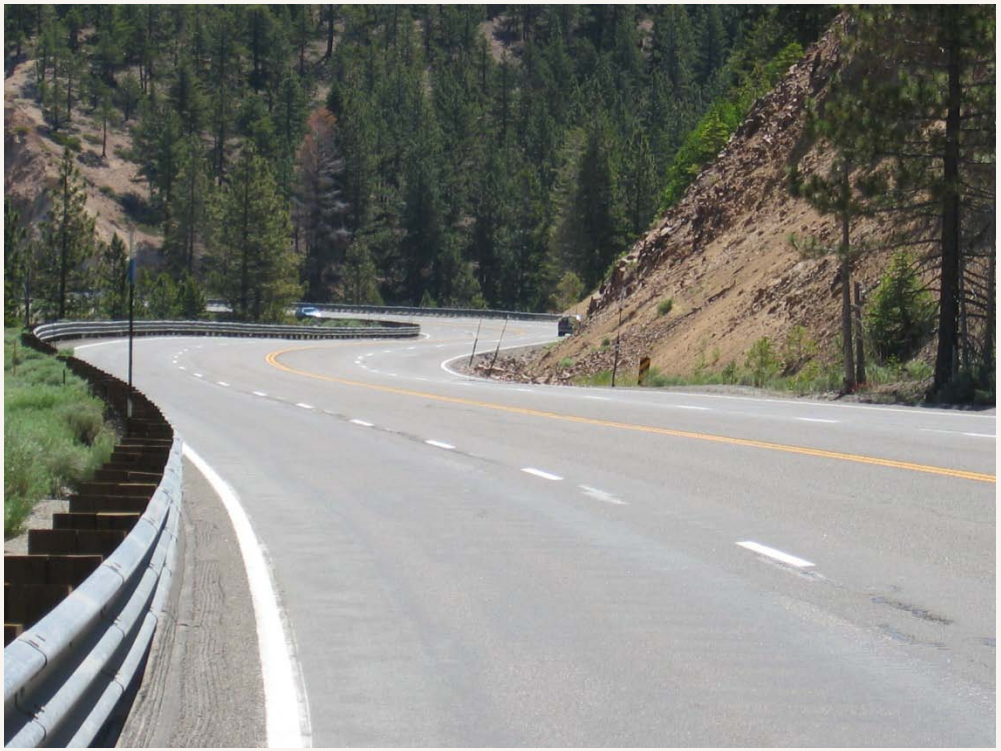
HSM Applications to Multilane Rural Highways and Urban Suburban Streets

Prediction of Crash Frequency and CMF's for Undivided Rural Multilane Highways

- Session #2



Predicting Crash Frequency and CMFs for Rural Undivided Multilane Highways

Learning Outcomes:

- Describe the models to Predict Crash Frequency for Undivided Rural Multilane Highways
- Calculate Predicted Crash Frequency for Undivided Rural Multilane Highways
- Describe Crash Modification Factors
- Apply Crash Modification Factors

Defining Rural Multilane Highways

Methodology applies to four-lane undivided and divided rural highways.

- "Rural":
  - Defined per AASHTO (2004) Guidelines
  - Places outside the boundaries of urban places where the population is less than 5,000 inhabitants.
- Any highway located outside the city limits of an urban agglomeration above 5,000 inhabitants is considered rural.
- The boundary delimitating rural and urban areas can at times be difficult to determine, especially since most multilane rural highways are located on the outskirts of urban agglomerations.

Defining Multilane Highways

Multilane Facilities:

- Have four through lanes with a continuous cross-section which provides two directions of travel
- May be divided with a rigid or flexible barrier, paved or landscaped median
- Should not have access and egress limited by grade-separated interchanges (i.e., not freeways).
- May have occasional grade-separated interchanges, but these should not be the primary form of access and egress

Limitations of Methodology

- Methodology incorporates the effects on safety of many *-but not all-* geometric and traffic control features.

- Only includes geometric design elements:
  - whose relationship to safety are well understood
  - Associated data is available for

- The Statistical Model:
  - treats the effects of individual geometric design element and traffic control features as independent of each other
  - Ignores any potential interactions between them.

Rural Multilane Highway Safety Prediction Methodology

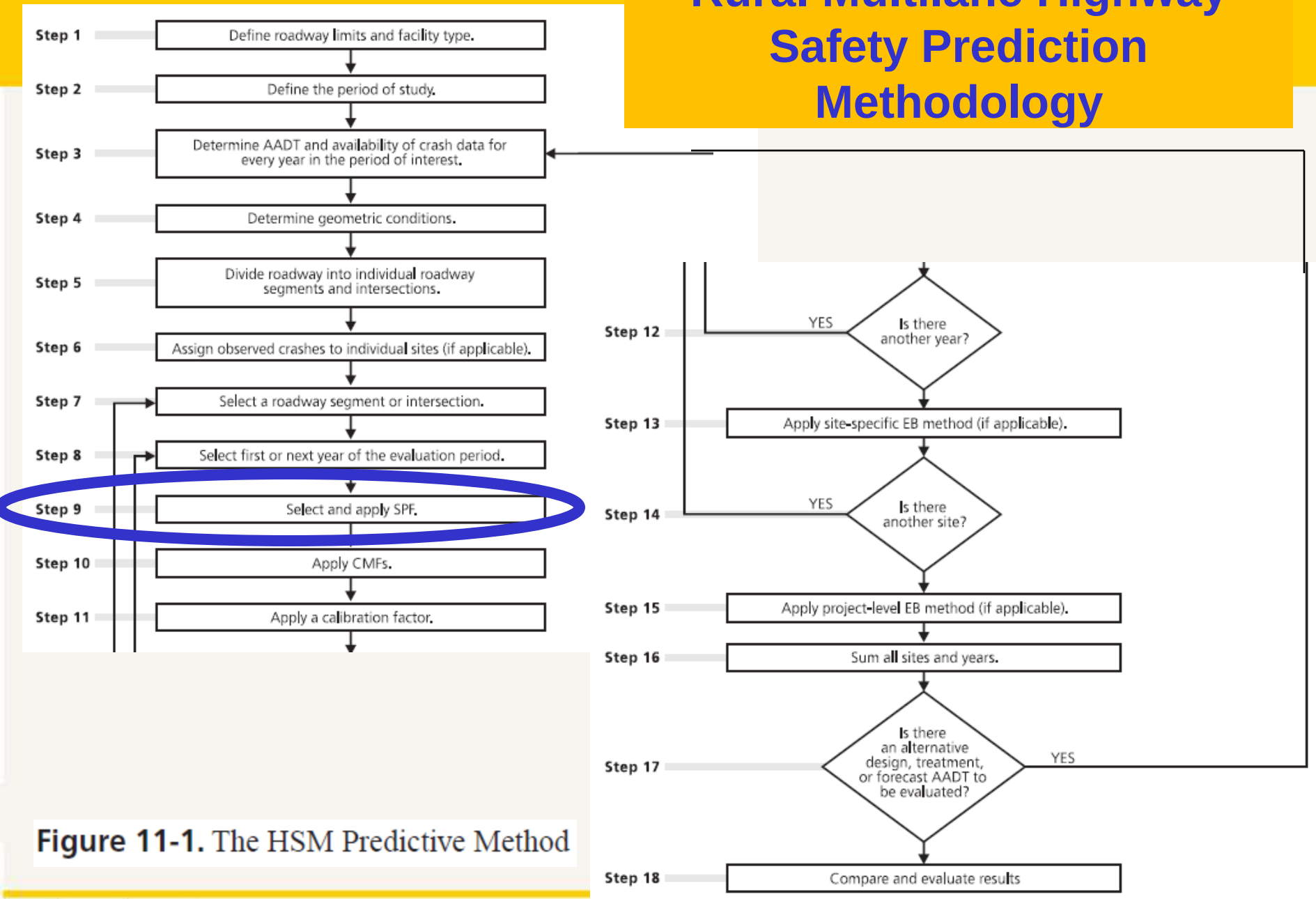


Figure 11-1. The HSM Predictive Method

Baseline Crash Frequency Prediction Models

- Baseline models are used for predicting the total accident frequency of each roadway segment or intersection on a four-lane divided or undivided highway.
- Baseline models predict annual crash frequencies for roadway segments or intersections as a function of traffic volumes for a specified set of nominal baseline conditions.
- Nominal baseline conditions include geometric design and traffic control elements, such as roads with 12-ft lane widths and 8-ft shoulder widths.
- Baseline estimates are adjusted by CMFs, which represent the safety effects of individual geometric design and traffic control elements that differ from the baseline conditions.

Rural Multilane Highway Safety Prediction Methodology

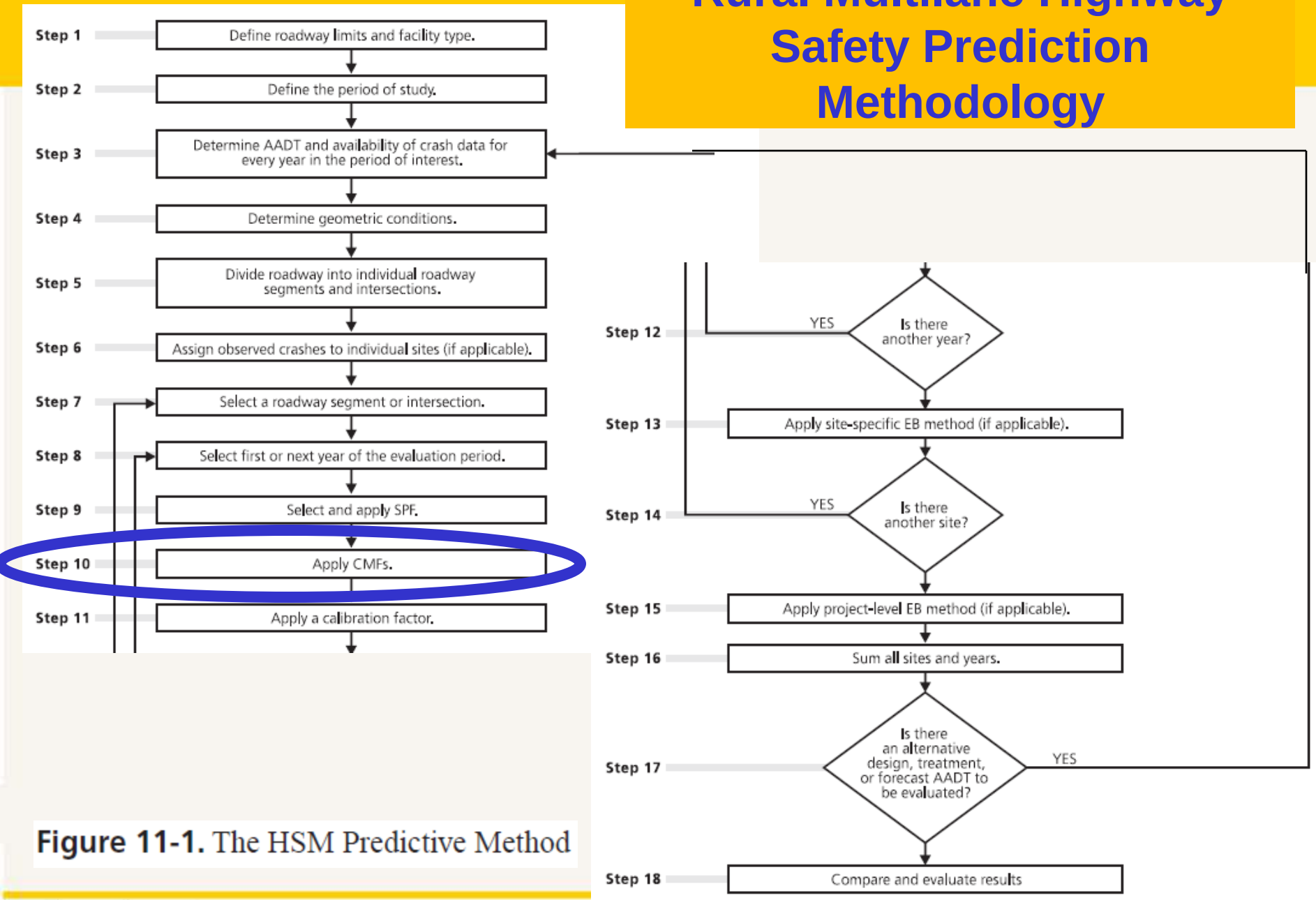


Figure 11-1. The HSM Predictive Method

Predicting Crash Frequency of Rural Multilane Highways

Separate Prediction Models for:

- Homogeneous highway segments
- Intersections
  - Sum of Individual Intersection Calculations

Definition of Segments and Intersections

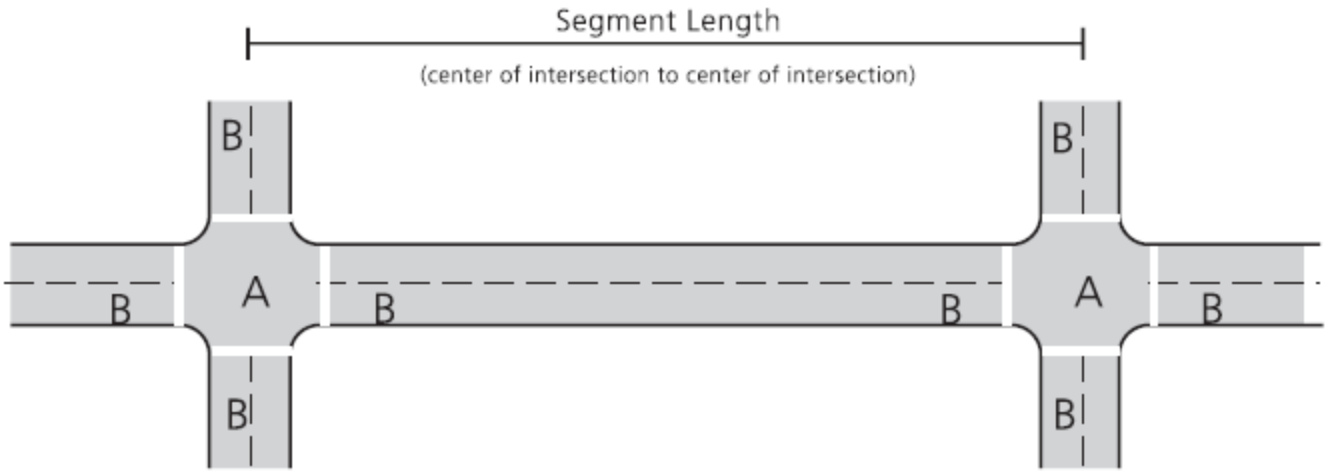


Figure 11-2. Definition of Segments and Intersections

A - All crashes that occur within this region are classified as intersection crashes

B – Crashes in this region may be segment or intersection related, depending on the characteristics of the crash

Definition of Segments and Intersections

Segments:

- Portions of the facility delimited by:
  - major intersections or
  - significant changes in the roadway cross-section or
  - geometric characteristics of the facility or
  - surrounding land uses.
- Roadway segments can be either undivided or divided.

Major intersections:

- Where the segment being analyzed intersects with:
  - major and minor arterials
  - major collectors
- And where traffic volumes (ADT) are available on all approaches.
  - application of the intersection procedures requires ADT on all intersection approaches.

Subdividing Roadway Segments

- Before applying the safety prediction methodology to an existing or proposed rural segment facility, the roadway must be divided into analysis units consisting of individual homogeneous roadway segments and intersections.
- A new analysis section begins at each location where the value of one of the following variables changes (alternatively a section is defined as homogenous if none of these variables changes within the section):
  - Average daily traffic (ADT) volume (veh/day)
  - Lane width (ft) and Shoulder width (ft) and type
  - Sideslope
  - Presence of a median
  - Major intersections

Subdividing Roadway Segments

Homogeneous roadway segments

- Lane width

Measured Lane Width	Rounded Lane Width
9.2 ft or less	9 ft or less
9.3 ft to 9.7 ft	9.5 ft
9.8 ft to 10.2 ft	10 ft
10.3 ft to 10.7 ft	10.5 ft
10.8 ft to 11.2 ft	11 ft
11.3 ft to 11.7 ft	11.5 ft
11.8 ft or more	12 ft or more

Subdividing Roadway Segments

Homogeneous roadway segments

- Shoulder width

Measured Shoulder Width	Rounded Shoulder Width
0.5 ft or less	0 ft
0.6 ft to 1.5 ft	1 ft
1.6 ft to 2.5 ft	2 ft
2.6 ft to 3.5 ft	3 ft
3.6 ft to 4.5 ft	4 ft
4.6 ft to 5.5 ft	5 ft
5.6 ft to 6.5 ft	6 ft
6.6 ft to 7.5 ft	7 ft
7.6 ft or more	8 ft or more

Subdividing Roadway Segments

Homogeneous roadway segments

- Median if present

Measured Median Width	Rounded Median Width
1 ft to 14 ft	10 ft
15 ft to 24 ft	20 ft
25 ft to 34 ft	30 ft
35 ft to 44 ft	40 ft
45 ft to 54 ft	50 ft
55 ft to 64 ft	60 ft
65 ft to 74 ft	70 ft
75 ft to 84 ft	80 ft
85 ft to 94 ft	90 ft
95 ft or more	100 ft

Cross Sectional Elements

Predicting Crash Frequency for an Entire Rural Multilane Segment

$$N_{predicted\ total} = Sum\ N_{rs} + Sum\ N_{int}$$

Three-step process:

1) Predict number of total roadway segment crashes per year (N_{rs})
2) Predict number of total intersection-related crashes per year (N_{int})
3) Combine predicted roadway segment and intersection related crashes to obtain the total ($N_{predicted\ total}$)

Crash Frequency Models for Rural Multilane Roadway Segments

Base Models and Adjustment Factors addresses two types of Roadway Segments:

1) Undivided Multilane Roads
2) Divided Multilane Roads

- Base models are the same for divided and undivided highways
- Regression Coefficients differ

Predicting Crash Frequency for Rural Multilane Highway Segments

Model for Rural Multilane Segments:

$$N_{spf\ ru} = e^{(a + b\ Ln\ AADT + Ln\ L)}$$

Where:

$N_{spf\ ru}$ = Baseline Total Crashes per year for segment

L = Length of roadway segment (miles)

ADT = Annual Average Daily Traffic (vehicles/day)

a & b = regression coefficients

Predicting Crash Frequency for Rural Multilane Highway Segments

Procedure for safety prediction for a divided or undivided roadway segment:

- Apply Base Models,
- Apply CMFs, and calibration factor

$$N_{spf\ ru} = e^{(a + b(\ln(ADT)) + \ln(L))}$$

$$N_{predicited\ rs} = N_{spf\ ru}\ (CMF_{1r} \times CMF_{2r} \times CMF_{ir})C_r$$

Rural Multilane Undivided Roadway Segments

Predicting Crash Frequency for Undivided Rural Multilane Highway Segments

Step #1 – Predict Crash Frequency:

$$N_{spf\ ru} = e^{(a + b\ Ln\ ADT + Ln\ L)}$$

Table 11-3. SPF Coefficients for Total and Fatal-and-Injury Crashes on Undivided Roadway Segments (for use in Equations 11-7 and 11-8)

Crash Severity Level	a	b	c
4-lane total	–9.653	1.176	1.675
4-lane fatal and injury	–9.410	1.094	1.796
4-lane fatal and injury[a]	–8.577	0.938	2.003

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included

Predicting Crash Frequency for Undivided Rural Multilane Highway Segments

Base Conditions for Multilane Rural Undivided Highway Segments

■ Lane width (LW)	12 feet
■ Shoulder width	6 feet
■ Shoulder type	Paved
■ Sideslopes	1V:7H or flatter
■ Lighting	None
■ Automated speed enforcement	None

Predicting Crash Frequency for Multilane Rural Undivided Highways – Example Calculation:

Where:

ADT = 16,000

Length = 8.0 miles

Lane width = 11.0 feet

Outside Shoulder Width = 4 feet aggregate

Side Slope = 1:6

Predicting Crash Frequency for Multilane Rural Undivided Highways – Example Calculation:

$$N_{spf\ ru} = e^{(a + b\ Ln\ ADT + Ln\ L)}$$

Table 11-3. SPF Coefficients for Total and Fatal-and-Injury Crashes on Undivided Roadway Segments (for use in Equations 11-7 and 11-8)

Crash Severity Level	a	b	c
4-lane total	–9.653	1.176	1.675

$$= e^{(-9.653 + 1.176 * Ln\ 16{,}000 + Ln\ 8.0)}$$

$$= e^{(3.81052)}$$

$$= 45.174 \text{ crashes per year}$$

Safety Performance Function (SPF)

Highway Safety Manual Approach:

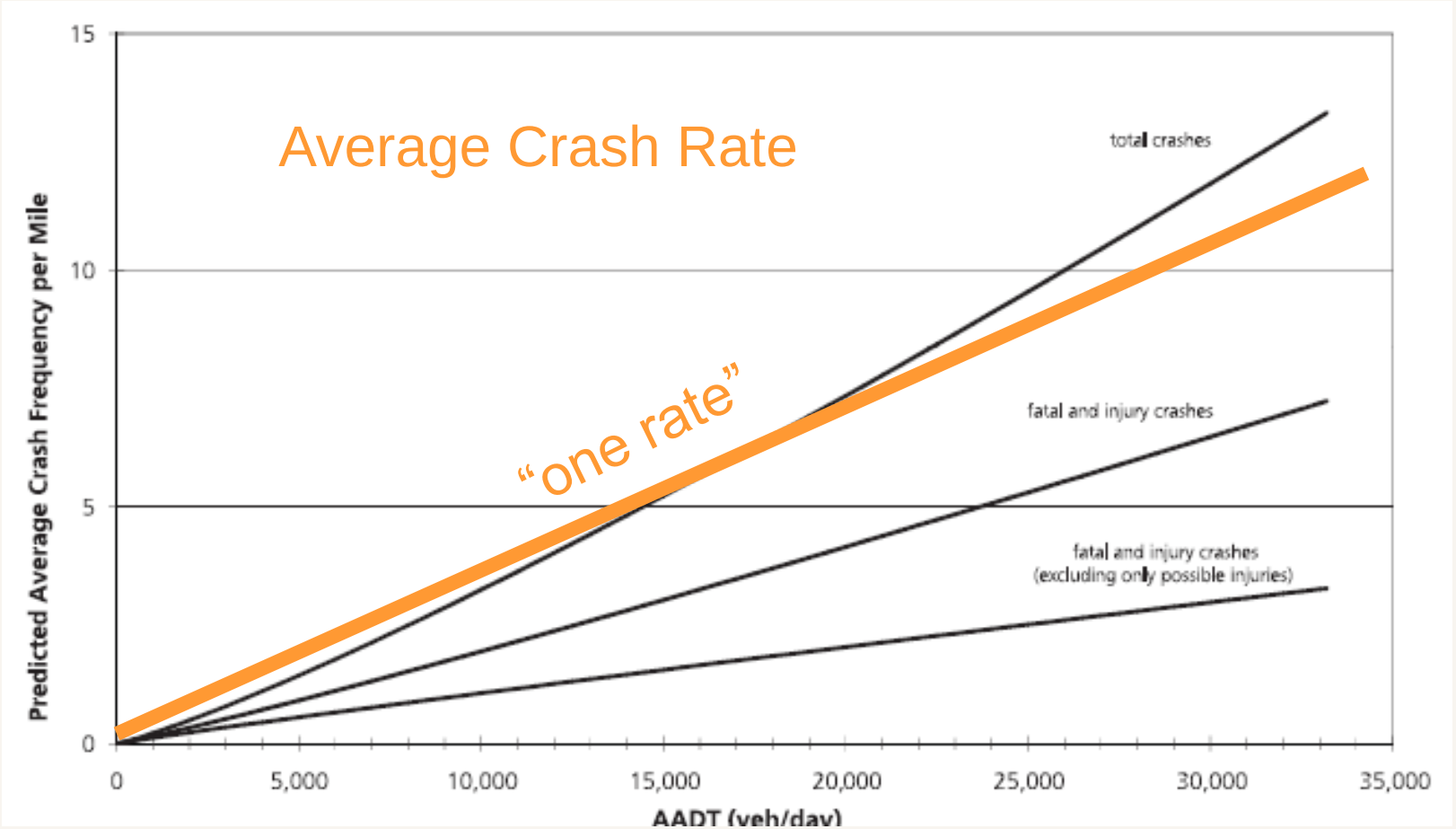
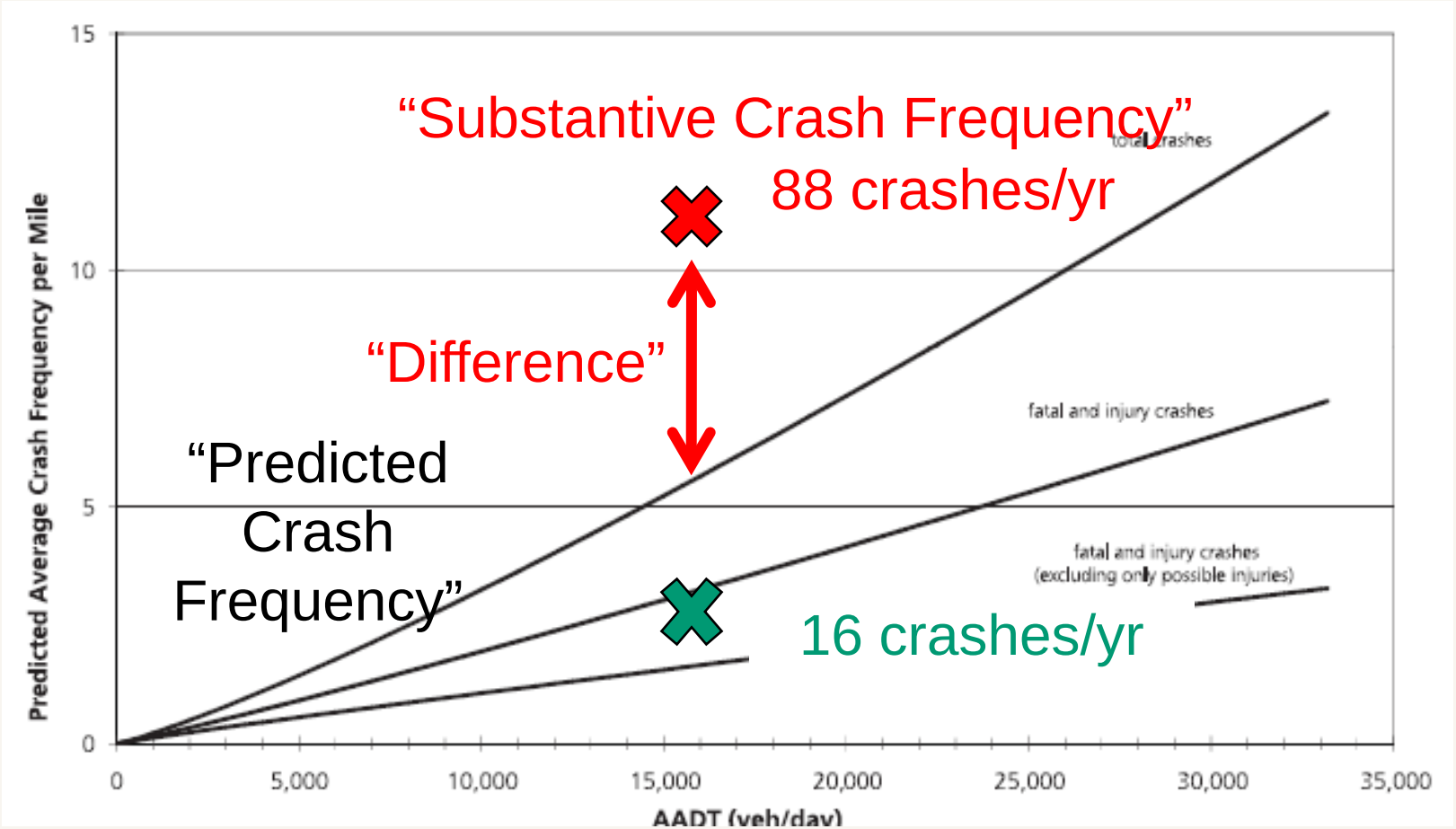


Figure 11-3. Graphical Form of the SPF for Undivided Roadway Segments

"Is this a Higher Crash Frequency Site?"

Highway Safety Manual Approach:



Proportion of Crashes by Collision Type

Table 11-4. Default Distribution of Crashes by Collision Type and Crash Severity Level for Undivided Roadway Segments

	Proportion of Crashes by Collision Type and Crash Severity Level			
		Severity Level		
Collision Type	**Total**	**Fatal and Injury**	**Fatal and Injury[a]**	**PDO**
Head-on	0.009	0.029	0.043	0.001
Sideswipe	0.098	0.048	0.044	0.120
Rear-end	0.246	0.305	0.217	0.220
Angle	0.356	0.352	0.348	0.358
Single	0.238	0.238	0.304	0.237
Other	0.053	0.028	0.044	0.064

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Predicting Crash Frequency for Multilane Rural Undivided Highways – Exercise:

Where:

ADT = 18,000

Length = 8.0 miles

Lane width = 11.0 ft

Outside Shoulder Width = 8 ft paved

Side Slope = 1:6

Predicting Crash Frequency for Multilane Rural Undivided Highways – Exercise:

Where:

ADT = 18,000 Length = 8.0 miles

Lane width = 11.0 ft Outside Shoulder Width = 8 ft paved

Side Slope = 1:6

$$N_{spf\ ru} = e^{(a + b\ \mathrm{Ln\ ADT} + \mathrm{Ln\ L})}$$

$$= e^{(\mathbf{-9.653} + \mathbf{1.176} * \mathrm{Ln}\ 18{,}000 + \mathrm{Ln}\ 8.0)}$$

$$= e^{(3.949)} = ?$$

Applying Crash Modification Factors

$$N_{predicted\ ru} = N_{spf\ ru} (CMF_1 \times CMF_2 \times \ldots)$$

- $N_{predicted\ ru}$ = predicted number of crashes after treatment/improvement

- $N_{spf\ ru}$ = base or existing number of crashes before treatment/improvement

- CMF = accident (crash) modification factor

CMF for Lane Width for Undivided Rural Multilane

$$CMF_{1ru} = (CMF_{RA} - 1.0)\, p_{RA} + 1.0$$

Table 11-11. CMF_{RA} for Collision Types Related to Lane Width

	Average Annual Daily Traffic (AADT) (vehicles per day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft or less	1.04	$1.04 + 2.13 \times 10^{-4}(AADT - 400)$	1.38
10 ft	1.02	$1.02 + 1.31 \times 10^{-4}(AADT - 400)$	1.23
11 ft	1.01	$1.01 + 1.88 \times 10^{-5}(AADT - 400)$	1.04
12 ft or more	1.00	1.00	1.00

Base condition is 12' wide lane, $p_{RA} = 0.27$

CMF for Lane Width for Undivided Rural Multilane

Example: for 11 foot lane and 18,000 ADT

Table 11-11. CMF_{RA} for Collision Types Related to Lane Width

	Average Annual Daily Traffic (AADT) (vehicles per day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft or less	1.04	$1.04 + 2.13 \times 10^{-4}(AADT - 400)$	1.38
10 ft	1.02	$1.02 + 1.31 \times 10^{-4}(AADT - 400)$	1.23
11 ft	1.01	$1.01 + 1.88 \times 10^{-5}(AADT - 400)$	1.04
12 ft or more	1.00	1.00	1.00

$$CMF_{1ru} = (CMF_{RA} - 1.0)\, p_{RA} + 1.0$$
$$= (1.04 - 1.0)\, 0.27 + 1.0$$
$$= (0.04)\, 0.27 + 1.0 = \mathbf{1.0108}$$

CMF for Shoulder Width for Undivided Rural Multilane

$$CMF_{2ru} = (CMF_{WRA}\ CMF_{TRA} - 1.0)\ P_{RA} + 1.0$$

Where:

- CMF_{2ru} = CMF for total crashes related to shoulder width
- CMF_{WRA} = CMF for related crashes base on shoulder width from Exhibit 11-12
- CMF_{TRA} = CMF for related crashes based on shoulder type from Exhibit 11- 13
- P_{RA} = proportion of total crashes constituted by related crashes (default value is 0.27)

CMF for Shoulder Width and Shoulder Type for Undivided Rural Multilane

Table 11-12. CMF for Collision Types Related to Shoulder Width (CMF_{WRA})

	Annual Average Daily Traffic (AADT) (vehicles per day)		
Shoulder Width	**< 400**	**400 to 2000**	**> 2000**
0 ft	1.10	$1.10 + 2.5 \times 10^{-4}(AADT - 400)$	1.50
2 ft	1.07	$1.07 + 1.43 \times 10^{-4}(AADT - 400)$	1.30
4 ft	1.02	$1.02 + 8.125 \times 10^{-5}(AADT - 400)$	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98 - 6.875 \times 10^{-5}(AADT - 400)$	0.87

Table 11-13. CMF for Collision Types Related to Shoulder Type and Shoulder Width (CMF_{TRA})

Shoulder Type	Shoulder Width (ft)						
	0	**1**	**2**	**3**	**4**	**6**	**8**
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

Undivided Segments: CMFs for Shoulder Width and Type – Example Calculation:

$$CMF_{2ru} = (CMF_{WRA} \times CMF_{TRA} - 1.0)\, p_{RA} + 1.0$$

-Four-lane undivided rural highway, 4-ft Gravel shoulder, 18,000 ADT: (Use $p_{RA} = 0.27$)

- From Exhibit 11-12: $CMF_{WRA} = 1.15$
- From Exhibit 11-13: $CMF_{TRA} = 1.01$

$$CMF_{2ru} = ((1.15)(1.01) - 1.0)\, 0.27 + 1.0$$
$$= (0.1615)(0.27) + 1.0$$
$$= \mathbf{1.044}$$

CMF for Side Slope (CMF_{3ru}) for Undivided Rural Multilane

Table 11-14. CMF for Sideslope on Undivided Roadway Segments (CMF_{3ru})

1:2 or Steeper	1:3	1:4	1:5	1:6	1:7 or Flatter
1.18	1.15	1.12	1.09	1.05	1.00

Base condition is 1:7 or Flatter

CMF for Lighting (CMF_{4ru}) for Undivided Rural Multilane

$$CMF_{4ru} = 1 - [(1 - 0.72P_{inr} - 0.83P_{pnr})P_{nr}]$$

Table 11-15. Nighttime Crash Proportions for Unlighted Roadway Segments

Roadway Type	Proportion of Total Night-Time Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatal and Injury p_{inr}	PDO p_{pnr}	p_{nr}
4U	0.361	0.639	0.255

Base condition is no lighting present on the segment

CMF for Automated Speed Enforcement (CMF_{5ru}) for Undivided Rural Multilane

- Base condition is no Automated Speed Enforcement present

$CMF_{5ru} = 1.00$

- Automated Speed Enforcement present;

Injury crashes, CMF = 0.83

= Total Crashes effect, $CMF_{5ru} = 0.95$

Applying CMFs to Predicted Crash Frequency for an Undivided Rural Multilane Highway – Example:

For Undivided Rural Multilane Highway:

16,000 ADT, Length = 8.0 miles, 11 foot lanes, 4 ft gravel shoulders with 1:6 side slope, no lighting, no automated speed enforcement:

$$N_{predicted\ ru} = N_{spf\ ru} (CMF_{1ru} \times CMF_{2ru} \times CMF_{3ru} \times CMF_{4ru} \times CMF_{5ru})$$

From Exhibit 11-11, $CMF_{ra} = 1.04$

$$CMF_{1ru} = (CMF_{RA} - 1.0)\ 0.27 + 1.0$$
$$= (1.04 - 1.0)\ 0.27 + 1.0$$
$$= \mathbf{1.0108}$$

Applying CMFs to Predicted Crash Frequency for an Undivided Rural Multilane Highway – Example:

For Undivided Rural Multilane Highway:

16,000 ADT, Length = 8.0 miles, 11 foot lanes, 4 ft gravel shoulders with 1:6 side slope, no lighting, no automated speed enforcement:

From Exhibit 11-12, $CMF_{wra} = 1.15$

And Exhibit 11-13, $CMF_{tra} = 1.01$

$$CMF_{2ru} = (CMF_{WRA}\ CMF_{TRA} - 1.0)\ 0.27 + 1.0$$
$$= (1.15 \times 1.01 - 1.0)\ 0.27 + 1.0$$
$$= \mathbf{1.044}$$

Applying CMFs for Side Slope, Lighting, and Auto Speed Enforcement – Example:

For Undivided Rural Multilane Highway:

16,000 ADT, Length = 8.0 miles, 11 foot lanes, 4 ft gravel shoulders with 1:6 side slope, no lighting, no automated speed enforcement:

$$N = N_{brbase} \times CMF_{1ru} \times CMF_{2ru} \times CMF_{3ru} \times CMF_{4ru} \times CMF_{5ru}$$

CMF_{3ru} from Exhibit 11-14 (Sideslopes) = 1.05

CMF_{4ru} from Exhibit 11-15 (Lighting) = 1.00

CMF_{5ru} (Automated Speed Enforcement) = 1.00

Applying CMFs to Predicted Crash Frequency for an Undivided Rural Multilane Highway – Example:

For Undivided Rural Multilane Highway:

16,000 ADT, Length = 8.0 miles, 11 foot lanes, 4 ft gravel shoulders with 1:6 side slope, no lighting, no automated speed enforcement:

$CMF_{1ru} = 1.011$ $CMF_{3ru} = 1.05$ $CMF_{5ru} = 1.00$

$CMF_{2ru} = 1.044$ $CMF_{4ru} = 1.00$

$$N_{ru} = N_{spf\ ru} \times CMF_{1ru} \times CMF_{2ru} \times CMF_{3ru} \times CMF_{4ru} \times CMF_{5ru}$$

$$= 45.174 \times 1.011 \times 1.044 \times 1.05 \times 1.00 \times 1.00$$

$$= \mathbf{50.04} \text{ crashes per year}$$

Applying CMFs to Predicted Crash Frequency for an Undivided Rural Multilane Highway – Exercise:

4-lane UnDivided Rural Highway:

- ADT = 18,000
- Length = 8.0 miles
- Lane width = 11.0 feet
- Outside shoulder width = 8 ft Gravel
- Side Slope = 1:6
- No lighting
- No Automated Speed Enforcement

$$N_{spf\ ru} = 51.9$$

Applying CMFs to Predicted Crash Frequency for an Undivided Rural Multilane Highway – Exercise:

4-lane UnDivided Rural Highway:

- ADT = 18,000, Length = 8.0 miles; Lane width = 11.0 feet; Outside shoulder width = 8 ft Gravel; Side Slope = 1:6; No lighting; No Automated Speed Enforcement

$N_{spf\ ru} = 51.9$

From Exhibit 11-11, $CMF_{ra} = 1.04$

$CMF_{1ru} = (CMF_{RA} - 1.0)\ 0.27 + 1.0$

$= (1.04 - 1.0)\ 0.27 + 1.0$

$= \ ?$

Applying CMFs to Predicted Crash Frequency for an Undivided Rural Multilane Highway – Exercise:

4-lane UnDivided Rural Highway:

- ADT = 18,000, Length = 8.0 miles; Lane width = 11.0 feet; Outside shoulder width = 8 ft Gravel; Side Slope = 1:6; No lighting; No Automated Speed Enforcement

$N_{spf\ ru}$ = 51.9

From Exhibit 11-12, CMF_{wra} = 0.87

And Exhibit 11-13, CMF_{tra} = 1.02

$$CMF_{2ru} = (CMF_{WRA}\ CMF_{TRA} - 1.0)\ 0.27 + 1.0$$
$$= (0.87 \times 1.02 - 1.0)\ 0.27 + 1.0$$
$$= \ ?$$

Applying CMFs to Predicted Crash Frequency for an Undivided Rural Multilane Highway – Exercise:

4-lane UnDivided Rural Highway:

- ADT = 18,000, Length = 8.0 miles; Lane width = 11.0 feet; Outside shoulder width = 8 ft Gravel; Side Slope = 1:6; No lighting; No Automated Speed Enforcement

$$N_{spf\ ru} = 51.9$$

CMF_{3ru} from Exhibit 11-14 (Sideslopes) = ?

CMF_{4ru} from Exhibit 11-15 (Lighting) = ?

CMF_{5ru} (Automated Speed Enforcement) = ?

Applying CMFs to Predicted Crash Frequency for an Undivided Rural Multilane Highway – Exercise:

4-lane UnDivided Rural Highway:

- ADT = 18,000, Length = 8.0 miles; Lane width = 11.0 feet; Outside shoulder width = 8 ft Gravel; Side Slope = 1:6; No lighting; No Automated Speed Enforcement

CMF_{1ru} = 1.0108 CMF_{3ru} = 1.05 CMF_{5ru} = 1.00

CMF_{2ru} = 0.97 CMF_{4ru} = 1.00

$$N_{ru} = N_{spf\ ru} \times CMF_{1ru} \times CMF_{2ru} \times CMF_{3ru} \times CMF_{4ru} \times CMF_{5ru}$$

= 51.9 x ____ x ____ x ____ x ____ x ____

= _____ crashes per year

Applying CMFs to Predicted Crash Frequency for an Undivided Rural Multilane Highway

Additional CMF's:

- Reduce Shoulder Width (e.g., 8 ft to 6 ft)
- Providing a raised Median
- Changing width of an existing median
- Flatten sideslopes
- Changing to a Less Rigid Roadside Barrier
- Install median barrier
- Use of Crash Cushions at Fixed Objects
- Install Continuous Shoulder Rumble Strips
- Horizontal Clearance

Adding a Median on Multi-Lane Roads

Table 13-11. Potential Crash Effects of Providing a Median on Multi-Lane Roads (8)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Provide a median	Urban (Arterial Multilane[a])	Unspecified	All types (Injury)	**0.78**[7]	**0.02**
			All types (Non-injury)	**1.09**[7]	**0.02**
	Rural (Multilane[a])		All types (Injury)	**0.88**	**0.03**
			All types (Non-injury)	**0.82**	**0.03**

Predicting Crash Frequency and CMFs for Rural Undivided Multilane Highways

Learning Outcomes:

- Described the models to Predict Crash Frequency for Undivided Rural Multilane Highways
- Calculated Predicted Crash Frequency for Undivided Rural Multilane Highways
- Described Crash Modification Factors
- Applied Crash Modification Factors

Predicting Crash Frequency and CMFs for Rural Undivided Multilane Highways

Questions and Discussion: