The appendices herein are supplemental to *NCHRP Research Report 972: Development of Safety Performance-Based Guidelines for the* Roadside Design Guide (NCHRP Project 15-65).

Appendix A: Roadside Risk Workbook

Appendix B: Derivations

Appendix C: Serious and Fatal Injury Crash Tables

Appendix D: Research Needs and Knowledge Gaps

APPENDIX A: ROADSIDE RISK WORKBOOK

A.1 INTRODUCTION

The following sections present, in a concise format, the tables, figures, charts, and nomographs needed for a performance-based risk assessment of roadside designs. The purpose of this document is not to provide all the background research for the risk assessment method but to simply present step-by-step instructions for performing the risk assessment and the necessary look-up tables.

A.2 PROCEDURE

The roadside risk assessment procedure is defined by the following two equations and the associated definitions provided below:

$$\mathrm{OUTCOME_S} = \sum_{j=1}^{N}\left[\mathrm{OUTCOME_j}\prod_{i=1}^{j-1}\mathrm{THR_i}\right] \qquad 1$$

$$\mathrm{OUTCOME_j} = \left[\frac{\mathrm{BEF_S}\cdot\mathrm{EAF_S}\cdot\mathrm{L_S}}{5280}\right]\cdot\left[\mathrm{P_{c_j}}\cdot\prod_{i=1}^{j-1}\mathrm{THR_i}\right]\cdot\left[\mathrm{P_{SEV_j}}\cdot(1-\mathrm{THR_j}\cdot\delta_j)\left(\frac{\mathrm{PSL_s^3}}{65^3}\right)\right] \qquad 2$$

$$\mathrm{OUTCOME_j} = \mathrm{ENCR_j}\ \mathrm{CRASH_j}\ \mathrm{SEV_j}$$

where:

$\mathrm{OUTCOME_S}$	=	The total number of crashes with the specified outcome on segment S involving all roadside features on the segment.
$\mathrm{OUTCOME_j}$	=	The number of crashes with the specified outcome involving feature j (e.g., the number of serious injury or fatal crashes involving impacts with a tree) per edge mile per year.
j	=	Feature number from 1 to N where N is the total number of features evaluated on the segment.
$\mathrm{BEF_S}$	=	The expected annual number of encroachments expected on a segment in edge encroachments/mi/yr assuming base conditions as a function of traffic volume (AADT).
$\mathrm{EAF_S}$	=	Highway and traffic characteristic encroachment adjustment factors for the highway segment of interest, S.
$\mathrm{L_S}$	=	Segment length in feet.
$\mathrm{P_{cj}}$	=	The conditional probability of a vehicle interacting with a roadside feature given an encroachment occurs. The length ratios are the probability of leaving the roadway in the given proportion of the roadway under the assumption that encroachments are equally likely anywhere on the segment. The form of $\mathrm{P_{cj}}$ depends on the type of object as shown below:

Continuous Features (e.g., guardrails, median barriers, terrain, etc.)

$$P_{cj} = \left[\frac{L_j}{L_S}\right] \cdot P_y(W_{Fj})$$

Discreet Features (e.g., trees, poles, bridge piers, water bodies, etc.)

$$P_{cj} = \left[\frac{L_j}{L_S}\right] \cdot P_y(W_{Fj}) + \left[\frac{L_{TMax}}{L_S}\right]\left[P_x(L_{TMax})(P_y(W_{Fj}) - P_y(W_{Bj}))\right]$$

P_{SEVj} = The conditional probability of observing the severity of interest given that there is an interaction with roadside feature j.

THR_j = The conditional probability of passing through, over, or under feature j given the vehicle interacts with feature j.

δ_j = 1 if only interactions with the feature that do not pass through the feature lead to an increase in harm (e.g., terrain).

= 0 if all interactions with the feature lead to an increase in harm regardless of whether the feature is passed through (e.g., longitudinal barriers).

PSL_s = Posted speed limit on the segment in mi/hr.

L_j = The effective length of an individual feature j along the segment in feet.

Continuous Features (e.g., longitudinal barriers, terrain, medians, etc)
The length of a continuous feature measured parallel to the roadway in feet where $L_j \leq L_S$.

Single Discreet Features
For single discreet features such as trees or utility poles, this is equal to the dimension of the feature parallel to the road or the diameter measured in feet. Add $W_V \sin \theta_{85}$ to the length or diameter for fixed objects.

Multiple Discreet Features
For features like a line of poles or series of bridge piers, the effective length is the length in feet from the upstream traffic face of the first feature to the downstream face of the last feature plus $W_V \sin \theta_{85}$ as long as the spacing between features is less than $W_B/\tan \theta_{15}$ and $L_j \leq L_S$. If the spacing between features is less than $\frac{W_{B\,FO}+W_V \cos \theta_{15}}{\tan \theta_{15}}$ then treat multiple features as single isolated features.

$P_y(Y_j)$ = Cumulative probability density function of the lateral extent of encroachment when lateral offset y = Y.

$P_x(X_j)$ = Sum of the cumulative probability density function of the maximum longitudinal extent of encroachment.

W_{Bj} = The distance in feet from the edge of the traveled way measured laterally to the farthest point of feature j plus $W_V \cos(\theta_{15})$ for discreet features.

W_{Fj} = The distance in feet from the edge of the traveled way to the closest face (i.e., traffic side) of feature j. For foreslopes, the distance is measured to the bottom of the foreslope.

W_V = Typical passenger vehicle width in feet (e.g., 6.5 ft).

L_{TMax} = The length in feet of the longest trajectory in the data base of trajectories used to calculate $P_x(X_j)$ and $P_y(Y_j)$ (i.e., 1,000 ft (Gabler 2022 Expected-a)).

θ_{15} = The 15th percentile encroachment angle in degrees (e.g., 5 degrees (Gabler 2022 Expected-a)).

θ_{85} = The 85th percentile encroachment angle in degrees (e.g., 22 degrees (Gabler 2022 Expected-a)).

The roadside risk assessment procedure is outlined in Table 53. The objective of the procedures is to calculate the expected average annual frequency of serious injury and fatal crashes (KA ROR crashes) on a roadway segment edge for a variety of alternatives and compare the results to the safety performance goal (i.e., $OUTCOME_{GOAL}$). The procedure requires information about the highway type and traffic as well as the characteristics of each alternative.

The procedure is most easily implemented using the form shown in Table 54. Table 55 shows the same form with instructions about where to find the necessary values for the computations.

Table 53. Risk-based safety performance design procedure.

Find: The expected average annual frequency of serious injury and fatal crashes on a roadway segment edge for the existing conditions and proposed alternatives (i.e., $OUTCOME_S$) and compare them to the safety performance goal (i.e., $OUTCOME_{GOAL}$).

Given: The traffic and site characteristics for each edge of the roadway where a vehicle might encroach:

1) Segment the roadway of interest into homogeneous sections and determine each segment length (L_S) where S is the segment number. A homogeneous section is one where all the roadway characteristics (e.g., lane width, curvature, grade, etc.) are the same.
2) Determine the total number of roadside or median features (N) as well as their location, lateral offset, size and type.
3) Calculate expected average annual frequency of serious injury and fatal collisions for feature j ($OUTCOME_j$) on each segment edge.
   a. Find the total base encroachment frequency (BEF_S) given the highway type (i.e., divided or undivided) and AADT from Table 56.
   b. Find the segment encroachment adjustment factors (EAF_S) from Table 56. Note that for horizontal curves and grade the adjustment will be different for each direction of travel.
   c. Find the conditional probability of a vehicle striking feature j based on its type (i.e., continuous or discreet) and lateral offset from the travelled way (i.e., $P_y(W_{Fj})$ and $P_y(W_{Bj})$) from Table 58.
   <u>Continuous Features</u> (e.g., guardrails, median barriers, terrain, etc.)
   $$P_{cj} = \left[\frac{L_j}{L_S}\right] \cdot P_y(W_{Fj})$$
   <u>Discreet Features</u> (e.g., trees, poles, bridge piers, water bodies, etc.)
   $$P_{cj} = \left[\frac{L_j}{L_S}\right] \cdot P_{y(W_{Fj})} + \left[\frac{1{,}000}{L_S}\right]\left[0.3508 \cdot (P_y(W_{Fj}) - P_y\,(W_{Bj}))\right]$$
   d. Find the conditional probability of the outcome of interest (P_{SEVj}, e.g., a KA crash) given an interaction with feature j from Table 62.
   e. Find the proportion of interactions that pass through feature j from Table 59 through Table 61 (THR_j).
   f. Let:
      $\delta_j = 1$ For all terrain features and other geometric features where the harm is only associated with those vehicles that do not make it through the feature.
      $\delta_j = 0$ For all longitudinal barriers, breakaway devices, crash cushions and guardrail terminals where the harm will be the same whether the vehicle passes through it or not.
   g. Calculate the feature risk from:
   $$OUTCOME_j = \left[\frac{BEF_S \cdot EAF_S \cdot L_S}{5280}\right] \cdot \left[P_{cj} \cdot \prod_{i=1}^{j-1} THR_i\right] \cdot \left[P_{SEV_j} \cdot (1 - THR_j \cdot \delta_j)\left(\frac{PSL_s^3}{65^3}\right)\right]$$
   IF j < N,
   THEN Go to the next feature by returning to Step 3a with j = j+1
   ELSE Continue to Step 4.
4) Calculate the risk for the entire segment from: $OUTCOME_S = \sum_{j=1}^{N} OUTCOME_j$
5) IF $OUTCOME_S \leq OUTCOME_{GOAL}$
   THEN The safety performance of the evaluated design for segment S meets the safety performance goal.

Table 54. Blank roadside risk assessment worksheet.

Worksheet A - General Information

Title			Roadway	Risk Goal:	
Analyst			Jurisdiction	Analysis Year	
Agency			MilePost	Analysis Date	
Input Data	**Value**	**Input Data**	**Value**	**Input Data**	**Base Condition**	**Value**
Outcome of Interest		Ditch Type		Grade (%)	Flat	
Highway Type		Foreslope 1 (H:V)		Horizontal Curve Radius (ft)	Tangent	Tangent
Functional Class		Foreslope 2 (H:V)		Degree of Curvature (deg/100 ft)	0	
Two-Way Total AADT (veh./day)		Backslope 1 (H:V)		Encroachment Side	R	
Percent Trucks (%)		Backslope 2 (H:V)		Total Number of Lanes	1	
Segment Length (miles)		Right Shoulder Width (ft)		Post Speed Limit (mi/hr)	65	
		Left Shoulder Width (ft)		Major Access Points (pts/mi)	0	
				Lane width (ft)	12	

Worksheet B - Encroachment Adjustment Factors

Horizontal	Grade	Side	Number of	Posted Speed	Access	
EAF_{HC}	EAF_{G}	EAF_{LR}	EAF_{LN}	EAF_{PSL}	EAF_{AC}	EAF_{S}

Worksheet C - Interactions with Roadside Features

j	$Feature_j$	$W_{F\,j}$	$W_{B\,j}$	L_j	BEF_S	EAF_S	$P_{c\,j}$	$P_{SEV\,j}$	δ_j	THR_j	$OUTCOME_j$
0	Cross Edge into Median or Roadside	0	0	-				0.0000	1	1.0000	

Total Outcomes/yr:

Table 55. Roadside risk assessment worksheet with instructions .

Worksheet A - General Information

Title Analyst Agency	Information provided by designer	Roadway Jurisdiction MilePost	Information provided by designer	Risk Goal: Analysis Year Analysis Date	Information Provided by designer

Input Data	Value	Input Data	Value	Input Data	Base Condition	Value
Outcome of Interest	Determine from project plans and specification	Ditch Type	Determine from project plans and specification	Grade (%)	Flat	Determine from project plans and specification
Highway Type		Foreslope 1 (H:V)		Horizontal Curve Radius (ft)	Tangent	
Functional Class		Foreslope 2 (H:V)		Degree of Curvature (deg/100 ft)	0	
Two-Way Total AADT (veh./day)		Backslope 1 (H:V)		Encroachment Side	R	
Percent Trucks (%)		Backslope 2 (H:V)		Total Number of Lanes	1	
Segment Length (miles)		Right Shoulder Width (ft)		Post Speed Limit (mi/hr)	65	
		Left Shoulder Width (ft)		Major Access Points (pts/mi)	0	
				Lane width (ft)	12	

Worksheet B - Encroachment Adjustment Factors

Horizontal	Grade	Side	Number of	Posted Speed	Access	
EAF_{HC}	EAF_{G}	EAF_{LR}	EAF_{LN}	EAF_{PSL}	EAF_{AC}	EAF_{S}
Determine from Table 57 based on values in Worksheet A						Calculate row

Worksheet C - Interactions with Roadside Features

j	Feature $_j$	$W_{F\,j}$	$W_{B\,j}$	L_j	BEF_S	EAF_S	$P_{c\,j}$	$P_{SEV\,j}$	δ_j	THR_j	$OUTCOME_j$
0	Determine from project plans and specification				Look up in Table 56 based on AADT, highway type, and land use	Enter value calculated in Worksheet B	See Table 58 and use equation matching feature j	Look up value in Table 62 for each feature j		Look up value for feature j in Tables 59 through 61	Calculate row
										Total Outcomes/yr:	Sum column

A.3 LOOK UP TABLES

All the lookup tables needed to perform the risk assessment calculations are presented in this section. The look up tables have already been referenced in Table 53 and Table 55.

Table 56. Base encroachment frequency,

Undivided Two Lane (PR Encr/mi/yr)	For AADT < 5,000 vehicles/day: $BEF_{UNDIV\ PR} = \left[\frac{AADT}{4{,}343}\right] \cdot e^{\left[0.4997-\left(\frac{0.2092 \cdot AADT}{1{,}000}\right)\right]}$	
	For AADT ≥ 5,000 vehicles/day $BEF_{UNDIV\ PR}$ = 1.1911 PR encr/mi/yr	1
Divided Four Lane (PR Encr/mi/yr)	For AADT < 24,000 vehicles/day $BEF_{DIV\ PR} = \left[\frac{AADT}{3{,}650}\right] \cdot e^{\left[-0.2104-\frac{0.0413 \cdot AADT}{1{,}000}\right]}$	
	For AADT ≥ 24,000 vehicles/day $BEF_{DIV\ PR}$ = 1.9773 PR encr/mi/yr	2

2-Way AADT (vehicles/day)	**2-Lane Undivided** (PR encr/mi/yr)	**4-Lane Divided** (PR encr/mi/yr)	**2-Way AADT** (vehicles/day)	**2-Lane Undivided** (PR encr/mi/yr)	**4-Lane Divided** (PR encr/mi/yr)
100	0.0664	0.0221	9,000	1.1911	1.3777
200	0.1301	0.0440	10,000	1.1911	1.4688
300	0.1910	0.0658	11,000	1.1911	1.5503
400	0.2494	0.0873	12,000	1.1911	1.6228
500	0.3054	0.1087	13,000	1.1911	1.6870
600	0.3588	0.1299	14,000	1.1911	1.7432
700	0.4100	0.1510	15,000	1.1911	1.7922
800	0.4588	0.1718	16,000	1.1911	1.8343
900	0.5055	0.1925	17,000	1.1911	1.8701
1,000	0.5501	0.2130	18,000	1.1911	1.9000
2,000	0.8924	0.4088	19,000	1.1911	1.9244
3,000	1.0860	0.5884	20,000	1.1911	1.9437
4,000	1.1746	0.7527	21,000	1.1911	1.9583
5,000	1.1911	0.9029	22,000	1.1911	1.9686
6,000	1.1911	1.0396	23,000	1.1911	1.9748
7,000	1.1911	1.1638	24,000	1.1911	1.9773
8,000	1.1911	1.2762	>25,000	1.1911	1.9773

Table 57. Encroachment adjustment factors (EAF_j).

Grade: EAF_G					Horizontal Curve Radius: EAF_{HC}					Encroachment Side: EAF_{LR}			
	Rural		Urban			Rural		Urban					
Percent Grade (%)	Undivided	Divided	Undivided	Divided	Degree of Curvature	Undivided	Divided	Undivided	Divided	Encroachment Side	AADT	Rural Divided	Urban Divided
-10	1.15	1.52	0.84	0.37	-25	3.11	1.00	2.07	1.00	L	1,000	0.48	0.73
-9	1.12	1.43	0.86	0.42	-20	2.13	1.00	1.63	1.00	L	5,000	0.67	0.85
-8	1.10	1.35	0.88	0.49	-15	1.46	1.00	1.28	1.00	L	10,000	0.77	0.90
-7	1.08	1.27	0.91	0.56	-10	1.00	1.00	1.00	1.00	L	20,000	0.89	0.96
-6	1.06	1.20	0.93	0.65	-5	1.00	1.00	1.00	1.00	L	30,000	0.97	0.99
-5	1.04	1.13	0.95	0.75	0	1.00	1.00	1.00	1.00	L	40,000	1.03	1.02
-4	1.02	1.06	0.98	0.87	5	1.00	1.00	1.00	1.00	L	50,000	1.07	1.04
-3	1.00	1.00	1.00	1.00	10	1.00	1.00	1.00	1.00	L	60,000	1.11	1.06
0	1.00	1.00	1.00	1.00	15	1.11	1.00	1.03	1.00	L	67,000	1.14	1.07
3	1.00	1.00	1.00	1.00	20	1.23	1.00	1.07	1.00	L	80,000	1.14	1.08
4	1.01	1.05	0.97	0.85	25	1.36	1.00	1.10	1.00	L	90,000	1.14	1.10
5	1.02	1.10	0.94	0.72						L	100,000	1.14	1.11
6	1.03	1.16	0.91	0.61						R	All	1.00	1.00
7	1.04	1.22	0.89	0.51									
8	1.05	1.28	0.86	0.43									
9	1.06	1.34	0.83	0.37									
10	1.08	1.41	0.81	0.31									

Total Lanes: EAF_{LN}					Access Density: EAF_{AD}					Posted Speed Limit: EAF_{PSL}			
	Rural		Urban			Rural		Urban				Rural	Urban
Total Number of Lanes	Undivided	Divided	Undivided	Divided	Major Access Points/mi	Undivided	Divided	Undivided	Divided	Post Speed Limit (mi/hr)	All Undivided	Divided	Divided
≤ 2	1.00	0.83	1.00	0.89	0	1.00	1.00	1.00	1.00	≤ 55	1.00	1.16	1.18
4	0.91	1.00	1.11	1.00	0.5	1.67	2.51	1.00	1.00	60	1.00	1.08	1.09
6	-	1.20	-	1.13	1.0	2.80	6.31	1.00	1.00	65	1.00	1.00	1.00
≥ 8	-	1.45	-	1.27	≥1.5	4.68	6.31	1.00	1.00	≥ 70	1.00	0.93	0.92

$$EAF_S = \prod_{i=1}^{N} EAF_i = EAF_{HC} \cdot EAF_G \cdot EAF_{LR} \cdot EAF_{LN} \cdot EAF_{PSL} \cdot EAF_{AD}$$

Table 58. Probability of encroachment reaching a feature at lateral offset Y (Py(Yj)).

Lateral Extent (ft)	**$P_y(Y_j)$**	**Lateral Extent** (ft)	**$P_y(Y_j)$**	**Lateral Extent** (ft)	**$P_y(Y_j)$**
1	0.9761	13	0.7376	45	0.4063
2	0.9431	14	0.7277	50	0.3622
3	0.9090	15	0.7191	55	0.3254
4	0.8844	16	0.7105	60	0.2887
5	0.8650	17	0.7008	65	0.2531
6	0.8394	18	0.6910	70	0.2307
7	0.8267	19	0.6825	75	0.2115
8	0.8089	20	0.6741	80	0.1918
9	0.7912	25	0.6238	85	0.1752
10	0.7737	30	0.5699	90	0.1624
11	0.7612	35	0.5082	95	0.1515
12	0.7488	40	0.4603	100	0.1416

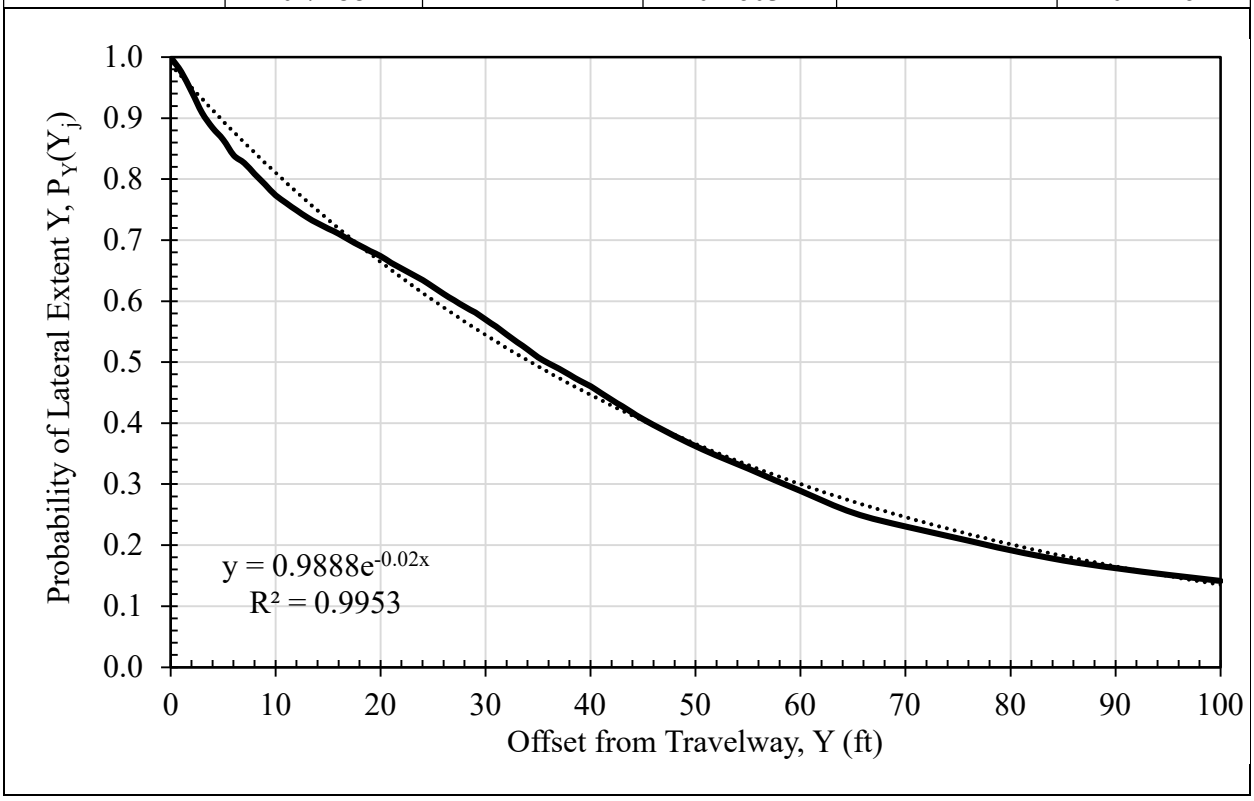

Table 59. Encroachments passing through, over or under barriers (THR_{BAR}) as a function of percent trucks. (Carrigan 2020)

		Percent Trucks (%)							
Test Level	**Coefficient A**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**50**
2	1.00	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.50
3	1.00	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.50
4	0.75	0.00	0.04	0.08	0.11	0.15	0.19	0.23	0.38
5	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$$\mathrm{THR_{BAR}} = \left[\frac{\mathrm{A} \cdot \mathrm{PT}}{100}\right]$$

Table 60. Encroachments passing all the way through a foreslope ($THR_{FORESLOPE}$).

Lateral Extent (ft)	**$THR_{FORESLOPE}$**					
	-12:1 or flatter	-10:1	-6:1	-4:1	-3:1	-2:1 or steeper
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
10	1.0000	1.0000	1.0000	1.0000	1.0000	0.9995
15	0.9996	0.9992	0.9993	0.9998	0.9997	0.9985
20	0.9981	0.9963	0.9962	0.9957	0.9966	0.9948
25	0.9961	0.9921	0.9911	0.9885	0.9887	0.9835
30	0.9938	0.9876	0.9851	0.9811	0.9782	0.9659
35	0.9902	0.9804	0.9784	0.9712	0.9643	0.9356
40	0.9877	0.9755	0.9731	0.9640	0.9516	0.9092
45	0.9843	0.9687	0.9639	0.9557	0.9381	0.8813
50	0.9819	0.9638	0.9567	0.9446	0.9252	0.8577
55	0.9790	0.9579	0.9507	0.9382	0.9139	0.8320
60	0.9772	0.9543	0.9451	0.9298	0.9018	0.8073
65	0.9743	0.9487	0.9384	0.9181	0.8852	0.7832
70	0.9714	0.9428	0.9330	0.9113	0.8757	0.7670
75	0.9708	0.9416	0.9296	0.9058	0.8638	0.7514
80	0.9697	0.9393	0.9264	0.8976	0.8550	0.7392
85	0.9670	0.9340	0.9227	0.8903	0.8453	0.7267
90	0.9654	0.9307	0.9168	0.8846	0.8377	0.7186
95	0.9648	0.9295	0.9139	0.8805	0.8323	0.7068
100	0.9633	0.9266	0.9104	0.8756	0.8275	0.7001

Table 61. Proportion of vehicles passing across the opposing lanes without striking an opposing vehicle given that the vehicle enters the opposing lanes (THR_{EOL}).

AADT	THR_{EOL}	AADT	THR_{EOL}	AADT	THR_{EOL}	AADT	THR_{EOL}
1,000	0.9302	13,000	0.8797	25,000	0.8006	37,000	0.6878
2,000	0.9269	14,000	0.8744	26,000	0.7925	38,000	0.6770
3,000	0.9234	15,000	0.8688	27,000	0.7841	39,000	0.6660
4,000	0.9198	16,000	0.8629	28,000	0.7756	40,000	0.6548
5,000	0.9161	17,000	0.8569	29,000	0.7667	41,000	0.6434
6,000	0.9121	18,000	0.8507	30,000	0.7577	42,000	0.6318
7,000	0.9080	19,000	0.8442	31,000	0.7484	43,000	0.6201
8,000	0.9038	20,000	0.8375	32,000	0.7389	44,000	0.6083
9,000	0.8993	21,000	0.8306	33,000	0.7291	45,000	0.5963
10,000	0.8947	22,000	0.8235	34,000	0.7191	>46,000	0.6000
11,000	0.8899	23,000	0.8161	35,000	0.7089		
12,000	0.8849	24,000	0.8085	36,000	0.6985		

Table 62. Outcomes for selected roadside and median features ($P_{SEV}\,j$).

Feature	K_{65}	KA_{65}	KAB_{65}	$KABC_{65}$	δ	Ref.
Longitudinal Barriers						
Cable Barrier	0.0009	0.0050	0.0297	0.0849	0	
Strong-Post W-Beam Barrier	0.0015	0.0094	0.0422	0.0977	0	(Carrigan 2020)
Weak-Post W-Beam Barrier	0.0006	0.0091	0.0321	0.1187	0	
Closed Faced Concrete Barriers	0.0021	0.0159	0.0810	0.1667	0	
Guardrail Terminals	RN	0.0500	RN	RN	0	(Ray 2018a)
Crash Cushions	RN	RN	RN	RN	0	
Terrain Features					1	
Foreslope Rollover	0.0142	0.0589	0.3138	0.4836	1	(Carrigan 2020)
Backslope Rollover	0.0142	0.0589	0.3138	0.4836	1	
Ditch Bottom Rollover	0.0142	0.0589	0.3138	0.4836	1	
Fixed Objects						
Trees and Utility Poles	0.0142	0.0589	0.3138	0.4836	0	(Carrigan 2020)
Bridge Piers	0.0278	0.0656	0.1729	0.2444	0	(Ray 2018b)
Other Users						
Crash in Opposing Lanes	0.0098	0.0451	0.1290	0.1938	1	(Carrigan 2020)
Crash in Work Zone	RN	RN	RN	RN	1	
Crash with Pedestrian/Cyclist	RN	RN	RN	RN	1	
Enter the following from above:					1	
Waterbody	0.0049	0.0343	0.1421	0.2254	1	(Carrigan 2020)
Minor Transportation Facility	RN	RN	RN	RN	1	
Major Transportation Facility	RN	RN	RN	RN	1	
Low Risk Environment	RN	0.0589	RN	RN	1	(Ray 2014b)
Medium Risk Environment	RN	0.4737	RN	RN	1	(Ray 2014b)
High Risk Environment	RN	1.0000	RN	RN	1	(Ray 2014b)

A.4 EXAMPLE

The following example will help to illustrate how the roadside risk assessment procedure is used to evaluate the decision of whether or not to install a cable median barrier. Equation 2, the governing equation, is shown below for convenience. Equations 1 and 2 and the required input data for the example problem are summarized by the forms shown in Table 63 through Table 65. The entries shown in the red hand-written font in Table 63 through Table 65 represent information that the designer would supply. The values entered in the green hand-written font would be looked up by the designer in the tables listed. The blue font represents values that must be calculated either by the designer or by a self-calculating worksheet or computer program.

$$\mathrm{OUTCOME_j} = \left[\frac{\mathrm{BEF_S} \cdot \mathrm{EAF_S} \cdot \mathrm{L_S}}{5280}\right] \cdot \left[\mathrm{P_{c_j}} \cdot \prod_{i=1}^{j-1} \mathrm{THR_i}\right] \cdot \left[\mathrm{P_{SEV_j}} \cdot (1 - \mathrm{THR_j} \cdot \delta_j)\left(\frac{\mathrm{PSL_s^3}}{65^3}\right)\right]$$

The layout for this example is shown in Figure 46. Example site layout and the user-supplied input information is shown in the top portions of Table 63 through Table 65. This example is a rural four-lane divided highway with a depressed, 60-ft wide median and a high-tension cable median barrier located 6-ft from the northbound lanes (primary direction).

The two-way total AADT at this location for the design year being evaluated is 36,000 vehicles/day including 5 percent trucks (PT). The posted speed limit is 70 mi/hr and the road is on a straight tangent section with a negative 5 percent grade in the northbound direction (primary direction). The roadway cross-section, shown in Figure 47, features a -4:1 slope with a -12:1 ditch bottom. In this example, the user wishes to compare a cable median barrier alternative with a no median barrier alternative, so the focus is on left edge encroachments from each direction only. Additional calculations would be required to determine the risk for right edge encroachments.

In Table 63 through Table 65, Worksheet A (i.e., the top of the form) contains basic identifying information that is generally not used in the analysis. The one exception is that a risk goal can be included at the upper right. A value of 0.0325 KA ROR crashes/edge-mi/yr is recommended as the default but the engineer can change this value to any suitable value for the highway agency. Worksheet B – Encroachment Adjustment Factors (i.e., the upper middle part of the form) is completed by looking up values in Table 57 based on the specific roadway geometrics and features. The product of all the values is calculated as:

$$\mathrm{EAF_S} = \prod_{i=1}^{N} \mathrm{EAF_i} = \mathrm{EAF_{HC}} \cdot \mathrm{EAF_G} \cdot \mathrm{EAF_{LR}} \cdot \mathrm{EAF_{LN}} \cdot \mathrm{EAF_{PSL}} \cdot \mathrm{EAF_{AD}}$$

and entered into the cell at the far-right side.

The values in Worksheet C - Interactions with Roadside Features are selected from a variety of tables as discussed below and as listed in Table 55. The lateral offset distances to the face ($W_{F\,j}$) and back ($W_{B\,j}$) and the length (L_j) of each feature along the road are taken from the plans or specifications for the alternative being analyzed. The value for BEF_S is found in Table 56 based on the AADT (36,000) listed in Worksheet A, in this case 1.9773. The value calculated in Worksheet B for the EAF_S is entered into the appropriate column in Worksheet C. The probability of a collision given an encroachment is found from one of the following:

<u>Continuous Features</u> (e.g., guardrails, median barriers, terrain, etc.)

$$P_{cj} = \left[\frac{L_j}{L_S}\right] \cdot P_y(W_{Fj})$$

<u>Discreet Features</u> (e.g., trees, poles, bridge piers, water bodies, etc.)

$$P_{cj} = \left[\frac{L_j}{L_S}\right] \cdot P_y(W_{Fj}) + \left[\frac{1{,}000}{L_S}\right]\left[0.3508 \cdot (P_y(W_{Fj}) - P_y\,(W_{Bj}))\right]$$

In this example, all the features are continuous features so the probability of a lateral extent for each offset ($P_Y(W_{F\,j})$) is found from Table 58 and entered into the appropriate cell in Worksheet C. The crash severity for each type of feature ($P_{SEV\,j}$) is found in Table 62 based on the type of feature list at the left side of Worksheet C. THR_j is determined separately for each feature of interest; for hardware use Table 59, and for foreslopes use Table 60. Values for $THR_{BACKSLOPE}$ do not exist yet so for the sake of the example, foreslope values are used (i.e., the probability of rolling over on a particular foreslope is the same as the backslope).

As shown in Table 63, with no median barrier present 0.0103 KA crashes/mi/yr could be expected from the left edge of the primary direction of travel. The opposing direction is symmetric except the grade would be positive 5 percent changing the EAF_G value from 1.13 to 1.10 and the resulting outcome frequency to 0.0101 KA crashes/mi/yr on the opposing left edge. Adding the KA crashes for both directions results in 0.0204 KA crashes/mi/yr combined. Just over 94 percent of the KA crashes are expected to be cross-median crashes and the remaining 6 percent are rollovers on either the fore- or backslopes.

As shown in Table 64 and Table 65, when a high-tension median barrier is installed on the northbound side, the total number of KA crashes increases slightly to 0.0110 (Table 64) in the primary direction and 0.0051 in the opposing directing (Table 65) for a total of 0.0161 KA crashes/yr, a 21 percent reduction in KA crashes/mi/yr. Cross-median crashes account for 6 precent of the KA crashes/mi/yr, median barrier crashes 90 percent, and terrain related rollover account for the remaining 4 percent. Adding the median barrier reduced the cross-median KA crashes from 0.0192 to 0.0010 KA crashes/mi/yr, a reduction of almost 88 percent. The median barrier was, therefore, highly effective in reducing the number of cross-median KA crashes. The median barrier alternative also reduced the terrain related rollover in the primary direction since more vehicles were kept off the sloping terrain. The relative risk of the median barrier alternative to the no median barrier alternative was 0.0161/0.0204 = 0.79. The median barrier would be effective in reducing the overall KA crash risk of the road segment by more than 20 percent and reducing the cross-median crash risk by almost 88 percent; a magnitude supported by some previous crash studies in the literature. (Ray 2009)

The foregoing analysis showed that adding a median barrier in this specific circumstance was risk beneficial, but the analysis did not answer the question of whether the median barrier alternative was cost beneficial. If so desired, the next step might be for the engineer to examine the economic benefits of the median barrier is so desired by the highway agency.

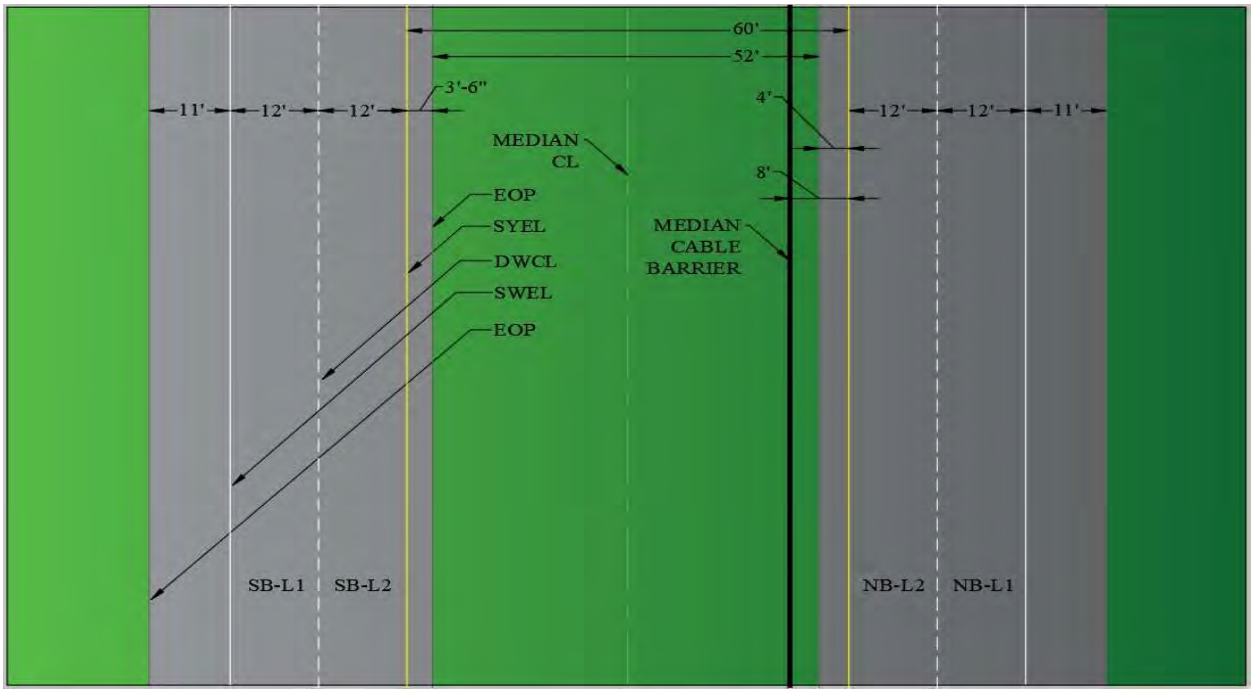

Figure 46. Example site layout.

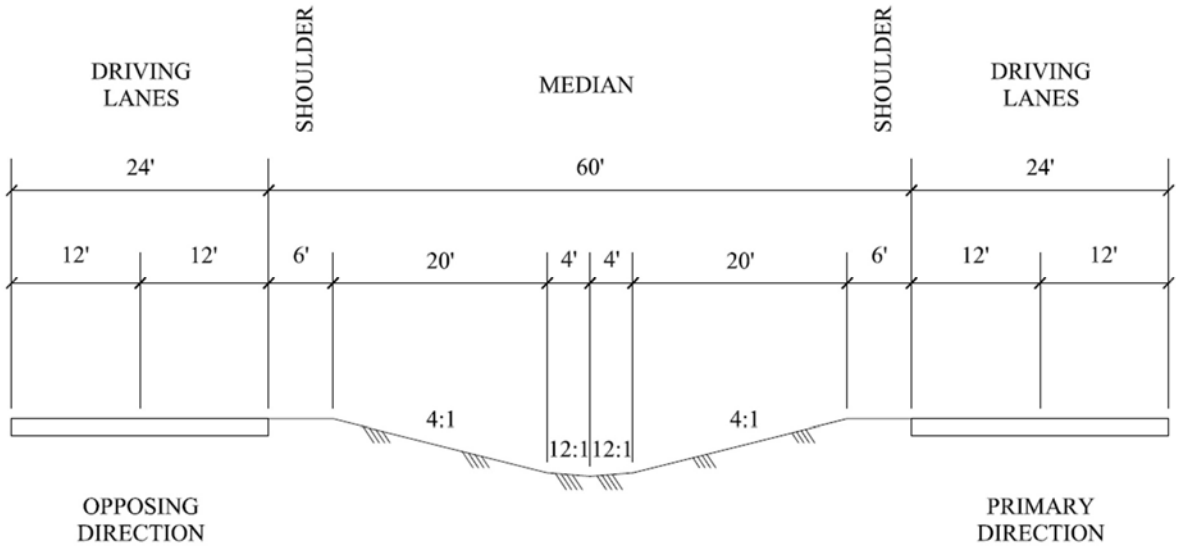

Figure 47. Highway cross-section for example. (NTSB 2013)

Table 63. Example input data and calculation form for primary direction – no median barrier alternative.

ALTERNATIVE: No Median Barrier

Worksheet A - General Information

Title	Primary Direction / No Median Barrier	Roadway	I-999	Risk Goal:	0·0325
Analyst	MHR	Jurisdiction	Z DOT	Analysis Year	2022
Agency	Roadsafe	MilePost	61·5	Analysis Date	11/25/2020

Input Data	Value	Input Data	Value	Input Data	Base Condition	Value
Outcome of Interest	KA	Ditch Type		Grade (%)	Flat	-5
Highway Type	D	Foreslope 1 (H:V)	4:1	Horizontal Curve Radius (ft)	Tangent	Tangent
Functional Class	RA	Foreslope 2 (H:V)	12:1	Degree of Curvature (deg/100 ft)	0	0
Two-Way Total AADT (veh./day)	36,000	Backslope 1 (H:V)	12:1	Encroachment Side	R	L
Percent Trucks (%)	5	Backslope 2 (H:V)	4:1	Total Number of Lanes	4	4
Segment Length (miles)	1	Right Shoulder Width (ft)	10	Post Speed Limit (mi/hr)	65	70
		Left Shoulder Width (ft)	6	Major Access Points (pts/mi)	0	0
				Lane width (ft)	12	12

Worksheet B - Encroachment Adjustment Factors

Horizontal	Grade	Side	Number of	Posted Speed	Access	
EAF_{HC}	EAF_G	EAF_{LR}	EAF_{LN}	EAF_{PSL}	EAF_{AC}	EAF_S
1·00	1·13	0·97	1·00	0·93	1·00	1·01

Worksheet C - Interactions with Roadside Features

j	$Feature_j$	$W_{F\,j}$	$W_{B\,j}$	L_j	BEF_S	EAF_S	$P_{c\,j}$	$P_{SEV\,j}$	δ_j	THR_j	$OUTCOME_j$
0	Cross Edge into Median or Roadside	0	0	5,280	1·9773	1·01	1.0000	0.0000	1	1.0000	0·0000
1	Foreslope 1	6	26	5,280	1·9773	1·01	0·6120	0·0589	1	0·9957	0·0004
2	Foreslope 2	26	30	5,280	1·9773	1·01	0·5699	0·0589	1	1·0000	0·0000
3	Backslope 1	30	34	5,280	1·9773	1·01	0·5206	0·0589	1	1·0000	0·0000
4	Backslope 2	34	54	5,280	1·9773	1·01	0·3325	0·0589	1	0·9957	0·0002
5	Enter Opposing Lanes	60	60	5,280	1·9773	1·01	0·2887	0·0451	1	0·6985	0·0097

Total KA Outcomes/yr: 0·0103

Table 64. Example input data and calculation form for primary direction – median barrier alternative.

ALTERNATIVE: Median Barrier Alternative

Worksheet A - General Information

Title	Primary Direction / Median Barrier	Roadway	I-999	Risk Goal:	0·0325
Analyst	MHR	Jurisdiction	Z DOT	Analysis Year	2022
Agency	Roadsafe	MilePost	61·5	Analysis Date	11/25/2020

Input Data	Value	Input Data	Value	Input Data	Base Condition	Value
Outcome of Interest	KA	Ditch Type		Grade (%)	Flat	-5
Highway Type	D	Foreslope 1 (H:V)	4:1	Horizontal Curve Radius (ft)	Tangent	Tangent
Functional Class	RA	Foreslope 2 (H:V)	12:1	Degree of Curvature (deg/100 ft)	0	0
Two-Way Total AADT (veh./day)	36,000	Backslope 1 (H:V)	12:1	Encroachment Side	R	L
Percent Trucks (%)	5	Backslope 2 (H:V)	4:1	Total Number of Lanes	4	4
Segment Length (miles)	1	Right Shoulder Width (ft)	10	Post Speed Limit (mi/hr)	65	70
		Left Shoulder Width (ft)	6	Major Access Points (pts/mi)	0	0
				Lane width (ft)	12	12

Worksheet B - Encroachment Adjustment Factors

Horizontal	Grade	Side	Number of	Posted Speed	Access	
EAF_{HC}	EAF_G	EAF_{LR}	EAF_{LN}	EAF_{PSL}	EAF_{AC}	EAF_S
1·00	1·13	0·97	1·00	0·93	1·00	1·01

Worksheet C - Interactions with Roadside Features

j	$Feature_j$	$W_{F\,j}$	$W_{B\,j}$	L_j	BEF_S	EAF_S	$P_{c\,j}$	$P_{SEV\,j}$	δ_j	THR_j	$OUTCOME_j$
0	Cross Edge into Median or Roadside	0	0	5,280	1·9773	1·01	1.0000	0.0000	1	1.0000	0·0000
1	TL3 High-Tension Cable Barrier	6	6	5,280	1·9773	1·01	0·8394	0·0050	0	0·0500	0·0105
2	Foreslope 1	6	26	5,280	1·9773	1·01	0·6120	0·0589	1	0·9957	0·0000
3	Foreslope 2	26	30	5,280	1·9773	1·01	0·5699	0·0589	1	1·0000	0·0000
4	Backslope 1	30	34	5,280	1·9773	1·01	0·5206	0·0589	1	1·0000	0·0000
5	Backslope 2	34	54	5,280	1·9773	1·01	0·3325	0·0589	1	0·9957	0·0000
6	Enter Opposing Lanes	60	60	5,280	1·9773	1·01	0·2887	0·0451	1	0·6985	0·0005
										Total KA Outcomes/yr:	0·0110

Table 65. Example input data and calculation form for opposing direction – median barrier alternative.

ALTERNATIVE: Median Barrier Alternative

Worksheet A - General Information

Title	Opposing Direction / Median Barrier	Roadway	I-999	Risk Goal:	0·0325
Analyst	MHR	Jurisdiction	Z DOT	Analysis Year	2022
Agency	Roadsafe	MilePost	61·5	Analysis Date	11/25/2020

Input Data	Value	Input Data	Value	Input Data	Base Condition	Value
Outcome of Interest	KA	Ditch Type		Grade (%)	Flat	5
Highway Type	D	Foreslope 1 (H:V)	4:1	Horizontal Curve Radius (ft)	Tangent	Tangent
Functional Class	RA	Foreslope 2 (H:V)	12:1	Degree of Curvature (deg/100 ft)	0	0
Two-Way Total AADT (veh./day)	36,000	Backslope 1 (H:V)	12:1	Encroachment Side	R	L
Percent Trucks (%)	5	Backslope 2 (H:V)	4:1	Total Number of Lanes	4	4
Segment Length (miles)	1	Right Shoulder Width (ft)	10	Post Speed Limit (mi/hr)	65	70
		Left Shoulder Width (ft)	6	Major Access Points (pts/mi)	0	0
				Lane width (ft)	12	12

Worksheet B - Encroachment Adjustment Factors

Horizontal	Grade	Side	Number of	Posted Speed	Access	
EAF_{HC}	EAF_G	EAF_{LR}	EAF_{LN}	EAF_{PSL}	EAF_{AC}	EAF_S
1·00	1·10	0·97	1·00	0·93	1·00	0·99

Worksheet C - Interactions with Roadside Features

j	$Feature_j$	$W_{F\,j}$	$W_{B\,j}$	L_j	BEF_S	EAF_S	$P_{c\,j}$	$P_{SEV\,j}$	δ_j	THR_j	$OUTCOME_j$
0	Cross Edge into Median or Roadside	0	0	5,280	1·9773	0·99	1.0000	0.0000	1	1.0000	0·0000
1	Foreslope 1	6	26	5,280	1·9773	0·99	0·6120	0·0589	1	0·9957	0·0004
2	Foreslope 2	26	30	5,280	1·9773	0·99	0·5699	0·0589	1	1·0000	0·0000
3	Backslope 1	30	34	5,280	1·9773	0·99	0·5206	0·0589	1	1·0000	0·0000
4	Backslope 2	34	54	5,280	1·9773	0·99	0·3325	0·0589	1	0·9957	0·0002
5	TL3 High-Tension Cable Barrier	54	54	5,280	1·9773	0·99	0·3325	0·0050	0	0·0500	0·0040
6	Enter Opposing Lanes	60	60	5,280	1·9773	0·99	0·2887	0·0451	1	0·6985	0·0005
										Total KA Outcomes/yr:	0·0051

APPENDIX B: DERIVATIONS

B.1 SHIELDING WITH MEDIAN BARRIER

$$\mathrm{OUTCOME_{CMC}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S \cdot L_S}}{5{,}280}\right] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot \left[\mathrm{P_{c\ CMC} \cdot P_{SEV_{CMC}} \cdot (1 - THR_{EOL} \cdot \delta_{CMC})}\right]$$

$$\mathrm{OUTCOME_{CMC}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S \cdot L_S}}{5{,}280}\right]\left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot \left[\frac{\mathrm{L_{CMC} \cdot P_Y(MW) \cdot P_{SEV\ CMC} \cdot (1 - THR_{EOL})}}{\mathrm{L_S}}\right]$$

$$\mathrm{OUTCOME_{BAR}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S \cdot L_S}}{5{,}280}\right] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot \left[\left(\mathrm{P_{c\ BAR} \cdot P_{SEV_{BAR}}}\right) + \left(\mathrm{P_{c\ CMC} \cdot P_{SEV_{CMC}} \cdot (1 - THR_{EOL} \cdot \delta_{CMC}) \cdot THR_{BAR}}\right)\right]$$

$$\mathrm{OUTCOME_{BAR}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S \cdot L_S}}{5{,}280}\right] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot \left[\frac{\mathrm{L_{BAR} \cdot P_Y(MW/2) \cdot P_{SEV\ BAR}}}{\mathrm{L_S}}\right]$$

$$\mathrm{RR_{CMC+BAR/CMC}} = 1 > \frac{\mathrm{OUTCOME_{BAR+CMC}}}{\mathrm{OUTCOME_{CMC}}} = \frac{\mathrm{OUTCOME_{BAR} + OUTCOME_{CMC} \cdot THR_{BAR}}}{\mathrm{OUTCOME_{CMC}}}$$

$$\mathrm{RR_{CMC+BAR/CMC}} = 1 > \frac{\left[\left(\frac{\mathrm{L_{BAR} \cdot P_Y}\left(\frac{\mathrm{MW}}{2}\right) \cdot \mathrm{P_{SEV\ BAR}}}{\mathrm{L_S}}\right) + \left(\frac{\mathrm{L_{CMC} \cdot P_Y(MW) \cdot P_{SEV\ CMC} \cdot (1 - THR_{EOL})}}{\mathrm{L_S}}\right) \cdot \mathrm{THR_{BAR}}\right]}{\left(\frac{\mathrm{L_{CMC} \cdot P_Y(MW) \cdot P_{SEV\ CMC} \cdot (1 - THR_{EOL})}}{\mathrm{L_S}}\right)}$$

Recognizing that the median barrier is continuous along the whole segment, therefore, $L_S = L_{CMC} = L_{BAR}$.

$$\mathrm{RR_{CMC+BAR/CMC}} = 1 > \frac{\left[\left(\mathrm{P_Y(MW/2) \cdot P_{SEV\ BAR}}\right) + \left(\mathrm{P_Y(MW) \cdot P_{SEV\ CMC} \cdot (1 - THR_{EOL}) \cdot THR_{BAR}}\right)\right]}{\left[\mathrm{P_Y(MW) \cdot P_{SEV\ CMC} \cdot (1 - THR_{EOL})}\right]}$$

where MW = The median width in feet.

B.2 RELOCATING NARROW FIXED OBJECTS

Assume the terrain in front of the fixed object is flatter than -10:1.

$$\mathrm{OUTCOME_{FO}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S \cdot L_S}}{5{,}280}\right] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot [\mathrm{P_{c\,FO} \cdot P_{SEV\,FO} \cdot (1 - THR_{FO} \cdot \delta_{FO})}]$$

Letting ∂_{FO}=0 and recognizing that $P_{SEV\,FO}$ = 0.0589 yields:

$$\mathrm{OUTCOME_{FO}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S \cdot L_S}}{5{,}280}\right] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) [\mathrm{P_{c\,FO} \cdot 0.0589}]$$

Let L_S=1,000, L_{TMax}=1,000 ft, L_{FO}=1 ft, and recall:

$$\mathrm{P_{cj}} = \left[\frac{\mathrm{L_{FO}}}{\mathrm{L_S}}\right] \mathrm{P_y(W_{F\,FO})} + \left[\frac{\mathrm{L_{TMax}}}{\mathrm{L_S}}\right] \left[\mathrm{P_x(L_{TMax})\big(P_y(W_{F\,FO}) - P_y(W_{B\,FO})\big)}\right]$$

$$= \left[\frac{\mathrm{L_{FO}}}{\mathrm{L_S}}\right] \mathrm{P_y(W_{F\,FO})} + \left[\frac{1{,}000}{\mathrm{L_S}}\right] \left[0.3508(\mathrm{P_y(W_{F\,FO}) - P_y(W_{B\,FO})})\right]$$

$$= \left[\frac{1}{1{,}000}\right] \mathrm{P_y(W_{F\,FO})} + \left[\frac{1{,}000}{1{,}000}\right] \left[0.3508(\mathrm{P_y(W_{F\,FO}) - P_y(W_{B\,FO})})\right]$$

Let $W_{F\,FO}$ -$W_{B\,FO}$ = 1 ft yields:

$$\mathrm{OUTCOME_{FO}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S}}{5.280}\right] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot 0.0589 \left[\left[\frac{\mathrm{P_y(W_{F\,FO})}}{1{,}000}\right] + \left[0.3508(\mathrm{P_y(W_{F\,FO}) - P_y(W_{B\,FO})})\right]\right]$$

B.3 SHIELDING OBJECT-FREE SLOPED TERRAIN

$$\mathrm{OUTCOME_{TER}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S \cdot L_S}}{5{,}280}\right] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot [\mathrm{P_{c\,TER} \cdot P_{SEV\,TER} \cdot (1 - THR_{TER} \cdot \delta_{TER})}]$$

Letting $\delta_{TER} = 1$, and $\mathrm{P_{c\,FO}} = \frac{\mathrm{L_{TER} \cdot P_Y(W_{TER})}}{\mathrm{L_S}}$ yields:

$$\mathrm{OUTCOME_{TER}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S \cdot L_S}}{5{,}280}\right] \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot \left[\frac{\mathrm{L_{TER} \cdot P_Y(W_{TER}) \cdot P_{SEV\,TER} \cdot (1 - THR_{TER})}}{\mathrm{L_S}}\right]$$

$$\mathrm{OUTCOME_{TER+BAR}} = \left[\frac{\mathrm{BEF_S \cdot EAF_S \cdot L_S}}{5{,}280}\right] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot \left[\left(\mathrm{P_{c\,BAR} \cdot P_{SEV_{BAR}}}\right) + (\mathrm{P_{c\,TER} \cdot P_{SEV\,TER} \cdot (1 - THR_{TER} \cdot \delta_{TER})) \cdot THR_{BAR}}) \right]$$

Letting $\delta_{TER} = 1$, $\mathrm{P_{c\,TER}} = \frac{\mathrm{L_{TER} \cdot P_Y(W_{TER})}}{\mathrm{L_S}}$ and $\mathrm{P_{c\,BAR}} = \frac{\mathrm{L_{BAR} \cdot P_Y(W_{BAR})}}{\mathrm{L_S}}$ yeilds:

$$\mathrm{OUTCOME_{TER+BAR}} = [\mathrm{BEF_S} \cdot \mathrm{EAF_S} \cdot \mathrm{L_S} \cdot 5280] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot \left[\left(\frac{\mathrm{L_{BAR}} \cdot \mathrm{P_Y(W_{BAR})} \cdot \mathrm{P_{SEV\,BAR}}}{\mathrm{L_S}}\right) + \left(\frac{\mathrm{L_{TER}} \cdot \mathrm{P_Y(W_{TER})} \cdot \mathrm{P_{SEV\,TER}} \cdot (1 - \mathrm{THR_{TER}} \cdot \delta_{\mathrm{TER}})) \cdot \mathrm{THR_{BAR}}}{\mathrm{L_S}}\right)\right]$$

$$\mathrm{RR_{TER+BAR+TER}} = 1 > \frac{\mathrm{OUTCOME_{TER+BAR}}}{\mathrm{OUTCOME_{TER}}} = \frac{\mathrm{OUTCOME_{BAR}} + \mathrm{OUTCOME_{TER}} \cdot \mathrm{THR_{BAR}}}{\mathrm{OUTCOME_{TER}}}$$

$$\mathrm{RR_{TER+B\quad/TER}} = 1 > \frac{\left(\frac{\mathrm{L_{BAR}} \cdot \mathrm{P_Y(W_{BAR})} \cdot \mathrm{P_{SEV\,BAR}}}{\mathrm{L_S}}\right) + \left(\frac{\mathrm{L_{TER}} \cdot \mathrm{P_Y(W_{TER})} \cdot \mathrm{P_{SEV\,TER}} \cdot (1 - \mathrm{THR_{TER}})) \cdot \mathrm{THR_{BAR}}}{\mathrm{L_S}}\right)}{\left(\frac{\mathrm{L_{TER}} \cdot \mathrm{P_Y(W_{TER})} \cdot \mathrm{P_{SEV\,CMC}} \cdot (1 - \mathrm{THR_{TER}})}{\mathrm{L_S}}\right)}$$

Recognizing that the barrier is continuous along the whole segment, therefore, $L_S = L_{TER} = L_{BAR}$:

$$\mathrm{RR_{TER+BAR/TER}} = 1 > \frac{[(\mathrm{P_Y(W_{BAR})} \cdot \mathrm{P_{SEV\,BAR}}) + (\mathrm{P_Y(W_{TER})} \cdot \mathrm{P_{SEV\,TER}} \cdot (1 - \mathrm{THR_{TER}})) \cdot \mathrm{THR_{BAR}})\,]}{[\mathrm{P_Y(W_{TER})} \cdot \mathrm{P_{SEV\,TER}} \cdot (1 - \mathrm{THR_{TER}})]}$$

B.4 Shielding Fixed Objects with Longitudinal Barriers

$\mathrm{OUTCOME_{BAR}}$ is the same as in Section B.1 and $\mathrm{OUTCOME_{TER}}$ is the same as in Section B.3.

$$\mathrm{OUTCOME_{FO}} = \left[\frac{\mathrm{BEF_S} \cdot \mathrm{EAF_S} \cdot \mathrm{L_S}}{5{,}280}\right] \cdot \left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot [\mathrm{P_{c\,FO}} \cdot \mathrm{P_{SEV\,FO}} \cdot (1 - \mathrm{THR_{FO}} \cdot \delta_{\mathrm{FO}})]$$

Letting $\delta_{\mathrm{FO}} = 1, \mathrm{THR_{FO}} = 0,$ and $\mathrm{P_{c\,FO}} = \frac{\mathrm{L_{FO}} \cdot \mathrm{P_y(W_{F\,FO})}}{\mathrm{L_S}} + \frac{\mathrm{L_{TMax}} \cdot [\mathrm{P_x(L_{TMax})(P_y(W_{F\,FO})} - \mathrm{P_Y(W_{B\,FO})}]}{\mathrm{L_S}}$ yeilds:

$$\mathrm{OUTCOME_{FO}} = \left[\frac{\mathrm{BEF_S} \cdot \mathrm{EAF_S} \cdot \mathrm{L_S}}{5{,}280}\right]\left(\frac{\mathrm{PSL_s^3}}{65^3}\right) \cdot \left[\left(\frac{\mathrm{L_{FO}} \cdot \mathrm{P_y(W_{F\,FO})}}{\mathrm{L_S}} + \frac{[\mathrm{L_{TMax}} \cdot \mathrm{P_x(L_{TMax})(P_y(W_{F\,FO})} - \mathrm{P_Y(W_{B\,FO})}]}{\mathrm{L_S}}\right) \cdot \mathrm{P_{SEV\,FO}}\right]$$

$$\mathrm{RR_{FO+TER+BAR/TER+BAR}} = 1 > \frac{\mathrm{OUTCOME_{FO+TER+BAR}}}{\mathrm{OUTCOME_{FO+T}}}$$

$$\mathrm{RR_{FO+TER+BAR/TER+BAR}} = 1 > \frac{\mathrm{OUTCOME_{BAR}} + \mathrm{OUTCOME_{TER}} \cdot \mathrm{THR_{BAR}} + \mathrm{OUTCOME_{FO}} \cdot \mathrm{THR_{BAR}} \cdot \mathrm{THRU_{TER}}}{\mathrm{OUTCOME_{TER}} + \mathrm{OUTCOME_{FO}} \cdot \mathrm{THR_{TER}}}$$

$$RR_{FO+TER+BAR/TER+BAR} = 1 > \frac{\left[\left(\frac{L_{BAR} \cdot P_Y(W_{BAR}) \cdot P_{SEV\ BAR}}{L_S}\right) + \left(\frac{L_{TER} \cdot P_Y(W_{TER}) \cdot P_{SEV\ TER} \cdot (1 - THR_{TER}))}{L_S}\right) \cdot THR_{BAR}\right]}{\left[\left(\frac{L_{TER} \cdot P_Y(W_{TER}) \cdot P_{SEV\ TER} \cdot (1 - THR_{TER})}{L_S}\right) + \left(\frac{L_{FO} \cdot P_y(W_{F\ FO})}{L_S} + \frac{[L_{TMAX} \cdot P_x(L_{TMax})(P_y(W_{F\ FO}) - P_Y(W_{B\ FO})]}{L_S}\right) \cdot P_{SEV\ FO} \cdot THR_{TER}\right]} + \frac{\left(\frac{L_{FO} \cdot P_y(W_{F\ FO})}{L_S} + \frac{[L_{TMAX} \cdot P_x(L_{TMax})(P_y(W_{F\ FO}) - P_Y(W_{B\ FO})]}{L_S}\right) \cdot P_{SEV\ FO} \cdot THR_{TER} \cdot THR_{BAR}}{\left[\left(\frac{L_{TER} \cdot P_Y(W_{TER}) \cdot P_{SEV\ TER} \cdot (1 - THR_{TER})}{L_S}\right) + \left(\frac{L_{FO} \cdot P_y(W_{F\ FO})}{L_S} + \frac{[L_{TMAX} \cdot P_x(L_{TMax})(P_y(W_{F\ FO}) - P_Y(W_{B\ FO})]}{L_S}\right) \cdot P_{SEV\ FO} \cdot THR_{TER}\right]}$$

$$RR_{FO+TER+BAR/TER+BAR} = 1 > \frac{[(L_{BAR} \cdot P_Y(W_{BAR}) \cdot P_{SEV\ BAR}) + (L_{TER} \cdot P_Y(W_{TER}) \cdot P_{SEV\ TER} \cdot (1 - THR_{TER} \cdot \delta_{TER})) \cdot THR_{BAR}) + (L_{FO} \cdot P_y(W_{F\ FO})]}{[L_{TER} \cdot P_Y(W_{TER}) \cdot P_{SEV\ TER} \cdot (1 - THR_{TER})] + [L_{FO} \cdot P_y(W_{F\ FO}) + (L_{TMAX} \cdot P_x(L_{TMax}) \left(P_y(W_{F\ FO}) - P_Y(W_{B\ FO})\right)] \cdot P_{SEV\ FO} \cdot THR_{TER}} + \frac{L_{TMAX} \cdot P_x(L_{TMax})(P_y(W_{F\ FO}) - P_Y(W_{B\ FO})) \cdot THR_{TER} \cdot THR_{BAR}}{[L_{TER} \cdot P_Y(W_{TER}) \cdot P_{SEV\ TER} \cdot (1 - THR_{TER})] + [L_{FO} \cdot P_y(W_{F\ FO}) + (L_{TMAX} \cdot P_x(L_{TMax}) \left(P_y(W_{F\ FO}) - P_Y(W_{B\ FO})\right)] \cdot P_{SEV\ FO} \cdot THR_{TER}}$$

B.5 BRIDGE RAIL SELECTION

$$OUTCOME_{BAR} = \left[\frac{BEF_S \cdot EAF_S \cdot L_S}{5280}\right] \cdot \left[P_{c\ BAR} \cdot \prod_{i=1}^{j-1} THR_i\right] \cdot \left[P_{SEV\ BAR} \cdot (1 - THR_{BAR} \cdot \delta_{BAR}) \left(\frac{PSL_s^3}{65^3}\right)\right]$$

$$OUTCOME_{PEN} = \left[\frac{BEF_S \cdot EAF_S \cdot L_S}{5280}\right] \cdot \left[P_{c\ PEN} \cdot \prod_{i=1}^{j-1} THR_i\right] \cdot \left[P_{SEV\ PEN} \cdot (1 - THR_{PEN} \cdot \delta_{PEN}) \left(\frac{PSL_s^3}{65^3}\right)\right]$$

Recognizing that $\partial_{BAR} = 0$, $\partial_{PEN} = 0$,

$$GOAL \geq OUTCOME_{BR} + OUTCOME_{PEN} \cdot THR_{BR}$$

$$GOAL \geq \left[\frac{BEF_S \cdot EAF_S \cdot L_S}{5280}\right] \cdot \left(\frac{PSL_s^3}{65^3}\right) \cdot \left[[P_Y(W_{F\ BAR}) \cdot P_{SEV\ BAR}] + [P_Y(W_{F\ PEN}) \cdot P_{SEV\ BAR} \cdot THR_{BR}]\right]$$

Assume the bridge railing has a 4-ft wide shoulder ($W_{F\ BAR}$ = 4 ft) and the bridge railing is 2-ft wide($W_{F\ PEN}$ = 6 ft).

$$GOAL \geq \left[\frac{BEF_S \cdot EAF_S \cdot L_S}{5280}\right] \cdot \left(\frac{PSL_s^3}{65^3}\right) \cdot \left[[P_Y(4) \cdot P_{SEV\ BAR}] + [P_Y(6) \cdot P_{SEV\ BAR} \cdot THR_{BR}]\right]$$

APPENDIX C: SERIOUS AND FATAL INJURY CRASH TABLES

Illinois

Complete data from Illinois was not available but Piper reports that there were 2,483 fatal and 19,279 serious injury roadway departure crashes in Illinois in 2010 through 2014 (see below). (Piper 2014) According to FHWA statistics, there were 296,084 edge miles of public roadway in Illinois that carry 2,260 100-million vehicle edge-miles travelled (HMVEMT) 2012.(FHWA 2020b)

Fatal and Serious Run-Off-Road Crash Rates in Illinois, 2010-2014.

Year	Number of KA Crashes	HMVEM	KA Crashes/HMVEM	Miles	KA Crashes/edge mile/yr
2010-2014	21,762	2,260	1.93	296,084	0.0073

Maine

Run-off-road crashes have long been the leading cause of roadway crash fatalities in the State of Maine due to the rural nature and mountainous topography of the State. Run-off-road fatalities account for 40 percent of all fatal crashes in the State of Maine. There are 23,400 miles of roadway in the State of Maine, most of which are rural two-lane roadways (i.e., there are only 367 miles of interstate in Maine). Highway Corridor Priority (HCP) mileages are from https://www.maine.gov/mdot/about/assets/hwy/#undefined1 and are assumed to be the same for all years. These 23,400 miles of roadway represent about 47,500 edge-miles of roadside. Between 2010 and 2018 there were 389 fatal and serious injury crashes in the State. (MDOT 2019) The expected frequency of fatal and incapacitating injury (KA) run-off-road crashes on the average mile of roadway in Maine in a year was 0.0083 KA ROR crashes/edge-mi/yr. The Statewide average KA ROR crash rate on a traffic volume basis was 1.33 KA crashes/HMVEM.

Maine uses an HCP value which is similar but not identical to the usual FHWA functional classifications. The KA ROR crash rate is always less than 0.025 KA ROR crashes/edge-mi/yr with the highest rate on undivided principal arterials (0.0247 KA ROR crashes/edge-mi/yr) and the lowest rate is on local roads and streets (0.0037 KA ROR crashes/edge-mi/yr.

The situation is quite different when viewed on a volume. The highest KA ROR crash rate on a volume basis are the local roads where the average rate was 2.89 KA ROR crashes/HMVEM. The lowest KA ROR crash rate on a volume basis were the Interstates and Principal Arterials where the rate was five times lower at 0.52 KA ROR crashes/HMVEM.

North Carolina

The 2010 to 2015 North Carolina HSIS data were used for this analysis. Run-off-road

crashes were identified using *RD_CONF, RODWYCLS*, *EVENT1*, *2*, *3*, *4*, and *SEVERITY* fields. All crashes were categorized according to whether they occurred on a divided (coded 3, or 4 in *RD_CONF* field) or undivided (coded 1, or 2 in *RD_CONF* field) road. The crashes which occurred on divided roads were then further divided into urban (coded 01, 02, 03, 04, or 05 in *RODWYCLS* field) and rural (coded 06, 07, 08, 09, or 10 in *RODWYCLS* field). The same further division was performed for crashes that occurred on undivided roads. This division of roadway type and location resulted in four categories: (1) divided urban, (2) divided rural, (3) undivided urban and (4) undivided rural. The vehicle file *EVENT* codes (*EVENT1*, *EVENT2*, *EVENT3*, *EVENT4*) for all vehicles involved a crash were aggregated into a single list. For each road type/location category the number of run-off-road crashes was tallied using the EVENT codes listed below. Finally, the crashes which had a fatality (coded 1 in *SEVERITY* field) or an A injury (coded 2 in *SEVERITY* field) were tallied. The mileage amounts for each type/location of roadway was collected from the HSIS roadway mileage by roadway category (2012 data) table of the North Carolina HSIS Guidebook. (Nujjetty 2014) HMVM traveled was collected for each year from the FHWA Highway Statistics Table VM-2.

North Carolina HSIS EVENT Field Codes.

Code	Event	Code	Event
01	'Ran off Road Right'	46	'Shoulder Barrier Face'
02	'Ran off Road Left'	47	'Median Barrier End'
03	'Ran off Road Straight Ahead'	48	'Median Barrier Face'
05	'Overturn/Rollover'	49	'Bridge Rail End'
06	'Crossed Centerline/Median'	50	'Bridge Rail Face'
20	'Parked Motor Vehicle'	51	'Overhead Part Underpass'
33	'Tree'	52	'Pier on Shoulder of Underpass'
35	'Luminaire Pole Non-Breakaway'	53	'Pier in Median of Underpass'
36	'Luminaire Pole Breakaway'	54	'Abutment of Underpass'
37	'Official Hwy Sign Non-Breakaway'	55	'Traffic Island Curb or Median'
38	'Official Highway Sign Breakaway'	56	'Catch Basin or Culvert on Shoulder'
39	'Overhead Sign Support'	57	'Catch Basin or Culvert on Median'
40	'Commercial Sign'	58	'Ditch'
41	'Guardrail End on Shoulder'	59	'Embankment'
42	'Guardrail Face on Shoulder'	60	'Mailbox', 61-'Fence or Fence Post'
43	'Guardrail End on Median'	62	'Construction Barrier'
44	'Guardrail Face on Median'	63	'Crash Cushion'
45	'Shoulder Barrier End'	64	'Other Fixed Object')

Ohio

The 2010 through 2015 Ohio HSIS data were used for this analysis. Run-off-road crashes were identified using *DIV_CODE, RODWYCLS*, *EVENT1*, *2*, *3*, *4*, and *SEVERITY* fields. All crashes were categorized according to whether they occurred on a divided (coded D in *DIV_CODE* field) or undivided (coded U in *DIV_CODE* field) road. The crashes which occurred on divided roads were then further divided into urban (coded 01, 02, 03, 04, or 05 in *RODWYCLS* field) and rural (coded 06, 07, 08, 09, or 10 in *RODWYCLS* field). The same further division was performed for crashes that occurred on undivided roads. This division of roadway type and location resulted in four categories: (1) divided urban, (2) divided rural, (3) undivided urban and (4) undivided rural. The vehicle file *EVENT* codes (*EVENT1*, *EVENT2*, *EVENT3*, *EVENT4*) for all vehicles involved a crash were aggregated into a single list. For each road

type/location category the number of run-off-road crashes was tallied using the EVENT codes listed below. Finally, the crashes which had a fatality (coded 1 in *SEVERITY* field) or an A injury (coded 2 in *SEVERITY* field) were tallied. The mileage amounts for each type/location of roadway was collected from the HSIS roadway mileage by roadway category (2011 data) table of the Ohio HSIS Guidebook. (Nujjetty 2015) HMVM traveled was collected for each year from the FHWA Highway Statistics Table VM-2.

Ohio HSIS EVENT Field Codes.

Code	Event	Code	Event
01	'Overturn/Rollover'	33	'Highway Traffic Sign Post'
03	'Immersion'	34	'Overhead Sign Post'
08	'Ran Off Road Right'	35	'Light/Luminaries Support'
09	'Ran Off Road Left'	36	'Utility Pole'
10	'Cross Median/Centerline'	37	'Other Post, Pole or Support'
11	'Downhill Runaway'	38	'Culvert'
21	'Parked Motor Vehicle'	39	'Curb'
22	'Work Zone Maintenance Equipment'	40	'Ditch'
25	'Impact Attenuator/Crash Cushion'	41	'Embankment'
27	'Bridge Pier or Abutment'	42	'Fence'
28	'Bridge Parapet'	43	'Mailbox'
29	'Bridge Rail'	44	'Tree'
30	'Guardrail Face'	45	'Other Fixed Object'
31	'Guardrail End'	46	'Work Zone Maintenance Equip.'
32	'Median Barrier'	47	'Unknown Fixed Object'

Washington State

The 2010 through 2017 State of Washington HSIS data were used for this analysis. Run-off-road crashes were identified using *RUR_URB, RODWYCLS*, *OBJECT1, OBJECT2*, and *SEVERITY* fields. All crashes were categorized according to whether they occurred on a divided (coded 01, 02, 04, 06, 07, or 09 in *RODWYCLS* field) or undivided (coded 03, 05, 08, or 10 in *RODWYCLS* field) road. The crashes which occurred on divided roads were then further divided into urban (coded U in *RUR_URB* field) and rural (coded R in *RUR_URB* field). The same further division was performed for crashes that occurred on undivided roads. This division of roadway type and location resulted in four categories: (1) divided urban, (2) divided rural, (3) undivided urban and (4) undivided rural. The accident file *OBJECT* codes (*OBJECT1*, *OBJECT2*) for <u>all</u> vehicles involved in a crash were aggregated into a single list. For each road type/location category the number of run-off-road crashes was tallied using the OBJECT codes listed in the table above. Finally, the crashes which had a fatality (coded 2, 3, or 4 in *SEVERITY* field) or an A injury (coded 5 in *SEVERITY* field) were tallied. The mileage amounts for each type/location of roadway was collected from the HSIS roadway mileage by roadway category (2014 data) table of the Ohio HSIS Guidebook. (Nujjetty 2015) HMVM traveled was collected for each year from the FHWA Highway Statistics Table VM-2.

State of Washington HSIS OBJECT Field Codes.

Code	Event	Code	Event
01	Beam Guardrail, Leading End	35	Concrete Barrier, Face Of (Did Not Go Thru, Over, or Under)
02	Beam Guardrail, Face Of (Did Not Go Thru, Over, or Under)	36	Concrete Barrier, Face Of (Did Go Thru, Over, or Under)
03	Beam Guardrail, Face Of (Did Go Thru, Over, or Under	37	Bridge Rail, Leading End
07	Concrete Median Barrier Wall	38	Bridge Rail, Face Of (Did Not Go Thru, Over, or Under)
08	Retaining Wall (Concrete, Rock, Brick, Etc.)	39	Bridge Rail, Face Of (Did Go Thru, Over, or Under)
09	Curb or Raised Traffic Island, Raised Median Curb	50	Temporary Traffic Sign or Barricade
11	Bridge Abutment	51	Road or Construction Machinery
12	Bridge Column, Pier or Pillar	52	Construction Materials
13	Wood Sign Post	56	Tree or Stump (Stationary)
14	Metal Sign Post	57	Boulder (Stationary)
15	Guide Post	58	Rock Bank or Ledge
16	Luminaire Pole or Base	59	Earth Bank or Ledge
17	Railway Signal or Pole	61	Snowbank
18	Utility Pole (Telephone, Power, Etc.)	63	Building
19	Traffic Signal Pole and/or Control Equipment	64	Fire Plug
20	Culvert End or Other Appurtenance in Ditch	65	Parking Meter
21	Roadway Ditch	66	Fence
74	Roadway Ditch	67	Domestic Animal (Ridden)
22	Overhead Sign Support	68	Animal Drawn Vehicle
30	Crash Cushion or Drums	69	Over Embankment/No Guardrail Present
31	Guardrail, Leading End	70	Into River, Lake, Swamp, Etc.
32	Guardrail, Face Of (Did Not Go Thru, Over, or Under)	71	Other Object
33	Guardrail, Face Of (Did Go Thru, Over, or Under)	73	Mailbox
34	Concrete Barrier, Leading End		

Fatal and Serious Injury Run-Off-Road Crashes in the State of Maine, 2010-2018.

Year	Number of KA Crashes						HMVM						KA Crashes/HMVEM						Miles						KA Crashes/edge mile/yr					
	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	TOTAL	Interstates	Principal Arterials	Collector	Minor Collector	Local	Total	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	Total	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	Total	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	Total
2010	89	37	72	76	106	380	59.76	17.40	25.16	24.83	18.34	145	0.62	1.06	1.43	1.53	2.89	1.31	1,760	1,335	2,211	3,731	14,363	23,400	0.0209	0.0139	0.0163	0.0102	0.0037	0.0081
2011	81	48	63	71	124	387	59.14	16.80	24.12	24.67	18.25	143	0.57	1.43	1.31	1.44	3.40	1.35	1,760	1,335	2,211	3,731	14,363	23,400	0.0190	0.0180	0.0142	0.0095	0.0043	0.0083
2012	82	66	79	100	144	471	59.97	16.80	24.02	24.56	18.34	144	0.57	1.96	1.64	2.04	3.93	1.64	1,760	1,335	2,211	3,731	14,363	23,400	0.0193	0.0247	0.0179	0.0134	0.0050	0.0101
2013	79	56	72	92	146	445	59.85	16.81	24.25	24.49	18.58	144	0.55	1.67	1.48	1.88	3.93	1.55	1,760	1,335	2,211	3,731	14,363	23,400	0.0186	0.0210	0.0163	0.0123	0.0051	0.0095
2014	64	65	61	79	88	357	59.61	17.33	23.33	24.59	18.57	143	0.44	1.88	1.31	1.61	2.37	1.24	1,760	1,335	2,211	3,731	14,363	23,400	0.0150	0.0243	0.0138	0.0106	0.0031	0.0076
2015	73	63	67	75	103	381	61.76	17.81	24.05	25.47	19.20	148	0.49	1.77	1.39	1.47	2.68	1.28	1,760	1,335	2,211	3,731	14,363	23,400	0.0172	0.0236	0.0152	0.0101	0.0036	0.0081
2016	79	58	76	86	82	381	63.13	18.03	24.08	25.56	19.05	150	0.52	1.61	1.58	1.68	2.15	1.27	1,760	1,335	2,211	3,731	14,363	23,400	0.0186	0.0217	0.0172	0.0115	0.0029	0.0081
2017	80	35	81	76	83	355	63.58	25.95	23.38	17.71	18.80	149	0.52	0.67	1.73	2.15	2.21	1.19	1,760	1,335	2,211	3,731	14,363	23,400	0.0188	0.0131	0.0183	0.0102	0.0029	0.0076
2018	69	34	71	67	92	333	64.29	25.89	23.39	17.63	18.93	150	0.44	0.66	1.52	1.90	2.43	1.11	1,760	1,335	2,211	3,731	14,363	23,400	0.0162	0.0127	0.0161	0.0090	0.0032	0.0071
Avg Annual	76	53	71	81	108	389							0.52	1.41	1.49	1.74	2.89	1.33							0.0182	0.0192	0.0161	0.0108	0.0037	0.0083

Fatal Run-Off-Road Crashes in the State of Maine, 2010-2018.

Year	Number of Fatal Crashes						HMVM						Fatal Crashes/HMVEM						Miles						Fatal Crashes/edge mile/yr					
	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	TOTAL	Interstates	Principal Arterials	Collector	Minor Collector	Local	Total	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	Total	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	Total	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	Total
2010	17	10	23	11	22	83	59.76	17.40	25.16	24.83	18.34	145	0.12	0.29	0.46	0.22	0.60	0.29	1,760	1,335	2,211	3,731	14,363	23,400	0.0040	0.0075	0.0104	0.0029	0.0015	0.0018
2011	7	11	14	17	22	71	59.14	16.80	24.12	24.67	18.25	143	0.05	0.33	0.29	0.34	0.60	0.25	1,760	1,335	2,211	3,731	14,363	23,400	0.0016	0.0082	0.0063	0.0046	0.0015	0.0015
2012	12	12	15	20	24	83	59.97	16.80	24.02	24.56	18.34	144	0.08	0.36	0.31	0.41	0.65	0.29	1,760	1,335	2,211	3,731	14,363	23,400	0.0028	0.0090	0.0068	0.0054	0.0017	0.0018
2013	10	7	9	17	24	67	59.85	16.81	24.25	24.49	18.58	144	0.07	0.21	0.19	0.35	0.65	0.23	1,760	1,335	2,211	3,731	14,363	23,400	0.0024	0.0052	0.0041	0.0046	0.0017	0.0014
2014	6	13	7	9	15	50	59.61	17.33	23.33	24.59	18.57	143	0.04	0.38	0.15	0.18	0.40	0.17	1,760	1,335	2,211	3,731	14,363	23,400	0.0014	0.0097	0.0032	0.0024	0.0010	0.0011
2015	13	11	13	16	22	75	61.76	17.81	24.05	25.47	19.20	148	0.09	0.31	0.27	0.31	0.57	0.25	1,760	1,335	2,211	3,731	14,363	23,400	0.0031	0.0082	0.0059	0.0043	0.0015	0.0016
2016	15	10	16	16	17	74	63.13	18.03	24.08	25.56	19.05	150	0.10	0.28	0.33	0.31	0.45	0.25	1,760	1,335	2,211	3,731	14,363	23,400	0.0035	0.0075	0.0072	0.0043	0.0012	0.0016
2017	8	7	12	16	13	56	63.58	25.95	23.38	17.71	18.80	149	0.05	0.13	0.26	0.45	0.35	0.19	1,760	1,335	2,211	3,731	14,363	23,400	0.0019	0.0052	0.0054	0.0043	0.0009	0.0012
2018	12	9	19	15	21	76	64.29	25.89	23.39	17.63	18.93	150	0.08	0.17	0.41	0.43	0.55	0.25	1,760	1,335	2,211	3,731	14,363	23,400	0.0028	0.0067	0.0086	0.0040	0.0015	0.0016
Avg Annual	10	10	13	16	20	69							0.07	0.27	0.30	0.33	0.54	0.24							0.0026	0.0075	0.0064	0.0041	0.0014	0.0015

Serious Injury Run-Off-Road Crashes in the State of Maine, 2010-2018.

	Number of Serious Crashes						HMVM						Serious Crashes/HMVEM						Miles						Serious Crashes/edge mile/yr					
Year	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	TOTAL	Interstates	Principal Arterials	Collector	Minor Collector	Local	Total	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	Total	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	Total	Interstates/Arterials	Other Principal Arterials	Collector	Minor Collector	Local	Total
2010	72	27	49	65	84	297	59.76	17.40	25.16	24.83	18.34	145.49	0.50	0.78	0.97	1.31	2.29	1.02	1760	1335	2211	3731	14363	23,400	0.0169	0.0202	0.0222	0.0174	0.0058	0.0063
2011	74	37	49	54	102	316	59.14	16.80	24.12	24.67	18.25	142.98	0.52	1.10	1.02	1.09	2.79	1.11	1760	1335	2211	3731	14363	23,400	0.0174	0.0277	0.0222	0.0145	0.0071	0.0068
2012	70	54	64	80	120	388	59.97	16.80	24.02	24.56	18.34	143.70	0.48	1.61	1.33	1.63	3.27	1.35	1760	1335	2211	3731	14363	23,400	0.0165	0.0404	0.0289	0.0214	0.0084	0.0083
2013	69	49	63	75	122	378	59.85	16.81	24.25	24.49	18.58	143.98	0.48	1.46	1.30	1.53	3.28	1.31	1760	1335	2211	3731	14363	23,400	0.0162	0.0367	0.0285	0.0201	0.0085	0.0081
2014	58	52	54	70	73	307	59.61	17.33	23.33	24.59	18.57	143.44	0.40	1.50	1.16	1.42	1.97	1.07	1760	1335	2211	3731	14363	23,400	0.0136	0.0390	0.0244	0.0188	0.0051	0.0066
2015	60	52	54	59	81	306	61.76	17.81	24.05	25.47	19.20	148.29	0.40	1.46	1.12	1.16	2.11	1.03	1760	1335	2211	3731	14363	23,400	0.0141	0.0390	0.0244	0.0158	0.0056	0.0065
2016	64	48	60	70	65	307	63.13	18.03	24.08	25.56	19.05	149.85	0.42	1.33	1.25	1.37	1.71	1.02	1760	1335	2211	3731	14363	23,400	0.0150	0.0360	0.0271	0.0188	0.0045	0.0066
2017	72	28	69	60	70	299	63.58	25.95	23.38	17.71	18.80	149.43	0.47	0.54	1.48	1.69	1.86	1.00	1760	1335	2211	3731	14363	23,400	0.0169	0.0210	0.0312	0.0161	0.0049	0.0064
2018	57	25	52	52	71	257	64.29	25.89	23.39	17.63	18.93	150.13	0.37	0.48	1.11	1.47	1.88	0.86	1760	1335	2211	3731	14363	23,400	0.0134	0.0187	0.0235	0.0139	0.0049	0.0055
Avg Annual	66	43	58	65	88	320							0.45	1.14	1.19	1.41	2.35	1.09							0.0156	0.0310	0.0258	0.0174	0.0061	0.0068

Fatal and Serious Injury Run-Off-Road Crashes in the State of North Carolina, 2010-2015.

Year	Number of KA					HMVM				KA Crashes/HMVEM				Edge Miles				KA Crashes/edge mile/yr			
	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	TOTAL	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided
2010	210	328	132	1037	1707	447.51	176.27	187.45	212.61	0.12	0.93	0.18	2.44	10,109	28,762	8,226	111,384	0.0208	0.0114	0.0160	0.0093
2011	186	351	137	994	1668	456.25	178.81	190.31	212.36	0.10	0.98	0.18	2.34	10,109	28,762	8,226	111,384	0.0184	0.0122	0.0167	0.0089
2012	185	374	110	984	1653	457.91	181.77	193.47	216.35	0.10	1.03	0.14	2.27	10,109	28,762	8,226	111,384	0.0183	0.0130	0.0134	0.0088
2013	178	344	113	953	1588	462.55	183.47	192.99	213.11	0.10	0.94	0.15	2.24	10,109	28,762	8,226	111,384	0.0176	0.0120	0.0137	0.0086
2014	229	382	123	853	1587	506.92	207.57	188.69	176.95	0.11	0.92	0.16	2.41	10,109	28,762	8,226	111,384	0.0227	0.0133	0.0150	0.0077
2015	264	439	47	1007	1757	524.64	217.81	195.53	180.80	0.13	1.01	0.06	2.78	10,109	28,762	8,226	111,384	0.0261	0.0153	0.0057	0.0090
Avg Annual	209	370	110	971	1660					0.11	0.97	0.14	2.41					0.0206	0.0129	0.0134	0.0087

Fatal Run-Off-Road Crashes in the State of North Carolina, 2010-2015.

Year	Number of Fatal Crashes					HMVM				Fatal Crashes/HMVEM				Edge Miles				Fatal Crashes/edge mile/yr			
	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	TOTAL	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided
2010	83	138	56	454	731	447.51	176.27	187.45	212.61	0.05	0.39	0.07	1.07	10,109	28,762	8,226	111,384	0.0082	0.0048	0.0068	0.0041
2011	79	135	47	410	671	456.25	178.81	190.31	212.36	0.04	0.38	0.06	0.97	10,109	28,762	8,226	111,384	0.0078	0.0047	0.0057	0.0037
2012	76	155	50	416	697	457.91	181.77	193.47	216.35	0.04	0.43	0.06	0.96	10,109	28,762	8,226	111,384	0.0075	0.0054	0.0061	0.0037
2013	94	145	58	429	726	462.55	183.47	192.99	213.11	0.05	0.40	0.08	1.01	10,109	28,762	8,226	111,384	0.0093	0.0050	0.0071	0.0039
2014	109	148	73	381	711	506.92	207.57	188.69	176.95	0.05	0.36	0.10	1.08	10,109	28,762	8,226	111,384	0.0108	0.0051	0.0089	0.0034
2015	119	181	21	453	774	524.64	217.81	195.53	180.80	0.06	0.42	0.03	1.25	10,109	28,762	8,226	111,384	0.0118	0.0063	0.0026	0.0041
Avg Annual	93	150	51	424	718					0.05	0.39	0.07	1.06					0.0092	0.0052	0.0062	0.0038

Serious Injury Run-Off-Road Crashes in the State of North Carolina, 2010-2015.

Year	Number of Serious Injury Crashes					HMVM				Serious Injury Crashes/HMVEM				Edge Miles				Serious Crashes/edge mile/yr			
	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	TOTAL	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided
2010	127	190	76	583	976	447.51	176.27	187.45	212.61	0.07	0.54	0.10	1.37	10109	28762	8226	111384	0.0126	0.0066	0.0092	0.0052
2011	107	216	90	584	997	456.25	178.81	190.31	212.36	0.06	0.60	0.12	1.38	10109	28762	8226	111384	0.0106	0.0075	0.0109	0.0052
2012	109	219	60	568	956	457.91	181.77	193.47	216.35	0.06	0.60	0.08	1.31	10109	28762	8226	111384	0.0108	0.0076	0.0073	0.0051
2013	84	199	55	524	862	462.55	183.47	192.99	213.11	0.05	0.54	0.07	1.23	10109	28762	8226	111384	0.0083	0.0069	0.0067	0.0047
2014	120	234	50	472	876	506.92	207.57	188.69	176.95	0.06	0.56	0.07	1.33	10109	28762	8226	111384	0.0119	0.0081	0.0061	0.0042
2015	145	258	26	554	983	524.64	217.81	195.53	180.80	0.07	0.59	0.03	1.53	10109	28762	8226	111384	0.0143	0.0090	0.0032	0.0050
Avg Annual	115	219	60	548	942					0.06	0.57	0.08	1.36					0.0114	0.0076	0.0072	0.0049

Fatal and Serious Injury Run-Off-Road Crashes in the State of Ohio, 2010-2015.

Year	Number of KA Crashes					HMVM				KA Crashes/HMVEM				Edge Miles				KA Crashes/edge mile/yr			
	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	TOTAL	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided
2010	672	483	246	1209	2610	542.90	213.87	200.77	160.82	0.31	1.13	0.31	3.76	7,234	6,548	7,005	25,319	0.0929	0.0738	0.0351	0.0478
2011	718	613	250	1206	2787	533.50	222.93	198.73	164.73	0.34	1.37	0.31	3.66	7,234	6,548	7,005	25,319	0.0992	0.0936	0.0357	0.0476
2012	672	559	250	1274	2755	542.47	219.84	201.80	163.04	0.31	1.27	0.31	3.91	7,234	6,548	7,005	25,319	0.0929	0.0854	0.0357	0.0503
2013	603	536	275	1167	2581	562.80	232.52	181.24	151.11	0.27	1.15	0.38	3.86	7,234	6,548	7,005	25,319	0.0834	0.0819	0.0393	0.0461
2014	712	579	228	1084	2603	564.93	229.68	184.67	148.38	0.32	1.26	0.31	3.65	7,234	6,548	7,005	25,319	0.0984	0.0884	0.0325	0.0428
2015	542	456	213	920	2131	564.42	234.48	186.18	151.65	0.24	0.97	0.29	3.03	7,234	6,548	7,005	25,319	0.0749	0.0696	0.0304	0.0363
Avg Annu	653	538	244	1143	2578					0.30	1.19	0.32	3.65					0.0903	0.0821	0.0348	0.0452

Fatal Run-Off-Road Crashes in the State of Ohio, 2010-2015.

Year	Number of Fatal Crashes					HMVM				Fatal Crashes/HMVEM				Edge Miles				Fatal Crashes/edge mile/yr			
	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	TOTAL	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided
2010	78	64	43	172	357	542.90	213.87	200.77	160.82	0.04	0.15	0.05	0.53	7,234	6,548	7,005	25,319	0.0108	0.0098	0.0061	0.0068
2011	97	73	46	186	402	533.50	222.93	198.73	164.73	0.05	0.16	0.06	0.56	7,234	6,548	7,005	25,319	0.0134	0.0111	0.0066	0.0073
2012	95	82	36	215	428	542.47	219.84	201.80	163.04	0.04	0.19	0.04	0.66	7,234	6,548	7,005	25,319	0.0131	0.0125	0.0051	0.0085
2013	61	66	43	208	378	562.80	232.52	181.24	151.11	0.03	0.14	0.06	0.69	7,234	6,548	7,005	25,319	0.0084	0.0101	0.0061	0.0082
2014	74	79	29	194	376	564.93	229.68	184.67	148.38	0.03	0.17	0.04	0.65	7,234	6,548	7,005	25,319	0.0102	0.0121	0.0041	0.0077
2015	74	62	25	159	320	564.42	234.48	186.18	151.65	0.03	0.13	0.03	0.52	7,234	6,548	7,005	25,319	0.0102	0.0095	0.0036	0.0063
Avg Annu	80	71	37	189	377					0.04	0.16	0.05	0.60					0.0110	0.0108	0.0053	0.0075

Serious Injury Run-Off-Road Crashes in the State of Ohio, 2010-2015.

Year	Number of Serious Injury					HMVM				Serious Injury				Edge Miles				Serious Crashes/edge mile/yr			
	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	TOTAL	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided
2010	594	419	203	1037	2253	542.90	213.87	200.77	160.82	0.27	0.98	0.25	3.22	7234	6548	7005	25319	0.0821	0.0640	0.0290	0.0410
2011	621	540	204	1020	2385	533.50	222.93	198.73	164.73	0.29	1.21	0.26	3.10	7234	6548	7005	25319	0.0858	0.0825	0.0291	0.0403
2012	577	477	214	1059	2327	542.47	219.84	201.80	163.04	0.27	1.08	0.27	3.25	7234	6548	7005	25319	0.0798	0.0728	0.0305	0.0418
2013	542	470	232	959	2203	562.80	232.52	181.24	151.11	0.24	1.01	0.32	3.17	7234	6548	7005	25319	0.0749	0.0718	0.0331	0.0379
2014	638	500	199	890	2227	564.93	229.68	184.67	148.38	0.28	1.09	0.27	3.00	7234	6548	7005	25319	0.0882	0.0764	0.0284	0.0352
2015	468	394	188	761	1811	564.42	234.48	186.18	151.65	0.21	0.84	0.25	2.51	7234	6548	7005	25319	0.0647	0.0602	0.0268	0.0301
Avg Annu	573	467	207	954	2201					0.26	1.04	0.27	3.04					0.0793	0.0713	0.0295	0.0377

Fatal and Serious Injury Run-Off-Road Crashes in the State of Washtington, 2010-2017.

Year	Number of KA Crashes					HMVM				KA Crashes/HMVEM				Edge Miles				KA Crashes/edge mile/yr			
	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	TOTAL	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided
2010	68	44	31	153	296	326.39	73.75	108.89	62.88	0.05	0.30	0.07	1.22	2,895	1,115	4,515	9,070	0.0235	0.0395	0.0069	0.0169
2011	69	33	42	162	306	324.94	74.59	107.47	62.54	0.05	0.22	0.10	1.30	2,895	1,115	4,515	9,070	0.0238	0.0296	0.0093	0.0179
2012	60	41	41	100	242	323.63	74.51	107.14	62.34	0.05	0.28	0.10	0.80	2,895	1,115	4,515	9,070	0.0207	0.0368	0.0091	0.0110
2013	81	34	36	98	249	334.57	81.27	100.29	55.98	0.06	0.21	0.09	0.88	2,895	1,115	4,515	9,070	0.0280	0.0305	0.0080	0.0108
2014	75	46	44	124	289	339.92	81.75	103.38	55.55	0.06	0.28	0.11	1.12	2,895	1,115	4,515	9,070	0.0259	0.0413	0.0097	0.0137
2015	91	44	50	111	296	348.23	83.16	107.76	57.38	0.07	0.26	0.12	0.97	2,895	1,115	4,515	9,070	0.0314	0.0395	0.0111	0.0122
2016	75	46	44	124	289	355.75	84.59	111.71	58.12	0.05	0.27	0.10	1.07	2,895	1,115	4,515	9,070	0.0259	0.0413	0.0097	0.0137
2017	91	44	50	111	296	358.44	84.78	112.70	58.28	0.06	0.26	0.11	0.95	2,895	1,115	4,515	9,070	0.0314	0.0395	0.0111	0.0122
Avg Annual	76	42	42	123	283					0.06	0.26	0.10	1.04					0.0263	0.0372	0.0094	0.0135

Fatal Run-Off-Road Crashes in the State of Washtingotn, 2010-2017.

Year	Number of Fatal Crashes					HMVM				Fatal				Edge Miles				Fatal Crashes/edge mile/yr			
	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	TOTAL	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided
2010	11	8	11	43	73	326.39	73.75	108.89	62.88	0.01	0.05	0.03	0.34	2,895	1,115	4,515	9,070	0.0038	0.0072	0.0024	0.0047
2011	17	11	13	37	78	324.94	74.59	107.47	62.54	0.01	0.07	0.03	0.30	2,895	1,115	4,515	9,070	0.0059	0.0099	0.0029	0.0041
2012	18	5	12	29	64	323.63	74.51	107.14	62.34	0.01	0.03	0.03	0.23	2,895	1,115	4,515	9,070	0.0062	0.0045	0.0027	0.0032
2013	22	8	12	28	70	334.57	81.27	100.29	55.98	0.02	0.05	0.03	0.25	2,895	1,115	4,515	9,070	0.0076	0.0072	0.0027	0.0031
2014	14	17	10	41	82	339.92	81.75	103.38	55.55	0.01	0.10	0.02	0.37	2,895	1,115	4,515	9,070	0.0048	0.0152	0.0022	0.0045
2015	27	10	13	38	88	348.23	83.16	107.76	57.38	0.02	0.06	0.03	0.33	2,895	1,115	4,515	9,070	0.0093	0.0090	0.0029	0.0042
2016	13	6	20	41	80	355.75	84.59	111.71	58.12	0.01	0.04	0.04	0.35	2,895	1,115	4,515	9,070	0.0045	0.0054	0.0044	0.0045
2017	29	9	20	29	87	358.44	84.78	112.70	58.28	0.02	0.05	0.04	0.25	2,895	1,115	4,515	9,070	0.0100	0.0081	0.0044	0.0032
Avg Annual	19	9	14	36	78					0.01	0.06	0.03	0.30					0.0065	0.0083	0.0031	0.0039

Serious Injury Run-Off-Road Crashes in the State of Washtington, 2010-2017.

Year	Number of Serious Injury Crashes					HMVM				Serious Injury Crashes/HMVEM				Edge Miles				Serious Crashes/edge mile/yr			
	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	TOTAL	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided	Urban Divided	Urban Undivided	Rural Divided	Rural Undivided
2010	57	36	20	110	223	326.39	73.75	108.89	62.88	0.04	0.24	0.05	0.87	2895	1115	4515	9070	0.0197	0.0323	0.0044	0.0121
2011	52	22	29	125	228	324.94	74.59	107.47	62.54	0.04	0.15	0.07	1.00	2895	1115	4515	9070	0.0180	0.0197	0.0064	0.0138
2012	42	36	29	71	178	323.63	74.51	107.14	62.34	0.03	0.24	0.07	0.57	2895	1115	4515	9070	0.0145	0.0323	0.0064	0.0078
2013	59	26	24	70	179	334.57	81.27	100.29	55.98	0.04	0.16	0.06	0.63	2895	1115	4515	9070	0.0204	0.0233	0.0053	0.0077
2014	59	31	23	59	172	339.92	81.75	103.38	55.55	0.04	0.19	0.06	0.53	2895	1115	4515	9070	0.0204	0.0278	0.0051	0.0065
2015	60	27	30	73	190	348.23	83.16	107.76	57.38	0.04	0.16	0.07	0.64	2895	1115	4515	9070	0.0207	0.0242	0.0066	0.0080
2016	62	40	24	83	209	355.75	84.59	111.71	58.12	0.04	0.24	0.05	0.71	2895	1115	4515	9070	0.0214	0.0359	0.0053	0.0092
2017	62	35	30	82	209	358.44	84.78	112.70	58.28	0.04	0.21	0.07	0.70	2895	1115	4515	9070	0.0214	0.0314	0.0066	0.0090
Avg Annual	57	32	26	84	199					0.04	0.20	0.06	0.71					0.0196	0.0284	0.0058	0.0093

APPENDIX D: RESEARCH NEEDS AND KNOWLEDGE GAPS

D.1 INTRODUCTION

The RDG is an evolving document that must periodically be updated to account for changes in roadside conditions, advances in technology and results of new research. There are always areas in such a document where additional research is needed or where there are gaps in knowledge that need to be filled. Research needs and knowledge gaps in the 2011 RDG were identified by examining the 2011 RDG in detail and examining other projects where research needs and objectives were outlined in order to develop a comprehensive list. The research needs and knowledge gaps identified in this section were obtained from:

- The research team's detailed review of the guidance provided in each chapter of the 2011 RDG.
- The recommendations from NCHRP Project 20-07(360) (Strategic Plan for AASHTO TCRS).
- Needs and gaps identified by NCHRP Project 20-07(383) (Update of the AASHTO Roadside Design Guide).

The first step was to perform a section-by-section review of the 2011 RDG and compile a list of all the specific guidance recommendations. There were 256 specific items of guidance identified in the 2011 RDG as a result of this process. Each item of guidance was categorized as one of the following: design, placement, how-to, maintenance or installation, manufacturing, or operational. In the process of listing the recommendations, research needs and gaps were also identified and noted. Sometimes the RDG itself points out the need for additional research or an insufficient basis for the current recommendations. Other times, the gap or need was apparent based on the source or age of the guidance. In addition to the 256 items of guidance, 42 knowledge gaps and 19 research needs were identified in the 2011 RDG. The complete database of guidance, knowledge gaps and research needs is included at the end of this appendix.

D.2 GUIDANCE

The source of the guidance (e.g., engineering judgement, crash data, computer modeling, etc.) was also determined and included in the table. In many cases the guidance is based on multiple sources (e.g., grading for terminals is based on two FHWA memos (FHWA 2004a; FHWA 2005) and observations of crash tests). A tally of the basis for all 256 items of guidance is shown in Table 66 (note: the sum of all the values is much more than 256 because some guidance use multiple bases). Guidance sources are categorized as was explained above (i.e., engineering judgment, experimental studies, and observational studies) based on references or discussion around the guidance in the RDG. There are times when the basis of some guidance is not explicitly stated, in these cases the research team made a best guess on the basis, usually identifying it as engineering judgement. Additionally, when the RDG references guidance documents such as the MUTCD or AASHTO Green Book, it is categorized as "Other Guidance."

As can be seen using the data Section D.5 (Source Data), the RDG is heavily reliant on engineering judgement since 199 of the 256 guidance recommendations (78 percent) involve at least some degree of engineering judgement. While it is sometimes unavoidable to incorporate engineering judgement, it is preferable to base guidance in the RDG on more quantitative data-

driven research. Guidance that is solely based on engineering judgement should probably be considered a future research need.

Table 66. Tally of basis of guidance in the 2011 RDG.

Engineering Judgement				**Experimental Studies**			**Observational Studies**			Other Guidance Document
Intuition	Consensus	Experience	Site History	Lab Studies	Crash Test	FEA	Crash Data	Observation	GM Proving	
144	34	98	4	4	36	20	21	9	3	25

Table 67was organized to identify the primary guidance for each section or feature (e.g., RDG Figures 3-6 and 3-7 for roadsides slopes and ditches). These particular recommendations generally involve making design decisions about the selection or use of roadside hardware and are therefore most applicable to development of a performance-based design procedure. The 15 primary guidance recommendations are shown in Table 67. These items represent the primary guidance that is most suitable for developing performance based quantitative procedures as described in this projects objectives.

Table 67. Primary guidance in the 2011 RDG.

Section	Table or Figure	Description of Guidance	Type of Guidance	Date	Basis		
					Engineering	Experimental Studies	Observational Studies
3.1	Tab. 3-1	Table of recommended clear zone by speed, ADT, & fore/back slope severity	Design	1966			✓
3.2.4	Fig. 3-6 & Fig. 3-7	Preferred foreslopes and backslopes for basic ditch configurations	Design	1975		✓	
3.4.2.1	¶ 1	Matching the inlet to the foreslope is desirable because it results in a much smaller target for the errant vehicles to hit, reduces erosion problems, simplifies mowing operations and minimizes snagging potential.	Design	1969	✓		
4.3.3	¶ 7	Multi-directional breakaway supports should be used in medians, traffic islands, etc. where impacts from more than one direction are likely	Placement	1969	✓		
4.8	Tab. 4-1	Objectives and strategies for reducing utility pole crashes	Design	Various	✓	✓	✓
4.9	Tab. 4-2	Objectives and strategies for reducing crashes with trees	Design	Various	✓	✓	✓

Table 67. Primary guidance in the 2011 RDG.

Section	Table or Figure	Description of Guidance	Type of Guidance	Date	Basis		
					Engineering	Experimental Studies	Observational Studies
5.6.4	Tab. 5-10	Table of Suggested Runout Lengths for Barrier Design.	Design	2009			✓
6.2	¶ 3, 4, 5 & Fig. 6-1	Figure of Guidelines for Median Barriers on High-Speed, fully controlled-access roadways. 2 paragraphs describing guidance provided in the figure.	Design	2003			✓
6.6.1	¶ All & Fig. 6-18	Figure and text describe guidance for placing median barriers in non-level medians.	Design	1977	✓		
8.3.3.2	¶ 1 & Fig. 8-2 & Fig. 8-3	Grading in the vicinity of a terminal or anchorage.	Design	2002	✓	✓	
8.4.3	Eq. 8-1, 8-2 & 8-3	Conservation of momentum equations applied to a vehicle impacting a series of containers.	Design	1987	✓		
8.4.5.1	¶ 1 & Tab. 8-11	Table with recommendation of the area that should be made available for CC installation.	Design	1970	✓		
9.1.1	Tab. 9-1	Table of example clear zone widths in work-zones by speed.	Design	NA	✓		
9.3.2	Tab. 9-4	Table of suggested priorities for application of protective vehicles & TMAs.	Design	NA	✓		
11.2.3	Tab. 11-1	Table of shoulder or turnout widths suitable to safely accommodate vehicles stopped at a mailbox.	Design	1984	✓		

D.3 KNOWLEDGE GAPS

Knowledge gaps are topics or issues that are not addressed by the RDG although they probably should be. Table 68 displays research needs identified during the research team's examination of the 2011 RDG as well as knowledge gaps identified in NCHRP 20-07(360) and NCHRP 20-07(383). Each source is provided in column 3, while column 2 provides the 2011 RDG chapter number and column 4 provides a brief description of the need. As an example of a knowledge gap, several of the knowledge gaps in Table 68 note that the selection of roadside and median barrier hardware does not address the test levels available in Report 350 or MASH. There is sometimes some overlap between a gap and a need as in this case where the RDG does mention test levels but since it only provides general guidance it is considered here to be a gap rather than a need. Other topics like the performance of roadside hardware for motorcycles or

motor coaches are completely unaddressed in the RDG and are, therefore, treated as gaps. At least six of the 47 gaps that were identified in the 2011 RDG are being or have been addressed by ongoing or recently completed NCHRP research. Several have been noted in NTSB recommendations, TRB AKD20 breakout session and a few have had research needs statements (RNS) developed as noted in Table 68. The AASHTO Technical Committee on Roadside Safety (TCRS) submits the RNS to the AASHTO Subcommittee on Design annually for consideration in developing the NCHRP research program. The descriptions of the knowledge gaps were generally taken directly from the source document (i.e., NCHRP 20-07(360) or NCHRP 20-07(383)) with only minor editorial revision so some of these gaps overlap.

Table 68. Knowledge gaps in the 2011 RDG.

Gap	RDG Section	Source	Description of Knowledge Gap	Related Work
1	5	20-07(360)	Gap: Work recently completed but not implemented - Guardrail test level selection guidelines.	NCHRP R638
2	5	20-07(360)	Gap: Work recently completed but not implemented - Criteria for the Restoration of Longitudinal Barriers, Phase II.	NCHRP 22-28
3	5	20-07(360)	Gap: Work recently completed but not implemented - Design Guidelines for TL3-TL5 Roadside Barrier Systems Placed on Mechanically Stabilized Earth (MSE) Retaining Walls.	NCHRP 22-20(02)
4	5	20-07(360)	Gap: On-going research - Identification of Factors related to Serious Injury and Fatal Motorcycle Crashes into Traffic Barriers.	NCHRP 22-26
5	5		Gap: On-going research - Determine if shielding with longitudinal barriers is needed for a variety of roadside obstacles and terrain features. Determine when the barrier does more harm than good.	NCHRP 15-65
6	5	20-07(360)	Gap with no Currently Planned Research - Evaluate the adequacy of barrier systems currently approved through NCHRP 350 or MASH for safely redirecting commercial passenger vehicles and develop guidelines.	NTSB H-12-26
7	5	20-07(360)	Gap which could be satisfied with existing or pending work and reorganization of RDG - Establish guidelines in the RDG regarding the selection and use of high-performance barriers, including 42" and 50" concrete barriers that are capable of redirecting heavy trucks.	NTSB H-05-31
8	5	20-07(360)	Gap which could be satisfied with existing or pending work and reorganization of RDG - Work with FHWA to establish performance and selection guidelines for state transportation agencies to use in developing objective guidelines for high-performance barriers applicable to new construction and rehabilitation projects.	NTSB H-12-25
9	5	20-07(360)	Gap which could be satisfied with existing or pending work and reorganization of RDG - Once barrier testing has	NTSB H-12-27

Table 68. Knowledge gaps in the 2011 RDG.

Gap	RDG Section	Source	Description of Knowledge Gap	Related Work
			been completed and selection guidelines have been developed, revise Ch. 5 of the RDG to incorporate guidance for the selection of high-performance barriers in new construction and rehabilitation projects.	
10	5	20-07(383)	Gap - Since most agencies are turning their focus to maintenance, rather than new construction, pavement elevations rise with resurfacing. This decreases the relative elevation of the rail, often outside tolerances. The RDG is silent on method to raise the effective height of low guardrails.	
11	5.2.1	20-07(383)	Gap - Address problems resulting from agencies managing antiquated systems built to lower standard than todays. Provide guidance to help address how to bridge these differences in standards.	
12	5.2.1	20-07(383)	Gap - There should be guidance relating to what to do when you can't install hardware the way it was crash-tested. Provide guidance or discussion on how to arrive at the best scenario available.	
13	5.2.4	RDG	Gap - Additional research is being conducted regarding motorcycle interaction with barriers.	
14	5.2.4	20-07(383)	Gap - Roadside hardware and motorcycles. We can report on the state of the practice as we know it based on European standards, but we don't know how the systems perform w/ MASH hardware.	
15	5.5.1	20-07(383)	Gap - How do you take all of the dynamic characteristics of a barrier into account when you are shielding an obstacle? There should be a definition or diagram comparing dynamic deflection and working width.	
16	5.6	20-07(383)	Gap - Guidance on how to measure guardrail height.	
17	5.6.2.1	RDG	Gap - The performance of guardrail terminals behind curbs has not been tested.	
18	5.6.4	20-07(383)	Gap - Need an agreed upon method to calculate the length of need on the inside of curves.	
19	5.6.6	RDG	Gap - Significant R&D has been undertaken to obtain a NCHRP Report 350 system for [short radius guardrail].	
20	5.6.6	20-07(383)	Gap - On-going research - How to accommodate crossroads or driveways in close proximity to bridges?	NCHRP 15-53
21	5.7.1	RDG	Gap - Additional research on this topic is needed (inadequate and damaged/neglected systems).	
22	6	20-07(360)	Gap which could be satisfied with existing or pending work and reorganization of RDG - Upon completion of FHWA testing of standard and high-performance portable	NTSB H-05-32

Table 68. Knowledge gaps in the 2011 RDG.

Gap	RDG Section	Source	Description of Knowledge Gap	Related Work
			concrete median barriers on unpaved surfaces, provide clear guidance in the RDG on the placement of portable concrete barriers on unpaved surfaces.	
23	7	20-07(360)	Gap: Work recently completed but not implemented - Tables for selection of MASH level 2-5 bridge rails.	NCHRP 22-12(03)
24	8	20-07(360)	Gap with no Currently Planned Research - Classification of Crash Cushions.	2013 RNS
25	8	20-07(383)	Gap - Possible new category relating to tension (restrained) terminals.	
26	8.3.6.1	20-07(383)	Gap - Discuss how to calculate LON for a buried-in-backslope terminal for backslopes steeper than 3:1.	
27	8.3.6.2	20-07(383)	Gap - Layout of terminals at the end of flared standard systems. (in-line with the flare, measured off the flare, for flared- or parallel-type terminals, etc.).	
28	8.4.5.6	RDG	Gap - There is limited information of actual repair times and costs for crash cushions.	
29	9	20-07(360)	Gap with no Currently Planned Research - Risk-Based Criteria and Selection Guidelines for Positive Protection in Work Zones.	2013 RNS
30	9	20-07(360)	Gap with no Currently Planned Research - Guidelines for anchoring portable barriers in work zones.	2010 RNS
31	9.2.1	20-07(383)	Gap - Do we use crash-tested working widths, or a risk-based approach based on the products exposure (e.g., PCB on a bridge deck a car could not develop a 25 deg. Trajectory.	
32	9.2.3	20-07(383)	Gap - the application of water-filled barriers, particularly as it relates to interfacing stiffer barriers. Same applies to water-filled terminals as well.	
33	9.4	RDG	Gap - Large trailer-mounted devices (arrow panels, variable message signs, and temporary traffic signals): Crash-worthiness criteria have not been established for devices in this category.	
34		20-07(360)	Gap with no Currently Planned Research - Development of plan/guidelines to improve roadway and roadsides for motorcyclists.	2010 RNS
350		20-07(360)	Gap with no Currently Planned Research - Guidelines for Design of Roadway and Roadside Features to Accommodate Automated Vehicles.	2013 RNS
36		20-07(360)	Gap which could be satisfied with existing or pending work and reorganization of RDG - Work with FHWA to develop and implement criteria based on traffic patterns passenger volume and bus types that can be used to assess	NTSB H-09-08

Table 68. Knowledge gaps in the 2011 RDG.

Gap	RDG Section	Source	Description of Knowledge Gap	Related Work
			the risks of rural travel by large busses.	
37		20-07(360)	Gap which could be satisfied with existing or pending work and reorganization of RDG - There are many instances within the RDG which indicate engineering judgement is necessary, but there is no specific guidance offered for applying the judgement. If we cannot install the ideal solution, should we quantify...	Breakout Sessions
38		20-07(360)	Gap which could be satisfied with existing or pending work and reorganization of RDG - Low cost/low volume roadways, objective criteria for urban roadsides, and new technologies.	Breakout Sessions
39	9.2.1.2.16	RDG	Gap - Anchoring PCB to the traveled way; Although these installations are in common use, only limited crash testing of these have been done.	
40		20-07(383)	Gap - RSAP chapter in the RDG.	
41		20-07(383)	Gap - More guidance on TL-2 hardware.	
42	5.1	RDG	Gap - Develop specific guidelines for when highway agencies should upgrade existing barriers as part of new or reconstruction projects, 3R projects or when a system is damaged beyond repair.	
43	5.6	20-07(383)	Gap - Placing tangent designed hardware on curves.	

Some of the knowledge gaps listed in Table 68 would be directly and almost immediately addressed by the methodology developed in this research including:

- Decision to use longitudinal barrier for shielding particular obstacles (Gap 5).
- Test level selection criteria for guardrails (Gap 1, 7, 8, 9, 23, and 41).
- Barriers for low volume roads and urban areas (Gap 38).
- Instructions for using RSAP in RDG (Gap 40).

Other knowledge gaps could be address with the methodology in this research, but additional data would be required to develop the guidance. These gaps include:

- Criteria for repair or upgrading barrier (Gap 2, 10, 11, 21, and 42).
- Barriers to accommodate motorcycles (Gap 4, 13, 14, and 34).
- Barriers accommodate commercial vehicles and motor coaches (Gap 6 and 36).
- Use and placement of barriers in non-ideal situations (Gap 12 and 37).
- Use and placement of barriers in work zones (Gap 29 and 31).

As this list illustrates, a safety-performance based design methodology would help to structure future research and implementation of research into the RDG.

D.4 RESEARCH NEEDS

Research needs are topics and issues that are addressed in the RDG but need to be reassessed either due to the age of the original research, changes in vehicle or barrier technology or the availability of need research methods to address the need. Like the descriptions of the knowledge gaps, the research needs descriptions were generally taken directly from the source documents (i.e., NCHRP 20-07(360) or NCHRP 20-07(383)) with only minor editorial revision so some of these gaps overlap. The list of 19 research needs identified in this project are presented in Table 69.

Table 69. Research needs in the 2011 RDG.

Need	Section	Source	Description of Research Need	Related Work
1	2	20-07(360)	Need: Work recently completed but not implemented - The Roadside Safety Analysis Program (RSAPv3) Update.	NCHRP 22-27
2	3	20-07(360)	Need: On-going research - Guidelines for Cost-effective Safety Treatment of Roadside Ditches.	NCHRP 16-05
3	3	20-07(360)	Need: On-going research - Development of Clear Recovery Area Guidelines.	NCHRP 17-11(02)
4	3	20-07(360)	Need: On-going research - Guidelines for Slope Traversability.	NCHRP 17-55
5	3.1	20-07(383)	Need - Push the forgiving roadside concept more. Show RSAP example of improved safety when removing specific roadside features.	
6	5	20-07(360)	Need: Work recently completed but not implemented - Selection, Use, and Maintenance of Cable Barrier Systems.	NCHRP R711
7	6	20-07(360)	Need: Covered by recently initiated research - Median barrier selection and placement guidelines.	NCHRP 22-31
8	6.6.1.3	RDG	Need - Placement criteria for median barriers on this cross-section are not clearly defined.	NCHRP 22-31
9	6.6.1.3	RDG	Need - Figure and text describe guidance for placing median barriers in non-level medians.	NCHRP 22-31
10	5.5.1	20-07(383)	Need - Better design guidance on pier shielding height for LRFD. ZOI and potential damage that can occur to piers when tall vehicles impact the barrier.	NCHRP 12-90
11	5.5.2	RDG	Need - Significant research is needed to develop more specific criteria for the use of this tall barrier for pier protection.	NCHRP 12-90
12	5.6.1		Need - Guidance is based on very old, very limited research. Shy-line offsets at different design speeds should be reassessed with new data.	
13	5.6.2	RDG	Need - Limited studies and computer simulations have provided some information on the dynamic behavior	

Table 69. Research needs in the 2011 RDG.

Need	Section	Source	Description of Research Need	Related Work
			and trajectories of vehicles traversing curbs or slopes.	
14	5.6.3		Need - Guidance is based on very old, very limited research. Table of Suggested Flare Rates for Barrier Design should be re-examined with new data.	
15	5.6.4		Need - Guidance is based on very old, very limited research. Table of Suggested Runout Lengths for Barrier Design should be re-examined with new data and methods.	
16	6.2	20-07(383)	Need - Optimizing median width and hardware in medians. Discussion of ADT vs crash experience.	
17	6.6.1.1	RDG	Need - Maximum redirection can be achieved if the area 1'-8' from ditch line on 1V:6H is avoided.	
18	6.6.1.1	RDG	Need - Quantify possible placement concerns when a rigid or semi-rigid barrier is located on one side of a traversable, sloped median.	
19	2	20-07(360)	Need: Work recently completed but not implemented - The Roadside Safety Analysis Program (RSAPv3) Update.	NCHRP 22-27

Some of the research needs listed in Table 69 would be directly and almost immediately used in the methodology developed in this research including:

- Guidelines for ditches (Need 2 and 17).
- Clear zone guidelines (Need 3 and 5).
- Guidelines for slope traversability (Need 4).
- Selection and placement guidelines for median barriers (Need 6, 7, 8, 9, 16, and 18).
- Guidelines for shielding bridge pier shielding (Need 10 and 11).
- Include RSAP in the RDG (Need 1 and 19).

Other research needs provide much needed updated information that could be used in the use of the safety-performance guidelines, including:

- New research to verify and update shy line offset table (Need 12).
- Placement of curbs in conjunction with barriers and slopes (Need 13).
- New research to verify and update flare rates table (Need 14).
- New research to verify and update run-out-length table (Need 15).

As this list illustrates, many of the already-identified research needs can be readily incorporated into the safety-performance based methodology developed in this research project. Five specific research needs statements shown in the following sections were developed in this project and forwarded to AASHTO Technical Committee on Roadside Safety and the TRB AKD20 Roadside Design Committee.

Research Need Statement #1

1. **Problem Title**
   Development of a Self-Calculating Workbook for Assessing Roadside and Median Risk
2. **Background**
   NCHRP 15-65 (Development of Safety Performance Based Design Guidelines for the Roadside Design Guide) established a new approach to roadside design which provides a consistent means to estimate the risk of a fatal or serious injury crash for roadside and median designs. The method is an encroachment-based model similar to that currently programed in RSAPv3 but instead of plotting and evaluating thousands of trajectories, a group of trajectories is treated as a statistical entity such that calculations can be based on the cumulative probability density functions of the lateral and longitudinal extents of encroachment. New models have also been developed to represent vehicles rolling over on terrain using the statistical properties of the trajectories. Incorporating these new models into a self-calculating workbook would make risk assessment of roadside and median design much quicker and result in more engineers implementing performance-based roadside designs.
3. **Literature Search Summary**
   The Roadside Safety Analysis Program (RSAP) was updated in 2012 in NCHRP 22-27. A risk-based module was added to RSAPv3 in NCHRP 22-12(03) (Recommended Guidelines for the Selection of test Levels 2 through 5 Bridge Railings) in 2014. One of the limitations of all previous versions of RSAP was the way the trajectories of encroaching vehicles were used. RSAP 2.0.3 assumed all trajectories were straight line extensions of the encroachment conditions and used a Monte Carlo simulation method to plot tens of thousands of trajectories. RSAPv3 improved on this by using almost 900 trajectories obtained from real-world crashes to account for driver input. Both approaches, however, relied on plotting tens of thousands of trajectories on the hypothetical roadside and looking for intersections with roadside features. Plotting and evaluating all these trajectories made RSAP slow and cumbersome to use since it required significant computational time especially for more complicated roadside or median designs. NCHRP 15-65 (Development of Safety Performance Based Design Guidelines for the Roadside Design Guide) replaced this computationally intensive method with a much more efficient method where a group of trajectories is considered as a statistical quantity. This means the statistics of the trajectory group are used rather than plotting and evaluating each individual trajectory. The resulting method is much faster and more easily used in computations.
4. **Research Objectives**
   The objective of this proposed research will be to develop self-calculating workbook that can be used by highway agency engineers and their consultants to assess the risk of and benefit-cost of alternative roadside and median designs. The alternative resulting in the lowest risk and/or highest benefit-cost can then be selected for implementation.
5. **Urgency and Potential Benefits**
   NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide) developed a new risk-based safety performance design method for

evaluating roadside designs. Providing design tools that engineers can use to adopt performance-based design approaches will help to identify the designs with the least risk and highest potential to improve roadside safety.

6. **Implementation Considerations and Supporters**

   Having a self-calculating workbook for assessing roadside and median designs would provide a valuable design tool for engineers seeking to minimize the risk of fatal and serious injury run-off-road crashes. The resulting workbook could be incorporated into updates of the Roadside Design Guide in much the same way that RSAP was included formerly as Appendix A. Design guidance has already been developed for the Roadside Design Guide using the roadside risk assessment method. A stand-alone tool would allow engineers to examine more detailed designs using the same method used to develop general guidance in the Roadside Design Guide.

7. **Recommended Research Funding and Research Period**

Research Funding:	$300,000
Implementation Funding:	$50,000 (training)
Research Period:	24 months

8. **Problem Statement Authors**

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9. **Potential Sponsoring Committees**

   TRB AKD20 (Roadside Safety Design)
   AASHTO TCRS (Technical Committee on Roadside Safety)

10. **Index Terms**

    Roadside design, Roadside Safety Analysis Program, RSAP, guardrail, bridge railing, median barrier, heavy vehicles, run off road crashes, crash testing.

Research Need Statement #2

1. **Problem Title**
   Modelling the Probability of Longitudinal Barrier Breach
2. **Background**
   While longitudinal barriers like guardrails and bridge railings are generally very effective in containing and redirecting vehicles there is always a small probability of a vehicle breaching the barrier. A barrier can be breached by penetrating through it, vaulting, or rolling over it, or under riding it. Sometimes the breach is a result of a larger vehicle exceeding the structural capacity of the barrier or rolling over the barrier as is the case for truck impacts with test level three barriers. In other cases, even the design vehicle may occasionally breach the barrier due to extreme impact conditions. Sometimes passenger vehicles may underride cable median barriers or w-beam barriers especially when the vehicle is not tracking. Another example of breaching with a design vehicle is when passenger vehicles vault over rigid concrete barriers at small impact angles. Quantifying these breach events is important because when the barrier is breached the vehicle will be exposed to the hazardous situation that the barrier was shielding the vehicle from. For example, breaching a bridge rail results in falling off the bridge endangering those in the area below and penetrating a median barrier may allow a vehicle to enter the opposing lanes of traffic and become involved in a cross-median crash. A better understanding of how often vehicles breach longitudinal barriers and the nature of those breaches will allow designers to better quantify the risks of serious and fatal crashes involving longitudinal barriers.
3. **Literature Search Summary**
   There is relatively little prior research on establishing the probability of barrier breach. Mak examined the issue with respect to bridge railings using crash statistics over 40 years ago but bridge railing design and testing standards have changed dramatically since that time. Ray and others examined cable barrier breach events involving passenger vehicles in 11 States and found that 10 percent or less of passenger vehicle crashes with cable median barrier resulted in penetrations. Gabler performed a study on metal beam median barriers in New Jersey and Ray examined concrete median breaches on the New Jersey Turnpike. Each of these studies examined a particular barrier being struck by a particular class of vehicles. What is needed, however, is a comprehensive assessment of the probability of breaching all barrier types and test levels of barrier when struck for all vehicle types, even those vehicles outside the design parameters of the barrier.
4. **Research Objectives**
   The objective of this proposed research will be to develop statistical models of the probability of breaching test level two through five longitudinal barriers as a function of barrier and vehicle type as well as test level. These models will be used to enhance risk-based roadside design procedures developed in NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide).
5. **Urgency and Potential Benefits**
   NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide) developed a new risk-based safety performance design method for

evaluating roadside designs. The results of this project can be directly implemented into the current method by updating the current simplified model. Updating the breach prediction will improve the accuracy and reliability of the design method.

6. **Implementation Considerations and Supporters**

   Probability models of barrier breaching can be used to update, expand and improve the risk-based design evaluation procedures developed in NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide). One of the key parameters is the probability of a barrier breach as a function of barrier and vehicle types and test levels. Estimating this probability is a key aspect of test level selection for median barriers and bridge railings in particular. The NCHRP 15-65 risk-based design method was developed for inclusion in an update to the Roadside Design Guide.

7. **Recommended Research Funding and Research Period**

Research Funding:	$400,000
Implementation Funding:	$50,000
Research Period:	54 months (36 months data collection)

8. **Problem Statement Authors**

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9. **Potential Sponsoring Committees**

   TRB AKD20 (Roadside Safety Design)
   AASHTO TCRS (Technical Committee on Roadside Safety)

10. **Index Terms**

    Roadside design, guardrail, bridge railing, median barrier, heavy vehicles, run off road crashes, crash testing.

Research Need Statement #3

1. **Problem Title**
   Risk-Based Assessment of Barrier Need for Terrain Features
2. **Background**
   One of the most common reasons for installing guardrails is to shield vehicles from roadside slopes and ditches. The guidelines for shielding slopes and terrain features in the Roadside Design Guide are based on very old research and the need to update these recommendations has been apparent for many years. There is no recent research on shielding the various ditch combinations, however, NCHRP 22-31 recently completed an update for fill slopes free of other obstacles. Similarly, there has never been an assessment of the risk of traversing cut slopes. While rollovers on slopes and in roadside and median ditches are certainly hazardous, collisions with guardrails and guardrail terminals can also be hazardous. Guardrail should only be used to shield terrain features when the likelihood of a serious or fatal crash on the terrain feature is greater than that of striking the guardrail. Determining a realistic probability of a roll over crash on a terrain features is vital to determining whether shielding with a guardrail diminishes or increases the risk of a fatal or serious injury crash.
3. **Literature Search Summary**
   There is a long history of crash statistics research and simulated vehicle trajectories research on slopes going back over 50 years. The RDG cites research conducted in 1971 by Michie and Bronstad and reported in NCHRP Report 118. A review of Report 118 indicates that the slope warrant dates further back to work performed in California in 1967. The commentary in Report 118 states that "the warrant curve for embankment slope versus height has not been revised, although many people have suggested that a revision is in order."

   While the need to re-examine this curve was noted almost 50 years ago, it has remained an important but unexamined feature of the RDG to the present time. Even the original researchers have pointed out that the results are confounded by uncertain data, fixed objects placed on slopes and small samples sizes. Additionally, it is undeniable that the vehicle fleet has changed dramatically since 1975 when the original slope traversability research was performed. Zegeer *et al.* concluded in 1987 when studying the effect of using guardrail for various sideslopes that the presence of guardrail "had no discernible effect on … rollover accidents or on accident severity for various levels of sideslope or recovery distance."

   Recent researchers like Glennon, Tamburri, Zegeer and Carrigan have independently noted that the Roadside Design Guide recommendations for slope shielding need to be re-examined. Several on-going or recently completed research projects examined vehicle trajectories on slopes and through ditches using the vehicle trajectory simulation program CarSim. NCHRP 16-05 (Guidelines for Cost-Effective Safety Treatments of Roadside Ditches) has explored vehicle traversing ditches and NCHRP 17-55 (Guidelines for Slope Traversability) has examined vehicle stability on slopes. These studies have resulted in

simulations of tens of thousands of trajectories that could be used to develop statistical models of the probability of rollover for a wide range of terrain features. The simulated trajectories produce a far richer range of data than can ever be obtained by examining crash data alone. These computer simulations can be used to develop a model which can be incorporated into the NCHRP 15-65 risk-based method for roadside design to predict lateral extent of encroachment and rollover.

4. **Research Objectives**

   The objective of this study is to use the results of existing vehicle trajectory simulations and crash data to develop statistical models of the probability of rolling over on a wide range of terrain features including roadside and median ditches and cut slopes. The resulting models will be used to update, expand, and improve the risk-based design evaluation procedures developed in NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide).

5. **Urgency and Potential Benefits**

   Terrain features like ditches are some of the most common roadside features shielded by guardrail. Making better, more data-driven decisions about when to use guardrail in these situations is critical to minimizing the risk of fatal and serious injury crashes. This proposed research will help enable roadside designers to put guardrails where it is most needed and avoid putting it in places where it will do more harm than good.

6. **Implementation Considerations and Supporters**

   NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide) developed a new risk-based safety performance design method for evaluating roadside designs which is being considered for inclusion in an update to the Roadside Design Guide. The researchers used simulated trajectories from NCHRP 17-55 (Guidelines for Slope Traversability) to model the probability of rollover on roadside slopes using survivability analysis. The same approach holds great promise for modeling other terrain features like ditches and cut slopes. The results of this project can be directly implemented into the current method thereby improving the accuracy and reliability of the design method.

7. **Recommended Research Funding and Research Period**

Research Funding:	$350,000
Implementation Funding:	$50,000
Research Period:	36 months

8. **Problem Statement Authors**

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9. **Potential Sponsoring Committees**

   TRB AKD20 (Roadside Safety Design)
   AASHTO TCRS (Technical Committee on Roadside Safety)

10. **Index Terms**

    Roadside design, guardrail, slopes, ditches, rollover, run off road crashes, crash data, computer simulation.

Research Need Statement #4

1. **Problem Title**
   Risk-Based Roadside Barrier Layout Recommendations
2. **Background**
   Guardrails are often used to shield vehicles from collisions with fixed roadside objects like poles, bridge piers, trees, and luminaires. The guardrail layout information used in the Roadside Design Guide dates back over 45 years to an informal approach developed for what would become the 1977 Barrier Guide. This approach introduced now-common layout variables like length of need, runout length, shy-line offset and flare rate to the roadside designer's vocabulary. The method was based on limited data that was available at the time, engineering judgement and broad assumptions. Today there is more information available to use in testing the assumptions and basis for the layout procedures. Several databases of real-world trajectories and the Naturalistic Driving Study are available and there is much more crash data available. The need for improving the guardrail layout procedures has been recognized by the roadside design community for some time and several recent research efforts have noted that the current procedures may not balance the risk of guardrail collisions to the risk of the unshielded collisions appropriately. The risk-based method developed in NCHRP 15-65 based the need for shielding fixed objects on tangent guardrail installations. This research would extend the method to account for flared installations and the whole range of layout parameters needed to design the guardrail installation for a particular site.
3. **Literature Search Summary**
   In 1974 Hatton developed the barrier layout method that is still used to this day. Hatton documented his method in a never-published internal FHWA paper where Hatton himself stated "there is no intention to imply that this approach is necessarily the correct approach". The runout length aspects of Hatton's method were the subject of vigorous debate in the roadside safety community 20 years ago. More recently, Johnson and Gabler examined the runout length issue using real-world trajectory data and found that the Roadside Design Guide approach intercepted between 80 and 90 percent of errant vehicle trajectories. Some key variables like shy line offset have never been validated or verified for modern vehicles or traffic. Runout length has been debated often and the current recommendations are based on speed and traffic volume rather than the geometry of the site. NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide) developed a risk-based method for assessing the need for shielding fixed objects using longitudinal barrier. The same method should be used to develop improved barrier layout procedures.
4. **Research Objectives**
   The objective of this research is to develop a risk-based guardrail layout method that balances the risk of fatal or serious injury crash involving a guardrail and terminal to the risk of a fatal or serious injury crash with the un-shielded features.
5. **Urgency and Potential Benefits**
   Fixed objects like poles, trees, bridge piers, large sign supports, and luminaires are some of the most common roadside features shielded by guardrails. Making better, more data-

driven decisions about how to layout a longitudinal barrier to most effectively shield fixed objects is critical to minimizing the risk of fatal and serious injury crashes.

6. **Implementation Considerations and Supporters**

   NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide) developed a new risk-based safety performance design method for evaluating roadside designs for inclusion in an update to the Roadside Design Guide. A method for assessing barrier need to shield fixed objects has already been developed using this method. The proposed research would enhance the design procedures and could be directly implemented in a future edition of the Roadside Design Guide.

7. **Recommended Research Funding and Research Period**

   Research Funding: $100,000
   Research Period: 12 months

8. **Problem Statement Authors**

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9. **Potential Sponsoring Committees**

   TRB AKD20 (Roadside Safety Design)
   AASHTO TCRS (Technical Committee on Roadside Safety)

10. **Index Terms**

    Roadside design, guardrail, terminal, fixed objects, run off road crashes.

Research Need Statement #5

1. **Problem Title**
   Risk-Based Work Zone Clear Zone Recommendations
2. **Background**
   The Roadside Design Guide integrates the clear zone concepts used for permanent roadside hardware installations into the design of work zones in Chapter 9. While the general clear zone concept is similar, it is largely based on engineering judgement, experience and intuition rather than a systematic assessment of risks. NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide) developed a new risk-based safety performance design method for evaluating roadside designs. The method can be extended to address work zone clear zone recommendations by modifying encroachment, trajectory, and crash severity models to account for the special circumstances of work zones. The currently ongoing NCHRP 17-88 (Roadside Encroachment Database Development and Analysis) project will produce data that can be used to develop guidelines for positive protection in work zones.
3. **Literature Search Summary**
   Most of the literature cited in Chapter 9 of the Roadside Design Guide refers to crash testing of temporary barriers and work zone traffic control devices. There are no references to the risk to workers and vehicle occupants of different work zone layouts or designs. One of the few attempts to quantify risk associated with work zone designs was by Porter. Porter used RSAP to evaluate layout options using a benefit-cost approach. Porter has updated his work using the new RSAPv3 in a not-yet-published FHWA study.
4. **Research Objectives**
   The objective of this proposed research is to develop risk based clear zone guidelines for work zones. The guidelines should account for the traffic conditions anticipated, the space required for work zone activities and possible shielding alternatives.
5. **Urgency and Potential Benefits**
   NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide) developed a new risk-based safety performance design method for evaluating roadside designs that should be extended to work zone. Doing so would make work zone clear zone recommendations more quantitative and data-driven and less subjective. Making better decisions about work zone layouts will help minimize deaths and serious injuries of both workers and vehicle occupants.
6. **Implementation Considerations and Supporters**
   The results of this research can be directly implemented in a future edition of the Roadside Design Guide and used to improve and extend the NCHRP 15-65 (Development of Safety Performance Based Guidelines for the Roadside Design Guide) risk-based roadside design method.
7. **Recommended Research Funding and Research Period**

Research Funding:	$300,000
Implementation Funding:	$50,000
Research Period:	36 months

8. **Problem Statement Authors**

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9. **Potential Sponsoring Committees**

   TRB AKD20 (Roadside Safety Design)
   AASHTO TCRS (Technical Committee on Roadside Safety)

10. **Index Terms**

    Work zone safety, work zone traffic control plans, roadside design, work zone crashes

D.5 SOURCE DATA

The following table is the full listing of the results of the effort to identify and categorize guidance in the RDG. Column definitions are as follows:

Section:	Section in which the guidance is discussed in the 2011 RDG.
Table/Figure/Paragraph:	Identifies the figure, table or paragraph number of the section where the guidance is presented in the 2011 RDG. The NCHRP project where the research needs and knowledge gap were identified is also listed in this column.
Section Title:	Title of the section in which the guidance is discussed.
Description of Guidance:	Brief description of the figure or table that contains the guidance or a synopsis/transcription of the text.
Reference:	Indicates if the guidance is supported by a reference to literature or research.
Type of Guidance:	Describes what kind of guidance it is or if it is a research need or knowledge gap.
Date:	Indicates when the research to support the guidance was performed. Blanks indicate the date is unknown.
Basis of the Guidance:	Indication of the basis for the guidance. In some cases (particularly when no research is referenced) the researchers have made assumption in this category.

Section	Table, Figure, or Paragraph	Source	Section Title	Description of Guidance	Reference or Related Work	Type of Guidance	Basis of Guidance			
							Dates From …	Engineering Judgement	Observational Studies	Experimental Studies
		20-07(383)		Gap: RSAP chapter in the RDG.		Gap				
2		20-07(360)	Economic Evaluation of Roadside Safety	Need: Work recently completed but not implemented - The Roadside Safety Analysis Program (RSAPv3) Update.	NCHRP 22-27	Need				
3		20-07(360)	Roadside Topography and Drainage Features	Need: On-going research - Guidelines for Cost-effective Safety Treatment of Roadside Ditches.	NCHRP 16-05	Need				
3		20-07(360)	Roadside Topography and Drainage Features	Need: On-going research - Development of Clear Recovery Area Guidelines.	NCHRP 17-11(02)	Need				
3		20-07(360)	Roadside Topography and Drainage Features	Need: On-going research - Guidelines for Slope Traversability.	NCHRP 17-55	Need				
3.1	Tab. 3-1		The Clear-Zone Concept	Table of recommended clear zone by speed, ADT, and fore/back slope.	No	Design	1966		1	
3.1		20-07(383)	The Clear-Zone Concept	Need: Push the forgiving roadside concept more. Show RSAP example of improved safety when removing specific hazards.		Need				
3.1	Tab. 3-2		The Clear-Zone Concept	Table of horizontal curve adjustment factor to clear-zone by radius and speed	No	Placement				
3.2.1	¶ 3		Foreslopes	If a foreslope steeper than 1V:3H begins closer to the edge of the traveled way than the suggested CZ distance for that specific roadway, a barrier might be recommended if the slope cannot be flattened.	No	Placement	NA	1	1	1
3.2.2	¶ 1		Backslopes	A steep rough-sided rock cut normally should begin outside the CZ or be shielded.	No	Placement	NA	1		
3.2.3	¶ 2 & Fig. 3-4		Transverse Slopes	Transverse slopes of 1V:10H are desirable… Transverse slopes of 1V:6H are suggested for high-speed roadways, particularly for the section of the transverse slope that is located immediately adjacent to traffic.	Y(7,3)	Design	1962	1	1	
3.2.4	Fig. 3-6 Fig. 3-7		Drainage Channels	Preferred foreslopes and backslopes for basic ditch configurations.	Y(14)	Design	1975			1
3.3.1	¶ 1		Recoverable Foreslopes	It is desirable to have the top of the slope rounded so an encroaching vehicle remains in contact w/ the ground.	Y(14)	Design	1975			1
3.3.2	¶ 1		Non-Recoverable Foreslopes	Clear-zone suggestions for partially non-recoverable foreslopes.	No	Design	NA	1		
3.3.4	¶ 1		Example of Clear-Zone Application on Variable Slopes	Clear-zone distances for embankments w/variable foreslopes ranging from essentially flat to 1V:4H may be averaged to produce a composite clear-zone distance. Slopes that change from fore to backslopes cannot be averaged and should be treated as drainage channel sections.	No	How-To	NA	1		
3.3.5	¶ 1		CZ Application for Drainage cha…	Roadside hardware should not be located in or near ditch bottoms or on the backslope near the drainage channel.	Y(14)	Placement	1975			1
3.3.6	¶ 2		Clear Zone for Auxiliary Lanes and Freeway Ramps	Clear-zone distance for ramps and transition curves of 1000' or greater should be determined from Ch. 3 "ASHTO: A Policy on Geometric Design for Highways and Streets."	Yes(4)	How-To	NA			
3.4.1	¶ 3		Curbs	When obstructions exist behind curbs, a minimum lateral offset of 3' should be provided… A minimum lateral offset of 1.5' should be used elsewhere.	Y(4)	Design	NA			
3.4.1	¶ 2		Curbs	In general, curbs are not desirable along high-speed roadways.	Y(9)	Placement	1974			1
3.4.1	¶ 3		Curbs	On new construction… fixed objects should be located…. in no case closer than 1.5' from curb.	Y(4)	Placement	NA			
3.4.2.1	¶ 1		Traversable Designs	Matching the inlet to the foreslope is desirable because it results in a much smaller target for the errant vehicles to hit, reduces erosion problems and simplifies mowing operations.	No	Design	1969	1		
3.4.2.1	Fig. 3-8		Traversable Designs	Specifies span length and pipe runner ID to make culverts traversable.	Y(12)	Placement	2008			1
3.4.3.2	¶ 1 Fig. 3-10		Traversable Designs	Grates consisting of pipes set on 24 in centers will significantly reduce wheel snagging. It is also recommended that the center of the bottom bar or pipe be set at 4-8" above culvert inlet.	No	Maint/Install	NA	1		
3.4.3.2	¶ 2		Traversable Designs	Single pipes with diameters of 24" or less will not require a grate.	Y(11)	Maint/Install				
3.4.4	¶ 2		Drop Inlets	No portion of the drop inlet should project more than 4 in above the ground line.	Y(10)	Design	1981	1		1
4.1	¶ 4		Acceptance Criteria for Breakaway Supports	Pendulum tests results for impacts at 22 mph may be extrapolated to predict 62 mph impact behavior, providing the support breaks free with little or no bending in the support.	No	How-To	NA	1		1
4.2	¶ 3		Design & Location Criteria for Breakaway & Non-Breakaway Supports	(3) establishes a maximum stub height of 4" to lessen the possibility of snagging the undercarriage of a vehicle after a support has broken away from its base and minimize vehicle instability if a wheel hits the stub.	Y(3)	Design	NA			
4.2	¶ 5		Design & Location Criteria for	It is critical that breakaway supports not be located near ditches, on steep slopes or where a vehicle is likely to be partially	No	Placement	NA	1		
4.3.2	¶ 3		Large Roadside Sign Supports	Slotted plates may be used on both sides of the post if impacts are expected from either direction.	No	Maint/Install	NA	1		
4.3.2	¶ 4		Large Roadside Sign Supports	The use of keeper plates is recommended to retain the clamping bolts even if the connection relaxes over time.	No	Maint/Install	NA	1		
4.3.2	¶ 5		Large Roadside Sign Supports	RE: perforated fuse plate: Because this design does not require its connections to be torqued to a specific value, it is relatively fail-safe and recommended for use in lieu of slotted fuse plates.	No	Maint/Install	NA	1		
4.3.2	Bullet 1		Large Roadside Sign Supports	The hinge should be >7' above ground so that no portion of the sign or upper section of the support is likely to penetrate the windshield of an impacting vehicle.	No	Manufacturer	NA	1		1
4.3.2	Bullet 2		Large Roadside Sign Supports	A post spaced with a clear distance of 7' from another post should have mass <44 lb./ft. The total mass below the hinge but above the shear plate of the breakaway base should not exceed 600 lbs. For 2 posts spaced <7', each post should have a mass <18 lb./ft.	No	Operational	NA	1		
4.3.3	¶ 2		Small Roadside Sign Supports	A steel plate measuring 4"x12"x.25" may be welded or bolted to the pipe support to prevent twisting from wind.	No	Maint/Install	NA	1		
4.3.3	¶ 3		Small Roadside Sign Supports	Diagonal bracing of a sign support should be avoided.	No	Maint/Install	NA	1		
4.3.3	¶ 4		Small Roadside Sign Supports	For single post w/ bending or yielding characteristics, the sign panels should be bolted w/ oversized washers to prevent the panel from separating on impact and penetrating a windshield.	No	Maint/Install	NA	1		
4.3.3	¶ 8		Small Roadside Sign Supports	The use of keeper plates is recommended to prevent the clamping bolts from walking under wind loads	No	Maint/Install	NA	1		
4.3.3	¶ 7		Small Roadside Sign Supports	Multi-directional breakaway supports should be used in medians, traffic islands, etc. where impacts from more than one direction are likely.	No	Placement	1969	1		
4.3.3	¶ 6		Small Roadside Sign Supports	Neither horizontal or inclined slip base designs should be used in medians, traffic islands or where impacts from more than one direction are possible.	No	Placement	NA	1		
4.4	¶ 1		Multiple Post Support for Signs	All breakaway supports having a clear distance of < 7' are considered to act together.	No	How-To	NA	1		
4.5.1	¶ 3		Breakaway Luminaire Supports	The height of poles w/ breakaway features should not exceed 60'.	No	Manufacturer	NA	1		
4.5.1	¶ 3		Breakaway Luminaire Supports	The mass of a breakaway luminaire support should not exceed 1,000 lbs.	No	Manufacturer	NA	1		
4.5.1	¶ 6		Breakaway Luminaire Supports	The electricity in the support should disconnect as close to the foundation as possible.	No	Manufacturer	NA	1		
4.5.1	¶ 7		Breakaway Luminaire Supports	If the support (is) within the design deflection distance of the barrier, it should be a breakaway design or the railing should be stiffened locally to minimize the resultant deflection.	No	Placement	NA	1		
4.7.1	¶ 1		Railroad Crossing Warning Dev	A longitudinal barrier is not used because there is seldom sufficient space for an end treatment and a longer obstacle is created by installing a guardrail, and a vehicle striking a barrier when a train is occupying the crossing may be redirected into the train.	No	Placement	NA	1		
4.8	Tab. 4-1		Utility Poles	Objectives and strategies for reducing utility pole crashes.	Y(8)	Design	Various	1	1	1
4.9	Tab. 4-2		Trees	Objectives and strategies for reducing crashes with trees.	Y(8)	Design	Various	1	1	1
4.9	¶ 2		Trees	Large trees should be removed from within the selected clear zone for new construction.	No	Design	NA	1		
4.9	¶ 9		Trees	Roadside barriers should only be used when the severity of striking the tree is > striking the barrier	No	Placement	NA	1		
5		20-07(360)	Roadside Barriers	Gap: Work recently completed but not implemented - Guardrail test level selection guidelines.	NCHRP R638	Gap				
5		20-07(360)	Roadside Barriers	Gap: Work recently completed but not implemented - Criteria for the Restoration of Longitudinal Barriers, Phase II.	NCHRP 22-28	Gap				
5		20-07(360)	Roadside Barriers	Gap: Work recently completed but not implemented - Design Guidelines for TL3-TL5 Roadside Barrier Systems Placed on Mechanically Stabilized Earth (MSE) Retaining Walls.	NCHRP 22-20(02)	Gap				

Section	Table, Figure, or Paragraph	Source	Section Title	Description of Guidance	Reference or Related Work	Type of Guidance	Basis of Guidance: Dates From …	Basis of Guidance: Engineering Judgement	Basis of Guidance: Observational Studies	Basis of Guidance: Experimental Studies
5		20-07(360)	Roadside Barriers	Gap: On-going research - Identification of Factors related to Serious Injury and Fatal Motorcycle Crashes into Traffic Barriers.	NCHRP 22-26	Gap				
5		20-07(360)	Roadside Barriers	Gap with no Currently Planned Research - Evaluate the adequacy of barrier systems currently approved through NCHRP 350 or MASH for safely redirecting commercial passenger vehicles and develop warrants.	NTSB H-12-26	Gap				
5		20-07(360)	Roadside Barriers	Gaps which could be satisfied with existing or pending work and reorganization of RDG - Establish warrants in the RDG regarding the selection and use of high-performance barriers, including 42" and 50" concrete barriers that are capable of	NTSB H-05-31	Gap				
5		20-07(360)	Roadside Barriers	Gaps which could be satisfied with existing or pending work and reorganization of RDG - Work with FHWA to establish performance and selection guidelines for state transportation agencies to use in developing objective warrants for high-performance barriers applicable to new construction and rehabilitation projects...	NTSB H-12-25	Gap				
5		20-07(360)	Roadside Barriers	Gaps which could be satisfied with existing or pending work and reorganization of RDG - Once barrier testing has been completed and selection guidelines have been developed, revise Ch. 5 of the RDG to incorporate guidance for the selection of high-performance barriers in new construction and rehabilitation projects.	NTSB H-12-27	Gap				
5		20-07(383)	Roadside Barriers	Gap: Since most agencies are turning their focus to maintenance, rather than new construction, pavement elevations rise with resurfacing. This decreases the relative elevation of the rail, often outside tolerances. The RDG is silent on method to raise the effective height of low guardrails.		Gap				
		20-07(383)		Gap: More guidance on TL-2 hardware.		Gap				
5		20-07(360)	Roadside Barriers	Need: Work recently completed but not implemented - Selection, Use, and Maintenance of Cable Barrier Systems.	NCHRP R711	Need				
5.1	¶ 3		Performance Requirements	Gap: Develop specific guidelines for when highway agencies should upgrade existing barriers as part of new or reconstruction projects, 3R projects or when a system is damaged beyond repair.	No	Gap				
5.1	¶ 3		Performance Requirements	As of January 1, 2011, newly tested or revised systems should be evaluated using MASH.	No	How-To	2011	1		
5.1	¶ 3		Performance Requirements	Highway agencies are encouraged to upgrade existing barriers that have not been accepted under 350 or MASH as part of new or reconstruction projects, 3R projects or when a system is damaged beyond repair.	No	Operational	2008	1		
5.2.1	¶ 1 & Fig. 5-1		Roadside Geometry and Terrain	Embankments with slope and height combinations on or bellow the curve do not require shielding unless they contain obstacles within the clear zone.	Y(15)	Design	1971		1	
5.2.1		20-07(383)	Roadside Geometry and Terrain	Gap: Address problems resulting from agencies managing antiquated systems built to lower standard than todays. Provide guidance to help address how to bridge these differences in standards.		Gap				
5.2.1		20-07(383)	Roadside Geometry and Terrain	Gap: There should be guidance relating to what to do when you can't install hardware the way it was crash-tested. Provide guidance or discussion on how to arrive at the best scenario available.		Gap				
5.2.1	¶ 1 & Fig. 5-2		Roadside Geometry and Terrain	Barrier consideration for embankments with slope and height combinations by AADT.	Y(8)	Design	1967			
5.2.1	¶ 1 & Fig. 5-3		Roadside Geometry and Terrain	Barrier consideration for embankments with slope and height combinations by AADT.	No	Design				
5.2.2	Tab. 5.2		Roadside Obstacles	Table of barrier guidelines for non-traversable terrain and roadside obstacles that are normally shielded.	Y(16)	Placement				
5.2.3	¶ 3		Bystanders, Pedestrians, and Bicyclists	For streets with speeds over 25 mph, separating the sidewalk from the edge of the roadway with a buffer space is encouraged.	No	Design	NA	1		
5.2.4	¶ 1		Motorcycles and Barrier Design	Gap: Additional research is being conducted regarding motorcycle interaction with barriers.		Gap				
5.2.4		20-07(383)	Motorcycles and Barrier Design	Gap: Roadside hardware and motorcycles. We can report on the state of the practice as we know it based on European standards but we don't know how the systems perform w/ MASH hardware.		Gap				
5.5.1		20-07(383)	Barrier Deflection Characteristics	Gap: How do you take all of the dynamic characteristics of a barrier into account when you are shielding an obstacle? There should be a definition or diagram comparing dynamic deflection and working width.		Gap				
5.5.1	¶ 1		Barrier Performance Capability	TL-3 barriers are the most commonly used systems. TL-2 barriers have been developed primarily for passenger cars and light trucks for locations that are typically posted at <45 mph.	No	How-To	NA	1		
5.5.1		20-07(383)	Barrier Deflection Characteristics	Need: Better design guidance on pier shielding height for LRFD. ZOI and potential damage that can occur to piers when tall vehicles impact the barrier.	NCHRP 12-90	Need				
5.5.1	¶ 1		Barrier Performance Capability	Locations with poor geometrics, high traffic volumes and/or speed and a significant volume of heavy truck traffic may justify a higher performance level or a stronger railing system (i.e. TL-4 or greater).	No	Placement	NA	1		
5.5.2	¶ 2		Barrier Deflection Characteristics	Soil compaction is of primary importance because benefits of stiffening can be undermined by weak soil.	No	Maint/Install	NA	1		
5.5.2	¶ 6		Barrier Deflection Characteristics	Need: Significant research is needed to develop more specific criteria to warrant the use of this tall barrier for pier protection.	NCHRP 12-90	Need				
5.5.2	¶ 1		Barrier Deflection Characteristics	If the distance between the barrier and the object or terrain feature is relatively large, a flexible barrier that deflects (lower impact forces) may be utilized. Otherwise semi-rigid or rigid may be only choice.	No	Placement	NA	1		
5.5.2	¶ 3		Barrier Deflection Characteristics	Trucks may lean over the barrier upon impact which could require an increased offset to prevent contact with the shielded object.	No	Placement	NA	1		
5.5.2	¶ 5		Barrier Deflection Characteristics	TL-3 barrier is typically sufficient to shield the motorist from a pier located within CZ, however structural issues with the bridge may call for the need for higher test level barriers no based on roadside safety criterion.	No	Placement	NA	1		1
5.5.2	¶ 5 Bullets 1 & 2		Barrier Deflection Characteristics	Height guidelines based on offset from traveled way to face of the pier.	Y(14)	Placement	1980	1		
5.5.2	¶ 6		Barrier Deflection Characteristics	Recommended that the tall wall be extended 10' in advance of the piers.	Y(14)	Placement	1980	1		
5.5.3	¶ 1		Site Conditions	If the barrier is to be placed on a slope steeper than 1V:10H, a flexible or semi-rigid type should be used.	Y(10,14,19)	Placement	1980	1		
5.5.3	¶ 1		Site Conditions	No barrier should be placed on any slope steeper than 1V:6H, unless it has been crash tested to 350 or MASH.	No	Placement	NA	1		
5.5.6.2	¶ 3		Crash Maintenance	W-beam guardrail that is damaged or deformed should not be re-run through a roller to correct the shape.	No	Maint/Install	NA	1		
5.5.6.2	¶ 2		Crash Maintenance	In urban settings where rail repair in traffic is difficult for a crew to accomplish w/o interfering w/ the motorists use of the roadway use rigid traffic barrier such as the concrete safety shape.	No	Placement	NA	1		
5.5.7	¶ 2		Aesthetic and Environmental Considerations	Considerations should be given to available sight distances as solid barriers can restrict sight distances.	No	Placement	NA	1		
5.6		20-07(383)	Placement Recommendations	Gap: Guidance on how to measure guardrail height.		Gap				
5.6		20-07(383)	Placement Recommendations	Gap: Placing tangent designed hardware on curves.		Gap				
5.6.1	Tab. 5-7		Barrier Offset	Table of suggested shy-line offsets at different design speeds.	No	Design	1963			1
5.6.1	¶ 2		Barrier Offset	It is generally desirable that there be uniform clearance between traffic and roadside features such as bridge railings, parapets, retaining walls and roadside barriers.	No	Design	NA	1		
5.6.1	¶ 2		Barrier Offset	A roadside barrier should be placed beyond the shy-line, particularly for relatively short, isolated installations. For long, continuous runs of barrier, this offset distance is not as critical, especially if the barrier is introduced beyond the shy line	No	Design	NA	1		
5.6.1	¶ 5		Barrier Offset	The available space between the barrier and the object may not be adequate for design deflection so the barrier should be stiffened in advance of and alongside the fixed object.	No	Design	NA	1		
5.6.1	Tab. 5-7		Barrier Offset	Need: Guidance is based on very old, very limited research. Shy-line offsets at different design speeds should be reassessed with new data.	No	Need				
5.6.1	¶ 1		Barrier Offset	Barrier should be placed as far from the traveled way as practical, while maintaining proper operation and performance of the system.	No	Placement	NA	1		
5.6.1	¶ 3		Barrier Offset	Where a roadside barrier is needed to shield an isolated condition, adherence to the uniform clearance criteria is not as	No	Placement	NA	1		
5.6.1	¶ 4		Barrier Offset	Obstruction being shielded is a rigid object, the barrier-to-object distance should be sufficient to avoid snagging by the vehicle on the rigid object.	No	Placement	NA	1		
5.6.1	Fig 5-33 & ¶ 6		Barrier Offset	RE: Shielding of slopes: 2' minimum distance is desirable for adequate post support but may vary depending on (site specific conditions).	No	Placement	NA	1		

Section	Table, Figure, or Paragraph	Source	Section Title	Description of Guidance	Reference or Related Work	Type of Guidance	Basis of Guidance: Dates From …	Engineering Judgement	Observational Studies	Experimental Studies
5.6.2	¶ 2		Terrain Effects	Need: Limited studies and computer simulations have provided some information on the dynamic behavior and trajectories of vehicles traversing curbs or slopes.		Need				
5.6.2.1	¶ 2		Curbs	Guardrail/curb combinations where high-speed, high-angle impact are likely discouraged.	No	Design	2005			1
5.6.2.1	¶ 2		Curbs	Where there are not alternatives to guardrail/curb combination, sloping curbs no higher than 4"and stiffening guardrail to decrease deflection to be considered along with other measures.	No	Design	NA	1		
5.6.2.1	Fig. 5-35(b) & ¶ 3		Curbs	Re: grade near terminal; Fig. 5-35(b) could be used for all speeds when barrier is required to be offset form the face of the rail or when a curb is required adjacent to a terminal.	No	Design	NA	1		
5.6.2.1	¶ 3		Curbs	Gap: The performance of guardrail terminals behind curbs has not been tested.		Gap				
5.6.2.1	Fig. 5-35(a) & ¶ 3		Curbs	Where the curb is offset or the barrier flares away from the edge of the roadway, the curb should be transitioned to a laydown curb, similar to Fig. 5-35a.	No	How-To	NA	1		
5.6.2.1	¶ 3		Curbs	Strong-post w-beam guardrail should not be located at an offset from a curb on roads w/ speeds >40mph.	No	Placement	NA	1		
5.6.2.2	¶ 6		Slopes	A rounded slope reduces the chances of an errant vehicle becoming airborne and affords the driver more control over the vehicle. Typically 4-6 ft. is used for slope rounding.	No	Design	NA	1		
5.6.2.2	¶ 1		Slopes	When a barrier is placed on >1V:10H, for certain angles and speeds an errant vehicle may go over many standard roadside barriers or impact them too low.	Y(10)	How-To	1962		1	
5.6.2.2	Fig. 5-37 ¶ 2		Slopes	Design parameters for vehicle encroachments on slopes, The primary area of concern is the zone of higher than normal bumper height.	No	How-To	NA	1		1
5.6.2.2	Tab.5-8 ¶ 3		Slopes	Example bumper trajectory data obtained from computer simulations (included to illustrate the problem rather than provide guidance).	No	How-To	NA			1
5.6.2.2	¶ 5		Slopes	Roadside barriers perform most effectively when they are installed on slopes of 1V:10H. Caution should be taken when considering installations on slopes as steep as 1V:6H; offset so that vehicle is at its normal attitude at the moment of impact.	No	Placement	NA	1		1
5.6.2.2	Fig. 5-38		Slopes	RE: Strong-post W-beam and thrie-beam guardrails shielding slopes: Existing barrier systems may be retained (within the	Y(19)	Placement	1972			1
5.6.3	Tab. 5-9		Flare Rate	Table of Suggested Flare Rates for Barrier Design.	Y(21,22)	Design	2008		1	1
5.6.3	Tab. 5-9		Flare Rate	Need: Guidance is based on very old, very limited research. Table of Suggested Flare Rates for Barrier Design should be	No	Need				
5.6.3	¶ 3		Flare Rate	Flatter flare rates may be used, particularly where extensive grading would be required to obtain a flat approach to the barrier from the traveled way.	No	Placement	NA	1		
5.6.3	¶ 3		Flare Rate	Flatter flare rate is suggested when a barrier is located within the shy-line offset distance.	No	Placement	NA	1		
5.6.4	Tab. 5-10		Length of Need	Table of Suggested Runout Lengths for Barrier Design.	Y(7,13,24)	Design	2009		1	
5.6.4	¶ 10 &		Length of Need	Equation for calculating the required length-of-need in advance of the area of concern for straight or nearly straight	No	Design	1977	1		
5.6.4	¶ 15		Length of Need	If charts are used to address the LON then the designer will need to review the site plan.	No	Design	NA	1		
5.6.4	Eq. 5-2		Length of Need	Flare rate equation for parallel installations (i.e. no flare rate) Eq. 5-1 reduces to this.	No	Design	1977	1		
5.6.4	Eq. 5-3		Length of Need	Lateral offset from the edge of the traveled way to beginning of LON equation .	No	Design	1977	1		
5.6.4		20-07(383)	Length of Need	Gap: Need an AASHTO blessed way to calculate the length of need on the inside of curves.		Gap				
5.6.4	¶ 11		Length of Need	The calculated LON should be adjusted upward to account for the industry's manufactured L of barrier sections.	No	Maint/Install	NA	1		
5.6.4	¶ 13		Length of Need	If the barrier ends near a cut section, it may be possible for the designer to consider anchoring in the backslope.	No	Maint/Install	NA	1		
5.6.4	Tab. 5-10		Length of Need	Need: Guidance is based on very old, very limited research. Table of Suggested Runout Lengths for Barrier Design shojld be re-examined with new data and methods.	N	Need				
5.6.4	¶ 17, point 1-3		Length of Need	Description of the three ranges of clear zone width are outlined.	No	Placement	NA	1		
5.6.4	¶ 18		Length of Need	On divided or 1-way traffic, the L of guardrail to protect the downstream corner of the area of concern is determined by plotting a line at an agency-defined exit angle. The guardrail should have the end anchor assembly downstream of this exit angle line.	No	Placement	NA	1		
5.6.4	¶ 19 Fig. 5-44		Length of Need	If the existing slope is steeper than 1V:10H, it is suggested that the slope be flattened.	No	Placement	NA	1		
5.6.4	¶ 6		Length of Need	The slopes between a barrier and the roadway should be 1V:10H or flatter, or the barrier should be far enough from the road that the vehicle is on the ground w/ suspension normal at the time of contact.	No	Placement	NA	1		1
5.6.4	¶ 7		Length of Need	Median barriers can be set closer to the edge of the driving lane w/o affecting vehicle placement. When the barrier is to the left the driver can clearly see how close the barrier is; however for a right shoulder installation, depth perception becomes more of a problem for many drivers.	No	Placement	NA	1		
5.6.4	¶ 8		Length of Need	If a semi-rigid railing is connected to a rigid barrier the tangent L should be at least as long as the transition section to reduce the possibility of pocketing at the transition and to increase chances of a smooth redirection.	No	Placement	NA	1		
5.6.5	¶ 2		Grading for Terminals	If the LON criteria results in a proposed terminal location where site conditions make appropriate terminal grading difficult, the designer should consider extending the barrier to such location where it can be appropriately terminated.	No	Placement	NA	1		
5.6.6	¶ 2		Guardrail Placed in Radius	Gap: Significant R&D has been undertaken to obtain a NCHRP Report 350 system for this application.		Gap				
5.6.6		20-07(383)	Guardrail Placed in Radius	Gap: On-going research - How to accommodate crossroads or driveways in close proximity to bridges?	NCHRP 15-53	Gap				
5.6.7.1	¶ 1 & Fig. 5-51		Guardrail Posts in Rock Formations	Holes are drilled into the rock formation and a coarse aggregate (ASTM C33 size 57) used as backfill.	Y(9)	Maint/Install	2003	1		1
5.6.7.2	¶ 2		Guardrail posts in Mow Strips	The depth of mow strips vary from several inches up to 8 in. The preferred W of a mow strip should accommodate the tire path of a typical road maintenance tractor behind the guardrail post.	Y(6)	Maint/Install	2004	1		1
5.6.7.2	¶ 3		Guardrail posts in Mow Strips	High tension cable barrier posts do not need a leave-out in the mow strip.	Y(6)	Maint/Install	2004	1		1
5.6.7.2	¶ 3 & Fig. 5-52		Guardrail posts in Mow Strips	The leave-out's critical measurement is from the back of the post to the edge of the mow strip and should be >7".	Y(6)	Maint/Install	2004	1		1
5.7.1	¶ 1		Structural Inadequacies	Gap: Additional research on this topic is needed (inadequate and damaged/neglected systems).		Gap				
6		20-07(360)	Median Barriers	Gaps which could be satisfied with existing or pending work and reorganization of RDG - Upon completion of FHWA	NTSB	Gap				
6		20-07(360)	Median Barriers	Need: Covered by recently initiated research - Median barrier selection and placement guidelines.	NCHRP 22-31	Need				
6.2	¶ 3, 4, 5 &		Guidelines for Median Barrier	Figure of Guidelines for Median Barriers on High-Speed, fully controlled-access roadways. Two paragraphs describing	Y(7,10)	Design	2003		1	
6.2	¶ 7		Guidelines for Median Barrier…	Use of Fig 6-1 guidelines on non-access controlled roadways should include engineering analyses and judgement that take into consideration such items as right-of-way, property access needs, # of intersections, etc.…	No	Design	2003		1	
6.2		20-07(383)	Length of Need	Need: Optimizing median width and hardware in medians. Discussion of ADT vs crash experience.		Need				
6.2	¶ 8		Guidelines for Median Barrier…	Barriers separating roadways at different elevations, use clear-zone criteria as guidance.	No	Placement	NA	1		
6.4.1	¶ 2		Crashworthy Median Barrier Systems	Tolerances for rigid barriers is 3 in lower and indefinitely higher. Semi-rigid systems should vary by only ±1" than their specified nominal mounting height. Flexible systems should vary by only ±2".	No	Maint/Install	NA	1		
6.4.2	¶ 2 & Fig.6-16		End Treatments	Breaks in median barrier can be flared in such a way that the upstream barrier shields the downstream if the minimum angle is 25 degrees.	No	Design	NA	1		
6.4.2	¶ 2		End Treatments	More severe crashes normally result from impacts with terminals and the cost of terminals when compared to the barrier itself, openings or breaks in median barriers should be kept to a minimum.	No	Placement	NA	1		
6.5.1	¶ 1		Barrier Performance Capability	A barrier capable of redirecting cars and light vans & trucks will be adequate (MASH TL3).	No	Design	NA			

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6.5.2	¶ 1		Barrier Deflection Characteristics	Relatively wide, flat medians are suited for flexible or semi-rigid barriers, provided the design deflection distance is < 1/2 the median width.	No	Placement	NA	1		
6.5.4	¶ 1		Costs	If a barrier can be placed in center of a median where less likely to be hit and repairs do not necessitate closing a lane, a flexible or semi-rigid barrier may be the best choice. However, if a barrier must be located adjacent to a high-speed, high-volume traffic lane, a rigid barrier requiring little maintenance is recommended.	No	Placement	NA	1		
6.5.5	¶ 1		Maintenance	A rigid barrier system is the barrier of choice in many locations particularly for high-volume urban freeways and expressways where the barrier must be located in close proximity to the traffic lane.	No	Placement	NA	1		
6.6.1	¶ All &		Terrain Effects - Median Section I	Figure and text describe guidance for placing median barriers in non-level medians.	No	Design	1977	1		
6.6.1.1	¶ 1		Terrain Effects - Median Section I	Evidence that a vehicle traveling up a slope steeper than 1V:6H before contacting the barrier may override it.	No	How-To	NA	1		
6.6.1.1	¶ 2		Terrain Effects - Median Section I	Need: Maximum redirection can be achieved if the area 1'-8' from ditch line on 1V:6H is avoided.	No	Need	NA			1
6.6.1.1	¶ 1		Terrain Effects - Median Section I	Need: Quantify possible placement concerns when a rigid or semi-rigid barrier is located on one side of a traversable, sloped median.		Need				
6.6.1.2	¶ All &		Terrain Effects - Median Section II	Figure and text describe guidance for placing median barriers in non-level medians.	No	Design	1977			
6.6.1.2	¶ 2		Terrain Effects - Median Section II	RE: retaining wall: Suggested that the base of the wall be contoured to the exterior shape of a concrete barrier.	No	Manufacturer	NA	1		
6.6.1.3	¶ 1		Terrain Effects - Median Section III	Need: Placement criteria for median barriers on this cross-section are not clearly defined.	NCHRP 22-31	Need				
6.6.1.3	¶ All & Fig. 6-18		Terrain Effects - Median Section III	Need: Figure and text describe guidance for placing median barriers in non-level medians.	NCHRP 22-31	Need				
6.6.2	¶ 2		Fixed objects w/in the Median	The designer should investigate the possible use of a crash cushion to shield the object.	No	Design	NA	1		
6.6.2	¶ 2		Fixed objects w/in the Median	Employ either a semi-rigid or rigid barriers w/ crash cushions or end treatments to shield the barrier ends.	No	Design	NA	1		
7		20-07(360)	Bridge Railings and Transitions	Gap: Work recently completed but not implemented - Tables for selection of MASH level 2-5 bridge rails.	NCHRP 22-12(03)	Gap				
7.2	¶ 1		Guidelines	A rigid railing requires approach guardrail and a transition section between barrier types.	No	Design	NA	1		
7.3	¶ 4		Appropriate TL selection	A safety-shaped railing can cause a large vehicle to roll up to 24° before it contacts the upper edge of the railing. Thus, a vertical face may be more desirable when heavy vehicle rollover is a primary concern.	No	Placement	NA		1	1
7.3	¶ 5		Appropriate TL selection	ZOI; Hardware attachments placed in these areas should be avoided when practical.	Y(11)	Placement	2003		1	1
7.4	¶ 5		Crash Tested Railing	All newly developed bridge railings should be successfully crash tested in accordance w/ MASH.	No	How-To	2011	1		
7.4	Tab. 7-1		Crash Tested Railing	Table of MASH Test Matrix for Bridge Railings.	Y(3)	How-To	2009			
7.5.1	¶ 1		Railing Performance	As a minimum, TL-3 bridge railings should be used on the NHS.	Y(9)	Placement	1996	1		
7.5.2	¶ 1		Compatibility	When the approach roadside barrier significantly differs in strength, height & deflection characteristics from the bridge railing, a crashworthy transition section is required.	No	Placement	NA	1		
7.5.5	¶ 1		Aesthetics	Any non-standard bridge railing designed primarily for appearance should be crash tested before being used.	Y(4)	Manufacturer	2006	1		1
7.5.6	Bullet 1-5		Protective Screening at Overpasses	List of guidelines analyzing overpass locations for installation of protective screening.	No	Design	NA	1		
7.6	¶ 1		Placement Recommendations	When the railing is located w/in the recommended shy-line offset the approach rail should have the appropriate flare rate.	No	Design	NA	1		
7.6	¶ 2		Placement Recommendations	Curb height is prescribed in LRFD as 6" preferred height, with a maximum of 8" on a sidewalk in front of the bridge rail.	Y(2)	Design	1994			
7.6	¶ 3		Placement Recommendations	A crash tested transition from the approach guardrail should be attached to the end of the bridge rail.	No	Design	NA	1		
7.6	¶ 2		Placement Recommendations	Curbs in front of railings should be avoided unless the bridge rail was crash tested w/a curb.	No	Maint/Install	NA	1		
7.6.1	¶ 1		Considerations for Urban & Low Volume Roads	Bridges in urban or low-volume road that carry low traffic volumes, reduced speed, or both may not need bridge railings designed to the same standard as bridge railings on high-speed, high-volume facilities.	No	Design	NA	1		
7.6.1	¶ 2		Considerations for Urban & Low Volume Roads	Bridge railings w/ adequate strength to prevent penetration from passenger vehicles and transitions that meet TL1 or TL2 bridge railings are generally acceptable for low-speed roadways 45 mph or less.	No	Design	NA	1		
7.6.1	¶ 3		Considerations for Urban & Low Volume Roads	When a bridge also serves pedestrians, 2 options for accommodating them typically are used: 1) raised curb w/ sidewalk in combination w/ an outer bridge barrier or 2) placing the barrier for maximum pedestrian protection.	No	Design	NA	1		
7.6.1	¶ 4		Considerations for Urban & Low Volume Roads	The use of a bridge railing may create a hazard unless the railing is terminated in an acceptable manner.	No	How-To	NA	1		
7.7.1	¶ 1		Identification of Potentially Obsolete Systems	Bridge railings designed to AASHTO specifications prior to 1964 may not meet current specifications.	No	How-To	NA	1		
7.8	Bullet 3		Transitions	The transition length should be 10-12x the difference in the lateral deflection of the 2 systems.	No	Design	NA	1		1
7.8	Bullet 4		Transitions	The stiffness of the transition should increase smoothly and continuously from the less rigid to the more rigid.	No	Design	NA	1		1
7.8	Bullet 5		Transitions	When drainage features are constructed in front of barriers they may initiate vehicle instability that can adversely affect the crashworthiness of the transition.	No	Design	NA	1		1
7.8	Bullet 5		Transitions	The slope between the edge of the traveled land and the barrier should be no steeper than 1V:10H.	No	Design	NA	1		1
7.8	¶ 1		Transitions	A transition section is needed where a semi-rigid approach barrier joins a rigid bridge railing.	No	How-To	NA	1		
7.8	Bullet 1		Transitions	The approach-rail/bridge-rail splice must be as strong as the approach rail itself so that it wont fail when struck by pulling out and allowing a vehicle to strike the end of the bridge railing. The use of cast-in-place anchor or through-bolt connections is recommended.	No	Maint/Install	NA	1		1
7.8	Bullet 2		Transitions	Tapering of the rigid bridge railing end behind the transition member at their connection point may be desirable, especially when the approach transition is recessed into the end of the bridge railing or other object.	No	Manufacturer	NA	1		1
8		20-07(360)	End Treatments	Gap with no Currently Planned Research - Classification of Crash Cushions.	2013 RNS	Gap				
8		20-07(383)	End Treatments	Gap: Possible new category relating to tension (restrained) terminals.		Gap				
8.1	¶ 5		Performance Requirements	Crashworthy end treatments are required for all new longitudinal barrier installations on the NHS when those end treatments are located within the clear zone and exposed to possible vehicular impacts.	No	Design	NA	1		
8.1	¶ 6		Performance Requirements	Upgrade existing terminals and crash cushions that have not been accepted under 350 or MASH as part of 3R projects or when a system is damaged beyond repair.	Y(6)	Maint/Install	2008	1		
8.2	¶ 1		Anchorage Design Concepts	All flexible and semi-rigid barriers need to be terminated w/ an anchor system at both ends.	No	Manufacturer	NA	1		
8.2	¶ 2		Anchorage Design Concepts	If the barrier end treatment is not required to be crashworthy a lower-cost anchorage system may be used.	No	Placement	NA	1		
8.3	¶ 1		Terminal Design Concepts	A terminal is considered essential if the end of a barrier is located w/in the CZ or in an area where it is likely to be struck by and errant motorist.	No	Design	NA	1		
8.3.2.1	¶ 2		Energy-Absorbing vs. Non-Energy-Absorbing Terminals	If the terrain beyond the terminal and immediately behind the barrier is not safely traversable an energy-absorbing terminal is recommended.	No	Design	2004	1		
8.3.2.2	¶ 1		Flared vs. Tangent Terminals	Tangent terminals may be installed w/ 1-2' offset from the line of barrier proper to minimize nuisance hits.	No	Design	NA	1		
8.3.2.2	¶ 1		Flared vs. Tangent Terminals	Flared terminals generally require a 4' offset although some designs have been successfully tested w/ offsets less than 3'. Because the flared terminal is located further from the traveled way, head-on impacts are less likely.	No	Design	NA			1
8.3.2.3	¶ 1		Length of Need Point	Most W-beam terminals have a LON point located 12'6" from the impact head of the unit.	No	Design	NA	1		
8.3.3.1	¶ 1		Advance Grading	For W-beam terminals, this area should have lateral slope of no steeper than 1V:10H to promote stability of a vehicle at the moment of contact and avoid its suspension from becoming extended or compressed.	Y(4,5)	Design	2005	1		1
8.3.3.1	¶ 1		Advance Grading	When grading platforms are built, a smooth transition to existing side slopes should be provided so that the entire roadside approach to the barrier remains traversable.	Y(4,5)	Maint/Install	2005	1		1
8.3.3.2	¶ 1 &		Adjacent Grading	Grading in the vicinity of a terminal or anchorage.	No	Design	2002	1		1
8.3.3.2	¶ 1		Adjacent Grading	On projects where grading isn't involved the area immediately behind the terminal should be similar in nature to the roadside immediately upstream of the terminal.	No	Design	NA	1		
8.3.3.2	¶ 1		Adjacent Grading	This area should be essentially flat so the terrain itself does not contribute to vehicle roll, pitch or yaw on impact.	Y(4,5)	Maint/Install	2005	1		1

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8.3.3.3	¶ 1		Runout Distance Grading	The lateral runout distance directly behind a terminal ideally should be at least as wide as the roadside clear distance immediately upstream of the terminal.	No	Design	NA	1		
8.3.3.3	¶ 3		Runout Distance Grading	The minimum recovery area behind and beyond a terminal should be obstacle-free area 75' long and 20' wide.	No	Design	2002	1		
8.3.3.3	¶ 2		Runout Distance Grading	If the barrier LON is adequate, a vehicle traveling 250' behind a barrier will not likely reach the object being shielded.	No	Maint/Install	NA	1	1	1
8.3.6.1		20-07(383)	Buried-in-Backslope Terminal	Gap: Discuss how to calculate LON for a buried-in-backslope terminal for backslopes steeper than 3:1.		Gap				
8.3.6.2		20-07(383)	Flared W-Beam Terminals	Gap: Layout of terminals at the end of flared standard systems. (in-line with the flare, measured off the flare, for flared- or parallel-type terminals, etc.).		Gap				
8.4	¶ 1		Crash Cushion Design Concept	Crash Cushions are ideally suited for use at locations where fixed objects cannot be removed, relocated, or made to break away, and where they cannot be adequately shielded by a longitudinal barrier.	No	How-To	NA	1		
8.4	¶ 2		Crash Cushion Design Concept	Crash Cushions commonly are applied at exit ramp gore on an elevated or depressed structure in which a bridge rail end or pier merits shielding. Crash cushions also are frequently used to shield the ends of median barriers.	No	How-To	NA	1		
8.4.3	Eq 8-1, 8-2, 8-3		Crash Cushions Based on Conservation of Momentum Principle	Conservation of momentum equations applied to a vehicle impacting a series of containers.	No	Design	1687	1		
8.4.3	¶ 4		Crash Cushions Based on Conservation of Momentum Principle	It is usually adequate to design this type of crash cushion to reduce the vehicle velocity to about 10 mph after the last module has been impacted.	No	Design	NA	1		
8.4.3	Fig. 8-38		Crash Cushions Based on Conservation of Momentum Principle	Figure of Conservation of Momentum Principle.	No	Design	NA	1		
8.4.3	¶ 11		Crash Cushions Based on Conservation of Momentum Principle	Moisture content of the loose sand should be 3% or less and clean sand should be used to minimize caking.	No	Maint/Install	NA	1		
8.4.3	¶ 12		Crash Cushions Based on Conservation of Momentum Principle	Mixing 5-25% (by volume) of rock salt w/ the sand will prevent wet sand from freezing under most conditions.	No	Maint/Install	NA	1		
8.4.3	¶ 13		Crash Cushions Based on Conservation of Momentum Principle	The use of sacked sand is no longer considered acceptable.	No	Maint/Install	NA	1		
8.4.3	¶ 10		Crash Cushions Based on Conservation of Momentum Principle	Recommend orienting sand barrel array at angles up to 15 toward approaching traffic as an alternative way to address the reverse direction impact concern.	No	Placement	NA	1		
8.4.3	¶ 10		Crash Cushions Based on Conservation of Momentum Principle	Space should be left behind the last row of modules so sand and debris will not be confined to produce a ramming effect. Approximately 1'6" is recommended minimum space needed.	No	Placement	NA	1		
8.4.3	¶ 9		Crash Cushions Based on Conservation of Momentum Principle	If space permits, extra rows of lighter modules may be placed alongside the array to make it softer for rear-corner angle impacts.	No	Placement	NA	1		
8.4.3	¶ 9		Crash Cushions Based on Conservation of Momentum Principle	In locations where the heavier modules may be exposed to reverse direction impacts, some agencies place lighter modules alongside the barrier.	No	Placement	NA	1		
8.4.5.1	¶ 1 & Tab. 8-11		Site Characteristics	Table with recommendation of the area that should be made available for CC installation.	No	Design	1970	1		
8.4.5.1	¶ 2		Site Characteristics	Fixed objects such as rigid barrier ends that are <3' wide should be shielded by a narrow crash cushion. Similarly, wide obstacles (>16') can be effectively shielded by sand barrel arrays.	No	Design	NA	1		
8.4.5.2	¶ 3		Crash Cushion Structural and Safety Characteristics	Additional lower mass sand barrel modules sometimes could be added to an array to reduce the expected deceleration forces to lower levels.	No	Placement	NA	1		
8.4.5.4	¶ 3		Maintenance Characteristics	Plastic sand barrels eventually will degrade from UV exposure; barrels older than 10 years should be inspected more frequently and replaced when necessary.	No	Maint/Install	NA	1		
8.4.5.5	Bullets 1-3		Selection Criteria	List of guidelines for selecting crash cushion types.	No	Design	NA	1		
8.4.5.6	¶ 2		Inclusion Area	Gap: There is limited information of actual repair times and costs for crash cushions.		Gap				
8.4.6	¶ 2		Placement Recommendations	For new construction, curbs should not be built where crash cushions are to be installed. Existing crash cushion locations should be reviewed to determine if the presence of a curb or a slope is like to affect performance.	No	Design	NA	1		
8.5	¶ 1		Delineation of End Treatments	Improved signing, pavement markings, or delineation may result in fewer crashes.	No	Placement	NA	1		
9		20-07(360)	Traffic Barriers, Traffic Control Devices,	Gap with no Currently Planned Research - Risk-Based Criteria and Selection Guidelines for Positive Protection in Work	2013 RNS	Gap				
9		20-07(360)	Traffic Barriers, Traffic Control Devices, and Other Safety Features in Work Zones	Gap with no Currently Planned Research - Warrants for anchoring portable barriers in work zones.	2010 RNS	Gap				
9.1.1	Tab. 9-1		Application of the CZ Concept in Work Zones	Table of example clear zone widths in work-zones by speed.	No	Design	NA	1		
9.1.1	¶ 3		Application of the CZ Concept in Work Zones	The width of commonly used work-zone clear zones range from 12-18'. The location of collateral hazards such as equipment and material storage can be controlled and should be subject to greater clear zone widths (30').	No	Design	NA	1		
9.1.1	¶ 1		Application of the CZ Concept in Work Zones	In work-zones, the clear zone requirements are less than those for the non-construction conditions.	No	How-To	NA	1		
9.2.1		20-07(383)	Temporary Longitudinal Barriers	Gap: Do we use crash-tested working widths or a risk based approach based on the products exposure (ex. PCB on a bridge deck a car couldn't develop a 25 deg. Trajectory.		Gap				
9.2.1	¶ 1		Temporary Longitudinal Barriers	Improper use of temporary traffic barriers can provide a false sense of security for both motorists and workers.	No	How-To	NA	1		
9.2.1	¶ 1 &		Temporary Longitudinal Barriers	Barriers are usually justified for bridge widening, shielding of roadside structures, roadway widening and separating 2-	Y(20)	Placement	1993	1		
9.2.1.2	¶ 7		Portable Concrete Barriers	Benefit/cost analyses of temporary concrete barriers indicate that total crash costs appear to be minimized for flare rates ranging from 4:1 to 8:1. A flare rate of 5:1 or 6:1 may be slightly more favorable in urban settings. A minimum offset of 2' from the traveled lane to the PCB is desirable.	Y(9)	Design				
9.2.1.2	¶ 4		Portable Concrete Barriers	Each section should be properly connected to the adjacent section to provide barrier continuity and to resist movement, snagging, and the instability of impacting vehicles.	No	Maint/Install	NA	1		
9.2.1.2	¶ 5		Portable Concrete Barriers	When lateral displacement of the barrier cannot be tolerated, anchoring the portable concrete barrier to the underlying surface may be necessary to prevent lateral movement. This can be done w/ pins or bolts attached to the pavement or bridge deck. The pins/bolts should not protrude beyond the face of the barrier.	No	Maint/Install	NA	1		
9.2.1.2	¶ 6		Portable Concrete Barriers	The designer should allow for adequate drainage through the barrier to minimize ponding against the barrier.	No	Manufacturer	NA	1		
9.2.2	Bullets 1-6		End Treatments	List of candidate treatments for exposed ends of barriers.	No	Design	NA	1		
9.2.3		20-07(383)	Transitions	Gap: the application of water-filled barriers, particularly as it relates to interfacing stiffer barriers. Same applies to water-filled terminals as well.		Gap				
9.2.3	¶ 1		Transitions	Adequate transitions should be made between temporary barriers of differing flexibility or between temporary and permanent barriers.	No	Placement	NA	1		
9.2.4	Bullet 1		Applications	For a short section of barrier <100' a trade-off should be made as to which risk is greater the risk that the obstacle or barrier presents to the motorist or the risk of leaving workers unprotected.	No	Design	NA	1		
9.2.4	Bullet 4		Applications	Openings in barriers should be avoided if possible. When necessary, the barrier ends should have an acceptable end treatment or offset.	No	Design	NA	1		
9.2.4	Bullet 5		Applications	For better night visibility, retroreflective devices or steady-burn warning lights may be mounted along the barrier.	No	Maint/Install	NA	1		
9.2.4	Bullet 5		Applications	A solid edge line may be placed on the pavement adjacent to the barrier to provide delineation.	No	Maint/Install	NA	1		
9.2.4	Bullet 2		Applications	Barriers may be used to channelize traffic but they should not be the primary tapering device. Lane tapers should be made of more forgiving channelizing devices such as barricades, drums, cones, etc..	Y(10,7)	Placement	2009			
9.2.4	Bullet 3		Applications	When temporary barriers are installed on both sides of traffic, the begining of the barriers should be staggered to minimize the tendency of drivers to shy away from suddenly introduced objects near the traveled way.	No	Placement	NA	1		
9.3.1	¶ 1		Stationary Crash Cushion	It should be emphasized that stationary crash cushions should be delineated to make them conspicuous at night.	No	Maint/Install	NA	1		

Section	Table, Figure, or Paragraph	Source	Section Title	Description of Guidance	Reference or Related Work	Type of Guidance	Basis of Guidance: Dates From …	Basis of Guidance: Engineering Judgement	Basis of Guidance: Observational Studies	Basis of Guidance: Experimental Studies
9.3.1.1	¶ 1		Sand-Filled Plastic Barrels	Because the sand-filled barrel system has virtually no redirective capability, it should be 30" wider than the fixed object it is shielding.	No	Design	NA	1		
9.3.1.1	Bullet 2		Sand-Filled Plastic Barrels	The lateral offset between the back edge of a sand-filled barrel crash cushion and the edge of the obstacle may be reduced to a minimum of 15" when a greater offset would cause unacceptable interference w/ traffic.	No	Design	NA	1		
9.3.1.1	Bullet 3		Sand-Filled Plastic Barrels	For ease of moving, barrels may be installed on pallets or a skid 4" or less in height.	No	Maint/Install	NA	1		
9.3.1.1	Bullet 3		Sand-Filled Plastic Barrels	Barrels should be regularly inspected because they are susceptible to nuisance hits & provide little or no safety reserve after being hit.	No	Maint/Install	NA	1		
9.3.2	Tab 9-4		Truck & Trailer Mounted Attenuators (TMAs)	Table of suggested priorities for application of protective vehicles & TMAs.	No	Design	NA	1		
9.3.2	¶ 4		Truck & Trailer Mounted Attenuators (TMAs)	Shadow trucks and barrier vehicles may be equipped w/ TMA. Advance sign trucks may use TMA if they encroach on the traveled way.	No	Placement	NA	1		
9.4	# 4		Traffic Control Devices	Gap: Large trailer-mounted devices (arrow panels, variable message signs, and temporary traffic signals): Crash-worthiness criteria have not been established for devices in this category.		Gap				
9.4.1	¶ 1		Channelizing Devices	These devices should adhere to the size and shape requirements in the latest edition of MUTCD.	Y(7)	Manufacturer	2009			
9.4.1	¶ 1		Channelizing Devices	When possible channelizing devices should be set 1-2' back from the edge of the traffic lane.	Y(4)	Placement	1990			1
9.5.2	¶ 2		Pavement Edge Drop Offs	No vert drop off greater than 2" should occur between adjacent lanes.	No	Design	2009	1		
9.5.2	¶ 3		Pavement Edge Drop Offs	Pavement edge drop offs greater than 3" immediately adjacent to traffic should not be left overnight.	No	Maint/Install	NA	1		
9.5.2	¶ 4		Pavement Edge Drop Offs	Placing a temp wedge of material along the face of the drop off. The wedge should consist of stable material placed at a 30-35 degree angle or flatter slope.	No	Maint/Install	NA	1		
9.5.2	¶ 5		Pavement Edge Drop Offs	Placing channelizing devices along the traffic side of the drop off and maintaining a 3' wide buffer.	No	Placement	NA	1		
10	¶ 3		Overview	Where curb is used, the lateral offset is measured from the face of the curb. A minimum of 1.5' should be provided from the face of the curb with 3' at intersections.	No	Design	NA	1		
10	¶ 3		Overview	Enhanced lateral offset of 4-6' to obstructions is a more appropriate guide for these environments	No	Placement	NA	1		
10	¶ 8		Overview	Appurtenances should be located as far away as practical but at least 4' from the face of the curb to minimize the probability of being hit by an errant vehicle.	No	Placement	NA	1		
10	¶ 8		Overview	Breakaway designs should be used for poles and appurtenances located <6' to the face of the curb.	No	Placement	NA	1		
10.1	¶ 1		Evaluation of Critical Urban Roadside Locations	Give priority attention for improvements to critical locations that are more prone to crashes.	No	How-To	NA	1		
10.1.1	¶ 1		Evaluation of Individual Sites	Regardless of curbing, the designer should strive for a wider lateral offset that is more reflective of either the off-peak operating speed (85th percentile) or design speed, whichever is greater.	No	How-To	NA	1		
10.1.3.1	¶ 2		Obstacles in Close Proximity to Curb Face or Lane Edge	W/o a vertical curb, lateral offsets of 12' on the outside of curves and 8' at tangent locations are reasonable goals when the clear zone widths cannot be achieved.	No	Design	2008		1	
10.1.3.1	¶ 2 & Fig 10-1		Obstacles in Close Proximity to Curb Face or Lane Edge	Recommended goal is to achieve at least 6' lateral offset from the face of the curb at these outside-of-curve locations while maintaining at least 4' lateral offset elsewhere. Displayed in 10-1.	No	Design	2008		1	
10.1.3.1	¶ 3 & Fig. 10-1		Obstacles in Close Proximity to Curb Face or Lane Edge	A drivers line of sight that is suitable to provide the required stopping sight distance should be maintained.	No	How-To	2008		1	
10.1.3.1	¶ 4		Obstacles in Close Proximity to Curb Face or Lane Edge	Lanes that function as higher speed lanes such as the extended-length turn lanes or bus lanes should be treated as travel lanes and clear-zone measurements then would begin at the right lane edge or curb face.	No	How-To	2008		1	
10.1.3.1	¶ 4		Obstacles in Close Proximity to Curb Face or Lane Edge	Other auxiliary lanes such as bicycle lanes can be included in the clear zone and the clear-zone measurements start at the right-lane edge marking for the motor vehicle lane.	No	How-To	2008		1	
10.1.3.2	¶ 2 & Fig. 10-2		Lane Merge Locations	The suggested lateral offset in the immediate vicinity of the taper point is 12' from the lane merge curb face. Illustrated in Fig 10-2.	No	Design	2008		1	
10.1.3.2	¶ 2		Lane Merge Locations	Breakaway objects should have lateral offsets of at least 4-6' at these locations.	No	Placement	2008		1	
10.1.3.3	¶ 2		Driveway Locations	Providing a lateral offset of 10-15' beyond the edge of driveway would reduce the potential for a fixed-object collision in this high-crash location.	No	Design	2008		1	
10.1.3.3	¶ 2 & Fig. 10-3		Driveway Locations	The resulting lateral offsets appropriate for driveway locations are displayed in Fig. 10-3. The drivers line of sight should be based on the expected speed of approaching vehicles.	No	Design	2008		1	
10.1.3.4	Bullet 2		Intersection Locations	A tangent lateral offset value for the intersection return should be 6' for curbed facilities w/ a minimum of 3'.	No	Design	2011			
10.1.3.4	Bullet 1		Intersection Locations	The island design should adhere to the criteria in AASHTO A Policy on Geometric Design of Highways...	No	How-To	2011			
10.1.3.4	Bullet 3		Intersection Locations	Pedestrian buttons should be placed on a breakaway pedestal pole adjacent to the directional ramp rather than on a rigid traffic signal pole when possible.	No	Placement	NA	1		
10.2.1.1	¶ 5		Curbs	Guardrails behind curbs should either be placed in the immediate vicinity of the curb to shield critical roadside features, or they should be located w/ a minimum lateral offset of 8' to enable vehicles w/ speeds of greater than 40 mph to return to their normal suspension state and minimize the likelihood that they cold vault the barrier.	No	Design	2005	1		1
10.2.1.1	¶ 3		Curbs	The min lateral offset of 1.5' should be provided beyond the face of curbs and any frangible obstructions.	No	Placement	2008		1	
10.2.1.2	¶ 2		Shoulders	It is desirable to maintain traversable conditions in the event an errant vehicle exits the road.	No	Maint/Install	2008		1	
10.2.3	Bullet 2		Placement of Landscaping, Trees and Shrubs	A clear vision space from 3-10' above grade is desirable along all streets and at all intersections.	No	Design	1997			
11.2.2	¶ 7		Mail Stop and Mailbox Location	Most vehicles stopped at a mailbox should be clear of the traveled way when the mailbox is place outside a 8' wide shoulder or turnout. Other widths are preferable up to 12' when it can be provided.	No	Design	1984	1		
11.2.2	¶ 2		Mail Stop and Mailbox Location	Mailboxes should be placed only on the right-hand side of the road in carrier's direction of travel.	No	Placement	1984	1		
11.2.2	¶ 3		Mail Stop and Mailbox Location	Placing of mailboxes along both high-speed and high volume highways should be avoided if other practical locations are available. Mailboxes should not be located where access is from the lanes of an expressway or where access, stopping or parking is otherwise prohibited by law or regulation.	No	Placement	1984	1		
11.2.2	¶ 5		Mail Stop and Mailbox Location	The least troublesome location for a mail stop at these intersections is adjacent to a crossroad lane leaving the intersection.	No	Placement	1984	1		
11.2.2	¶ 5 & Fig. 11-4		Mail Stop and Mailbox Location	Figure 11-4 shows the suggested minimum clearance distance to the nearest mailbox for mail stops at intersections.	No	Placement	1994	1		
11.2.2	¶ 6		Mail Stop and Mailbox Location	Mailboxes should be located so that a vehicle stopped at it is clear of the adjacent traveled way. The higher the traffic volume or speed, the greater the clearance should be.	No	Placement	1984	1		
11.2.2	¶ 7		Mail Stop and Mailbox Location	To provide space outside of the all-weather surface to open a mailbox door, it is recommended that the roadside face of a mailbox be set 6-8" outside the all-weather surface of the shoulder or turnout.	No	Placement	1994	1		
11.2.2	¶ 7		Mail Stop and Mailbox Location	When a mailbox is installed in the vicinity of an existing guardrail, it should be placed behind the guardrail.	No	Placement	1984	1		
11.2.3	Tab. 11-1		Mailbox Turnout Design	Table of shoulder or turnout widths suitable to safely accommodate vehicles stopped at mailbox.	No	Design	1984	1		
11.2.3	Fig. 11-5		Mailbox Turnout Design	Dimensioning of suggested mailbox turnout.		Design	1994	1		
12.3	¶ 2		Clear Zone	Even on low-volume roads, a clear area should be provided to permit a disabled vehicle to pull completely off the road whenever practical.	No	Design	NA	1		
12.8	¶ 4		Bridges	It is critical that the approach rail be physically attached to the bridge rail and that the approach rail be stiffened to match the deflection characteristics of the bridge rail itself. Reduced post spacing is the minimum treatment advisable.	No	How-To	NA	1		
		20-07(360)		Gap with no Currently Planned Research - Development of plan/guidelines to improve roadway and roadsides for motorcyclists.	2010 RNS	Gap				
		20-07(360)		Gap with no Currently Planned Research - Guidelines for Design of Roadway and Roadside Features to Accommodate Automated Vehicles.	2013 RNS	Gap				

Section	Table, Figure, or Paragraph	Source	Section Title	Description of Guidance	Reference or Related Work	Type of Guidance	Basis of Guidance			
							Dates From …	Engineering Judgement	Observational Studies	Experimental Studies
		20-07(360)		Gaps which could be satisfied with existing or pending work and reorganization of RDG - Work with FHWA to develop and implement criteria based on traffic patterns passenger volume and bus types that can be used to assess the risks of rural travel by large busses.	NTSB H-09-08	Gap				
		20-07(360)		Gaps which could be satisfied with existing or pending work and reorganization of RDG - There are many instances within the RDG which indicate engineering judgement is necessary, but there is no specific guidance offered for applying the judgement. If we cannot install the ideal solution, should we quantify...	Breakout Sessions	Gap				
		20-07(360)		Gaps which could be satisfied with existing or pending work and reorganization of RDG - Low cost/low volume roadways, objective criteria for urban roadsides, and new technologies.	Breakout Sessions	Gap				
5.6.2.1.1	¶ 1		Guardrail/Curb Combinations	A strong post w-beam guardrail can be used with any combination of a sloping-faced curb that is 6" or shorter if installed flush with the face of the guardrail on roads w/ speeds up to 50mph…	No	Placement	NA	1		
5.6.2.1.1	¶ 3		Guardrail/Curb Combinations	Curb/Guardrail Combinations for Strong Post W-Beam Guardrail for roads <45mph.	Y(17)	Placement	2005		1	1
5.6.2.1.1	¶ 4		Guardrail/Curb Combinations	Curb/Guardrail Combinations for Strong Post W-Beam Guardrail for roads 45-50mph.	Y(17)	Placement	2005		1	1
5.6.2.1.1	¶ 5		Guardrail/Curb Combinations	Curb/Guardrail Combinations for Strong Post W-Beam Guardrail for roads >50mph.	Y(17)	Placement	2005		1	1
9.2.1.16	¶ 2		Minimizing Deflection	Gap: Anchoring PCB to the traveled way; Although these installations are in common use, only limited crash testing of these have been done.		Gap				
9.2.1.16	¶ 1		Minimizing Deflection	When minimal deflection distances are available, strengthened, stiffened or anchored barriers and connectors may be used. Candidate sites include bridge approaches, excavations, etc.	Y(18)	Placement				
9.2.1.17	¶ 1		Restricted Sites	Barriers at some sites may be exposed to impact angles substantially greater than the 25 degree design.	Y(19)	How-To	1994			
9.3.2.2.1	¶ 2		Buffer Distance	The truck's parking break should be set, the transmission placed in gear, and front wheels turned away from the work area.	No	How-To	NA	1		
9.3.2.2.1	¶ 1 & Tab. 9-5		Buffer Distance	Buffer distances range from 50-200'. Buffer distances should be based on horizontal & vertical geometries, sight distance, average speed and type of operation. Example of guidelines in Table 9-5.	No	Placement	NA			1
9.3.2.2.1	¶ 2		Buffer Distance	A minimum distance of 30' between the truck and work zone is recommended.	No	Placement	NA			1
9.3.2.2.2	¶ 1		Mass of a Shadow Vehicle	The mass of the shadow vehicle should be similar to the mass of the vehicle w/ which the TMA was crash tested.	No	How-To	NA	1		
9.3.2.2.3	¶ 1		Delineation	Delineation should be used on TMAs to make them conspicuous at night.	No	Maint/Install	NA	1		
10.2.4.3.2	¶ 3		Crash Cushions	Curbs should be removed in front of crash cushions. When necessary for drainage, an existing curb no higher than 4" can be left in place unless it has contributed to poor performance in avoiding vaulting.	No	Placement	NA	1		
					Total =	316		199	28	47
					Gaps =	42				
					Needs =	18				
					Guidance =	256				