Application of the Highway Safety Manual to Predict Crash Frequency

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Abstract

The American Association of State Highway Transportation Officials (AASHTO) published the First Edition of the Highway Safety Manual (HSM) in July 2010. The HSM provides a comprehensive set of tools for managing and measuring safety. As a guidebook it outlines methods for developing and managing a roadway safety management system, a catalogue of crash modification factors for various features, and a method to predict average crash frequency and severity. The predictive method of the HSM will allow agencies to forecast the change in crash frequency or severity on a roadway due to changes in traffic volume or roadway geometry.

The City of Missoula, Montana, USA, conducted a corridor planning project on a 2.4 km segment of Russell Street, a minor arterial with average daily traffic (ADT) volumes of 20,000 vehicles per day. The project quantitatively assessed the change in future crash frequency for seven scenarios of differing traffic volumes, intersection control, cross sections, and levels of access management. The quantitative safety analysis results were combined with traffic operations and environmental analyses to inform the decision process for selecting a final concept. This paper presents an overview of the HSM predictive methodology; a discussion of its application to the Russell Street corridor; and, discussion of the method's general application in Australia.

1. Introduction

1.1 What is the Highway Safety Manual?

The American Association of State Highway Transportation Officials (AASHTO) published the first edition Highway Safety Manual (HSM) in July, 2010. Since 1999, the United States of America National Cooperative Highway Research Program sponsored seven independent research projects to develop different parts and chapters of the manual. All of the research projects were conducted under the guidance of: the Transportation Research Board Joint Task Force for the Development of the Highway Safety Manual (ANB25T); the research panels selected for each separate contract; and, beginning in 2007, a Task Force of AASHTO leaders.

The HSM is intended to be: a definitive, science-based guidebook that provides quantitative methods for conducting safety evaluations. It is not intended to establish a standard or recommended practice.

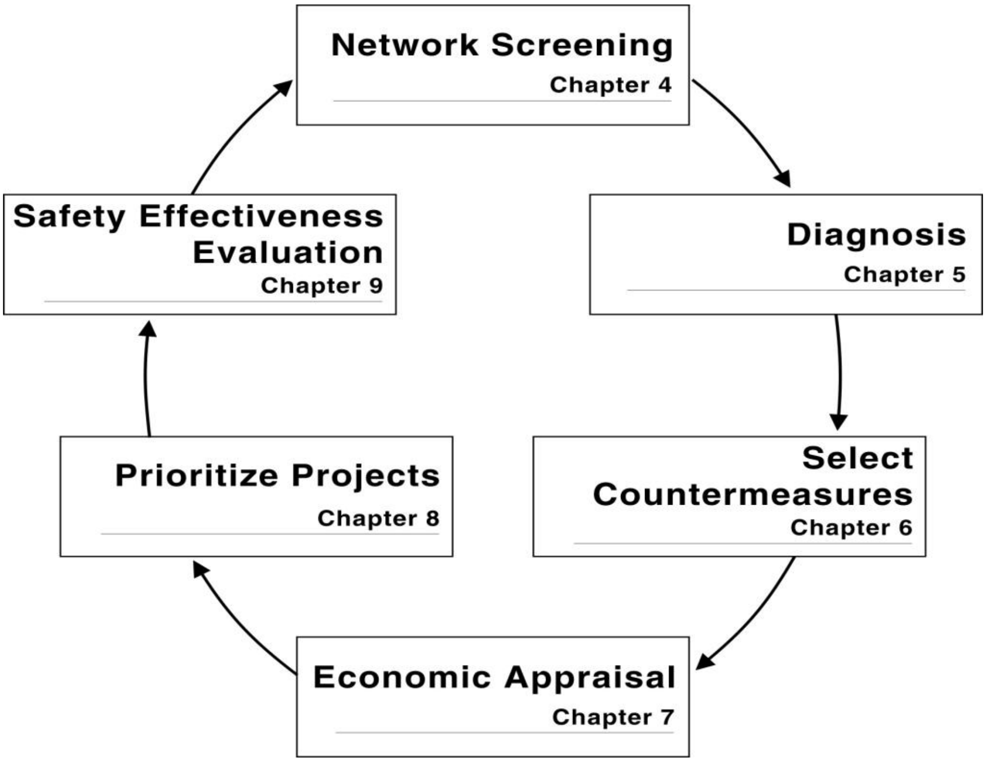
The manual contains four major parts:

1. *Part A: Introduction, Human Factors and Fundamentals* – this part of the manual describes the purpose and scope of the HSM, explaining the relationship of the HSM to planning, design, operations, and maintenance activities.

2. *Part B: Roadway System Management* has six chapters, with each chapter covering one of the steps in the roadway safety management process. The roadway safety management process is used by most jurisdictions to monitor and reduce crash frequency and severity on existing roadway networks. Exhibit 1 shows a schematic of the Part B process.

   The elements included in Part B of the HSM that could be the most valuable in Australia and New Zealand are the performance measures for network screening in *Chapter 4: Network Screening*, and the evaluation methods in *Chapter 9: Safety Effectiveness Evaluation*. While all elements of Part B's safety management process could be valuable, these sections include elements that are unique compared to other resources currently available in Australia and New Zealand.

Exhibit 1: Part B: Roadway Safety Management Process



3. *Part C: Predictive Method* provides a method for estimating expected average crash frequency on a network, facility, or individual site as a function of roadway geometry and traffic volume. Therefore it is possible to predict changes in expected average crash frequency as a function of a change in roadway characteristics, or a change in traffic volume.

The predictive method in Part C is expected to have the most relevance in Australia and New Zealand compared to other parts of the HSM because it:

1) provides a quantitative estimate of crash frequency that can be compared to other quantitative measures in an evaluation, and
2) overcomes many of the statistical biases evident in many current evaluation methods.

4. *Part D: Crash Modification Factors* provides a catalogue of treatments and, where applicable, the associated Crash Modification Factor (CMF) for roadway segments, intersections, interchanges, special facilities, and road networks. The CMFs are used in a similar way as a Crash Reduction Factor (CRF) is used in Australia and New Zealand (although a CRF=1-CMF), to quantify the potential change in crash frequency as a result of geometric or operational modifications to a site.

   The factors presented in Part D could be beneficial in Australia and New Zealand because standard errors are presented for each factor, which represents the variability of the estimated change in crash frequency. By providing the standard error with the factor crash frequency estimation can be associated with a 95th-percentile confidence interval by adding and subtracting two times the standard error to the CMF value.

1.2 Case Study Project Background

This paper presents a case study of the application of the HSM Part C Predictive Method to the Russell Street Corridor in Missoula, Montana. Overall, the purpose of the Russell Street project was to conduct an alternatives analysis and identify the most feasible corridor cross-sections for the entire corridor. The project quantitatively considered safety, traffic operations, and pedestrian and bicycle level of service[1]. This paper will focus on the safety evaluations, including: an overview of the Part C: Predictive Method, a summary of how it was applied to evaluate Russell Street , feedback from the client on the use of the HSM, and a discussion of the potential for transferring the HSM methods to Australian roads.

1.2.1 Project Study Area

The Russell Street corridor is located in Missoula, Montana in the United States (see Exhibit 2). Missoula has a population of approximately 57,000 residents in the city itself, and close to 100,000 in the entire surrounding valley. The city is also home to the University of Montana.

Exhibit 3 shows the approximately 2.4 km corridor from Broadway Street on the north to 14th Street-Mount Avenue on the south.

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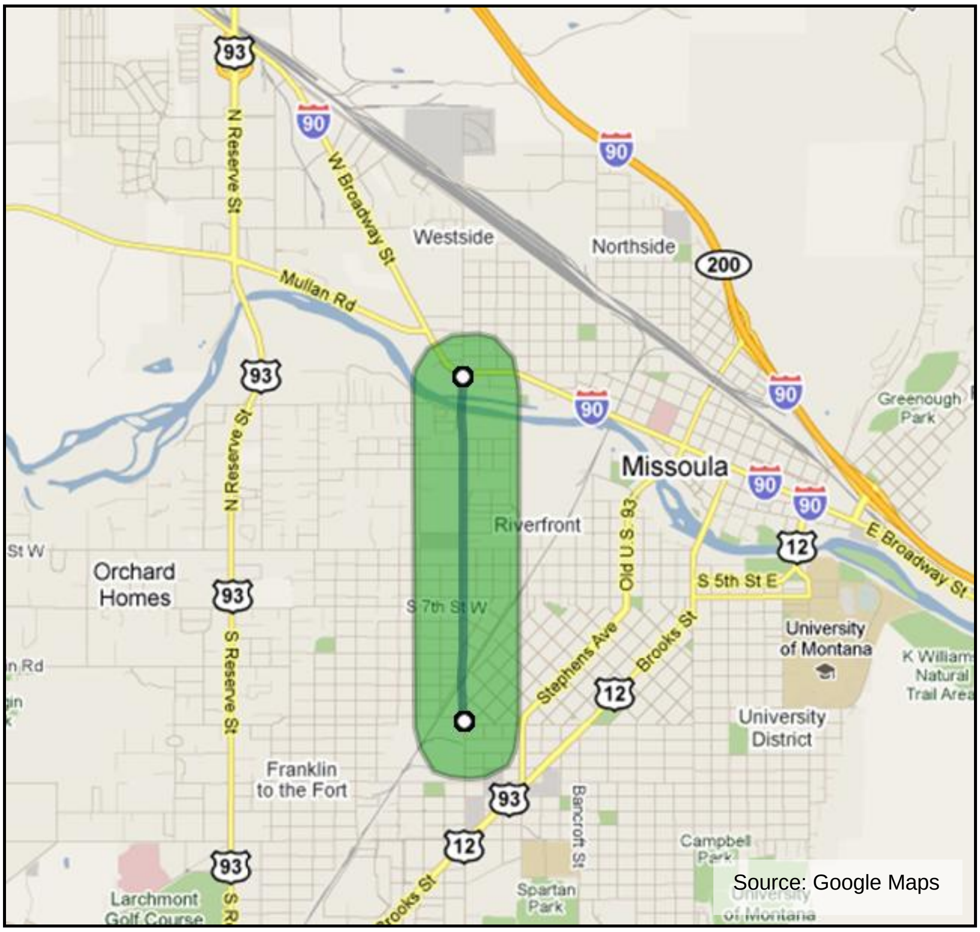
[1] This project also involved the application of the multimodal level-of-service methods developed for the upcoming 2010 *Highway Capacity Manual* to evaluate level-of-service for bicyclists and pedestrians.

Exhibit 2: Regional Map of Study Area

Source: Google Maps

Exhibit 3: Study Corridor



Source: Google Maps

1.2.2 Land Use Context

This corridor is of particular importance to the residents of Missoula as it includes one of five bridge crossings of the Clark Fork River in the city. Downtown Missoula is located on the north side of the river. The south side of the river is primarily residential neighbourhoods. However, immediately south of the river along Russell Street are a handful of large industrial parcels, some of which are still in use, while the others are considered opportunities for redevelopment.

1.2.3 Transport Context

The existing roadway is primarily either a two-lane undivided facility or a three-lane facility with a centre two-way left-turn lane. There is a short section where it is a four-lane undivided facility near the centre of the corridor. Exhibit 4 illustrates a three-lane section of the facility with two-way left-turn lane.

Exhibit 4: Three-Lane Section of Russell Street

The existing bridge is two-lanes wide with narrow footpaths on either side. Paved bicycle lanes and shoulders are generally absent from the corridor, as are footpaths for pedestrians. Nevertheless, it is an important corridor for bicycling and walking, as two east-west shared-use pathways cross the roadway. Existing average daily traffic (ADT) volumes range from 20,000 to 25,000 vehicles per day, with volumes slightly higher on the north side.

1.2.4 Crash Context

Over a 5-year period from 1 July 2004 to 30 June 2008 a total of 406 crashes were reported within the study segment of Russell Street, at intersections and along the roadway between intersections. Approximately one-third of these crashes resulted in an injury or fatality to at least one individual. A summary of crash frequency by crash location and severity is provided in Exhibit 5.

Exhibit 5: Summary of Crash Frequency by Location and Severity

Location	Total Number of Crashes	Number of Fatal/ Injury Crashes	Number of Property Damage Only Crashes
Segments	99	32	67
Intersection	*307*	*97*	210
Total	*406*	*129*	*277*

The crash rate along the corridor was approximately 5.2 crashes per million vehicle kilometres. Twenty-one crashes, or five percent of all crashes, involved a bicyclist.

Crashes have occurred along the entire corridor which required a comprehensive approach to safety analysis to provide an overall reduction in crash frequency.

1.2.5 Project History and Objective

The objective of this project was to update a traffic analysis completed for the project environmental study. The analysis considered updated regional travel demand model projections, detailed traffic operational analyses using VISSIM microsimulation software, and incorporated quantitative performance measures for safety and non-motorized transport. The analysis considered alternatives including reconstructing the entire corridor as a five-lane roadway with a divided median or a centre two-way left-turn lane, depending on the section. It also recommended traffic signals at the major intersections. Bicycle lanes and footpaths would be provided along the length of the corridor. To quantify the potential changes in crash frequency of this and other alternatives the predictive method from Part C of HSM was applied.

2. Urban/Suburban Arterials HSM Predictive Method

This section provides an overview of the HSM predictive method. The HSM predictive method is an 18-step method to estimate the expected average crash frequency (by total crashes, crash severity or crash type) of a roadway network, facility, or site. In the predictive method the roadway is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments, referred to as “sites.” Different facility types are determined by surrounding land use, roadway cross-section, and degree of access. For each facility type a number of different site types may exist, such as divided and undivided roadway segments, and unsignalised and signalised intersections. A roadway network consists of a number of contiguous facilities.

The method is used to estimate the expected average crash frequency of an individual site, with the cumulative sum of all sites used as the estimate for an entire facility or network. The estimate is for a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and annual average traffic (AADT) volumes are known or forecast.

At the highest level there are three major steps in the predictive method:

1. The predicted average crash frequency of an individual site, $N_{predicted}$, is estimated based on the geometric design, traffic control features, and traffic volumes of that site.
2. For an existing site or facility, the observed crash frequency, $N_{observed,}$ for that specific site or facility is combined with $N_{predicted,}$ to improve the statistical reliability of the estimate (empirical Bayes method). The result is the expected average crash frequency, $N_{expected.}$ This is an estimate of the long term average crash frequency that would be expected for the facility, given sufficient time to make a controlled observation, which is rarely possible.
3. The sum of the crash frequencies for all of the sites is used as the estimate of the expected average crash frequency for an entire facility or network.

The generalized process to calculate $N_{predicted}$ is:

$$N_{predicted} = N_{spf\ x} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) \times C_x$$

Where,

$N_{predicted}$ = predicted average crash frequency for a specific year for site type *x;*

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

CMF_{yx} = Crash Modification Factors specific to SPF for site type *x*;

C_x = calibration factor to adjust SPF for local conditions for site type *x.*

The first step in the process to estimate the predicted average crash frequency, $N_{predicted,}$ is to select the predictive model applicable to the site under consideration. The predictive models, N_{spf}, are also called Safety Performance Functions (SPFs). The SPFs in the HSM were developed using regression models from data for a number of similar sites across a number of States in the United States. They have been developed for specific site types and specific "base conditions," which are the specific geometric design and traffic control features of a "base" site. SPFs are typically a function of a few variables, including AADT and study segment length.

More information on the development of the SPFs included in the HSM and the methodology to predict safety performance on urban and suburban arterials is available in *NCHRP Web-Only Document 129: Phases I and II* available online.[2] In general the SPFs included in the HSM were initially developed as negative binomial regression models. The independent variables for urban and suburban multiple-vehicle, non-driveway roadway segment models included ADT and, when statistically significant, shoulder width and on-street parking. Single-vehicle crashes also included a roadside hazard rating. Lane width was considered, but was not found to be significant at a 5-percent lever of greater. At intersections, the independent variables that were found to be significant were ADT for major street and ADT for the minor street approaches.

The second step in the process is to adjust the base prediction to account for differences between the base and local geometric conditions. Crash Modification Factors (CMFs) are used to account for the specific site conditions that vary from the base conditions. A CMF represents the ratio of the expected average crash frequency of a site with one set of conditions to the expected average crash frequency of the same site with a change in one particular condition. For example, the SPF for four legged signalised intersections on urban and suburban arterials assumes filtered left-turn signal phasing. If the intersection under consideration has protected or protected/filtered signal phasing, CMFs are applied to modify the base prediction to local conditions.

After modifying the base prediction to local conditions with CMFs, a calibration factor (C_x) is used to account for differences between the jurisdiction(s) for which the models were developed and the jurisdiction for which the predictive method is applied. The SPFs should be calibrated to local condition prior to applying the models; however if this is not possible a relative analysis, in which the percent change in crash frequency is considered, can be conducted. A calibration factor was not developed for this project, due to a lack of data and available resources.

The $N_{predicted}$ will be calculated a number of different times as a function of the number of sites being analysed, the type and severity of crashes being predicted, and, for urban and suburban arterials, the mode of travel under consideration. This will be demonstrated further in the case study presented in this paper.

Further, and as appropriate, the empirical Bayes (EB) method could also be applied to the predicted crashes as a function of the available data and the type of study being conducted. The EB method is a typical weighting process between the predicted average crash frequency and the existing data, as a function of how well the SPF fits the original data used to develop the model (e.g. the better the data fits the model, the more weight that is given to the predicted average crash frequency).This method was not applied in this case study because there was insufficient data available; therefore the process to estimate $N_{expected.}$ is not presented here.

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[2] http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w129p1&2.pdf

Overall, key advantages of the HSM predictive method are:

- Regression-to-the-mean bias is addressed because the method concentrates on long term expected average crash frequency rather than short-term observed crash frequency.
- Reliance on availability of crash data for any one site is reduced by incorporating predictive relationships based on data from many similar sites.
- The SPF models in the HSM are based on the negative binomial distribution, which are better suited to modelling the high natural variability of crash data than traditional modelling techniques, which are based on the normal distribution.
- The predictive method provides a method of crash estimation for sites or facilities that have not been constructed or have not been in operation long enough to make an estimate based on observed crash data.

3. Case Study Analysis

The following section presents the results of the analysis.

3.1 Design Alternatives

Alternatives were developed at two different stages. Alternatives 1 through 5 were developed during the original environmental documentation, while Option 6 was developed by a citizen’s group and Option 7 was developed by members of the project’s advisory committee (MDT and City engineers and City officials) after the first project was completed.[3]

The project alternatives are categorised into either a three-lane or a five-lane designation as a function of the volume scenario applied to the analysis. In the three-lane scenario, Russell Street is generally a three-lane roadway in the study area in the regional travel demand model, and in the other, it is a five-lane roadway in the model. These two model runs produced two different sets of ADT volumes, which were used to analyse the respective alternatives.

Alternative 1, the No-Build scenario, was evaluated under both the three-lane and five-lane volume scenarios to perform a relative analysis. The three-lane alternatives (2, 3, and 6) generally have three-lane cross-sections south of Wyoming Street. The five-lane alternatives (4, 5-R, and 7) generally have five-lane cross sections for the length of the corridor.

Exhibit 6 illustrates the general roadway cross-section and intersection control planned under each alternative by major intersection and roadway segment. Exhibit 6 also shows that the scenarios differ in terms of their use of roundabouts and traffic signals. Alternative 4 is the only Build scenario to exclusively use traffic signals; it was recommended by the original environmental analysis.

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[3] These last two alternatives were referred to as “Options” based on a technicality of the environmental process. For the purposes of this paper, “alternatives” refers to all seven design alternatives, including the two “options.”

Exhibit 6: Design Alternatives

Segment/ Intersection	DEIS Alternatives						
	Alt 1[1]	Alt 2	Alt 3	Alt 4	Alt 5-R	Option 6	Option 7
W. Broadway	🚦	🚦	🚦	🚦	🚦	🚦	🚦
W. Broadway to Wyoming	┃╎┃ 2	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃
Wyoming	🛑	◎	◎	🚦	🚦	○	🚦
Wyoming to S. 3rd	┃╎┃	┃╎┃	┃╎┃	┃┃╎┃┃	┃┃╎┃┃	┃╎┃	┃┃╎┃┃
S. 3rd	🚦	◎	◎	🚦	◎	○	🚦
S. 3rd to S. 5th	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃╎┃	┃┃╎┃┃
S. 5th	🚦	◎	◎	🚦	◎	○	🚦
S. 5th to S. 6th	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃╎┃	┃╎┃
S 6th to S. 8th	┃┃	┃╎┃	┃╎┃	┃┃╎┃┃	┃┃╎┃┃	┃╎┃ 3	┃╎┃
S. 8th to S. 11th-Knowles	┃┃	┃┃	┃╎┃	┃┃╎┃┃	┃┃╎┃┃	┃┃	┃╎┃
S. 11th-Knowles	🛑	○	○	🛑	🛑	○	🛑
S. 11th- Knowles to S. 14th-Mount	┃┃ to ┃┃┃┃	┃┃ to ┃┃╎┃┃	┃┃ to ┃┃╎┃┃	┃┃╎┃┃	┃┃╎┃┃	┃╎┃	┃╎┃ to ┃┃╎┃┃
S. 14th-Mount	🚦	◎	◎	🚦	🚦	🚦	🚦

Symbol	Description	Symbol	Description
┃┃ 2 Lanes	This symbol represents one travel lane in each direction and no median.	🛑 TWSC	This symbol represents an unsignalised intersection with two-way, stop control.
┃┃┃┃ 4 Lanes	This symbol represents two travel lanes in each direction and no median.	🚦 Signal	This symbol represents an intersection with a traffic signal control.
┃╎┃ 2+ Lanes	This symbol represents one travel lane in each direction with a raised or painted median.	○ SL rbt	This symbol represents an intersection with a single lane roundabout.
┃┃╎┃┃ 4+ Lanes	This symbol represents two travel lanes in each direction with a raised or painted median.	◎ ML rbt	This symbol represents an intersection with a multilane roundabout.

[1] Alternative 1 has the same cross-section, lane configurations, and traffic control as existing conditions.
[2] The existing bridge is a two-lane bridge.
[3] In Option 6, two travel lanes are provided between 7th and 8th.

3.2 Applying the HSM

The methods from Chapter 12 of the HSM, described in Section 2, were applied to each of the design alternatives shown in Exhibit 6. The general steps involved in this are: 1) Data Collection, 2) Calculate Predicted Crashes, and 3) Evaluate Results.

3.2.1 Data Collection

Exhibit 7 below shows the general data collection needs for roadway segments and how the project team collected the data. Exhibit 8 shows the same for intersections. Much of this is standard data that needs to be collected for most traffic studies. The primary additional data that needed to be collected to satisfy the requirements of the formulas in the urban and suburban arterial predictive method were fixed object density and offset distance, driveway information, and information related to the presence of schools and alcohol sales establishments in the vicinity of signalised intersections. The project team collected data primarily through using field measurements, scaled aerials, Google Streetview, and concept plans.

Exhibit 7: Roadway Segment Data Collection

Item	**Units**	**How**
Segment Length	Miles (Kilometres)	Scaled Aerial
Through Lanes	Number	Field Visit, Concept Plans
Median	Type	Field Visit, Concept Plans
On-Street Parking	Type	Field Visit, Concept Plans
Fixed Object Density	Objects per Mile (Kilometre)	Scaled Aerial, Photos, Google Streetview
Average Offset of Fixed Objects	Feet	Scaled Aerial
Roadway Lighting	Presence/ Absence	Field Visit, Concept Plans
Speed Limit	mi/h (km/h)	Field Visit, Concept Plans
AADT Volumes	Vehicles per Day	Tube Counts, Regional Model
Number/Type of Driveways	Major or Minor; Industrial/ Institutional, Commercial, Residential, Other	Field Visit, Scaled Aerial

Exhibit 8: Intersection Data Collection

Item*	Units	How
Intersection Legs	Number	Field Visit, Concept Plans
Traffic Control	Signal or Stop (Roundabout is an AMF)	Field Visit, Concept Plans
LT Lanes	Number of Approaches	Field Visit, Concept Plans
LT Phasing	Number of Approaches	Field Visit, Concept Plans
RT Lanes	Number of Approaches	Field Visit, Concept Plans
RTOR Prohibited[1]	Number of Approaches	Field Visit, Concept Plans
Lighting	Presence/Absence	Field Visit, Concept Plans
Maximum Pedestrian Crossing Distance	Number of Lanes	Field Visit, Concept Plans
Bus Stops, Schools	Number within 300 meters of Signalised Intersection	Field Visit, Scaled Aerial, Google Streetview
AADT Volumes	Vehicles per Day	Turning Movement Counts, Regional Model
Pedestrian Activity	Number of Crossings per Day	Default from HSM

*Refers to right-hand drive in US

[1] RTOR = Right-turn on Red

For the purposes of this case study summary, Exhibit 9 is the data input summary for the Russell Street/3rd Street intersection. Overall, similar data was compiled and summarized into a spreadsheet for each different intersection and segment under each alternative under consideration.

Exhibit 9: Russell Street/3rd Street Data

Item	Value
Intersection Legs	4
Traffic Control	Signal
Approaches with LT Lanes	4
LT Phasing	Permissive/Protected Phasing on 2 Approaches
Approaches with RT Lanes	3
Approaches with RTOR Prohibited	0
Lighting	Present
Maximum Pedestrian Crossing Distance	5 Lanes
Bus Stops within 300 meters Alcohol Sales Establishments	7
Schools within 300 meters	0
Alcohol Sales Establishments within 300 meters	2
Red Light Camera	None
AADT (Russell Street)	33,910 vehicles/day
AADT (3rd Street)	25,790 vehicles/day
Pedestrian Crossings	240/day

3.2.2 Calculate Predicted Crashes

As explained in Section 2, the purpose of the predictive method is to estimate expected average crash frequency for a particular roadway segment or intersection. Thus, in a design or planning process, alternatives can also be compared from a safety performance perspective by predicting expected average crash frequency under Alternative 1 versus Alternative 2.

For the Russell Street project, the predicted average motor vehicle crash frequency was estimated for each intersection and each roadway segment under each alternative, and summed up the results to get a total predicted crash frequency for each alternative. The scope of the project did not include developing calibration factors, or applying the EB method, so the resulting total predicted crash frequencies were compared on a relative basis. Therefore, each build alternative was compared to the no-build alternative, assuming the respective volume scenario, to determine the relative change in predicted average crash frequency.

A general overview of the predictive method was provided in Section 2. Additional description of the method, including a schematic of the calculations and procedure are provided in Attachment "A."

3.2.3 Evaluate Results

Exhibit 10 shows the results of the analysis, as reported in terms relative to the respective no-build scenario (e.g., Alternative 3 is expected to have a crash frequency of 67% of the no-build assuming the 3-lane volume scenario).

Exhibit 10: HSM Analysis Results

	3-Lane Volume Scenario				**5-Lane Volume Scenario**			
	Alt 1	**Alt 2**	**Alt 3**	**Option 6**	**Alt 1**	**Alt 4**	**Alt 5-R**	**Option 7**
Percentage of Crashes Compared to No-Build Scenario (Alternative 1)	100%	67%	65%	85%	100%	70%	63%	73%

Exhibit 10 shows that on a relative basis, Alternatives 2, 3, and 5-R would yield the largest reduction in crash frequency as compared to the respective base prediction. This is because Alternatives 2, 3, and 5-R include options for roundabouts at major intersections. In the 3-lane volume scenario, Alternative 3 shows an additional reduction in expected crash frequency as compared to Alternative 2 because there are more medians in Alternative 3, especially in the southern portion of the corridor. Option 6 has the smallest decline in crash frequency as compared to other alternatives in large part because it generally did not include median restrictions.

The differences between three-lane alternatives can be seen in Exhibit 11, which show the relative predicted average crash frequencies by segment and intersection. For example, at 2nd Street, 0 to 50-percent of No-Build alternative crashes are expected to occur under Alternatives 2 and 3, but 99-percent or more are expected under Option 6.

Exhibit 11: Results for 3-Lane Alternatives

The proportions shown in Exhibit 11 are for motor vehicle crashes. There is no predictive method for pedestrian and bicyclist crashes at a roundabout. Consequently a fair comparison could not be made between alternatives in regards to these types of crashes.

3.2.4 Challenges

The methods in the HSM are new, as this is the first edition of the manual. Furthermore, this was one of the first applications of the HSM in the US. Consequently a handful of challenges were encountered along the way.

The first challenge the team encountered was that, as specified in the HSM, the models should be calibrated to local conditions to be effective. To date neither Missoula nor the State of Montana has developed calibration factors appropriate in this area. Consequently, our analysis could not be calibrated. To overcome this, the results of the analysis were reported on a relative basis to the no-build alternative, Alternative 1. Since we were utilizing two volume scenarios, we analysed Alternative 1 under both scenarios (i.e. 3-lane volumes, and 5-lane volumes) and then compared all of the three-lane alternatives to Alternative 1 with the three-lane volume scenario and in turn compared the five-lane alternatives to Alternative 1 with the five-lane volume scenario.

The other significant challenge was that the HSM does not contain predictive models for crashes involving bicyclists and pedestrians at roundabout intersections. Consequently, the team was not able to include bicyclist and pedestrian crashes in the results of the analysis. As was previously mentioned, there was a significant level of concern from Missoula residents regarding the safety of pedestrians and bicyclists along the corridor. To address this concern, the team utilised methods from the forthcoming 2010 *Highway Capacity*

Manual to analyse level-of-service for pedestrians and bicyclists, which measures the relative comfort of an urban street for these users of the roadway.

In general SPFs are not provided in the First Edition of the HSM for specific intersection types or unique geometric conditions. These challenges will be overcome slowly as more SPFs are developed by practitioners and future editions of the HSM are developed.

4. Conclusion and Discussion

4.1 Feedback from Montana Department of Transportation

Because this was one of the first project applications of the HSM, after the project was completed the Montana Department of Transportation staff was contacted to get their feedback. The primary benefit they saw in the analysis was it allowed them to better understand the trade-offs between different design features. It allowed them to see that the roadway design they had recommended in the initial analysis provided a significant expected crash reduction as compared to the no-build alternative, which gave them support for implementing it.

These results did not surprise the agency; however the results did allow the agency to better communicate to the general public and to elected officials the trade-offs among design concepts, and advantages of the recommended roadway in terms of crash reduction as compared to other alternatives or doing nothing. They did note that this ability was somewhat limited by having to report relative results for the two different volume scenarios being used. The lack of absolute numbers made it difficult to directly compare the five-lane alternatives to the three-lane alternatives.

4.2 Transferability of Predictive Method

While the predictive method was developed using US data, the calibration procedure incorporated into the method allows for its use in quantitative safety evaluations outside of the US. The calibration procedure adjusts the base prediction (developed by US studies) to local conditions by accounting for non-geometric characteristics that influence safety (e.g., weather, driver demographics, or land use).

In summary the calibration factor is a ratio of observed crash frequency to the predicted crash frequency for a particular facility. The subsequent factor is applied as the calibration factor for other similar facilities within a jurisdiction. In “International Crash Experience Comparisons Using Prediction Models” Turner et. al (2007) demonstrate that the HSM calibration procedure can be used as a procedure for transferring models across international boundaries; even from right-hand drive to left-hand drive countries. In this analysis Turner et al, recalibrated safety performance functions for two-lane rural highways from the United States to and from New Zealand and applied goodness of fit tests to test the validity of the model transfer. The researchers concluded that “it would not be unreasonable to transfer the models”. Thus, while it would be best to have locally derived models, it can be extrapolated that with proper calibration and testing, HSM models could be transferred across international boundaries.

Use of the calibration procedure outside of the US is best considered as a short-term means for conducting predictive crash evaluations. Development of Australia-specific SPFs or New Zealand-specific SPFs is expected to provide a more accurate estimate of crash frequency if the method is applied regularly and over a period of several years.

Where an SPF is desired for a facility type that is not included in the First Edition of the HSM, calibration is not an option. This is the case in Queensland where Transport and Main

Roads is developing SPFs to evaluate the crash benefits associated with implementing Variable Speed Limits on freeways in southeast Queensland.

4.3 Transferability of Crash Modification Factors

The CMFs provided in Part D of the HSM are based on empirical studies conducted in the US and therefore are reflective of US driver behaviour and roadway characteristics. While they can be applied outside of the US, local research is expected to provide more accurate factors, where available. For example, in Australia or New Zealand where Austroads publishes a listing of CRFs, the Austroads data is preferred. If a factor for a particular treatment (e.g., widening shoulders, installing a turn lane, etc.) has not been developed locally, but international research has identified a reduction factor the factor should be considered a “trend” and used with caution.

References

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Shane Turner, Bhagwant Persaud, Michael Chou, Craig Lyon, and Aaron Roozenburg, *International Crash Experience Comparisons Using Prediction Models*, Transportation Research Board, 2007

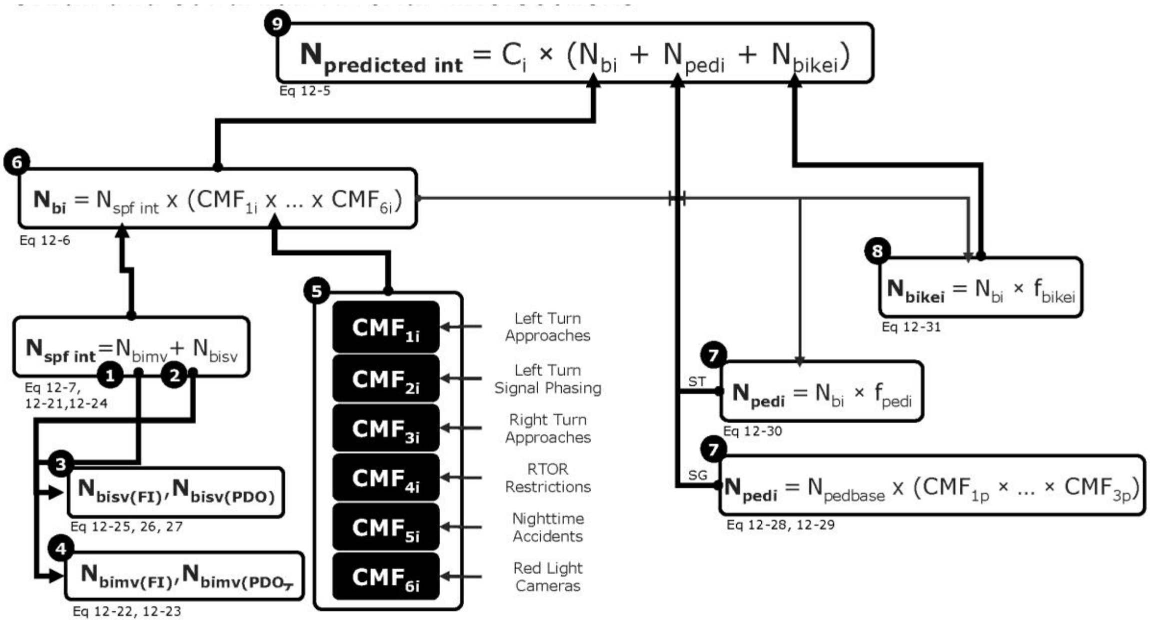
Attachments

A: Schematic of Predictive Method Procedure and Calculations

Attachment "A"

Exhibit A-1 shows a schematic of the calculations necessary to estimate predicted average crash frequency, $N_{predicted}$, at one site on the corridor. The following text provides a summary-level description of applying this process to the Russell Street/3rd Street intersection.

Exhibit A-1: HSM Chapter 12 Intersection Calculations



Steps 1 and 2 involve calculating the base estimate of motor vehicle crashes, $N_{spf\ int}$, based on SPFs found in the HSM. This estimate is the sum of two crash types: multiple vehicle crashes, N_{bimv}, and single vehicle crashes, N_{bisv}. These calculations are based on AADT volumes and coefficients from the HSM, based on the intersection type.

In Steps 3 and 4, the severity of crashes is calculated for both crash types. The HSM aggregates crashes into two levels of severity: fatality/injury (FI) and property damage only (PDO). These estimates are calculated from equations contained within the HSM based on the intersection type.

Following this, the base estimate of motor-vehicle crashes, $N_{spf\ int}$, is modified by the appropriate Crash Modification Factors (CMF) (step 5) to reflect variations from the base condition assumed by the SPF. For signalised intersections, such as Russell Street/3rd Street, there are CMFs to account for left-turn lanes, left-turn signal phasing, right-turn lanes, right-turn-on-red (RTOR) restrictions, intersection lighting, and red light cameras. This completes Step 6. N_{bi}, the estimate of motor vehicle crashes, carries into Step 9 at the top of Exhibit 9.

Pedestrian and bicycle crashes were not calculated separately in this analysis (Steps 7 and 8) because at this time there is no method for calculating those types of crashes at roundabouts.

The final step in calculating the predicted average crash frequency for motor vehicles would be to apply a calibration factor (C_i). As previously described, currently there are no calibration factors for Montana. Therefore a calibration factor was not applied, or in other words $C_i = 1.0$.