon) = \frac{\exp[-\lambda_i \exp(\varepsilon)] \lambda_i^{ni}}{n!}$$

(6)

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:

$$P(n_i) = \frac{\Gamma(\theta+n_i)}{\Gamma(\theta) n!} u_i^\theta (1 - u_i)^{n_i}$$

(7)

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

Compared with Poisson model, Negative Binomial model has an additional parameter $\alpha$ such that

$$\text{Var}[n_i] = E[n_i] \{1 + \alpha E[n_i]\}$$

(8)

RESULTS AND DISCUSSION

HSM Calibration Models

The five steps listed in the HSM to correctly calibrate a model were applied to Riyadh urban roadways as follow (8):

1. 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. Segments were selected as random as possible to be representative of the Riyadh analysis region.

2. The number of crashes that occurred on the analyzed segments were collected from local Riyadh databases for the years (2004-2006), excluding all the intersection crashes.

3. Estimate annual crashes using SPFs in equations 2 and 3.

4. 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.

### 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 (27), as

  \[
  \text{CMF} = 1 + P_{pk}(f_{pk} - 1) \tag{9}
  \]

  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 (8). 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 (28), as

  \[
  \text{CMF} = 1 - (P_{nr} \times (1.0 - 0.72 P_{inn} - 0.83 P_{pnr})) \tag{10}
  \]

  Where:
  - \(P_{inn}\) = 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 \(P_{nr}\), \(P_{inn}\), and \(P_{pnr}\) for urban four-lane divided roadway segments are 0.410, 0.364 and 0.636, respectively resulting in CMF=0.914.

- **Median width**: The CMF was estimated based on Table 12-22 of the HSM, 2010 (8).

### 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:

\[
F = \exp (-4.84 + 0.507 \times \text{Ln AADT} + 0.735 \times \text{L} + 0.422 \times \text{PARK}) \tag{11}
\]

Where:
- AADT= 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:

\[ CMF_j = \exp(\beta_j) \]  \hspace{1cm} (12)

Where:

- \( CMF_j \) = CMF for variable \( j \)
- \( \beta_j \) = 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 2. All the factors are statistically significant at a 95% confidence level.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ESTIMATE</th>
<th>Std Error</th>
<th>Wald 95% confidence Limits</th>
<th>Wald Chi-Square</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-4.84</td>
<td>1.22</td>
<td>-7.23</td>
<td>-2.45</td>
<td>15.74</td>
</tr>
<tr>
<td>Ln AADT</td>
<td>0.507</td>
<td>0.111</td>
<td>0.289</td>
<td>0.726</td>
<td>20.71</td>
</tr>
<tr>
<td>Segment Length</td>
<td>0.735</td>
<td>0.114</td>
<td>0.511</td>
<td>0.958</td>
<td>41.55</td>
</tr>
<tr>
<td>Parking</td>
<td>0.422</td>
<td>0.139</td>
<td>0.078</td>
<td>0.624</td>
<td>6.37</td>
</tr>
<tr>
<td>Dispersion</td>
<td>0.145</td>
<td>0.041</td>
<td>0.0836</td>
<td>0.252</td>
<td></td>
</tr>
<tr>
<td>Deviance</td>
<td>185.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson Chi-sq</td>
<td>172.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log-Likelihood</td>
<td>-406.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Lighting: The Riyadh Locally-Derived Values for \( \text{Pnr,Pinr and Ppnr} \) 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.

5. Computing the calibration factor using equation 4:

\[ C_r = \frac{\sum \text{all sites observed crashes}}{\sum \text{all sites predicted crashes}} \]

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 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 low compared with the jurisdictions from which the HSM’s urban/suburban SPFs were developed.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Single vehicle</th>
<th>Multiple vehicle</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed crashes</td>
<td>319</td>
<td>271</td>
<td>590</td>
</tr>
<tr>
<td>Predicted crashes using HSM default CMFs</td>
<td>184</td>
<td>1700</td>
<td>1884</td>
</tr>
<tr>
<td>Predicted crashes using Riyadh CMFs</td>
<td>98</td>
<td>954</td>
<td>1052</td>
</tr>
<tr>
<td>Calibration factor using HSM CMFs</td>
<td>1.73</td>
<td>0.16</td>
<td>0.31</td>
</tr>
<tr>
<td>Calibration factor using special CMFs for FI crashes</td>
<td>3.25</td>
<td>0.28</td>
<td>0.56</td>
</tr>
</tbody>
</table>

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

- Crashes involving both slight injury and property damage only may be recorded as "Property Damage Only" crashes (4)
- Slight injury crashes may suffer from underreporting.
- 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.

**Developed models**

**Jurisdiction-Specific 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 simply keeps the form of HSM base SPF in view of its simplicity and its minimal requirements on data availability:

\[ N = \text{EXP} [\beta_0 + \beta_1 \text{AADT} + \beta_2 L] \]  

(13)

Where,

- \( N \) = number of predicted crashes.
- \( \text{AADT} \) = Annual Average Daily Traffic.
- \( L \) = Segment Length (mi), and
- \( \beta_0, \beta_1, \text{and} \beta_2 \) are parameters to be estimated.
The second model type is full model that takes the form of the SPF as shown in the equation below.

\[ N = \exp\left(\beta_0 + \sum_{i=1}^{p} \beta_i x_i \right) \]  

(14)

Where,
\[ x_i = \text{independent variable, and} \]
\[ p = \text{number of independent variables}. \]

**Total crash FI SPFs**

Table 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) and McFadden’s R² values for total full model is slightly 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 the LL value. In view of this, it can be concluded that total full model is slightly better compared to the simple model. The full model has four variables: ln(AADT), Segment length, Speed limit and driveway density.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total simple</th>
<th></th>
<th>Total full</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>P-value</td>
<td>Estimate</td>
<td>P-value</td>
</tr>
<tr>
<td>Intercept</td>
<td>-3.90</td>
<td>0.001</td>
<td>-4.76</td>
<td>0.0001</td>
</tr>
<tr>
<td>Ln AADT</td>
<td>0.435</td>
<td>0.007</td>
<td>0.583</td>
<td>0.0001</td>
</tr>
<tr>
<td>Segment length</td>
<td>0.730</td>
<td>0.001</td>
<td>0.770</td>
<td>0.0001</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>-</td>
<td></td>
<td>-0.025</td>
<td>0.010</td>
</tr>
<tr>
<td>Driveway Density</td>
<td>-</td>
<td></td>
<td>0.0144</td>
<td>0.02</td>
</tr>
<tr>
<td>Dispersion</td>
<td>0.11</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviance/DF(Deviance)</td>
<td>1.04 (176.49)</td>
<td></td>
<td>1.05 (175.94)</td>
<td></td>
</tr>
<tr>
<td>Pearson Chi-sq/DF(Pearson Chi-sq)</td>
<td>0.89 (151.46)</td>
<td></td>
<td>0.90 (150.14)</td>
<td></td>
</tr>
<tr>
<td>LL</td>
<td>-356</td>
<td>0.10</td>
<td>-350</td>
<td>0.12</td>
</tr>
<tr>
<td>McFadden’s R²</td>
<td>0.10</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIC</td>
<td>734</td>
<td>730</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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, 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.
**Type specific SPF**

Because of the differences in the characteristics associated with Single Vehicle (SV) and Multiple Vehicles (MV) crashes, many researchers (29-31) 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 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 and McFadden’s $R^2$ 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: Type Specific models

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SV Simple</th>
<th>SV Full</th>
<th>MV Simple</th>
<th>MV Full</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.801</td>
<td>0.20</td>
<td>-1.63</td>
<td>0.237</td>
</tr>
<tr>
<td>Ln AADT</td>
<td>0.210</td>
<td>0.09</td>
<td>0.310</td>
<td>0.056</td>
</tr>
<tr>
<td>Segment length</td>
<td>0.677</td>
<td>0.001</td>
<td>0.627</td>
<td>0.0001</td>
</tr>
<tr>
<td>Speed Limit</td>
<td>-</td>
<td>-0.021</td>
<td>0.0196</td>
<td></td>
</tr>
<tr>
<td>Driveway Density</td>
<td>-</td>
<td>0.012</td>
<td>0.0806</td>
<td></td>
</tr>
<tr>
<td>Log DW</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Shoulder width</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Dispersion</td>
<td>0.095</td>
<td>0.007</td>
<td>0.106</td>
<td>0.001</td>
</tr>
<tr>
<td>Deviance/D F (Deviance)</td>
<td>1.04</td>
<td>(157.5)</td>
<td>0.920</td>
<td>(138)</td>
</tr>
<tr>
<td>Pearson Chi-sq/DF (Pearson Chi-sq)</td>
<td>0.94 (150)</td>
<td>0.920 (138)</td>
<td>0.980 (148.2)</td>
<td>0.827 (124.05)</td>
</tr>
<tr>
<td>LL</td>
<td>-260</td>
<td>-256</td>
<td>-251</td>
<td>-246</td>
</tr>
<tr>
<td>McFadden’s $R^2$</td>
<td>0.11</td>
<td>0.13</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td>BIC</td>
<td>572</td>
<td>518</td>
<td>540</td>
<td>453</td>
</tr>
</tbody>
</table>

As seen in Table 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 crashes 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 (32) pointed out that wider shoulders increase the risk of sideswipe crashes by encouraging inappropriate use of the shoulder for merging or lane changing maneuvers.

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 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.

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

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Developed Models</th>
<th>Calibrated Models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total simple</td>
<td>Total full</td>
</tr>
<tr>
<td>MAD</td>
<td>2.62</td>
<td>1.43</td>
</tr>
<tr>
<td>MSPE</td>
<td>10.75</td>
<td>4.27</td>
</tr>
<tr>
<td>MPB</td>
<td>2.15</td>
<td>1.98</td>
</tr>
<tr>
<td>BIC</td>
<td>734</td>
<td>730</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>HSM default values</th>
<th>Riyadh local values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>SV</td>
</tr>
<tr>
<td>MAD</td>
<td>2.65</td>
<td>2.37</td>
</tr>
<tr>
<td>MSPE</td>
<td>12.24</td>
<td>7.84</td>
</tr>
<tr>
<td>MPB</td>
<td>2.30</td>
<td>2.40</td>
</tr>
<tr>
<td>BIC</td>
<td>1024</td>
<td>872</td>
</tr>
</tbody>
</table>

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 the 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 simple developed 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.
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 approach for SV and MV models outperform the HSM default values’ approach in MAD, MSPE, MPB and BIC. This indicates that locally derived CMFs using severe collision data perform better than HSM default CMFs.

CONCLUSION

The objective of this paper 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 the 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. Among the goals of this paper is to determine the effect of angle parking on severe collisions for urban four-lane divided roadways.

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 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.

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 paper 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.
- Ensuring 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 replacement with parallel parking in possible places, using the regulated parking instead of the free parking system, or protected parking spaces when right of way is sufficient.
- Median width in Riyadh urban roads can be reduced to the standard width in order to increase the lane widths.

In a nutshell, these models can be used to estimate severe collisions on multi-lane arterial segments between intersections. 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.

Due to the lack of information on PDO data in Riyadh makes it difficult to investigate and analyze the factors associated with PDO crashes. Obtaining more valuable data about PDO crashes in Riyadh will be helpful in improving future research. The results presented in this study were concluded based on urban roads, future studies with different data sources are needed to confirm the findings concluded in this study. The study lays an important foundation to the application of HSM is developing countries. Although locally estimated CMFs with HSM SPFs can be implemented in Riyadh, conducting similar studies for intersection SPFs and extending the study to other countries in the region could be needed to reach more general conclusions.

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REFERENCES


