ATTACHMENT D

Consideration of Roadside Features in the Highway Safety Manual

Characterization of the Roadsides Edges

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INTRODUCTION

The roadside crash modification function, $CMF_{ROADSIDE}$ is assumed to have the following form:

$$CMF_{ROADSIDE} = \left[\beta_{SHLD} \cdot X_{SHLD} \cdot \prod_{j=1}^{m1} CMF_j\right] + \left[\beta_{UNSHLD} \cdot X_{UNSHLD} \cdot \prod_{k=1}^{m2} CMF_k\right]$$

Where:

X_{SHLD} =	Proportion of the segment edge where longitudinal barriers are installed where $0 \leq X_{SHLD} \leq 1$.
X_{UNSHLD} =	Proportion of the segment edge where there are unshielded ditches or roadside slopes and other unshielded fixed objects where $0 \leq X_{UNSHLD} \leq 1$.
Condition that:	$1 = X_{SHLD} + X_{UNSHLD}$ (100% of the segment edge is accounted for).
β_{SHLD} =	A regression coefficient associated with the segment edges where longitudinal barriers are installed.
β_{UNSHLD} =	A regression coefficient associated with the segment edges where there are unshielded ditches, roadside slopes or fixed objects like trees, tree lines, utility poles, bridge piers, etc.
CMF_j =	Crash modification factors associated with roadside feature j that modify the ROR crashes associated with longitudinal barriers. These CMFs would account for characteristics like barrier type, barrier terminals, barrier transitions, barrier offset, etc.
CMF_k =	Crash modification factors associated with roadside feature k that modify the ROR crashes associated with unshielded roadsides. These CMFs would account for characteristics like the presence of ditches, the density of narrow fixed objects, and other unshielded objects.

Recall CMF_j and CMF_k were set to unity to determine β_{SHLD} and β_{UNSHLD} for base conditions. The development of $CMF_{ROADSIDE}$ is presented in Attachment C16. This document describes the roadside conditions for the base segment edges where CMF_j and CMF_k, were set to unity.

The State of Ohio maintains a longitudinal barrier database but does not maintain a database of all roadside features. Data on roadside features was therefore collected for base segments to conduct this analysis. To minimize collection efforts and ensure accuracy across the study period, the base segments which did not change during the study period were considered in this effort. This resulted in 132 divided and 159 undivided base segments from 2002 to 2010.

Washington maintains the Roadside Features Inventory Program (RFIP) which is a dataset of roadside features cataloged by route, milepost, and year. The RFIP data was merged with the base segment edges used in the development of the SPF resulting in 26 divided and 5,840 undivided segments. These base segments were not consistent between 2002 and 2007. Unfortunately, it is unclear whether the roadside features varied from year to year or data collection practices varied. For example, a roadway segment which did not have a sign for three years then had a sign could indicate that the sign was a new installation or it could indicate that the sign was not flagged during previous data collection efforts in that area.

The following analysis examines the roadside hazards present along the right base segment edges of both divided and undivided highways in Ohio and Washington State. The mean densities of these hazards for each state and highway type are calculated and values are recommended for use in the development of CMF_j and CMF_k.

ROADSIDE HAZARDS

Upon identifying the segments, collecting the necessary data for Ohio, and merging the Ohio and Washington data with HSIS base segment edges, the roadside hazards were classified into three categories:

- Longitudinal Barriers,
- Narrow Fixed Objects (NFOs), and
- "Other" hazards.

Longitudinal barriers include all traffic barriers that are placed on the roadside to redirect encroaching vehicles and provide shielding from NFOs and other hazards. These barriers include rigid (e.g., concrete safety and F-shape barriers), semi-rigid (e.g., w-beam and thrie-beam guardrails), and flexible (e.g., cable) barriers.

NFOs are considered "point" hazards that occur on the roadside. These hazards have a single milepost value to describe their location in the datasets. A fixed object may vary in diameter or width, but a hazard was considered to be a NFO if the dimension along the roadside was 1.5 feet or less.

"Other" hazards are hazards that are considered to have a measurable length along the roadside with beginning and ending milepost values. Only hazards on the Primary Right Edge (PRE) and Opposing Right Edge (ORE) were considered. Recall the PRE and ORE encompasses both edges of an undivided highway, but only the outside edges of a divided highway. Unfortunately, the data available for medians was inconsistent. The lack of median hazard data is not believed to present a problem because the model already deciphers between the frequency of crashes on divided and undivided highway and the frequency of left and right edge crashes. This data will be used for adjust the crash severity, not frequency part of the model which should not be impacted by placement of the hazard on the roadside or median.

The following section describes the steps taken for each state to collect the roadside hazard data and merge the data with the HSIS database. A discussion on the characterization of the roadside characteristics for the base segment edges follows.

OHIO

Longitudinal Barriers

The Ohio Department of Transportation (ODOT) longitudinal barrier database is the result of the collection of data for internal purposes, which characterized barriers into three groups: Rigid, Semi-Rigid, and Flexible barriers. The specific barriers listed were "Guardrail", "Jersey Slope: Short", "Jersey Slope: Tall", "Nucor", "Single Slope", and "Other".

When characterizing the base segment roadside characteristics, the assumptions made in the development of $CMF_{ROADSIDE}$ must be kept in mind. When developing $CMF_{ROADSIDE}$, the amount of longitudinal barrier was considered, not the type. Therefore, when characterizing the roadside it is important to know the amount of longitudinal barriers. As such, the database was simplified to a single spreadsheet consisting of longitudinal barrier lengths and locations. This spreadsheet was then associated with the HSIS data to determine the portion of base segment edges which are shielded.

Narrow Fixed Objects and Other Hazards

The Ohio Department of Transportation (ODOT) has an online photolog database of a portion of their State highways. [OHIO01] This online photolog database was accessed supplement the longitudinal barrier data and record NFOs and "Other" objects within 50 feet of the travel way. The milepost locations and offset distances for NFO and Other objects that were not shielded by a longitudinal barrier were recorded for each edge of the study segments discussed above. Any object located behind another object that is closer to the road was not recorded. These objects are considered protected by the object that is closer to the road.

Offset values were estimated from the photologs. The distances were estimated from the edge of the travel way to the face of the object. Examples of NFOs recorded for Ohio segments include:

- Small Sign,
- Mailbox post,
- Single tree,
- Large shrub,
- Utility pole,
- Underground utility marker,
- Fire hydrant,
- Posts for large sign (see example in Figure 1), and
- Warning light assemblies and gates for RR crossing.

An example of "Posts for large sign" can be seen in Figure 1. In this scenario, both of the sign posts would be recorded, as well as the shortened utility pole just to the left side of it. The large tree just off to the right side of the picture would be recorded as well.

Figure 1. Example of "Posts for Large Sign" NFO in Ohio. [OHIO01]

Examples of "Other" objects recorded for Ohio segments include:

- Fence of any type,
- Building,
- Tree line,
- Rock outcropping,
- Water body,
- Boulder,
- Large sign at ground level (see example in Figure 2),
- Cabinet,
- Statue, and
- Silo.

An example of an “Other” object is shown in Figure 2. This large sign at ground level has length, which was measured along the road. Had this particular example been raised up on posts, the posts would have been recorded as a NFO instead of an “Other” object.

Figure 2. Example of an “Other” Object in Ohio. [OHIO01]

WASHINGTON STATE

The Roadside Features Inventory Program (RFIP) database is a database of roadside features (including hazards and barriers) collected from 2006-2011 using GPS technology. The RFIP database was created and populated using State Route Milepost (SRMP) values, instead of the Accumulated Route Milepost (ARM) values the HSIS database uses. HSIS base segments ARM values were converted to SRMP values to facilitate merging of the two databases.

Washington State publishes highway logs [WSDOT1] annually. These highway logs include information on the ARM and SRMP. These logs were used to generate equivalencies between the ARM And SRMP values and allowed the HSIS data and RFIP data to be merged. The RFIP features of interest were then added to the base segment edges using the State Route numbers and the SRMP. Unfortunately, the RFIP database did not include offset values for any of the hazards, so hazard offset values are limited to the data collected for Ohio.

Longitudinal Barriers

The following features were considered to be longitudinal barriers:

- Bridge Rail,
- Cable Barrier,
- Concrete Barrier,
- Guardrail,
- Impact Attenuator, and
- Special Use Barrier.

The RFIP data is stored in separate files. The files were merged into a single file and the duplicate and overlapping milepost values were removed. This was necessary because each feature was captured using GPS technology separately, even if the features were overlapped at the connection. As an example, when the crew captured a w-beam guardrail attached to a bridge rail, they would capture the beginning and ending mileposts for the w-beam, including the section overlapping to the concrete bridge rail. The crew would also record the starting and ending mileposts of the bridge rail. In order to capture the entire w-beam as well as the entire bridge rail, the area where these two features are connected to each other was captured twice.

As it was desired to know the proportion of the segment edge that is shielded and not a linear measurement of each type of shielding, all instances of overlapping mileposts were to be removed. Identification of the particular type of longitudinal barrier was not important, only if some type of longitudinal barrier was present or not. Visual Basic code within Microsoft Excel was used to accomplish this and create a single longitudinal barrier spreadsheet. The single new generalized longitudinal barrier dataset was then attached to the segments.

Narrow Fixed Objects (NFOs)

Each NFO was first considered against the longitudinal barrier database discussed above. NFOs that were located between the beginning and ending mileposts of a longitudinal barrier were removed because it is assumed they were located behind a longitudinal barrier and therefore shielded. The remaining non-shielded NFOs were then added to the base segment edges.

The RFIP hazards that the research team considered to be NFOs are as follows:

- Down Guy Anchor;
- Hydrant;
- Mailbox;
- Miscellaneous Fixed Object;
- Pedestal;
- Pipe End;
- Support – includes "Wood Sign Post", "Metal Sign Post", "Luminaire Pole or Base", "Utility Pole", and "Other";
- Tree; and
- Tree Group (please see discussion below).

All of these features were point objects – that is, they had only a single milepost for a location – except for the "Tree Group" hazard, which had beginning and ending milepost values.

Work by Hummer was used to convert the tree groups to individual trees. Hummer concluded "[a] group of trees was considered as one continuous object rather than a [sic] several point objects when there were eight or more trees within 150 ft." [HUMM86] There is a lot of variability when dealing with trees. Trees not only range in diameter, but also in placement, therefore, no single conversion will work in all instances. This approximation, however, is considered appropriate. Using the approximation (150 ft. = 8 trees), the Tree Group hazard was converted into single trees merged with the base segments.

"Other" Hazards

The RFIP hazards that the research team considered to be "Other" hazards are as follows:

- Cabinet,
- Culvert End,
- Down Guy,
- Fence,
- Guy Wire,
- Rock Outcropping, and
- Wall.

Both "Culvert End" and "Cabinet" hazards had only a single milepost location value, but these objects are believed to be too large to be considered "narrow" fixed objects. Since the diameters of these objects were not known, the upper-bound criteria of a "narrow" fixed object (1.5 feet) was added to the milepost to give the object an assumed length. The original milepost was then renamed the beginning milepost and the new value added to it was named the ending milepost.

In some instances, these objects occupied the same mile posts. Recall the offsets of these features are unknown. It appeared, therefore, that these objects occupy the same space. The "Other" hazards were combined into a single dataset to remove redundancies. As was done with the NFOs, the new consolidated "Other" dataset was then merged with the Longitudinal Barrier dataset to remove those hazards that were shielded before adding the " Other" hazards to the base segment edges.

SUMMARY

The unshielded NFOs and "Other" hazards as well as the longitudinal barriers were merged with the primary right edge and opposing right edge for each base segment in Washington and Ohio to represent the roadside characteristics of these edges. The NFOs were added as point objects while the "Other" hazards and longitudinal barrier hazards were added with lengths along the roadway. These roadside characteristics were then summarized for use in the development of CMF_j and CMF_k. The summarizing of the roadside characteristics are described in the next section.

CHARACTERIZATION OF THE ROADSIDE

The mean densities and offsets were calculated for divided and undivided primary right base segment edge and opposing right base segment edge, for each state and then combined values were derived.

LONGITUDINAL BARRIERS

When determining the mean proportion of roadside edge shielded by a longitudinal barrier, the total length of longitudinal barriers present on that edge in feet was divided by the length of the base segment edge in miles. All of these calculated proportions were then summed and divided by the total number of base segment edges to determine the mean proportion of longitudinal barrier in feet per mile of segment edge, as shown here:

$$Mean\ LB = \frac{\sum \frac{L_{LBi}}{L_{EDGEi}}}{\#\ of\ edges}$$

Where: L_{LBi} = Total length of longitudinal barriers located on edge *i* (feet),
L_{EDGEi} = Length of edge *i* (miles),
# of edges = Total number of primary right and opposing right base segment edges.
LB = proportion of roadside edge shielded by longitudinal barriers (feet/mile).

Offsets distances to hazards is not available in the RFIP data. The offset values collected for Ohio were measured from the edge of travelway to each object in feet. A mean offset distance was then calculated for each right edge of each base segment. The overall mean was then calculated for longitudinal barriers, NFOs and "Other" hazards using the following equation:

$$Mean\ Offset\ Distance = \frac{\sum Offset_i}{\#\ of\ edges}$$

Where: $Offset_i$ = Mean offset distance for edge *i* (feet),
# of edges = Total number of primary right and opposing right base segment edges.

The mean proportion of shielded edge and offset to the shielding are shown in Table 1.

Table 1. Mean Proportion of Shielded Edge and Offset to Longitudinal Barrier.

Highway Type	State	LB Proportion of Shielded Edge (ft/mile)	LB Offset (ft)	Total # Right Edges	Total Right Edge Miles
Undivided	OH	810	8.34	318	127.5
	WA	551		11,680	2,912.2
	Combined	558		11,998	3,039.7
Divided	OH	1,669	10.23	264	132.4
	WA	1,523		52	8.2
	Combined	1,645		316	140.6

NARROW FIXED OBJECTS (NFOS)

It was desired to learn the mean density of the NFOs for each base primary right edge and opposing right edge. The number of NFOs on a particular right edge was divided by the length (miles) of that edge. All of these values were then summed and divided by the total number of base right edges. The governing equation is shown below:

$$Mean\ NFO\ Density\ (\#/edge\ mile) = \frac{\sum \frac{\#NFO_i}{L_{EDGEi}}}{\#\ of\ edges}$$

Where: #NFOi = number of Narrow Fixed Objects located on edge i,
L_{EDGE} = length of edge i (miles),
# of edges = total number of primary right and opposing right base segment edges.

The mean offset distance was calculated using the same equation above that was used to calculate the offset distances of the longitudinal barriers. Again, the offset distances were collected for Ohio. No offset values were present in the RFIP database for Washington State. The mean NFO density and offsets are shown in Table 2.

Table 2. Mean NFO Density and Offsets.

Highway Type	State	NFO Density (#/mile)	NFO Offset (feet)	Total # Right Edges	Total Right Edge Miles
Undivided	OH	53	37.56	318	127.5
	WA	32		11,680	2,912.2
	Combined	33		11,998	3,039.7
Divided	OH	28	31.34	264	132.4
	WA	57		52	8.2
	Combined	33		316	140.6

OTHER HAZARDS

While the mean proportion of shielded roadside edges and the mean density of unshielded NFOs has been determined, there are hazards which do not fit in either of those two groups which also need to be characterized. The "other" hazards group is the third and last group of roadside hazards. This group includes all unshielded hazards not in the longitudinal barrier group or NFO group. Hazards in this group have a length. The total length of "Other" hazards (feet) present on each base segment edge i was divided by the length of the base segment edge i (miles) to determine the proportion of primary right and opposing right base segment edges where other hazards are present (i.e., feet/miles). These proportions were then summed and divided by the total number of base segment right edges to determine the mean proportion of the roadside edges where unshielded "Other" hazards are present as shown here:

$$Mean\ PO = \frac{\sum \frac{L_{OTHERi}}{L_{EDGEi}}}{\#\ of\ edges}$$

Where: L_{OTHERi} = total length of Other hazards located on that edge of that segment (feet),
L_{EDGEi} = length of that edge of that segment (miles),
# of edges = total number of primary right and opposing right base segment edges.
PO = Proportion of edge where "Other" hazards are present (feet/mile).

The mean offset distance for the PO was calculated as shown above for longitudinal barriers. As with the longitudinal barriers and NFOs, the offset distances were collected for Ohio and not available in the Washington RFIP dataset. The mean PO and offset value results are shown in Table 3.

Table 3. Mean Proportion and Offsets of "Other" Hazards.

Highway Type	State	PO (feet/ mile)	Offset (feet)	Total # Right Edges	Total Right Edge Miles
Undivided	OH	519	42.25	318	127.5
	WA	463		11,680	2,912.2
	Combined	465		11,998	3,039.7
Divided	OH	482	43.99	264	132.4
	WA	1,228		52	8.2
	Combined	605		316	140.6

SUMMARY

The Ohio online Pathweb photolog database was used to collect the longitudinal barrier, NFO, and "Other" hazard data presented for Ohio and used to characterized the Ohio base segment edges. Washington State provided the Roadside Features Inventory Program (RFIP) database, which was used to characterize the Washington base segment edges.
Safety Performance Functions (SPFs) have been developed individually for Ohio and Washington, but a combined model has been recommended for inclusion in the HSM. The roadside characteristics should therefore represent the combined model. The values discussed above are shown in Table 4 as a combined dataset. These data will be used to develop CMF_j and CMF_k.

Table 4. Mean Proportions, Densities, and Offsets for Roadside Hazards.

Highway Type	State	NFO Density (#/mile)	NFO Offset (feet)	PO (feet/ mile)	PO Offset (feet)	LB (feet/mil e)	LB Offset (feet)	Total # Right Edges	Total Right Edge Miles
Undivided	OH	53	37.56	519	42.25	810	8.34	318	127.5
	WA	32		463		551		11,680	2,912.2
	Combined	33		465		558		11,998	3,039.7
Divided	OH	28	31.34	482	43.99	1,669	10.23	264	132.4
	WA	57		1,228		1,523		52	8.2
	Combined	33		605		1,645		316	140.6

REFERENCES

HUMM86 "Safety Effects of Cross-Section Design for Two-Lane Roads – Data Base User's Guide", pg. 35, Federal Highway Administration, Office of Safety and Traffic Operations Research and Development, Washington, D.C. 20590, December, 1986.

OHIO01 ODOT Pathweb online photolog database: http://pathweb.pathwayservices.com/ohiopublic/, accessed 24 February, 2015.

WSDOT1 Washington State Department of Transportation State Highway Log Online Database: http://www.wsdot.wa.gov/mapsdata/roadway/statehighwaylog.htm, Accessed 24 February, 2015.