

ERRATA

March 2016

Dear Customer:

Recently, we were made aware of some technical revisions that need to be applied to the *Highway Safety Manual, 1st Edition*, and the *Highway Safety Manual Supplement*.

Changes are reflected by color-coded highlights on individual pages throughout errata file. 2010 changes are highlighted in **blue**, 2012 changes are highlighted in **red**, and 2016 changes are highlighted in **green**.

Please scroll down to see the full erratum.

In the event that you need to download this erratum file again, please download from:
<http://downloads.transportation.org/HSM-1-M-Errata.pdf>.

In order to see color-coding on a hard copy printout, please select “Document and Markups” in the Print dialog box when selecting your print options so that highlighting will be displayed properly.

Then, please replace the existing pages with the corrected pages to ensure that your edition is both accurate and current.

AASHTO staff sincerely apologizes for any inconvenience.

Errata to the *Highway Safety Manual*, 1st Edition and Supplement

• 2010 errata changes in **blue** • 2012 errata changes in **red** • 2016 errata changes in **green (bold)**

Page	Existing Text	Corrected Text
Vol. 1		
2-12	In Section 2.5, first paragraph, there is a duplicate partial second sentence	Paragraph should read: “This section considers major road design elements, related driver tasks, and human errors associated with common crash Types. It is not intended to be a comprehensive summary, but is intended to provide examples to help identify opportunities where an understanding of the influence of human factors can be applied to improve design.”
2-17	In Slow-Moving or Stopped Vehicles Ahead Section change opening of first sentence: “For the controlled-access mainline,…”	Sentence should read: “As for the controlled-access mainline,…”
3-17	The term $e^{(-0.4865)}$ is used in Equation 3-4.	Change the term to $e^{(-0.312)}$.
3-21	Answer to Example 1: “Using Equation 3-7, expected crashes . . .”	Change to “Using Equation 3-3 and a calibration factor = 1.0, expected crashes . . .”
3-21	Answer to Example 2: Using Equation 3.8 . . .”	Change the answer to “Using Equation 3.7 . . .”
3-33	2nd to last equation on page began with $\hat{\mu}_{\text{Year } 4} = (5 + 7 - 11 + 9) / (0.87 + 0.71 + 0.64 + 1) = 32 / 3.22 = 9.94$ estimate of crashes for the last year:	Change to the following: $\hat{\mu}_{\text{Year } 4} = (5 + 7 + 11 + 9) / (0.87 + 0.71 + 0.64 + 1) = 32 / 3.22 = 9.94$ estimate of crashes for the last year:
4-9	In Table 4-2, third column, Rows 11 and 12: “Expected average crash frequency at the site”	Please change text to: “Expected average crash frequency per year at the site”
4-17	The Coefficient of Variation for Segment B1 is shown as $CV_{B1} = \frac{\sqrt{7.7}}{5.7} = 0.53$	The denominator should be 5.2: $CV_{B1} = \frac{\sqrt{7.7}}{5.2} = 0.53$
4-35	In the table showing Ranking Based on RSI, the Average RSI Cost for Intersection 6 is \$48,900.	The Average RSI cost for Intersection 6 should be \$42,800.
4-42	The calculation of crash frequency variance shown in the table in Step 3 indicates the variance for Signal is 10.5 and the variance for TWSC is 18.8.	The variance for Signal should be 13.75, and the variance for TWSC should be 10.5.
4-46	In Table 4-10, the heading for the last column is “Average 3-Year Expected…”	Change this heading to “Average 3-Year Predicted . . .”

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4-46	Eq. 4-16 is incorrect.	Replace Eq. 4-16 with the following: $\sigma = \sqrt{k N_{\text{predicted}}^2}$
4-47	In Table 4-11, all “N” should be changed	Make the following change to the equations in the table: “ $N_{\text{predicted}}$ ”
4-47	In Table 4-11, Eq. III:	Please make the following change to the equation: $N_{\text{predicted}} \leq N_{\text{observed}} < (N_{\text{predicted}} + 1.5 \times (\sigma))$
4-55	In the Alpha and Beta calculations table: $s^2 = 0.034$, $\alpha = 0.91$, $\beta = 3.2$	Make the following change in the equation: $s^2 = 0.037$, $\alpha = 0.80$, $\beta = 2.84$
4-57	In the Ranking Based on Probability table: Wrong values for probability of specific crashes for signalized intersections were provided	Corrected values and ranking based on formulas provided
4-60	In Eq. 4-26, the last item under “where” is $N_{\text{predicted},1(\text{FI})}$.	Change this item to $N_{\text{predicted},n(\text{FI})}$.
7-7	In Section 7.4.3.4, item 1-a-ii is shown as $(P/F, i, y) = (1 + i)(-y)$.	Change this item to $(P/F, i, y) = (1 + i)^{(-y)}$.
7-14	Table 12 is referenced in the last paragraph.	Change the reference to Table 7-5.
7-17	Equation 7-10: $\Delta N_{\text{expected}(PDO)} = N_{\text{expected}(total)} - N_{\text{expected}(FI)}$	Make the following change in the equation: $\Delta N_{\text{expected}(PDO)} = \Delta N_{\text{expected}(total)} - \Delta N_{\text{expected}(FI)}$
7-17	In Step 4, Eq. 7-13 is shown as: $AM_{(total)} = AM_{(PDO)} \times AM_{(FI)}$.	Change Eq. 7-13 to: $AM_{(total)} = AM_{(PDO)} + AM_{(FI)}$.
7-18	Following Eq. 7-14, at the end of second line of the where list, the $(P/F, i, y)$ is calculated as $(1 + i) - y$.	Change this calculation to $(1 + i)^{(-y)}$.
7-19	In Table 7-10, Columns 2 and 4 need to be revised, as does the heading for Column 2.	Substitute Table 7-10 with the attached revised table.
7-19	The first line under Results states, “The estimated present value monetary benefit of installing a roundabout at Intersection 2 is \$33,437,850.”	Change the amount to \$5,675,500.

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9-8	Step 2 of Figure 9-2 states, “Calculate the predicted crash frequency for each site summed over the entire before period.”	Change “predicted” to “expected.”
9-21	Eq. A-10 is referenced in the last column in the table under Step 6.	Change the reference to Eq. 9A.1-11.
9-36	In Equation 9A.1-5: “OR_i = Odd Ration at site i”	Make the following text change: “OR_i = Odd Ratio at site i”
9-41	Eq. 9A.2-16 is shown as Safety Effectiveness = $100 \times (1 - R)$.	Change this equation to Safety Effectiveness = $100 \times (1 - OR)$.
Vol. 2		
C-14	After Figure C-3, a heading was inadvertently omitted.	Add the heading “C.6.3 Safety Performance Functions (SPFs)” immediately following Figure C-3.
C-14	The term $e^{(-0.4865)}$ is used in Eq. C-4.	Change the term to $e^{(-0.312)}$.
C-15	C.6.3 Crash Modification Factors (CMFs)	Renumber the heading as “C.6.4 Crash Modification Factors (CMFs).”
C-18	C.6.4 Calibration of Safety Performance Functions to Local Conditions	Renumber the heading as “C.6.5 Calibration of Safety Performance Functions to Local Conditions.”
C-18	C.6.5 Weighting Using the Empirical Bayes Method	Renumber the heading as “C.6.6 Weighting Using the Empirical Bayes Method.”
10-17	In Table 10-3 Note: “Accident...Exhibit 10-4.”	Remove the note
10-23	The 3rd row about (CMF_{3r}) in Table 10-7 references Table 10-7.	Change this reference to Equation 10-13.
10-23	The 6th row about (CMF_{6r}) in Table 10-7 references Table 10-11.	Change this reference to Equation 10-17.
10-25	The calculation $0.98 + 6.875$ is used in an equation within the last row in Table 10-9.	Change the calculation to $0.98 - 6.875$.

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10-26	In the last paragraph, first sentence: “...Table 9, Figure 8, and Table 10...”	Make the following text change: “...Tables 10-9 and 10-10, and Figure 10-8...”
10-42	A 1,2000-ft horizontal curve radius is used in the 5th bullet under the heading “The Facts”.	Change the horizontal curve radius to 1,200 ft.
11-10	The second sentence of Step 12 reads, “Otherwise, proceed to Step 14.”	Change “Step 14” to “Step 13.”
11-11	In the first definition: “...rural two-lane, two-way road facility...”	Make the following text change: “...rural multi-lane highway...”
11-16	In the first paragraph, first sentence: “...in Table 11-3...”	Make the following change: “...in Table 11-4...”
11-18	In the second paragraph, second sentence: “The SPFs for undivided roadway...”	Make the following text change: “The SPFs for divided roadway...”
11-19	In the first paragraph, first sentence: “The default proportions in Table 11-5...”	Make the following Table number change: “The default proportions in Table 11-6...”
11-31	Paragraph 1, line 7 refers to Table 13-9.	Change this reference to Table 13-13.
11-33	Eq. 11-18 is shown as $CMF_{li} = \frac{0.016 \times skew}{(0.98 + 0.16 \times skew)} + 1.0$	Change the denominator as follows: $CMF_{li} = \frac{0.016 \times skew}{(0.98 + 0.016 \times skew)} + 1.0$
11-33	Eq. 11-19 is shown a $CMF_{li} = \frac{0.017 \times skew}{(0.52 + 0.17 \times skew)} + 1.0$	Change the denominator as follows: $CMF_{li} = \frac{0.017 \times skew}{(0.52 + 0.017 \times skew)} + 1.0$
11-34	Eq. 11-20 is shown as $CMF_{li} = \frac{0.053 \times skew}{(1.43 + 0.53 \times skew)} + 1.0$	Change the denominator as follows: $CMF_{li} = \frac{0.053 \times skew}{(1.43 + 0.053 \times skew)} + 1.0$

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11-34	Eq. 11-21 is shown as $CMF_{li} = \frac{0.048 \times skew}{(0.72 + 0.48 \times skew)} + 1.0$	Change the denominator as follows: $CMF_{li} = \frac{0.048 \times skew}{(0.72 + 0.048 \times skew)} + 1.0$
11-35	In the CMF_{4i}—Lighting section: “This CMF applies to total intersections crashes (not including vehicle-pedestrian and vehicle-bicycle collisions).”	Make the following text change: “This CMF applies to total intersection crashes.”
11-50	Step 10, Intersection Skew Angle calculates CMF _{li} as follows: $CMF_{li} = \frac{0.016 \times skew}{(0.98 + 0.16 \times skew)} + 1.0$ $CMF_{li} = \frac{0.016 \times 30}{(0.98 + 0.16 \times 30)} + 1.0 = 1.08$	Change this calculation to: $CMF_{li} = \frac{0.016 \times skew}{(0.98 + 0.016 \times skew)} + 1.0$ $CMF_{li} = \frac{0.016 \times 30}{(0.98 + 0.016 \times 30)} + 1.0 = 1.08$
11-50	The final calculation in Step 10 is: $CMF_{comb} = 1.08 \times 0.56 \times 0.90 = 0.54.$	Change this calculation to $CMF_{comb} = 1.33 \times 0.56 \times 0.90 = 0.67.$
11-50	Step 11, Calculation of Predicted Average Crash Frequency, indicates the results are $= 0.928 \times 1.50 \times (0.54) = 0.752$ crashes/year.	Change these results to $= 0.928 \times 1.50 \times (0.67) = 0.933$ crashes/year.
11-52	Column 2 of the table for Worksheet SP3B lists CMF for Intersection Skew Angle for the Total Crash Severity Level in Row 1 as 1.08 and the Fatal and Injury Crash Severity Level in Row 2 as 1.09.	Change the CMF for Intersection Skew Angle for the Total Crash Severity Level to 1.33 and the Fatal and Injury Crash Severity Level to 1.50.
11-52	Column 6 of the table for Worksheet SP3B lists Combined CMF for the Total Crash Severity Level in Row 1 as 0.54 and the Fatal and Injury Crash Severity Level in Row 2 as 0.44.	Change the Combined CMF in Column 6 to 0.67 for the Total Crash Severity Level in Row 1 and to 0.61 for the Fatal and Injury Crash Severity Level in Row 2.
11-52	Column 5 of the Worksheet SP3C show the values for Combined CMFs are 0.54 for Total Crash Severity Level in Row 1, 0.44 for Fatal and Injury Crash Severity Level in Row 2, and 0.44 for Fatal and Injury Crash Severity Level in Row 3.	Change these values to 0.67, 0.61, and 0.61, respectively.

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11-52	Column 7 of the Worksheet SP3C show the values for Predicted Crash Frequency are 0.752 for Total Crash Severity Level in Row 1, 0.286 for Fatal and Injury Crash Severity Level in Row 2, 0.178 for Fatal and Injury Crash Severity Level in Row 3, and 0.466 for Property Damage Only in Row 4.	Change these values to 0.933, 0.396, 0.247, and 0.537, respectively.
11-53	The values in Columns 3, 5, 7, and 9 in the table for Worksheet SP3D are incorrect.	Substitute the table for Worksheet SP3D with the attached revised table.
11-53	In the table for Worksheet SP3E, the values for Predicted Average Crash Frequency listed in Column 2 are 0.752, 0.286, 0.178, 0.466 crashes/year.	Change these values to 0.933, 0.396, 0.247, and 0.537, respectively.
11-55	The values in Columns 2, 3, 4, 7, and 8 for Intersections shown in Worksheet SP4A are incorrect.	Substitute the table for Worksheet SP4A with the attached revised table.
11-55	The final calculation for Intersection 1 is shown as: $w = \frac{1}{1 + 0.460 \times (0.752)} = 0.743$	Change this calculation to $w = \frac{1}{1 + 0.460 \times (0.933)} = 0.700$
11-56	Under the subheading Column 8—Expected Average Crash Frequency, the calculation for Intersection 1 is shown as follows: $N_{expected} = 0.743 \times 0.752 + (1 - 0.743) \times 3 = 1.330.$	Change this calculation to $N_{expected} = 0.700 \times 0.933 + (1 - 0.700) \times 3 = 1.554.$
11-56	The values and the reference to Worksheet 3A in the table for Worksheet SP4B are incorrect.	Substitute the table for Worksheet SP4B with the attached revised table.
11-58	The headings and values shown in the tables for Worksheet SP5A and SP5A Continued are incorrect.	Substitute the tables for Worksheet SP5A and SP5A Continued with the attached revised table.
11-58	In Worksheet SP5A: there are subhead errors in columns 1-7	Revert back to original edition's subhead values

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11-59	The calculation for w_0 in Column 9 is shown as $= \frac{1}{1 + \frac{1.968}{4.347}}$ $= 0.688$	Change the calculation to $= \frac{1}{1 + \frac{2.109}{4.528}}$ $= 0.682$
11-59	The calculation for N_0 in Column 10 is shown as $= 0.688 \times 4.347 + (1 - 0.688) \times 9 = 5.799.$	Change the calculation to $0.682 \times 4.528 + (1 - 0.682) \times 9 = 5.950.$
11-59	The calculation for w_1 in Column 11 is shown as $= \frac{1}{1 + \frac{2.009}{4.347}}$ $= 0.684$	Change this calculation to $= \frac{1}{1 + \frac{2.076}{4.528}}$ $= 0.686$
11-59	The calculation for N_1 in Column 12 is shown as $= 0.684 \times 4.347 + (1 - 0.684) \times 9 = 5.817.$	Change this calculation to $= 0.686 \times 4.528 + (1 - 0.686) \times 9 = 5.932.$
11-59	The calculation for $N_{expected/comb}$ in Column 13 is shown as: $= \frac{5.799 + 5.817}{2}$ $= 5.808$	Change this calculation to: $= \frac{5.950 + 5.932}{2}$ $= 5.941$
11-60	The values shown in the table for Worksheet SP5B are incorrect.	Substitute the table for Worksheet SP5B with the attached revised table.
11-61	The first sentence in the section on Results reads, “The predicted average crash frequency for the proposed four-lane facility project is 4.4 crashes per year, and the predicted crash reduction for the project is 8.1 crashes per year.”	Change the numbers to 4.5 crashes per year for the predicted average crash frequency and 7.8 crashes per year for the predicted crash reduction.
11-61	The values in Table 11-26 are incorrect.	Substitute Table 11-26 with the attached revised table.
12-10	In the 12th bullet: • “For all intersections...”	Remove the bullet

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12-10	In the 16 th bullet: “Number of major-road approaches with left-turn signal phasing (0, 1, or 2) (signalized intersections only) and type of left-turn signal phasing (permissive, protected/permissive, permissive/protected, or protected).”	Make the following text change: “Number of approaches with left-turn signal phasing (0, 1, 2, 3, or 4) (signalized intersections only) and type of left-turn signal phasing (permissive, protected/permissive, permissive/protected, or protected).”
12-10	At the end of the page, there is a missing bullet	Add bullet text: • Pedestrian volumes
12-12	The second sentence of Step 12 reads, “Otherwise, proceed to Step 14.”	Change “Step 14” to “Step 13.”
12-15	In the middle of the page there is a missing bullet	Add bullet text after “Presence/type of median”: • Presence of TWLTL
12-15	At the end of the page, there is a missing bullet	Add bullet text after “Speed” category: • Automated Enforcement
12-28	In the last paragraph, first sentence: “The SPF for each of the four intersection...”	Make the following change in the text by adding this to the end of the sentence: “...and intersection-related crashes.”
12-41	In the last paragraph, first sentence: “The CMF applies...cross-median collisions...”	Make the following text change to: “The CMF applies...cross-median collisions...”
12-43	Paragraph 1, line 2 of Section 12.7.2 refers to CMF_{4i} .	Change CMF_{4i} to CMF_{6i} .
12-86	Paragraph 1, Line 1 of the section on Results refers to “the unsignalized intersection in Sample Problem 4.”	Change “unsignalized” to “signalized.”
12-114	Column head (7) of Worksheet 2C Continued refers to Worksheet SP4B.	Change the reference to Worksheet 2B.
12-115	Column head (7) of Worksheet 2E Continued refers to Worksheet SP4B.	Change the reference to Worksheet 2B.
A-5-A-7	In Table A-2: “Average Annual Daily Traffic”	Make this change throughout the table: “Annual Average Daily Traffic”

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A-5	In Table A-2, the row for Presence of Lighting for Chapter 11 shows the “X” in the Required column	The “X” should be in the Desirable column.
A-5	In Table A-2, the row for Sideslope for Chapter 11 shows the “X” not aligned in the Required column.	The “X” should be in the Required column.
A-5	In Table A-2 Rural Multilane Highways, “For divided highways only:”	Add italics: “<i>For divided highways only:</i>”
A-6	In Table A-2, Urban and Suburban Arterials: “Low-speed vs. intermediate or high speed”	Please change to the following: “Posted speed limit”
A-6	In Table A-2, the row for Presence of Lighting for Chapter 11 reads “Need actual datad.”	The final d should be deleted so that the text reads “Need actual data.”
A-6	In Table A-2, the row for Intersection Skew Angle for Chapter 11 does not have a superscript.	Insert a superscript “d” to indicate a cross reference to table note d. The text should read, “Assume no skew ^d ”
A-7	In Table A-2, Pedestrian Volume for Chapter 12 refers to “Estimate with Table 12-21.”	Change the cross reference to Table 12-15.
A-8	The first line of Example Calibration Factor Calculation refers to Equation 10-18.	Change the cross reference to Equation 10-10.
A-8	In Equation 10-10: $N_{spf \text{ int}} = e^{[-5.73 \dots]}$	Make the following change in the equation: $N_{spf \text{ int}} = e^{[-5.13 \dots]}$
A-8	In the calculation for predicted crash frequency, the sample indicates that $N_{bibase} = e^{(-5.73 + 60 \times \ln(4000) + 0.20 \times \ln(2000))}$ = 3.922 crashes/year	The correct values should be $N_{bibase} = e^{(-5.13 + 60 \times \ln(4000) + 0.20 \times \ln(2000))} = 3.922$ crashes/year
A-8	In the paragraph following the N_{bibase} calculation, the first sentence states, “The intersection has a left-turn lane on the major road, for which CMF_{1i} is 0.67, and a right-turn lane on one approach, a feature for which CMF_{2i} is 0.98.”	Change this text to read: “The intersection has a left-turn lane on the major road, for which CMF_{1i} is 0.82, and a right-turn lane on one approach, a feature for which CMF_{2i} is 0.96.”

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A-8	In the last equation on the page, the calculation for predicted average crash frequency is recorded as “ $2.152 \times 0.67 \times 0.98 \times 3 = 4.240$ crashes in three years, shown in Column 9.”	The correct values for this calculation are actually “ $3.922 \times 0.82 \times 0.96 \times 3 = 9.262$ crashes in three years, shown in Column 9.”
A-8	The final paragraph, second sentence on page A-8 indicates, “. . . The sum of the observed crash frequencies in Column 10 (43) is divided by the sum of the predicted average crash frequencies in Column 9 (45.594) to obtain the calibration factor, C_i , equal to 0.943. It is recommended that calibration factors be rounded to two decimal places, so calibration factor equal to 0.94 should be used . . .”	These sentences of the paragraph should read, “. . . The sum of the observed crash frequencies in Column 10 (43) is divided by the sum of the predicted average crash frequencies in Column 9 (87.928) to obtain the calibration factor, C_i , equal to 0.489. It is recommended that calibration factors be rounded to two decimal places, so calibration factor equal to 0.49 should be used . . .”
A-9	The values in Columns 3, 5, 7, and 9 of Table Ex-1 are incorrect.	Substitute the table for Table Ex-1 with the attached revised table.
A-11	In Table A-3, Table 11-19 Intersections “X”	Make the following change in the table: Table 11-19 Roadway Segments “X”
A-14	In the paragraph, Crash Severity and Collision Type for Single-Vehicle Crashes by Intersection Type	Add the following text: The default values for f_{bisv} in Equation 12-27 should be replaced with locally available data.
A-14	In the last paragraph, second sentence: “For a given facility type and speed category,...”	Make the following text change: “For a given facility type,...”
A-20	In Eq. A-9: $N_{predicted\ w1} = \sum_{j=1}^5 \sqrt{k_{rmj} N_{rmj}} + \sum_{j=1}^5 \sqrt{k_{rsj} N_{isj}} + \sum_{j=1}^5 \sqrt{k_{rdj} N_{rdj}} + \sum_{j=1}^4 \sqrt{k_{imj} N_{imj}} + \sum_{j=1}^4 \sqrt{k_{isj} N_{isj}}$	Make the following change in the equation: $N_{predicted,\ w1} = \left[\sum_{j=1}^5 \sqrt{k_{rmj} N_{rmj}^2} + \sum_{j=1}^5 \sqrt{k_{rsj} N_{rsj}^2} + \sum_{j=1}^5 \sqrt{k_{rdj} N_{rdj}^2} + \sum_{j=1}^4 \sqrt{k_{imj} N_{imj}^2} + \sum_{j=1}^4 \sqrt{k_{isj} N_{isj}^2} \right]^2$

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Vol. 3		
D-3	A sentence for Row “T” in Table D-1 was omitted.	Add “A list of these treatments is presented in the appendices to each chapter” as the final sentence in this row.
D-5	Item 2 in Section D.4.4, Application of CMFs to Estimate Crash Frequency, refers to “...an expected number of crashes...”	Change this phrase to “...a predicted number of crashes...”
13-22	There is no specific table referenced in the first sentence of the first paragraph to Section 13.5.2.2.	Reference Table 13-21.
13-24	Table 13-2 is referenced in the 2nd paragraph to Section 13.5.2.4.	Change the reference to Table 13-23.
13-35	Table 13-411 is referenced in the 2nd paragraph to Section 13.8.2.7.	Change the reference to Table 13-41.
13-48	Table 13-54 is missing a row for installing pedestrian-activated flashing yellow beacons with overhead signs. In addition, the treatment to provide pedestrian overpasses and underpasses has a trend for urban arterials.	Replace Table 13-54 with the attached revision.
13-51	Figure 13-11 was calculated using the metric coefficient 0.2	Make the following change to the figure: Figure calculated using the converted coefficient 0.322
14-10	Exhibit 14-8 is referenced in the last paragraph.	Change the reference to Table 14-4.
14-19	Eq. 14-3 is shown as $CMF_{li} = \frac{0.016 \times skew}{(0.98 + 0.16 \times skew)} + 1.0$	Change the denominator as follows: $CMF_{li} = \frac{0.016 \times skew}{(0.98 + 0.016 \times skew)} + 1.0$
14-19	Eq. 14-4 is shown as $CMF_{li} = \frac{0.053 \times skew}{(1.43 + 0.53 \times skew)} + 1.0$	Change the denominator as follows: $CMF_{li} = \frac{0.053 \times skew}{(1.43 + 0.053 \times skew)} + 1.0$
14-20	Eq. 14-5 is shown as $CMF_{li} = \frac{0.017 \times skew}{(0.52 + 0.17 \times skew)} + 1.0$	Change the denominator as follows: $CMF_{li} = \frac{0.017 \times skew}{(0.52 + 0.017 \times skew)} + 1.0$

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14-20	Eq. 14-6 is shown as $CMF_{li} = \frac{0.048 \times skew}{(0.72 + 0.48 \times skew)} + 1.0$	Change the denominator as follows: $CMF_{li} = \frac{0.048 \times skew}{(0.72 + 0.048 \times skew)} + 1.0$
14-42	Exhibit 14-38 is referenced in the 3rd paragraph to Section 14.7.2.8.	Change the reference to Table 14-28.
14-52	The final sentence of Section 14A.5.1.8 reads, “The LPI provides pedestrians an opportunity to begin crossing without concern for turning vehicles (assuming right-on-red is <u>permitted</u>).”	This sentence should read, “The LPI provides pedestrians an opportunity to begin crossing without concern for turning vehicles (assuming right-on-red is <u>prohibited</u>).”
15-4	There are unknown crash effects for modifying ramp type or configuration and for providing pedestrian facilities on ramp terminals.	Replace Table 15-1 with the attached revision. The two rows referring to modifying ramp type or configuration and to providing pedestrian facilities on ramp terminals have been deleted.
15-6	Eq. 15-3: $CMF = \frac{1.576 \times e^{(-4.55 \times 0.12)}}{1.576 \times e^{(-4.55 \times 0.20)}} = 0.69$	Revise the equation: $CMF = \frac{1.576 \times e^{(-4.55 \times 0.20)}}{1.576 \times e^{(-4.55 \times 0.12)}} = 0.69$
15-11	A bulleted item is missing under Section 15A.3.1, Ramp Roadways.	Add the following bulleted item: ■ Modify ramp type or configuration.
15-12	A bulleted item is missing under Section 15A.3.1, Bicyclists and Pedestrians.	Add the following bulleted item: ■ Provide pedestrian facilities on ramp terminals.
16-6	Exhibit 16-5 is referenced in the 2nd sentence to Section 16.4.2.1.	Change the reference to Figure 16-1.
16-6	Figure 16-1 is referenced in the 3rd sentence to Section 16.4.2.1.	Change the reference to Figure 16-2.

Errata to the *Highway Safety Manual*, 1st Edition and Supplement

• 2010 errata changes in **blue** • 2012 errata changes in **red** • 2016 errata changes in **green (bold)**

Page	Existing Text	Corrected Text
17-5	There are unknown crash effects for mitigating aggressive driving through engineering and for implementing older driver education and retesting programs.	Replace Table 17-4 with the attached revision. The two rows referring to mitigating aggressive driving through engineering and to implementing older driver education and retesting programs have been deleted.
17-14	A subsection is missing under Section 17A.4.1.	Add the following subsection and text after the 3rd paragraph to subsection 17A.4.1.6: 17A.4.1.7. Conduct Enforcement to Reduce Red-Light Running Automated enforcement for red-light running, combined with appropriate enabling legislation, potentially reduces crashes.
17-14 to 17-16	As a result of adding a subsection that was missing under Section 17A.4.1, renumber the remaining subsections.	Renumber as follows: ■ Section 17A.4.1.7 as Section 17A.4.1.8 ■ Section 17A.4.1.8 as Section 17A.4.1.9 ■ Section 17A.4.1.9 as Section 17A.4.1.10 ■ Section 17A.4.1.10 as Section 17A.4.1.11 ■ Section 17A.4.1.11 as Section 17A.4.1.12

Supplement

18-42

In Eq. 18-35:

$$CMF_{8, fs, ac, sv, z} = \left(1.0 - \sum_{i=1}^m P_{c,i} \times f_{c,i} \right) \times \exp(a \times [W_s - 10]) + \left(\sum_{i=1}^m P_{c,i} \times f_{c,i} \right) \times \exp(b \times [W_s - 10])$$

Make the following change to the equation:

$$CMF_{8, fs, ac, sv, z} = \left(1.0 - \sum_{i=1}^m P_{c,i} \right) \times \exp(a \times [W_s - 10]) + \left(\sum_{i=1}^m P_{c,i} \right) \times \exp(b \times [W_s - 10])$$

Errata to the *Highway Safety Manual*, 1st Edition and Supplement

• 2010 errata changes in blue • 2012 errata changes in red • 2016 errata changes in green (bold)

Page	Existing Text	Corrected Text
18-43	In Eq. 18-36: $CMF_{\theta, f_s, ac, sv, f_i} = \left(1.0 - \sum_{i=1}^m P_{c,i} \times f_{c,i} \right) \times$ $f_{tan} + \left(\sum_{i=1}^m P_{c,i} \times f_{c,i} \right) \times 1.0$	Make the following change to the equation: $CMF_{\theta, f_s, ac, sv, f_i} = \left(1.0 - \sum_{i=1}^m P_{c,i} \right) \times$ $f_{tan} + \left(\sum_{i=1}^m P_{c,i} \right) \times 1.0$
18-52	In the first paragraph, last sentence; and the third paragraph, last sentence: "...is less than 0.75 ft, then it should..."	Make the following text change: "...is less than 0.75 ft, then W_{icb} should..."
19-67	Following Table 19-42	Please add the following text: "The curve entry speeds need to be calculated for all curves from milepost 0.0 to the end of the analysis segment. This may include segments of an adjacent ramp that are not included in the current analysis segment. For each curve, record the entry speed, the total length of the curve, and the length of the current analysis segment. Once the procedure on the following pages is completed, return to Equation 19-33. In this equation, the summation term only includes entry speeds and radii that have a length in the current analysis segment. All other curves analyzed should be ignored if they are not part of the current analysis segment."
Throughout	Some equations using natural logarithm were inadvertently typeset with "In" instead of "ln".	Please replace the "In" with "ln" in these equations.

information in a timely fashion, when they are overloaded with information, or when their expectations are not met, slowed responses and errors may occur.

Design that conforms to long-term expectancies reduces the chance of driver error. For example, drivers expect that there are no traffic signals on freeways and that freeway exits are on the right. If design conforms to those expectancies it reduces the risk of a crash. Short-term expectancies can also be impacted by design decisions. An example of a short-term expectation is that subsequent curves on a section of road are gradual, given that all previous curves were gradual.

With respect to traffic control devices, the positive guidance approach emphasizes assisting the driver with processing information accurately and quickly by considering the following:

- *Primacy*—Determine the placements of signs according to the importance of information, and avoid presenting the driver with information when and where the information is not essential.
- *Spreading*—Where all the information required by the driver cannot be placed on one sign or on a number of signs at one location, spread the signage along the road so that information is given in small chunks to reduce information load.
- *Coding*—Where possible, organize pieces of information into larger units. Color and shape coding of traffic signs accomplishes this organization by representing specific information about the message based on the color of the sign background and the shape of the sign panel (e.g., warning signs are yellow, regulatory signs are white).
- *Redundancy*—Say the same thing in more than one way. For example, the stop sign in North America has a unique shape and message, both of which convey the message to stop. A second example of redundancy is to give the same information by using two devices (e.g., “no passing” indicated with both signs and pavement markings).

2.5. IMPACTS OF ROAD DESIGN ON THE DRIVER

This section considers major road design elements, related driver tasks, and human errors associated with common crash types. It is not intended to be a comprehensive summary, but is intended to provide examples to help identify opportunities where an understanding of the influence of human factors can be applied to improve design.

2.5.1. Intersections and Access Points

As discussed in Section 2.2, the driving task involves control, guidance, and navigation elements. At intersections, each of these elements presents challenges:

- *Control*—The path through the intersection is typically unmarked and may involve turning;
- *Guidance*—There are numerous potential conflicts with other vehicles, pedestrians, and cyclists on conflicting paths; and
- *Navigation*—Changes in direction are usually made at intersections, and road name signing can be difficult to locate and read in time to accomplish any required lane changes.

In the process of negotiating any intersection, drivers are required to:

- Detect the intersection;
- Identify signalization and appropriate paths;
- Search for vehicles, pedestrians, and bicyclists on a conflicting path;
- Assess adequacy of gaps for turning movements;
- Rapidly make a stop/go decision on the approach to a signalized intersection when in the decision zone; and
- Successfully complete through or turning maneuvers.

Slow-Moving or Stopped Vehicles Ahead

As for the controlled-access mainline, rear-end and sideswipe crashes occur when drivers encounter unexpected slowing or stopped vehicles and realize too late their closing speed.

Poor Visibility of Vulnerable Road Users or Animals

Vulnerable road user and animal crashes may occur due to low contrast with the background and drivers' inability to detect pedestrians, cyclists, or animals in time to stop.

2.6. SUMMARY—HUMAN FACTORS AND THE HSM

This chapter described the key factors of human behavior and ability that influence how drivers interact with the roadway. The core elements of the driving task were outlined and related to human ability so as to identify areas where humans may not always successfully complete the tasks. There is potential to reduce driver error and associated crashes by accounting for the following driver characteristics and limitations described in the chapter:

- *Attention and information processing*—Drivers can only process a limited amount of information and often rely on past experience to manage the amount of new information they must process while driving. Drivers can process information best when it is presented in accordance with expectations, sequentially to maintain a consistent level of demand, and in a way that it helps drivers prioritize the most essential information.
- *Vision*—Approximately 90 percent of the information used by a driver is obtained visually (17). It is important that the information be presented in a way that considers the variability of driver visual capability so that users can see, comprehend, and respond to it appropriately.
- *Perception-reaction time*—The amount of time and distance needed by one driver to respond to a stimulus (e.g., hazard in road, traffic control device, or guide sign) depends on human elements, including information processing, driver alertness, driver expectations, and vision.
- *Speed choice*—Drivers use perceptual and road message cues to determine a speed they perceive to be safe. Information taken in through peripheral vision may lead drivers to speed up or slow down depending on the distance from the vehicle to the roadside objects (38). Drivers may also drive faster than they realize after adapting to highway speeds and subsequently entering a lower-level facility (37).

Knowledge of both engineering principles and the effects of human factors can be applied through the positive guidance approach to road design. The positive guidance approach is based on the central principle that road design that corresponds with driver limitations and expectations increases the likelihood of drivers responding to situations and information correctly and quickly. When drivers are not provided or do not accept information in a timely fashion, when they are overloaded with information, or when their expectations are not met, slowed responses and errors may occur.

An understanding of human factors and their affects can be applied to all projects regardless of the project focus. Parts B, C, and D provide specific guidance on the roadway safety management process, estimating safety effects of design alternatives, and predicting safety on different facilities. Considering the effect of human factors on these activities can improve decision making and design considerations in analyzing and developing safer roads.

2.7. REFERENCES

- (1) Alexander, G. J. and H. Lunenfeld. *Driver Expectancy in Highway Design and Traffic Operations*. Publication No. FHWA-TO-86-1. Federal Highway Administration, U.S. Department of Transportation, Washington, DC. 1986.
- (2) Alexander, G. and H. Lunenfeld. *Positive guidance in traffic control*. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1975.

While the functional form of the SPFs varies in the HSM, the predictive model to estimate the expected average crash frequency $N_{\text{predicted}}$, is generally calculated using Equation 3-3.

$$N_{\text{predicted}} = N_{\text{SPF } x} \times (CMF_{1x} \times CMF_{2x} \times \dots \times CMF_{yx}) \times C_x \quad (3-3)$$

Where:

- $N_{\text{predicted}}$ = predictive model estimate of crash frequency for a specific year on site type x (crashes/year);
- $N_{\text{SPF } x}$ = predicted average crash frequency determined for base conditions with the Safety Performance Function representing site type x (crashes/year);
- CMF_{yx} = Crash Modification Factors specific to site type x ;
- C_x = Calibration Factor to adjust for local conditions for site type x .

The HSM provides a detailed predictive method for the following three facility types:

- *Chapter 10*—Rural Two-Lane Two-Way Roads;
- *Chapter 11*—Rural Multilane Highways;
- *Chapter 12*—Urban and Suburban Arterials.

Advantages of the Predictive Method

Advantages of the predictive method are that:

- Regression-to-the-mean bias is addressed as the method concentrates on long-term expected average crash frequency rather than short-term observed crash frequency.
- Reliance on availability of limited crash data for any one site is reduced by incorporating predictive relationships based on data from many similar sites.
- The method accounts for the fundamentally nonlinear relationship between crash frequency and traffic volume.
- The SPFs in the HSM are based on the negative binomial distribution, which are better suited to modeling the high natural variability of crash data than traditional modeling techniques based on the normal distribution.

First-time users of the HSM who wish to apply the predictive method are advised to read Section 3.5 (this section), read the Part C—Introduction and Applications Guidance, and then select an appropriate facility type from Chapters 10, 11, or 12 for the roadway network, facility, or site under consideration.

3.5.2. Safety Performance Functions

Safety Performance Functions (SPFs) are regression equations that estimate the average crash frequency for a specific site type (with specified base conditions) as a function of annual average daily traffic (AADT) and, in the case of roadway segments, the segment length (L). Base conditions are specified for each SPF and may include conditions such as lane width, presence or absence of lighting, presence of turn lanes, etc. An example of an SPF (for roadway segments on rural two-lane highways) is shown in Equation 3-4.

$$N_{\text{SPF } rs} = (AADT) \times (L) \times (365) \times 10^{(-6)} \times e^{(-0.312)} \quad (3-4)$$

Where:

- $N_{\text{SPF } rs}$ = estimate of predicted average crash frequency for SPF base conditions for a rural two-lane two-way roadway segment (described in Section 10.6) (crashes/year);
- $AADT$ = average annual daily traffic volume (vehicles per day) on roadway segment;
- L = length of roadway segment (miles).

Applying Multiplicative Crash Modification Factors

Example 1

Treatment 'x' consists of providing a left-turn lane on both major-road approaches to an urban four-leg signalized intersection, and treatment 'y' is permitting right-turn-on-red maneuvers. These treatments are to be implemented, and it is assumed that their effects are independent of each other. An urban four-leg signalized intersection is expected to have 7.9 crashes/year. For treatment t_x , $CMF_x = 0.81$; for treatment t_y , $CMF_y = 1.07$.

What crash frequency is to be expected if treatment x and y are both implemented?

Answer to Example 1

Using Equation 3-3 and a calibration factor = 1.0, expected crashes = $7.9 \times 0.81 \times 1.07 = 6.8$ crashes/year.

Example 2

The CMF for single-vehicle run-off-the-road crashes for a 1 percent increase in grade is 1.04 regardless of whether the increase is from 1 percent to 2 percent or from 5 percent to 6 percent. What is the effect of increasing the grade from 2 percent to 4 percent?

Answer to Example 2

Using Equation 3-7, expected single-vehicle run-off-the-road crashes will increase by a factor of $1.04^{(4-2)} = 1.04^2 = 1.08 = 8$ percent increase.

Multiplication of CMFs in Part C

In the Part C predictive method, an SPF estimate is multiplied by a series of CMFs to adjust the estimate of crash frequency from the base condition to the specific conditions present at a site. The CMFs are multiplicative because the effects of the features they represent are presumed to be independent. However, little research exists regarding the independence of these effects, but this is a reasonable assumption based on current knowledge. The use of observed crash frequency data in the EB Method can help to compensate for bias caused by lack of independence of the CMFs. As new research is completed, future HSM editions may be able to address the independence (or lack of independence) of these effects more fully.

Multiplication of CMFs in Part D

CMFs are also used in estimating the anticipated effects of proposed future treatments or countermeasures (e.g., in some of the methods discussed in Section C.8). The limited understanding of interrelationships between the various treatments presented in Part D requires consideration, especially when more than three CMFs are proposed. If CMFs are multiplied together, it is possible to overestimate the combined effect of multiple treatments when it is expected that more than one of the treatments may affect the same type of crash. The implementation of wider lanes and wider shoulders along a corridor is an example of a combined treatment where the independence of the individual treatments is unclear, because both treatments are expected to reduce the same crash types. When CMFs are multiplied, the practitioner accepts the assumption that the effects represented by the CMFs are independent of one another. Users should exercise engineering judgment to assess the interrelationship or independence, or both, of individual elements or treatments being considered for implementation.

Compatibility of Multiple CMFs

Engineering judgment is also necessary in the use of combined CMFs where multiple treatments change the overall nature or character of the site; in this case, certain CMFs used in the analysis of the existing site conditions and the proposed treatment may not be compatible. An example of this concern is the installation of a roundabout at an urban two-way stop-controlled or signalized intersection. The procedure for estimating the crash frequency after installation of a roundabout (see Chapter 12) is to estimate the average crash frequency for the existing site conditions (as an SPF for roundabouts in currently unavailable), and then apply a CMF for a conventional intersection to roundabout conversion. Installing a roundabout changes the nature of the site so that other CMFs applicable to existing urban two-way stop-controlled or signalized intersections may no longer be relevant.

Estimating Average Crash Frequency without Assuming Similar Crash Frequency in All Periods

This estimation of the average crash frequency of a specific roadway or facility in a certain period is conducted using crash counts from other periods without assuming that the expected average crash frequency of a specific roadway or facility's expected average crash frequency is similar in all periods. Equation 3A-5 presents the relationship that estimates a specific unit for the last period of a sequence.

$$\hat{\mu}_Y = \sum_{y=1}^Y X_y / \sum_{y=1}^Y d_y \quad (3A-5)$$

Where:

$\hat{\mu}_Y$ = most likely estimate of μ_Y (last period or year);

μ_y = $\mu_y \times d_y$ where y denotes a period or a year ($y=1, 2, \dots, Y$; while Y denotes the last period or last year);
e.g., for first period d_1 = relationship of μ_1/μ_Y ;

X_y = the counts of crashes for each period or Year y .

Equation 3A-6 presents the estimate of the variance of $\hat{\mu}_Y$.

$$\hat{V}(\hat{\mu}_Y) = \sum_{y=1}^Y X_y / \left(\sum_{y=1}^Y d_y \right)^2 \quad (3A-6)$$

Where:

$\hat{\mu}_Y$ = most likely estimate of μ_Y (last period or year);

d_y = the μ_1/μ

X_y = the counts of crashes for each period or Year y .

For this estimate, it is necessary to add all crash counts reported during this year for all intersections that are similar to the intersection, under evaluation, throughout the network. Using the example given in Figure 3A-1 to illustrate this estimate, the proportion of the crashes counts per year in relation to the annual total crash counts for all similar intersections was calculated. The results are shown in Table 3A-2, e.g., 27 percent of annual crashes occur in the first year, 22 percent in the second year, etc.

Each yearly proportion is modified in relation to the last year, e.g., $d_1 = \mu_1/\mu_4 = 0.27/0.31 = 0.87$, as shown in Table 3A-2.

Table 3A-2. Illustration of Yearly Proportions and Relative Last Year Rates

	Year 1	Year 2	Year 3	Year 4 = Y
Proportion of Crashes	0.27	0.22	0.20	0.31
d_y (relative to the last year)	0.87	0.71	0.64	1

For each year, the crashes counts are 5, 7, 11, and 9, see Figure 3A-1. Using Equations 3A-5 and 3A-6:

$\hat{\mu}_{\text{Year 4}} = (5 + 7 + 11 + 9)/(0.87 + 0.71 + 0.64 + 1) = 32/3.22 = 9.94$ estimate of crashes for the last year:

$\hat{\sigma} = \sqrt{32 / 3.22^2} = \pm 1.8$ crashes as the standard error of the last year's estimate

Failure to account for the effects of RTM introduces the potential for “RTM bias”, also known as “selection bias”. RTM bias occurs when sites are selected for treatment based on short-term trends in observed crash frequency. For example, a site is selected for treatment based on a high observed crash frequency during a very short period of time (e.g., two years). However, the site’s long-term crash frequency may actually be substantially lower and therefore the treatment may have been more cost-effective at an alternate site.

Performance Threshold

A performance threshold value provides a reference point for comparison of performance measure scores within a reference population. Sites can be grouped based on whether the estimated performance measure score for each site is greater than or less than the threshold value. Those sites with a performance measure score less than the threshold value can be studied in further detail to determine if reduction in crash frequency or severity is possible.

The method for determining a threshold performance value is dependent on the performance measure selected. The threshold performance value can be a subjectively assumed value, or calculated as part of the performance measure methodology. For example, threshold values are estimated based on: the average of the observed crash frequency for the reference population, an appropriate safety performance function, or Empirical Bayes methods. Table 4-2 summarizes whether or not each of the performance measures accounts for regression-to-the-mean bias or estimates a performance threshold, or both. The performance measures are presented in relative order of complexity, from least to most complex. Typically, the methods that require more data and address RTM bias produce more reliable performance threshold values.

Table 4-2. Stability of Performance Measures

Performance Measure	Accounts for RTM Bias	Method Estimates a Performance Threshold
Average Crash Frequency	No	No
Crash Rate	No	No
Equivalent Property Damage Only (EPDO) Average Crash Frequency	No	No
Relative Severity Index	No	Yes
Critical Rate	Considers data variance but does not account for RTM bias	Yes
Excess Predicted Average Crash Frequency Using Method of Moments	Considers data variance but does not account for RTM bias	Yes
Level of Service of Safety	Considers data variance but does not account for RTM bias	Expected average crash frequency plus/minus 1.5 standard deviations
Excess Expected Average Crash Frequency Using SPFs	No	Predicted average crash frequency at the site
Probability of Specific Crash Types Exceeding Threshold Proportion	Considers data variance; not effected by RTM Bias	Yes
Excess Proportions of Specific Crash Types	Considers data variance; not effected by RTM Bias	Yes
Expected Average Crash Frequency with EB Adjustments	Yes	Expected average crash frequency per year at the site
Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment	Yes	Expected average crash frequency per year at the site
Excess Expected Average Crash Frequency with EB Adjustments	Yes	Expected average crash frequency per year at the site

$$\text{Coefficient of Variation (CV)} = \frac{\sqrt{\text{Var}(\text{Performance Measure})}}{\text{Performance Measure}} \quad (4-1)$$

A large CV indicates a low level of precision in the estimate, and a small CV indicates a high level of precision in the estimate. The calculated CV is compared to a specified limiting CV. If the calculated CV is less than or equal to the CV limiting value, the performance measure meets the desired precision level, and the performance measure for a given window can potentially be considered for use in ranking the segment. If the calculated CV is greater than the CV limiting value, the window is automatically removed from further consideration in potentially ranking the segment based upon the value of the performance measure.

There is no specific CV value that is appropriate for all network screening applications. However, by adjusting the CV value the user can vary the number of sites identified by network screening as candidates for further investigation. An appropriate initial or default value for the CV is 0.5.

Peak Searching Method

Question

Segment B, in an urban four-lane divided arterial reference population, will be screened using the Excess Expected Average Crash Frequency performance measure. Segment B is 0.47 mi long. The CV limiting value is assumed to be 0.25. If the peak searching method is used to study this segment, how is the methodology applied and how is the segment potentially ranked relative to other sites considered in the screening?

Answer

Iteration #1

The following table shows the results of the first iteration. In the first iteration, the site is divided into 0.1-mi windows. For each window, the performance measure is calculated along with the CV.

The variance is given as:

$$VAR_B = \frac{(5.2 - 5.7)^2 + (7.8 - 5.7)^2 + (1.1 - 5.7)^2 + (6.5 - 5.7)^2 + (7.8 - 5.7)^2}{(5 - 1)} = 7.7$$

The Coefficient of Variation for Segment B1 is calculated using Equation 4-1 as shown below:

$$CV_{B1} = \frac{\sqrt{7.7}}{5.2} = 0.53$$

Example Application of Expected Average Crash Frequency with Empirical Bayes Adjustment (Iteration #1)

Subsegment	Window Position	Excess Expected Average Crash	
		Frequency	Coefficient of Variation (CV)
B1	0.00 to 0.10 mi	5.2	0.53
B2	0.10 to 0.20 mi	7.8	0.36
B3	0.20 to 0.30 mi	1.1	2.53
B4	0.30 to 0.40 mi	6.5	0.43
B5	0.37 to 0.47 mi	7.8	0.36
	Average	5.7	—

Because none of the calculated CVs are less than the CV limiting value, none of the windows meet the screening criterion, so a second iteration of the calculations is required.

STEP 4—Rank Locations and Compare**Relative Severity Index (RSI)**

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The average RSI costs are calculated by dividing the RSI crash cost for each intersection by the number of crashes for the same intersection. The average RSI cost per intersection is also compared to the average RSI cost for its respective population.

The following table shows the intersection ranking for all 20 intersections based on their average RSI costs. The RSI costs for Intersection 7 would be compared to the average RSI cost for the unsignalized intersection population. In this instance, the average RSI cost for Intersection 7 (\$31,700) is less than the average RSI cost for all unsignalized intersections (\$39,700 from calculations in Step 3).

Ranking Based on Average RSI Cost per Intersection

Intersection	Average RSI Cost ^a	Exceeds RSI_p
2	\$57,600	X
14	\$52,400	X
6	\$42,800	X
9	\$44,100	X
20	\$43,100	X
3	\$42,400	X
4	\$42,000	X
12	\$41,000	X
11	\$39,900	X
16	\$39,500	
19	\$37,800	
1	\$37,400	
13	\$34,800	
8	\$34,600	
18	\$34,100	
17	\$32,900	
7	\$31,700	
5	\$31,400	
10	\$31,000	
15	\$30,600	

^aAverage RSI Costs per Intersection are rounded to the nearest \$100.

4.4.2.5. Critical Rate

The observed crash rate at each site is compared to a calculated critical crash rate that is unique to each site. Sites that exceed their respective critical rate are flagged for further review. The critical crash rate depends on the average crash rate at similar sites, traffic volume, and a statistical constant that represents a desired confidence level.

Data Needs

- Crashes by location
- Traffic Volume

STEP 3—Calculate Crash Frequency Variance per Reference Population
Excess Predicted Average Crash Frequency Using Method of Moments

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Use Equation 4-13 to calculate variance. Alternatively, variance can be more easily calculated with common spreadsheet programs.

$$Var(N) = \frac{\sum_{i=1}^n (N_{\text{observed},i} - N_{\text{observed},rp})^2}{n_{\text{sites}} - 1} \quad (4-13)$$

Where:

$Var(N)$ = Variance

$N_{\text{observed},rp}$ = Average crash frequency, per reference population

$N_{\text{observed},i}$ = Observed crash frequency per year at site i

n_{sites} = Number of sites per reference population

Calculate the crash frequency variance calculation for the TWSC reference population:

$$S_{TWSC}^2 = \frac{112.8}{6} = 18.8$$

The variance for signal and TWSC reference populations is shown in the following table:

Reference Population	Crash Frequency	
	Average	Variance
Signal	6.1	13.75
TWSC	7.1	10.5

STEP 4—Calculate Adjusted Observed Crash Frequency per Site
Excess Predicted Average Crash Frequency Using Method of Moments

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Using the variance and average crash frequency for a reference population, find the adjusted observed crash frequency for each site using Equation 4-14.

$$N_{\text{observed},i(adj)} = N_{\text{observed},i} + \frac{N_{\text{observed},rp}}{Var(N)} \times (N_{\text{observed},rp} - N_{\text{observed},i}) \quad (4-14)$$

STEP 1—Estimate Predicted Average Crash Frequency Using an SPF**Level of Service of Safety (LOSS)**

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Use the predictive method and SPFs outlined in Part C to estimate the average crash frequency. The predicted average crash frequency is summarized in Table 4-10:

Table 4-10. Estimated Predicted Average Crash Frequency from an SPF

Intersection	Year	AADT		Predicted Average Crash Frequency from an SPF	Average 3-Year Predicted Crash Frequency from an SPF
		Major Street	Minor Street		
2	1	12,000	1,200	1.7	1.7
	2	12,200	1,200	1.7	
	3	12,900	1,300	1.8	
3	1	18,000	800	2.1	2.2
	2	18,900	800	2.2	
	3	19,100	800	2.2	
7	1	21,000	1,000	2.5	2.6
	2	21,400	1,000	2.5	
	3	22,500	1,100	2.7	
10	1	15,000	1,500	2.1	2.2
	2	15,800	1,600	2.2	
	3	15,900	1,600	2.2	
15	1	26,000	500	2.5	2.3
	2	26,500	300	2.2	
	3	27,800	200	2.1	
17	1	14,400	3,200	2.5	2.6
	2	15,100	3,400	2.6	
	3	15,300	3,400	2.6	
19	1	15,400	2,500	2.4	2.5
	2	15,700	2,500	2.5	
	3	16,500	2,600	2.6	

STEP 2—Calculate Standard Deviation**Level of Service of Safety (LOSS)**

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Calculate the standard deviation of the predicted crashes. Equation 4-16 is used to calculate the standard deviation. This estimate of standard deviation is valid since the SPF assumes a negative binomial distribution of crash counts.

$$\sigma = \sqrt{kN_{\text{predicted}}^2} \quad (4-16)$$

Where:

σ = Standard deviation

k = Overdispersion parameter of the SPF

$N_{\text{predicted}}$ = Predicted average crash frequency from the SPF

As shown, the standard deviation calculations for Intersection 7 are

$$\sigma = \sqrt{0.40 \times 2.6^2} = 1.6$$

The standard deviation calculation is performed for each intersection. The standard deviation for the TWSC intersections is summarized in the following table:

Intersection	Average Observed Crash Frequency	Predicted Average Crash Frequency from an SPF	Standard Deviation
2	11.7	1.7	1.1
3	7.7	2.2	1.4
7	11.3	2.6	1.6
10	5.7	2.2	1.4
15	5.7	2.3	1.5
17	4.3	2.6	1.6
19	3.7	2.5	1.6

STEP 3—Calculate Limits for LOSS Categories

Level of Service of Safety (LOSS)

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Calculate the limits for the four LOSS categories for each intersection using the equations summarized in Table 4-11.

Table 4-11. LOSS Categories

LOSS	Condition	Description
I	$\sigma < N_{\text{observed}} < (N_{\text{predicted}} - 1.5 \times (\sigma))$	Indicates a low potential for crash reduction
II	$(N_{\text{predicted}} - 1.5 \times (\sigma)) \leq N_{\text{observed}} < N_{\text{predicted}}$	Indicates low to moderate potential for crash reduction
III	$N_{\text{predicted}} \leq N_{\text{observed}} < (N_{\text{predicted}} + 1.5 \times (\sigma))$	Indicates moderate to high potential for crash reduction
IV	$N_{\text{observed}} \geq (N_{\text{predicted}} + 1.5 \times (\sigma))$	Indicates a high potential for crash reduction

This sample calculation for Intersection 7 demonstrates the upper limit calculation for LOSS III.

$$N_{\text{predicted}} + 1.5 \times (\sigma) = 2.6 + 1.5 \times (1.6) = 5.0$$

A similar pattern is followed for the other LOSS limits.

The values for this calculation are provided in the following table:

LOSS Limits for Intersection 7

Intersection	LOSS I Limits	LOSS II Limits	LOSS III Upper Limit	LOSS IV Limits
7	0 to 0.2	0.2 to 2.6	2.6 to 5.0	≥ 5.0

STEP 4—Calculate Alpha and Beta Parameters *Probability of Specific Crash Types Exceeding Threshold Proportion*

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Calculate the sample mean proportion of target crashes by type or severity for all sites under consideration using Equation 4-21.

$$\overline{p_i^*} = \frac{\sum p_i}{n_{\text{sites}}}, N_{\text{observed},i} \geq 2 \quad (4-21)$$

Where:

n_{sites} = Total number of sites being analyzed

$\overline{p_i^*}$ = Mean proportion of target crash types

p_i = Observed proportion

Calculate Alpha (α) and Beta (β) for each subcategory using Equations 4-22 and 4-23.

$$\alpha = \frac{\overline{p_i^*}^2 - \overline{p_i^*}^3 - s^2(\overline{p_i^*})}{\text{Var}(N)} \quad (4-22)$$

$$\beta = \frac{\alpha}{\overline{p_i^*}} - \alpha \quad (4-23)$$

Where:

$\text{Var}(N)$ = Variance (equivalent to the square of the standard deviation, s^2)

$\overline{p_i^*}$ = Mean proportion of target crash types

The calculation for the two-way stop-controlled subcategory is:

$$\alpha = \frac{0.22^2 - 0.22^3 - 0.037 \times 0.22}{0.037} = 0.80$$

$$\beta = \frac{0.80}{0.22} - 0.80 = 2.84$$

The following table shows the numerical values used in the equations and summarizes the alpha and beta calculations for the TWSC intersections:

Alpha and Beta Calculations

Subcategories	s^2	$\overline{p_i^*}$	α	β
TWSC	0.037	0.22	0.80	2.84

The TWSC intersection population is ranked based on the Probability of Specific Crash Types Exceeding Threshold Proportion Performance Measure as shown in the following table:

Ranking Based on Probability of Specific Crash Types Exceeding Threshold Proportion Performance Measure

Intersections	Probability
2	1.00
11	0.98
9	0.83
12	0.75
16	0.48
6	0.48
13	0.48
20	0.41
4	0.35
17	0.25
5	0.21
1	0.19
18	0.19
7	0.13
10	0.13
3	0.04

4.4.2.10 Excess Proportion of Specific Crash Types

Sites are evaluated to quantify the extent to which a specific crash type is overrepresented compared to other crash types at a location. The sites are ranked based on excess proportion, which is the difference between the true proportion, p_i , and the threshold proportion, p_i^* . The excess is calculated for a site if the probability that a site's long-term observed proportion is higher than the threshold proportion, p_i^* , exceeds a certain limiting probability (e.g., 90 percent).

Data Needs

- Crash data by type and location

Strengths and Limitations

The strengths and limitations of the Excess Proportions of Specific Crash Types Proportion performance measure include the following:

Strengths	Limitations
Can also be used as a diagnostic tool	Does not account for traffic volume.
Considers variance in data	Some sites may be identified for further study because of unusually low frequency of non-target crash types
Not effected by RTM Bias	

Procedure

Calculation of the excess proportion follows the same procedure outlined in Steps 1 through 5 of the Probability of Specific Crash Types Exceeding Threshold Proportions method. Therefore, the procedure outlined in this section builds on the previous method and applies results of sample calculations shown above in the example table of Step 6.

STEP 2—Calculate Annual Correction Factor***Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment***

1	2	3	4	5	6	7
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Calculate the annual correction factor (C_n) at each intersection for each year and each severity (i.e., total and FI).

The annual correction factor is predicted average crash frequency from an SPF for year n divided by the predicted average crash frequency from an SPF for year 1. This factor is intended to capture the effect that annual variations in traffic, weather, and vehicle mix have on crash occurrences. (3)

$$C_{n(\text{total})} = \frac{N_{\text{predicted},n(\text{total})}}{N_{\text{predicted},1(\text{total})}} \quad \text{and} \quad C_{n(FI)} = \frac{N_{\text{predicted},n(FI)}}{N_{\text{predicted},1(FI)}} \quad (4-26)$$

Where:

$C_{n(\text{total})}$ = Annual correction factor for total crashes

$C_{n(FI)}$ = Annual correction factor for fatal or injury crashes, or both

$N_{\text{predicted}, n(\text{total})}$ = Predicted number of total crashes for year n

$N_{\text{predicted},n(FI)}$ = Predicted number of fatal or injury crashes, or both, for year n

Shown below is the calculation for Intersection 7 based on the annual correction factor for year 3. The predicted crashes shown in the equation are the result of Step 1 and are summarized in the table that follows.

$$C_{3(\text{total})} = \frac{2.7}{2.5} = 1.1$$

$$C_{3(FI)} = \frac{1.1}{1.0} = 1.1$$

This calculation is repeated for each year and each intersection. The following table summarizes the annual correction factor calculations for the TWSC intersections:

7.4.3.4. Method Two—Convert Non-Uniform Annual Benefits to Present Value

Some countermeasures yield larger changes in expected average crash frequency in the first years after implementation than in subsequent years. In order to account for this occurrence over the service life of the countermeasure, non-uniform annual monetary values can be calculated as shown in Step 1 below for each year of service. The following process is used to convert the project benefits of all non-uniform annual monetary values to a single present value:

1. Convert each annual monetary value to its individual present value. Each future annual value is treated as a single future value; therefore, a different present worth factor is applied to each year.
 - a) Substitute the $(P/F, i, y)$ factor calculated for each year in the service life for the $(P/A, i, y)$ factor presented in Equation 7-2.

i) $(P/F, i, y)$ = a factor that converts a single future value to its present value

ii) $(P/F, i, y) = (1+i)^{(-y)}$

Where:

i = discount rate (i.e., the discount rate is 4 percent, $i = 0.04$)

y = year in the service life of the countermeasure(s)

2. Sum the individual present values to arrive at a single present value that represents the project benefits of the project.

The sample problems at the end of this chapter illustrate how to convert non-uniform annual values to a single present value.

7.5. ESTIMATE PROJECT COSTS

Estimating the costs associated with implementing a countermeasure follows the same procedure as performing cost estimates for other construction or program implementation projects. Similar to other roadway improvement projects, expected project costs are unique to each site and to each proposed countermeasure(s). The cost of implementing a countermeasure or set of countermeasures could include a variety of factors, e.g., right-of-way acquisition, construction material costs, grading and earthwork, utility relocation, environmental impacts, maintenance, and other costs, including any planning and engineering design work conducted prior to construction.

The AASHTO Redbook states, “Project costs should include the present value of any obligation to incur costs (or commit to incur costs in the future) that burden the [highway] authority’s funds.” (1) Therefore, under this definition the present value of construction, operating, and maintenance costs over the service life of the project are included in the assessment of expected project costs. Chapter 6 of the AASHTO Redbook provides additional guidance regarding the categories of costs and their proper treatment in a benefit-cost or economic appraisal. Categories discussed in the Redbook include:

- Construction and other development costs
- Adjusting development and operating cost estimates for inflation
- The cost of right-of-way
- Measuring the current and future value of undeveloped land
- Measuring current and future value of developed land
- Valuing already-owned right-of-way
- Maintenance and operating costs
- Creating operating cost estimates

Table 7-3. Expected Average Crash Frequency at Intersection 2 WITHOUT Installing the Roundabout

Year in service life (y)	Major AADT	Minor AADT	$N_{\text{expected(total)}}$	$N_{\text{expected(FI)}}$
1	23,553	1,758	10.4	5.2
2	23,906	1,785	10.5	5.3
3	24,265	1,812	10.5	5.3
4	24,629	1,839	10.6	5.4
5	24,998	1,866	10.7	5.4
6	25,373	1,894	10.7	5.4
7	25,754	1,923	10.8	5.5
8	26,140	1,952	10.9	5.5
9	26,532	1,981	11.0	5.5
10	26,930	2,011	11.0	5.6
Total			107.1	54.1

The roadway agency finds the societal crash costs shown in Table 7-4 acceptable. The agency decided to conservatively estimate the economic benefits of the countermeasures. Therefore, they are using the average injury crash cost (i.e., the average value of a fatal (K), disabling (A), evident (B), and possible injury crash (C) as the crash cost value representative of the predicted fatal and injury crashes.

Table 7-4. Societal Crash Costs by Severity

Injury Severity	Estimated Cost
Fatal (K)	\$4,008,900
Cost for crashes with a fatal and/or injury (K/A/B/C)	\$158,200
Disabling Injury (A)	\$216,000
Evident Injury (B)	\$79,000
Possible Injury (C)	\$44,900
PDO (O)	\$7,400

Source: *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*, FHWA-HRT-05-051, October 2005

Assumptions regarding the service life for the roundabout, the annual traffic growth at the site during the service life, the discount rate and the cost of implementing the roundabout include the following:

	Intersection 2
Countermeasure	Roundabout
Service Life	10 years
Annual Traffic Growth	2%
Discount Rate (i)	4.0%
Cost Estimate Method	\$695,000

The following steps are required to solve the problem.

- *Step 1*—Calculate the expected average crash frequency at Intersection 2 without the roundabout.
- *Step 2*—Calculate the expected average crash frequency at Intersection 2 with the roundabout.
- *Step 3*—Calculate the change in expected average crash frequency for total, fatal and injury, and PDO crashes.
- *Step 4*—Convert the change in crashes to a monetary value for each year of the service life.
- *Step 5*—Convert the annual monetary values to a single present value representative of the total monetary benefits expected from installing the countermeasure at Intersection 2.

A summary of inputs, equations, and results of economic appraisal conducted for Intersection 2 is shown in Table 7-5. The methods for conducting the appraisal are outlined in detail in the following sections.

Step 3—Calculate the expected change in crash frequency for total, fatal and injury, and PDO crashes.

The difference between the expected average crash frequency with and without the countermeasure is the expected change in average crash frequency. Equations 7-8, 7-9, and 7-10 are used to estimate this change for total, fatal and injury, and PDO crashes.

$$\Delta N_{\text{expected}(FI)} = N_{\text{expected}(FI)} - N_{\text{expected roundabout}(FI)} \quad (7-8)$$

$$\Delta N_{\text{expected}(total)} = N_{\text{expected}(total)} - N_{\text{expected roundabout}(total)} \quad (7-9)$$

$$\Delta N_{\text{expected}(PDO)} = \Delta N_{\text{expected}(total)} - \Delta N_{\text{expected}(FI)} \quad (7-10)$$

Where:

$\Delta N_{\text{expected}(total)}$ = Expected change in average crash frequency due to implementing countermeasure;

$\Delta N_{\text{expected}(FI)}$ = Expected change in average fatal and injury crash frequency due to implementing countermeasure; and

$\Delta N_{\text{expected}(PDO)}$ = Expected change in average PDO crash frequency due to implementing countermeasure.

Table 7-8 summarizes the expected change in average crash frequency due to installing the roundabout.

Table 7-8. Change in Expected Average in Crash Frequency at Intersection 2 WITH the Roundabout

Year in service life, y	$\Delta N_{\text{expected}(total)}$	$\Delta N_{\text{expected}(FI)}$	$\Delta N_{\text{expected}(PDO)}$
1	4.6	4.3	0.3
2	4.6	4.3	0.3
3	4.6	4.3	0.3
4	4.7	4.4	0.3
5	4.7	4.4	0.3
6	4.7	4.4	0.3
7	4.8	4.5	0.3
8	4.8	4.5	0.3
9	4.8	4.5	0.3
10	4.8	4.6	0.2
Total	47.1	44.2	2.9

Step 4—Convert Change in Crashes to a Monetary Value

The estimated reduction in average crash frequency can be converted to a monetary value for each year of the service life using Equations 7-11 through 7-13.

$$AM_{(PDO)} = \Delta N_{\text{expected}(PDO)} \times CC_{(PDO)} \quad (7-11)$$

$$AM_{(FI)} = \Delta N_{\text{expected}(FI)} \times CC_{(FI)} \quad (7-12)$$

$$AM_{(total)} = AM_{(PDO)} + AM_{(FI)} \quad (7-13)$$

Where:

$AM_{(PDO)}$ = Monetary value of the estimated change in average PDO crash frequency for year, y;

$CC_{(PDO)}$ = Crash cost for PDO crash severity;

$AM_{(FI)}$ = Monetary value of the estimated change in fatal and injury average crash frequency for year y;

$CC_{(FI)}$ = Crash cost for FI crash severity; and

$AM_{(total)}$ = Monetary value of the total estimated change in average crash frequency for year y.

Table 7-9 summarizes the monetary value calculations for each year of the service life.

Table 7-9. Annual Monetary Value of Change in Crashes

Year in service life, y	$\Delta N_{(FI)}$	FI Crash Cost	$AM_{(FI)}$	$\Delta N_{(PDO)}$	PDO Crash Cost	$AM_{(PDO)}$	$AM_{(total)}$
1	4.3	\$158,200	\$680,260	0.3	\$7,400	\$2,220	\$682,480
2	4.3	\$158,200	\$680,260	0.3	\$7,400	\$2,220	\$682,480
3	4.3	\$158,200	\$680,260	0.3	\$7,400	\$2,220	\$682,480
4	4.4	\$158,200	\$696,080	0.3	\$7,400	\$2,220	\$698,300
5	4.4	\$158,200	\$696,080	0.3	\$7,400	\$2,220	\$698,300
6	4.4	\$158,200	\$696,080	0.3	\$7,400	\$2,220	\$698,300
7	4.5	\$158,200	\$711,900	0.3	\$7,400	\$2,220	\$714,120
8	4.5	\$158,200	\$711,900	0.3	\$7,400	\$2,220	\$714,120
9	4.5	\$158,200	\$711,900	0.3	\$7,400	\$2,220	\$714,120
10	4.6	\$158,200	\$727,720	0.2	\$7,400	\$1,480	\$729,200

Step 5—Convert Annual Monetary Values to a Present Value

The total monetary benefits expected from installing a roundabout at Intersection 2 are calculated as a present value using Equations 7-14 and 7-15.

Note—A 4 percent discount rate is assumed for the conversion of the annual values to a present value.

Convert the annual monetary value to a present value for each year of the service life.

$$PV_{\text{benefits}} = \text{Total Annual Monetary Benefits} \times (P/F, i, y) \quad (7-14)$$

Where:

PV_{benefits} = Present value of the project benefits per site in year y ;

$(P/F, i, y)$ = Factor that converts a single future value to its present value, calculated as $(1+i)^{-y}$;

i = Discount rate (i.e., the discount rate is 4 percent, $i = 0.04$); and

y = Year in the service life of the countermeasure.

If the annual project benefits are uniform, then the following factor is used to convert a uniform series to a single present worth:

$$(P/A, i, y) = \frac{(1.0 + i)^{(y)} - 1.0}{i \times (1.0 + i)^{(y)}} \quad (7-15)$$

Where:

$(P/A, i, y)$ = factor that converts a series of uniform future values to a single present value.