HSM Applications to Multilane Rural Highways and Urban Suburban Streets

Predicting Crash Frequency and CMFs for Rural Divided Multilane Highways

- Session #3

Predicting Crash Frequency and CMFs for Rural Divided Multilane Highways

Learning Outcomes:

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

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), Shoulder width (ft), Shoulder Type
  - Side slope
  - 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

- Presence of a median

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 or more	100-ft

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 ($N_{predicted}$)

Predicting Crash Frequency for Rural Multilane Highway Segments

Model for Rural Multilane Segments:

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

Where:

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

L = Length of roadway segment (miles)

AADT = 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 roadway segment:

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

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

$$N_{predicted\ rs} = N_{spf\ rd}\,(CMF_{1r} \times CMF_{2r} \times CMF_{ir})C_r$$

Predicting Safety Performance of Rural Multilane Divided Highways

Step #1 – Predict Crash Frequency:

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

Table 11-5. SPF Coefficients for Total and Fatal-and-Injury Crashes on Divided Roadway Segments (for use in Equations 11-9 and 11-10)

Severity Level	a	b	c
4-lane total	–9.025	1.049	1.549
4-lane fatal and injury	–8.837	0.958	1.687
4-lane fatal and injury[a]	–8.505	0.874	1.740

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

c = used to determine overdispersion parameter "k" for applying EB

$$k = \frac{1}{e^{(c+In(L))}}$$

Predicting Safety Performance of Rural Multilane Divided Highways

Base Conditions for Multilane Rural Divided Highway Segments

Baseline Geometric Conditions:

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

Predicting Safety Performance of Rural Multilane Divided Highways – Example:

4-lane Divided Rural Highway:

ADT = 16,000
Length = 8.0 miles
Lane width = 11.0 feet
Side Slope = 1:6
Outside shoulder width = 8 feet aggregate
Median width = 24 feet – no barrier
No Lighting
No Automated Speed Enforcement

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

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

Exhibit 11-8: SPF Coefficients for Total and Fatal-and-Injury Accidents on Divided Roadway Segments (for use in Equations 11-9 and 11-10)

Severity level	a	b	c
4-lane total	-9.025	1.049	1.549

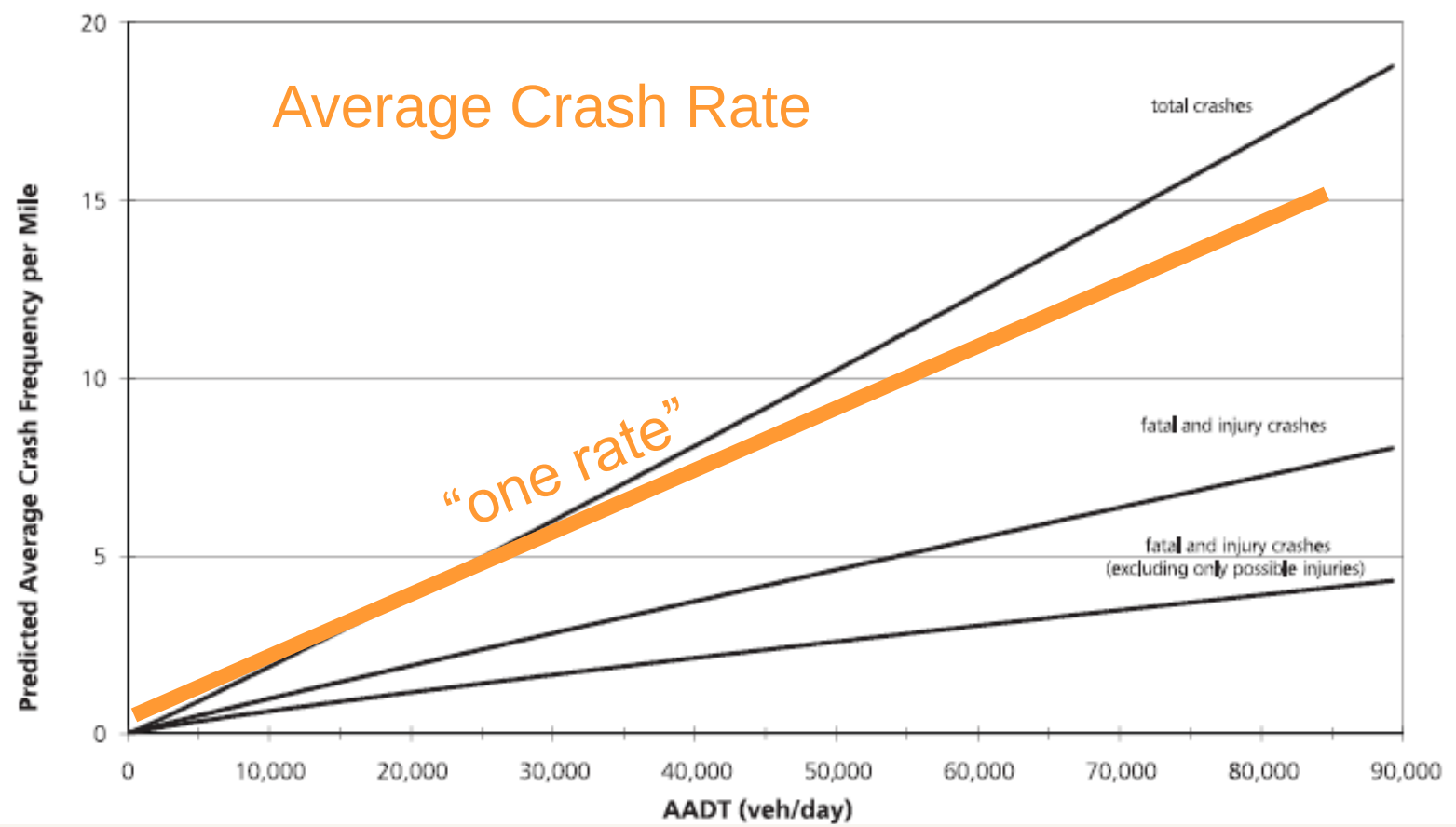
$$= e^{(-9.025 + 1.049 * \text{Ln } 16{,}000 + \text{Ln } 8.0)}$$

$$= e^{(3.2091)}$$

$$= \mathbf{24.76} \text{ crashes per year}$$

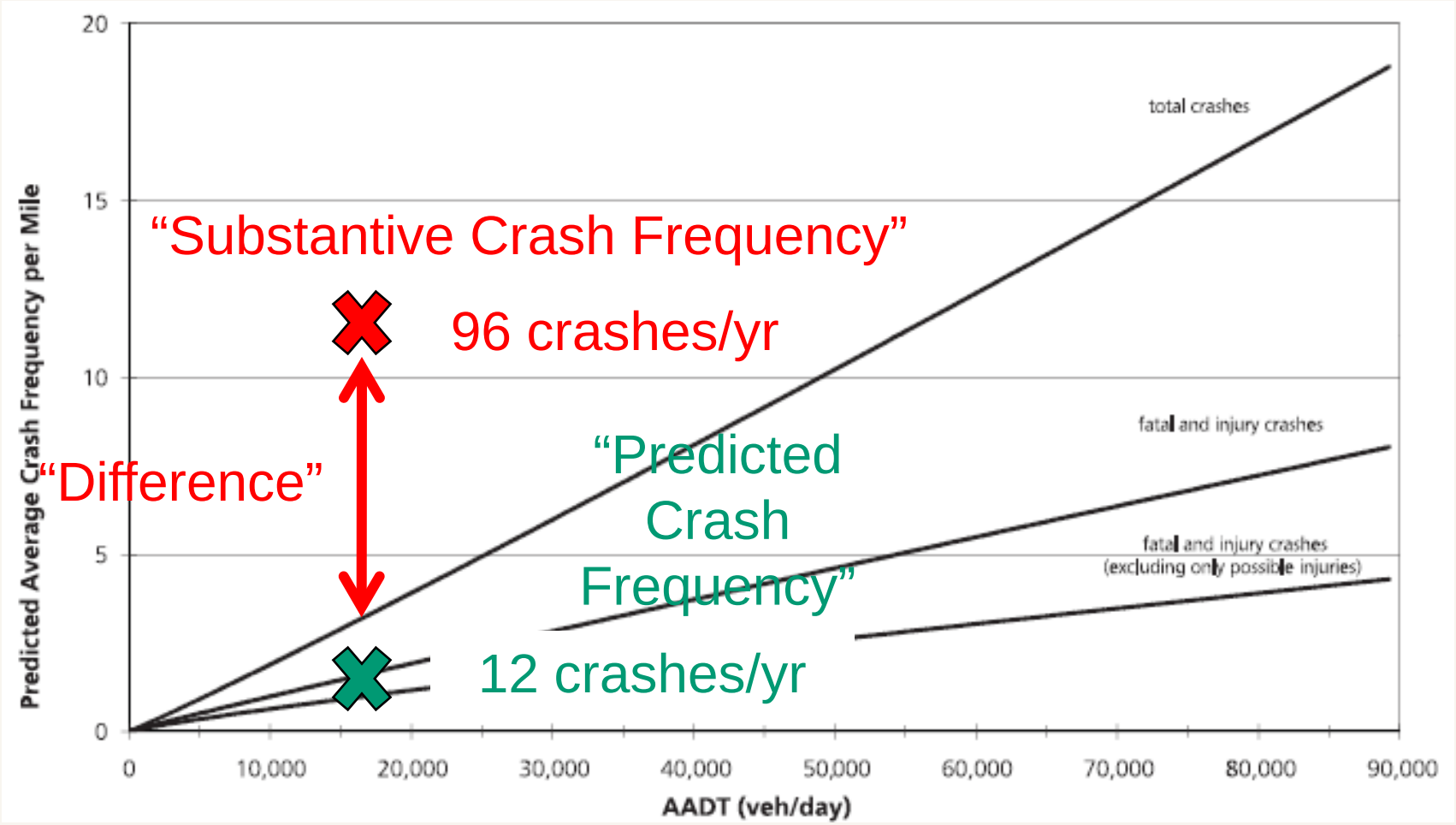
Safety Performance Function (SPF)

Highway Safety Manual Approach:



“Is this a Higher Crash Frequency Site?”

Highway Safety Manual Approach:



Proportion of Crashes by Collision Type

Table 11-6. Default Distribution of Crashes by Collision Type and Crash Severity Level for Divided 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	0.006	0.013	0.018	0.002
Sideswipe	0.043	0.027	0.022	0.053
Rear-end	0.116	0.163	0.114	0.088
Angle	0.043	0.048	0.045	0.041
Single	0.768	0.727	0.778	0.792
Other	0.024	0.022	0.023	0.024

[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 Divided Highways – Example Calculation:

Where:

ADT = 18,000

Length = 8.0 miles

Lane width = 11.0 ft

Outside Shoulder Width = 8 ft gravel

Side Slope = 1:6

Median width = 24 feet – no barrier

No Lighting

No Automated Speed Enf

Predicting Crash Frequency for Multilane Rural Divided Highways – Exercise Calculation:

Where:

ADT = 18,000 Length = 8.0 miles

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

Side Slope = 1:6 Median Width = 24 ft

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

$$= e^{(\mathbf{-9.025} + \mathbf{1.049} * Ln\ 18{,}000 + Ln\ 8.0)}$$

$$= e^{(3.3327)} = \ ?\ \text{crashes per year}$$

Applying Crash Modification Factors

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

- $N_{predicted\ rd}$ = predicted number of crashes after treatment/improvement
- $N_{spf\ rd}$ = base or existing number of crashes before treatment/improvement
- CMF = crash modification factor

CMF for Lane Width for Divided Rural Multilane

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

Table 11-16. CMF for Collision Types Related to Lane Width (CMF_{RA})

	Annual Average Daily Traffic (AADT) (vehicles/day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft	1.03	$1.03 + 1.38 \times 10^{-4}(AADT - 400)$	1.25
10 ft	1.01	$1.01 + 8.75 \times 10^{-5}(AADT - 400)$	1.15
11 ft	1.01	$1.01 + 1.25 \times 10^{-5}(AADT - 400)$	1.03
12 ft	1.00	1.00	1.00

Base condition is 12' wide lane, $p_{RA} = 0.50$

CMF for Lane Width for Divided Rural Multilane

Example: for 11 foot lane and 18,000 ADT

Table 11-16. CMF for Collision Types Related to Lane Width (CMF_{RA})

	Annual Average Daily Traffic (AADT) (vehicles/day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft	1.03	$1.03 + 1.38 \times 10^{-4}(AADT - 400)$	1.25
10 ft	1.01	$1.01 + 8.75 \times 10^{-5}(AADT - 400)$	1.15
11 ft	1.01	$1.01 + 1.25 \times 10^{-5}(AADT - 400)$	1.03
12 ft	1.00	1.00	1.00

$$CMF_{1rd} = (CMF_{RA} - 1.0)\, p_{RA} + 1.0$$
$$= (1.03 - 1.0)\, 0.50 + 1.0$$
$$= (0.03)\, 0.50 + 1.0 = \mathbf{1.015}$$

CMF for Shoulder Width and Shoulder Type for Divided Rural Multilane

Table 11-17. CMF for Right Shoulder Width on Divided Roadway Segments (CMF_{2rd})

Average Shoulder Width (ft)				
0	2	4	6	8 or more
1.18	1.13	1.09	1.04	1.00

Note: This CMF applies to paved shoulders only.

Base condition is 8’ wide shoulder;
Effect of other shoulder types other than paved shoulders is unknown

CMF for Median Width for medians without Barrier

Table 11-18. CMFs for Median Width on Divided Roadway Segments without a Median Barrier (CMF_{3rd})

Median Width (ft)	CMF
10	1.04
20	1.02
30	1.00
40	0.99
50	0.97
60	0.96
70	0.96
80	0.95
90	0.94
100	0.94

Note: This CMF applies only to medians without traffic barriers.

- Baseline: 30 ft median width
- Accounts for total crashes on segment
- Median width mainly affects median related crashes (20% of all crashes and cross-median crashes = 12% of all crashes on divided hwys)

Medians with traffic barriers: CMF = 1.0

CMF for Lighting (CMF_{4rd}) for Divided Rural Multilane

Table 11-19. Nighttime Crash Proportions for Unlighted Roadway Segments

	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
Roadway Type	Fatality and Injury p_{inr}	PDO p_{pnr}	p_{nr}
4D	0.323	0.677	0.426

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

$$= 1 - [(1 - 0.72 \times 0.323 - 0.83 \times 0.677) \times 0.426]$$

$$= \mathbf{0.912}$$

* Base condition is no lighting present on the segment

CMF for Lighting (CMF_{4rd}) for Divided Rural Multilane

Table 13-56. Potential Crash Effects of Providing Highway Lighting (7,8,12,27)

Treatment	Setting (Road Type)	Traffic Volume	Crash Type (Severity)	CMF	Std. Error
Provide highway lighting	All settings (All types)	Unspecified	All types (Nighttime injury) (8)	**0.72**	**0.06**
			All types (Nighttime non-injury) (8)	**0.83**	**0.07**
			All types (Nighttime injury) (15)	0.71	N/A
			All types (Nighttime all severities) (15)	0.80	N/A

CMF for Automated Speed Enforcement (CMF_{5rd}) for Divided Rural Multilane

- Base condition is no Automated Speed Enforcement present

$CMF_{5rd} = 1.00$

- Automated Speed Enforcement present;

Injury crashes, CMF = 0.83

= Total Crashes effect, $CMF_{5rd} = 0.94$

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

For Divided Rural Multilane Highway:

16,000 ADT, Length = 8.0 miles, 10 foot lanes, 6 ft paved shoulders, 25 foot median with no barrier, no lighting, no automated speed enforcement:

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

From Table 11-16, $CMF_{ra} = 1.15$

$$CMF_{1rd} = (CMF_{ra} - 1.0)\ 0.50 + 1.0$$
$$= (1.15 - 1.0)\ 0.50 + 1.0$$
$$= \mathbf{1.075}$$

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

For Divided Rural Multilane Highway:

16,000 ADT, Length = 8.0 miles, 10 foot lanes, 6 ft paved shoulders, 25 foot median with no barrier, no lighting, no automated speed enforcement:

From Table 11-17, CMF_{2rd}= 1.04

Applying CMFs for Median Width, Lighting, and Auto Speed Enforcement – Example:

For Divided Rural Multilane Highway:

16,000 ADT, Length = 8.0 miles, 10 foot lanes, 6 ft paved shoulders with 1:6 side slope, 25 foot median with no barrier, no lighting, no automated speed enforcement:

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

CMF_{3rd} from Table 11-18 (Median Width) = 1.00

25' rounds to 30 foot median

CMF_{4rd} from Table 11-19 (Lighting) = 1.00

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

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

For Divided Rural Multilane Highway:

16,000 ADT, Length = 8.0 miles, 10 foot lanes, 6 ft paved shoulders, 25 foot median with no barrier, no lighting, no automated speed enforcement:

CMF_{1rd} = 1.075

CMF_{2rd} = 1.040

CMF_{3rd} = 1.00

CMF_{4rd} = 1.00

CMF_{5rd} = 1.00

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

$$= 24.76 \times 1.075 \times 1.040 \times 1.00 \times 1.00 \times 1.00$$

$$= \mathbf{27.68} \text{ crashes per year}$$

Applying CMFs to Predicted Crash Frequency for an Divided Rural Multilane Highways

Additional CMF's:

- Horizontal Clearance
- Median Width Conversion w and w/o Barrier
- Providing a Barrier
- Changing to a Less Rigid Roadside Barrier
- Use of Crash Cushions at Fixed Objects
- Use of Horizontal Alignment + Advisory Speed Signs
- Providing Rumble Strips
- Access Control

Install Continuous Shoulder Rumble Strips on Multilane Highways

Table 13-44. Potential Crash Effects of Installing Continuous Shoulder Rumble Strips on Multilane Highways (6)

Treatment	Setting (Road Type)	Traffic Volume (AADT)	Crash Type (Severity)	CMF	Std. Error
Install continuous milled-in shoulder rumble strips	Rural (Multi-lane divided)	2,000 to 50,000	All types (All severities)	**0.84**	**0.1**
			All types (Injury)	*0.83*	*0.2*
			SVROR (All severities)	*0.90**	*0.3*
			SVROR (Injury)	*0.78**	*0.3*

CMF for Access Control for 4-Ln Divided Highways

* From TTI synthesis

$$CMF_{dd} = (e^{b * (Dd - Dbase)} - 1.0) P_s + 1.0$$

Where:

D_d = Driveway Density (Driveways per mile)

D_{base} = Base driveway density of 5 per mile

b = coefficient

P_s = subset proportion

Table 3-26. Coefficient Values for Driveway Density for Rural Highways.

Model Source	Roadway Type	Crash Severity	Subset of Influenced Crash Types	Subset Proportion, P_s	Coefficient b
Wang et al. (4)	Rural, 4-lane, divided	All	All	1.0	0.034

CMF for Access Control for 4-Ln Divided Highways: Example

For 4-Ln Divided, 32 driveways in 1.8 miles

Driveway Density = 32/1.8 = 17.8

$$CMF_{dd} = (e^{b(Dd - Dbase)} - 1.0) P_s + 1.0$$

Table 3-26. Coefficient Values for Driveway Density for Rural Highways.

Model Source	Roadway Type	Crash Severity	Subset of Influenced Crash Types	Subset Proportion, P_s	Coefficient b
Wang et al. (4)	Rural, 4-lane, divided	All	All	1.0	0.034

$$CMF_{dd} = (e^{0.034(17.8 - 5)} - 1.0) \times 1.0 + 1.0$$

$$= 1.544$$

Applying Crash Modification Factor for Access for Rural Divided Highways – Question:

4-lane Divided Rural Highway:

ADT = 26,000 Length = 1.8 miles

Lane width = 12.0 feet Driveways = 20

CMF_{dd} = 1.23

a) 1.23
b) 1.023
c) 1.46
d) 1.046

Applying Crash Modification Factor for Access for Rural Divided Highways – Answer:

4-lane Divided Rural Highway:

ADT = 26,000 Length = 1.8 miles

Lane width = 12.0 feet Driveways = 20 Dd = 20/1.8 = 11.1

$$CMF_{dd} = (e^{b(Dd - Dbase)} - 1.0)\ P_s + 1.0$$

Table 3-26. Coefficient Values for Driveway Density for Rural Highways.

Model Source	Roadway Type	Crash Severity	Subset of Influenced Crash Types	Subset Proportion, P_s	Coefficient b
Wang et al. (4)	Rural, 4-lane, divided	All	All	1.0	0.034

$$\mathbf{CMF_{dd} = (e^{0.034(11.1 - 5)} - 1.0) \times 1.0 + 1.0}$$

$$= \ ?$$

Predicting Crash Frequency and CMFs for Rural Divided Multilane Highways

Learning Outcomes:

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

Predicting Crash Frequency and CMFs for Rural Divided Multilane Highways

Questions and Discussion: