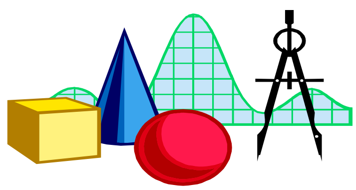
Texas Department of Transportation

Texas Transportation Institute

Roadway Safety Design

An Engineer's Guide to Evaluating the Safety of Design Alternatives



Course Notes

Product 5-4703-01-P3

SAFETY BY DESIGN

Multilane Highways and Freeways Workshop
July 2009
Published: February 2010
http://tti.tamu/documents/5-4703-01-P3.pdf

INCORPORATING SAFETY INTO THE HIGHWAY DESIGN PROCESS:
MULTILANE HIGHWAYS AND FREEWAYS WORKSHOP

Date:
Location:
Instructor:

Agenda

9:00	Introduction
9:15	Session 1: Review of Highway Safety Issues
9:30	Session 2: Overview of Safety Evaluation
9:55	Break
10:10	Session 2: Overview of Safety Evaluation (continued)
10:40	Session 3: Procedure for Multilane Highway Segments
12:00	Lunch Break
1:00	Session 4: Procedure for Freeway Segments
2:00	Session 5: Procedure for Interchange Ramps
2:20	Break
2:35	Session 6: Section Evaluation
3:10	Session 7: Alternatives Analysis
4:00	Wrap-Up, Complete Course Review Form
4:10	Adjourn

Course Materials:	Course Workbook *Roadway Safety Design Workbook* Texas Roadway Safety Design (TRSD) software
Web Site:	http://tcd.tamu.edu/documents/rsd.htm

Incorporating Safety into the Highway Design Process

Part I. Introduction to Workshop Series

Texas Department of Transportation

2009

Welcome

- **Introductory Session**
  - ***Objectives, outcomes, scope, main points***
  - ***Background***
  - ***Agenda***
- **Instructors**
  - ***Jim Bonneson***
  - ***Mike Pratt***
    - **Researchers with TTI**
    - **College Station**

SAFETY BY DESIGN

Objectives & Outcomes

- **Objectives**
  - ***To inform participants about:***
    - **Safety impacts of design alternatives**
    - **Availability of tools for evaluating safety impact**
  - ***To demonstrate how to apply these tools***
- **Outcomes**
  - ***Participants should be able to:***
    - **Apply the evaluation tools to typical designs**
    - **Evaluate the safety associated with a design**

Scope

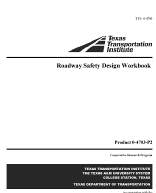
- **Scope**
  - ***Workshop is intended to show engineers and technicians how various analysis tools can be used to evaluate the level of safety associated with a roadway***
  - ***Analysis based on facility components***
    - **Roadway segment**
    - **Intersection**
    - **Interchange ramp**

Main Points

- **Seven Points to Remember**
  1. ***Large variability in crash data makes it difficult to observe a change in crash frequency due to change in geometry at one site***
  2. ***Statistical evaluation of many crashes at many treated sites is needed to quantify true effect of a change***
  3. ***Adherence to design controls does not ensure safety***
  4. ***Many geometric design elements influence safety***
  5. ***Evaluation should focus on key design elements***
  6. ***Evaluation is most helpful in complex or atypical situations***
  7. ***Engineer should weigh all impacts when deciding***

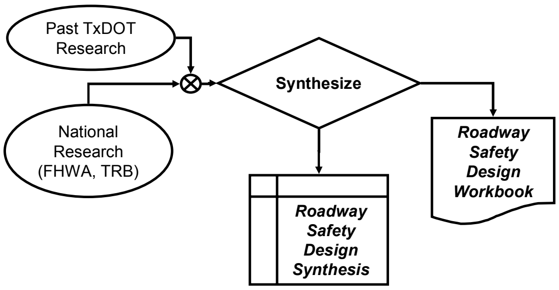
Background

- **Project 0-4703**
  - ***"Incorporating Safety into the Highway Design Process"***
  - ***Project Director:***
    - **Elizabeth Hilton / Rory Meza**
  - ***Key product:***
    - **Roadway Safety Design Workbook (Report 0-4703-P2)**
  - ***Procedure used...***



Background

- **Safety Information Development Process**



More Information

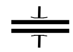
- **Safety Resources from Project 0-4703**
  - ***Roadway Safety Design Workbook***
  - ***Roadway Safety Design Synthesis***
  - ***Procedures Guide***
  - ***Texas Roadway Safety Design software***
- **Web Address**
  - ***http://*** **tcd.tamu.edu/documents/rsd.htm**
  - ***Also link from DES-PD site*** **CROSSROADS**
  - ***Check periodically for updates***

Agenda

- **Session 1:**
  - ***Review of highway safety issues***
- **Session 2:**
  - ***Overview of safety evaluation***
- **Session 3:**
  - ***Procedure for multilane highway segments***
- **Lunch Break**

Agenda

- **Session 4:**
  - ***Procedure for freeway segments***

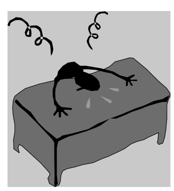


- **Session 5:**
  - ***Procedure for interchange ramps***

- **Session 6:**
  - ***Section evaluation***
- **Session 7:**
  - ***Alternatives analysis***

Policy on Questions

- **Policy Points**
  - ***Questions are encouraged***
  - ***Please ask them as they occur to you***



Questions?

1. Highway Safety Issues

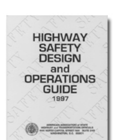
- Key Highway Design Elements
- Safety-Conscious Design
- Crash Data Variability

Key Design Elements

- Design Elements that Influence Safety
  - *Design speed*
  - *Lane width*
  - *Shoulder width*
  - *Median width and type*
  - *Bridge width*
  - *Structural capacity*
  - *Horizontal alignment*
  - *Vertical curvature*
  - *Grade*
  - *Stopping sight distance*
  - *Cross slope*
  - *Superelevation*
  - *Vertical clearance*
  - *Length of speed change lane*
  - *Horizontal clearance*
  - *Guardrail length*

Safety-Conscious Design

- AASHTO Guidance
  - *"Consistent adherence to minimum [design criteria] values is not advisable"*
  - *"Minimum design criteria may not ensure adequate levels of safety in all situations"*
  - *"The challenge to the designer is to achieve the highest level of safety within the physical and financial constraints of a project"*
    - Highway Safety Design and Operations Guide, 1997



Crash Data

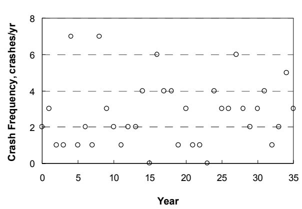
- **Existing Crash Databases**
  - *TxDOT - CRIS*
  - *Local databases*
- **Severity Scale**
  - *K: Fatal*
  - *A: Incapacitating injury*
  - *B: Non-incapacitating injury*
  - *C: Possible injury*
  - *PDO: property damage only*

  Our focus (K, A, B, C)
- **Reporting Threshold**
  - *$1000, informally varies among agencies*

Crash Data Variability

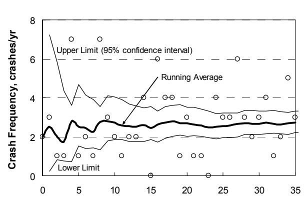
- **Questions**
  - *What is the true mean crash frequency?*
  - *Is a 3-year average reliable?*
  - *Why are there reductions following years 4, 8, 16, 27?*

Each data point represents 1 year of crash data at the site



Crash Data Variability

- **Observations**
  - *The average of 3 years (= 6 crashes)*
    - **2.0 crashes/yr**
    - **0.7 to 4.3 crashes/yr (± 115%)**
  - *The average of 35 years (= 100 crashes)*
    - **2.8 crashes/yr**
    - **2.2 to 3.3 (± 20%)**
  - ***One site rarely has enough crashes to yield an average with a precision of ± 20%***



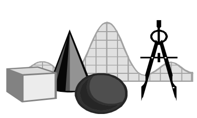
Overcoming Variability

- Summary
  - *Large variability makes it difficult to observe a change in crash frequency due to change in geometry at one site*
  - *Large variability in crash data may frustrate attempts to confirm expected change*
  - *Large databases needed to overcome large variability in crash data*
  - *Statistics must be used to accurately quantify effect*

Questions – Comments?

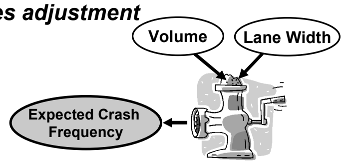
2. Safety Evaluation

- Safety Prediction Model
- Analysis Procedures
- Texas Roadway Safety Design Software



Safety Prediction Model

- **Model**
  - ***Crash frequency, $C = C_b \times AMF_{lw} \times AMF_{sw} \ldots$***
- **Model Components**
  - ***Base model, C_b***
  - ***Accident modification factors, AMF_i***
  - ***Empirical Bayes adjustment***

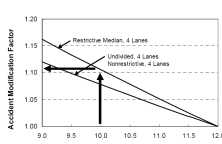


Base Model

- **Purpose**
  - ***Crash frequency for "typical" segment***
  - ***Typical: 12 ft lanes, 8 ft outside shoulder, etc.***
  - ***Injury (plus fatal) crash frequency***
- **Calibration**
  - ***Analyst can adjust model estimate to better match local conditions***
    - **Know that models are calibrated using Texas data**
    - **If, after using models for several projects, it appears that models consistently over-estimate or under-estimate crash frequency, then calibration may be needed**

Accident Modification Factor

- **Definition**
  - ***Change in crash frequency for a specific change in geometry***
  - ***Adapts base model to atypical conditions***
  - ***One AMF per design element (e.g., lane width)***
  - ***More than 70 AMFs in Workbook***
- **Example: 4 lane highway**
  - ***Base condition: 12 ft lanes***
  - ***Roadway has 10 ft lanes***
  - ***AMF = 1.11***

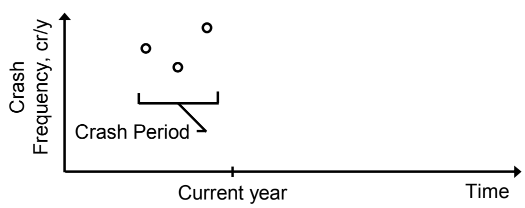


Empirical Bayes Adjustment

- **Questions**
  - *What if X crashes were reported in last 3 yrs?*
  - *Should we use "C" or "X/3" as best estimate?*
  - *"C" represents average for typical locations*
  - *"X/3" represents location of interest, but has some uncertainty attached*
- **Answers**
  - *Use weighted average of both "C" and "X/3"*
  - *Result is more accurate than "C" or "X/3"*
  - *See Procedures Guide (0-4703-P5)*

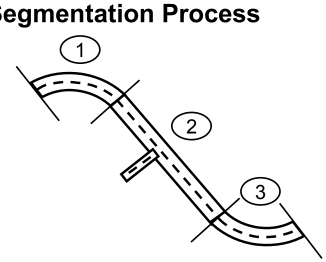
Empirical Bayes Adjustment

- **Application**
  - *Need at least 2 years of recent crash data*
  - *Need geometric and traffic data during period coincident with crash history*



Analysis Procedures

- **Safety Prediction Procedure**
- **Segmentation Process**



Safety Prediction Procedure

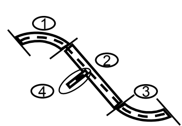
- Overview
  - *Six steps*
  - *Use base model and AMFs in Workbook*
  - *Evaluate a specific roadway segment or intersection (i.e., facility component)*
  - *See Procedures Guide (0-4703-P5)*
- Output
  - *Estimate of crash frequency for segment or intersection*

Step 1

- Identify Roadway Section
  - *Define limits of roadway section of interest*
    - May equal limits of design project
    - May only be a short length of road within the project
  - *May include one or more components*

Step 2

- Divide Section into Components
  - *Analysis based on facility components*
    - Intersection or
    - Interchange ramp or
    - Roadway "segment"
  - *"Segmentation Process"*
    - Discussed in detail shortly



Step 3

- **Gather Data for Subject Component**
  - ***Data may include***
    - **Roadway geometry (lane width, etc.)**
    - **Traffic (ADT, truck percentage, etc.)**
    - **Traffic control devices (stop sign, signal)**
    - **Crash data (for empirical Bayes analysis)**
  - ***What data do I need?***
    - **Consult Workbook or Spreadsheet**

Steps 4, 5, & 6

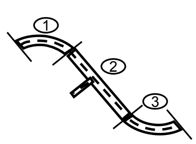
4. Compute Expected Crash Frequency
   - ***Use equations in Workbook***

5. Repeat Steps 3 and 4 for Each Component

6. Add Results for Roadway Section
   - ***Add crash estimates for all components***
   - ***Sum represents the expected crash frequency for the roadway section***

Segmentation Process

- **Overview**
  - ***Divide roadway section into homogeneous segments (Step 2)***



Homogeneous Segment

- Definition
  - *A homogeneous segment has the same basic character for its full length*
    - Lane width
    - Shoulder width
    - Number of lanes
    - Curvature
    - Median type
    - Median width

Segmentation Process

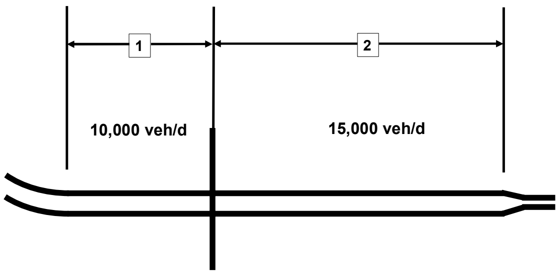
- Define Initial Segments
  - *Begin new segment when:*
    - ADT changes by 5% or more
    - Number-of-lanes changes
    - Sharp horizontal curvature begins or ends
    - Two-way left-turn lane begins or ends
    - Median begins or ends
    - Lane width changes by 1 ft or more
  - *Intersections or ramp terminals are not necessarily segment end points*
  - *Curve length includes spirals, if present*

Segmentation Process

- Adjust Length of Short Segments
  - *If, after subdivision, a segment is < 0.1 mi*
    - Combine it with adjacent non-curved segments until the new segment is at least 0.1 mi long
    - Use an average value for any design element that changes within this new segment
  - *Example:*
    - Lane width increases from 10 ft to 11 ft midway along a 0.1 mi segment
    - Cannot subdivide since length = 0.1 mi
    - So, estimate safety using average lane width of 10.5 ft

Segmentation Process

- Example



Questions – Comments?

TRSD Spreadsheet

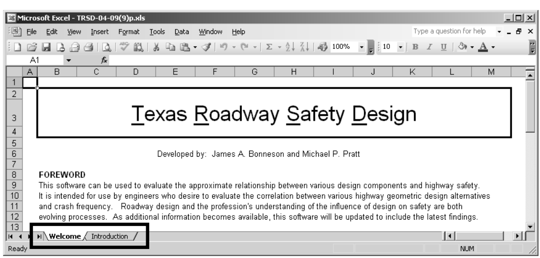
- Texas Roadway Safety Design Spreadsheet
  - *Overview*
  - *Navigation*
  - *Input*
  - *Calculations*
  - *Calibration factors*
  - *Output*
  - *Analysis types*

TRSD Overview

- **Facility Types**
  - ***Freeways***
  - ***Rural Highways***
  - ***Urban Streets***
  - ***Ramps***
  - ***Frontage Roads***
  - ***Rural Intersections***
  - ***Urban Intersections***

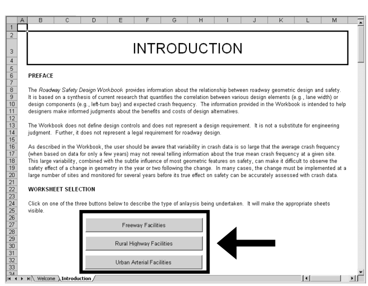
Navigation

- **Welcome Screen**
  - ***Tab for Introduction (User's Guide)***



Navigation

- **Introduction Screen**
  - ***Spreadsheet selection buttons***
  - ***User's Guide***

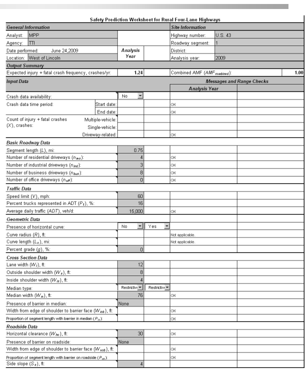


Navigation

- **Rural Highway Facilities**
  - *Rural two-lane highways*
  - *Rural four-lane highways*
  - *Inside barrier*
  - *Outside barrier*
  - *Vertical*
  - *Interchange ramps*
  - *Rural signalized intersection*
  - *Rural unsignalized intersection*

Navigation

- **Rural Four-Lane Highways**
  - *Let's take a closer look...*

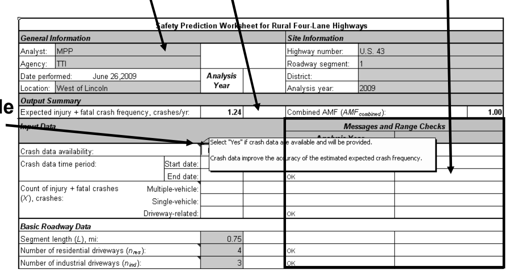


Navigation

White & gray cells: protected
Blue cells: input data

Messages and range checks for input data

Notes provide info.



Input Data

- Crash data
- Basic data
- Traffic data
- Geometric data

Input Data			
Crash data availability:		No	
Crash data time period:	Start date:		
	End date:		
Count of injury + fatal crashes (X), crashes:	Multiple-vehicle:		
	Single-vehicle:		
	Driveway-related:		
Basic Roadway Data			
Segment length (L), mi:		0.75	
Number of residential driveways (n_{res}):		4	
Number of industrial driveways (n_{ind}):		3	
Number of business driveways (n_{bus}):		8	
Number of office driveways (n_{off}):		0	
Traffic Data			
Speed limit (V), mph:		60	
Percent trucks represented in ADT (P_t), %:		16	
Average daily traffic (ADT), veh/d:		15,000	
Geometric Data			
Presence of horizontal curve:		No	Yes
Curve radius (R), ft:			
Curve length (L_c), mi:			
Percent grade (g), %:		0	
Cross Section Data			
Lane width (W_l), ft:		12	
Outside shoulder width (W_s), ft:		8	
Inside shoulder width (W_{is}), ft:		4	
Median type:		Restrictiv	Restrictiv
Median width (W_m), ft:		76	
Presence of barrier in median:		None	
Width from edge of shoulder to barrier face (W_{icb}), ft:			
Proportion of segment length with barrier in median (P_{ib}):			
Roadside Data			
Horizontal clearance (W_{hc}), ft:		30	
Presence of barrier on roadside:		None	
Width from edge of shoulder to barrier face (W_{ocb}), ft:			
Proportion of segment length with barrier on roadside (P_{ob}):			
Side slope (S_s), ft:		4	

Input Data

- **Close-Up View**

Geometric Data		
Presence of horizontal curve:	No	No
Curve radius (R), ft:		
Curve length (L_c), mi:		
Percent grade (g), %:	0	

Geometric Data		
Presence of horizontal curve:	Yes	No
Curve radius (R), ft:	1500	
Curve length (L_c), mi:	0.2	
Percent grade (g), %:	0	

Calculations

Individual AMFs

Combined AMF

Accident Modification Factors	*Analysis Year*	
Horizontal curve radius (AMF_{cr}):	1.00	
Grade (AMF_g):	1.00	
Outside clearance (no barrier) (AMF_{ocnb}):	1.00	
Outside clearance (some barrier) (AMF_{ocsb}):	1.00	
Outside clearance (full barrier) (AMF_{ocfb}):	1.00	
Side slope (AMF_{ss}):	1.00	
Lane width (AMF_{lw}):	1.00	
Outside shoulder width (AMF_{osw}):	1.00	
Inside shoulder width (AMF_{isw}):	1.00	
Median width (no barrier) (AMF_{mwnb}):	1.00	
Median width (some barrier) (AMF_{mwsb}):	1.00	
Median width (full barrier) (AMF_{mwfb}):	1.00	
Truck presence (AMF_{tk}):	1.00	
Combined AMF (product of all AMFs above) ($AMF_{combined}$):	1.00	

Calculations

Calibration factor →

Crash analysis →

Crash frequency →

Expected Crash Frequency		
Calibration factor (f):	1.00	
Multiple-Vehicle Crash Analysis		
Over-dispersion parameter (k):	3.08	
Base crash frequency (C_b), crashes/yr:	0.23	
Expected crash frequency (C), crashes/yr:	0.23	
Crash data time period (y), yr:		
Weight associated with C (w):		
Adjusted crash frequency given X (C_X):		
Expected crash frequency (C_{mv}), crashes/yr:	0.23	
Single-Vehicle Crash Analysis		
Over-dispersion parameter (k):	4.3	
Base crash frequency (C_b), crashes/yr:	0.54	
Expected crash frequency (C), crashes/yr:	0.54	
Crash data time period (y), yr:		
Weight associated with C (w):		
Adjusted crash frequency given X (C_X):		
Expected crash frequency (C_{sv}), crashes/yr:	0.54	
Driveway Crash Analysis		
Over-dispersion parameter (k):	1.11	
Number of equivalent residential driveways (n_e):	30.68	
Base crash frequency (C_b), crashes/yr:	0.47	
Expected crash frequency (C), crashes/yr:	0.47	
Crash data time period (y), yr:		
Weight associated with C (w):		
Adjusted crash frequency given X (C_X):		
Expected crash frequency (C_{dw}), crashes/yr:	0.47	
Total expected crash frequency, crashes/yr:	1.24	

Calibration Factors

- **Local Calibration Factors**
  - ***Factor is multiplied by base model estimate***
  - ***If changed to say 1.10, estimate increases 10%***
  - ***Models currently calibrated using CRIS data***

Calibration Parameters								
Base Models				Model: $a\ (c\ ADT)^b$				
Median Type	**Through Lanes**	**Crash Type Subset**	**Location**	***a***	***b***	***c***	**Over-Disp. (k)**	**Calib. Factor (f)**
Undivided	4	Multiple-vehicle	Segment	0.00749	1.63	0.001	3.08	1.00
		Single-vehicle	Segment	0.109	0.631	0.001	4.3	1.00
		Driveway-related	Driveway	0.0169	0.738	0.000067	1.11	1.00
Nonrestrictive	4	Multiple-vehicle	Segment	0.00527	1.8	0.001	3.08	1.00
		Single-vehicle	Segment	0.0776	0.667	0.001	4.3	1.00
		Driveway-related	Driveway	0.017	1.44	0.000067	1.11	1.00
Restrictive	4	Multiple-vehicle	Segment	0.00549	1.49	0.001	3.08	1.00
		Single-vehicle	Segment	0.106	0.707	0.001	4.3	1.00
		Driveway-related	Driveway	0.0152	1.04	0.000067	1.11	1.00
Driveway Model				Model: $n_{res} + e\ n_{ind} + f\ n_{bus} + g\ n_{off}$				
Median Type	**Through Lanes**	**Crash Type Subset**	**Location**	***e***	***f***	***g***		
Undivided	4	Driveway-related	Driveway	2.68	2.33	9.76		
Nonrestrictive	4	Driveway-related	Driveway	2.68	2.33	9.76		
Restrictive	4	Driveway-related	Driveway	2.68	2.33	9.76		

Calibration Parameters

- **Crash Distributions**
  - ***For some AMFs***
  - ***Values represent proportion of crashes influenced by specific geometric design elements (e.g., shoulder width, lane width)***

Crash Distribution					
Crash Type No.	**Crash Type Subset**	**Median Type**	**Through Lanes**	**Proportion Crashes**	**Applicable AMFs**
1	Single-vehicle run-off-road crashes, either side.	Undivided	4	0.32	Outside clearance (no barrier), Side slope,
		Nonrestrictive	4	0.32	Outside shoulder width
	Single-vehicle run-off-road crashes, right side only.	Restrictive	4	0.3	
2	Single-vehicle run-off-road, same-direction sideswipe, and multiple-vehicle opposite direction.	Undivided	4	0.44	Lane Width
		Nonrestrictive	4	0.44	
		Restrictive	4	0.59	
3	Single-vehicle run-off-road (left-side only) and multiple-vehicle opposite direction.	Undivided	4		Inside shoulder width
		Nonrestrictive	4		
		Restrictive	4	0.24	

Output Summary

- **Output**
  - ***Estimate of expected crash frequency***
    - **For analysis year and crash period (EB)**
    - **Injury (plus fatal) crashes**
    - **All crash types (single vehicle, rear-end, etc.)**
  - ***AMF indicates deviation from "typical"***

Safety Prediction Worksheet for Rural Four-Lane Highways

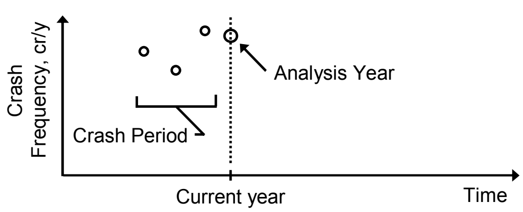
General Information				*Site Information*	
Analyst:	MPP			Highway number:	U.S. 43
Agency:	TTI			Roadway segment:	1
Date performed:	June 24,2009	*Analysis Year*		District:	
Location:	West of Lincoln			Analysis year:	2009
Output Summary					
Expected injury + fatal crash frequency, crashes/yr:		**1.24**		Combined AMF ($AMF_{combined}$):	**1.00**

Analysis Types

- **Types 1 and 2**
  - ***Type 1 – No Crash Data***
    - **Use calibrated base model in Workbook**
  - ***Type 2 – With Crash Data***
    - **Use calibrated base model <u>and</u> crash data**
    - **Use EB analysis to get weighted average of both**
- **TRSD Definitions**
  - ***Analysis year***
    - **Year for which expected crash frequency estimate is desired**
  - ***Crash period***
    - **Time period representing crash data**

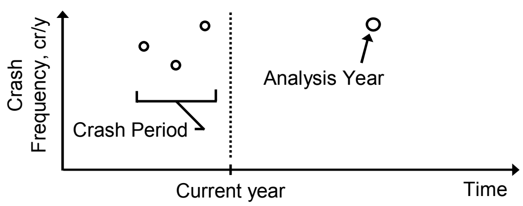
Analysis Types

- **Type 1 – No Crash Data**
  - ***Provide geometry and traffic for analysis year***
- **Type 2 – With Crash Data**
  - ***Provide geometry and traffic for <u>both</u> analysis year and crash period***



Analysis Types

- **Types 1 and 2 Analyses**
  - ***Analysis year can be current year, or***
  - ***Any specified year***



Analysis Type

- **Analysis Type Selection in TRSD**
  - ***Indicate the analysis type by selecting***
    - **No – Type 1 analysis (no crash data)**
    - **Yes – Type 2 analysis (with crash data)**

		Crash Period	Analysis Year		
Date performed: June 24,2009				District:	
Location: West of Lincoln				Analysis year:	2009
Output Summary					
Expected injury + fatal crash frequency, crashes/yr:		**1.20**	**1.20**	Combined AMF ($AMF_{combined}$):	**1.00**
Input Data				***Messages and Range Checks***	
				Crash Period	***Analysis Year***
Crash data availability:		Yes			
Crash data time period:	Start date:	1/1/1999		OK	
	End date:	12/31/2001		OK	
Count of injury + fatal crashes (X), crashes:	Multiple-vehicle:	2			
	Single-vehicle:	1			
	Driveway-related:	1		OK	
Basic Roadway Data					
Segment length (L), mi:		0.75	0.75		
Number of residential driveways (n_{res}):		4	4	OK	OK
Number of industrial driveways (n_{ind}):		3	3	OK	OK
Number of business driveways (n_{bus}):		8	8	OK	OK
Number of office driveways (n_{off}):		0	0	OK	OK

Questions – Comments?

3. Highway Segments

- **Overview**
  - ***Safety prediction model***
  - ***Accident modification factors***
  - ***Exercises***

Safety Prediction Model

- **Components**
  - ***Base model, C_b***
  - ***Accident modification factors, AMF_i***
- **Relationship** **Page 3-9**

$$C = C_b \times AMF_{cr} \times AMF_g \ldots \qquad \textbf{(3-15)}$$

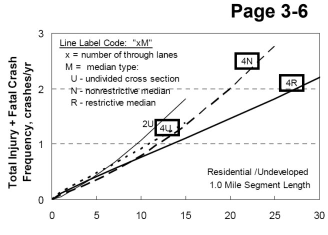
where:

C = expected injury (plus fatal) crash frequency, crashes/yr;
C_b = base injury (plus fatal) crash frequency, crashes/yr;
AMF_{cr} = horizontal curve accident modification factor; and
AMF_g = grade accident modification factor.

Base Model

- **Base Model**
  - ***Equations in Workbook***
    - **Based on typical conditions**
    - **Injury (plus fatal) crashes**
    - **All crash types**

Page 3-6



Base Model

- **Base Conditions**
  - ***Typical conditions***
  - ***AMFs are used to adjust base model estimate to conditions at a specific site***

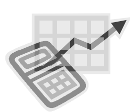
Characteristic	Base Condition
Rural Highways – Two or Four Lanes	
Horizontal curve radius	tangent (no curve)
Grade	flat (0% grade)
Lane width	12 ft
Outside shoulder width	8 ft
Rigid or semi-rigid barrier	not present
Horizontal clearance	30 ft
Side slope	1V:4H
Rural Highways – Four Lanes	
Inside shoulder width [1]	4 ft
Median width [2]	16 ft for nonrestrictive median 76 ft for restrictive median
Truck presence	16% trucks

Notes:
1 - Applies to highways with a restrictive median.
2 - Nonrestrictive median: TWLTL or flush-paved median.
Restrictive median: depressed median.

Page 3-7

Accident Modification Factors

- **AMFs in Workbook**
  - ***13 available for multilane highways***
  - ***Most are functions of geometric variables (e.g., radius, lane width, etc.)***
  - ***AMFs developed to work with base model (i.e., same underlying base conditions)***

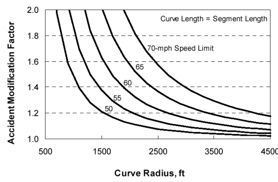


Accident Modification Factors

- **Multilane Highway**
  - ***Curve radius***
  - ***Grade***
  - ***Outside clearance***
    - **No barrier**
    - **Some barrier**
    - **Full barrier**
  - ***Side slope***
  - ***Lane width***
  - ***Shoulder width***
    - **Outside**
    - **Inside**
  - ***Median width***
    - **No barrier**
    - **Some barrier**
    - **Full barrier**
  - ***Truck presence***

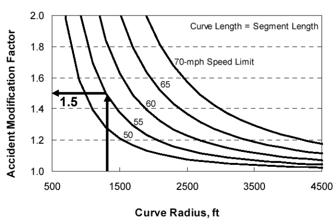
Curve Radius

- **Base Condition**
  - *No curvature*
- **Limits**
  - *Minimum radius corresponds to AMF = 2.0*
- **Notes**
  - *If spirals present, include their length in curve length*



Example

- **Questions**
  - *What is the AMF for a 1300-ft radius curve?*
    - Speed limit = 55 mph
    - Curve length = segment length



Grade

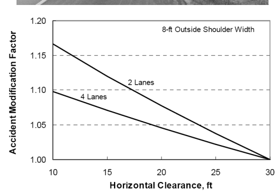
- **Base Condition**
  - *No grade*
- **Limits**
  - *Grade ≤ 8%*
- **Notes**
  - *"Upgrade" and "Downgrade" have same effect on safety*

Note About Limits

- **Bounds on Input Variables**
  - ***Based on range of data used to develop AMF***
  - ***If range is exceeded:***
    - **We are not sure what AMF value is**
    - **Extrapolation is risky**
    - **Recommend not exceeding AMF value at limit**
  - ***Example:***
    - **Bound on grade is 8%**
    - **For grade of 9%, what is the AMF?**
    - **Recommend using 1.16 (the value for 8%)**

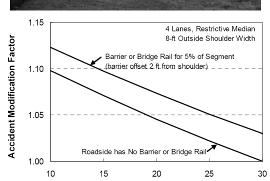
Outside Clearance

- **No Barrier**
- **Base Conditions**
  - ***30-ft clearance***
  - ***8-ft shoulder***
- **Limits**
  - ***Clearance ≤ 30 ft***
- **Notes**
  - ***Measure clearance from traveled way***



Outside Clearance

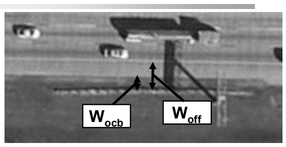
- **Some Barrier**
- **Base Conditions**
  - ***30-ft clearance***
  - ***8-ft shoulder***
- **Limits**
  - ***Clearance ≤ 30 ft***
- **Notes**
  - ***Use Outside Barrier worksheet***
  - ***Not for justifying addition or removal***



Example

- **Given**
  - ***Segment length: 0.75 mi***
  - ***Outside shoulder width: 8 ft***
  - ***Horizontal clearance: 20 ft***
  - ***Two segments of outside barrier***
    - **Left side between MP 1.2 and 1.25**
      - **Length = 0.05 mi, offset (W_{off}) = 9.7 ft from traveled way**
    - **Right side between MP 1.3 and 1.33**
      - **Length = 0.03 mi, offset (W_{off}) = 11 ft from traveled way**
- **Question**
  - ***What is the outside clearance AMF?***

Example



- **Solution**
  - ***Equations on p. 3-14***
  - ***What is the average barrier offset from edge of shoulder (W_{ocb})?***
  - ***What proportion of the segment has barrier (P_{ob})?***
  - ➔ ***Use Outside Barrier sheet to compute*** ⬅
    - **Crash Period (fill out if crash data available)**
    - **Analysis Year (always fill out)**

Example

- **Solution**
  - ***Assume no crash data***

Outside Barrier Data Calculation Worksheet for Freeways and Rural Highways

Crash Period *(fill out this section only if crash data are available)*

Input Data				Messages
Some barrier present on roadside				Enter barrier elements below.
Segment length (L), mi:		Outside shoulder width (W_s), ft:		

Barrier Segment	Location	Length ($L_{ob,off}$), mi	Width from Edge of Traveled Way to Face of Barrier (W_{off}), ft		Ratio ($L_{ob,off}$ / [W_{off} - W_s])
1			OK		

Analysis Year *(always fill out this section when barrier is present on, or planned for, the segment)*

Input Data				Messages
Some barrier present on roadside				Enter barrier elements below.
Segment length (L), mi:	0.75	Outside shoulder width (W_s), ft:	8	

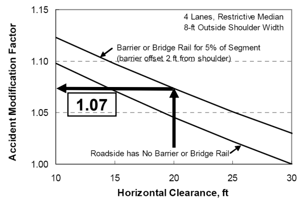
Barrier segment	Location	Length ($L_{ob,off}$), mi	Width from Edge of Traveled Way to Face of Barrier (W_{off}), ft			Ratio ($L_{ob,off}$ / [W_{off} - W_s])
1	MP 1.2 to MP 1.25	0.05	OK	9.7		0.03
2	MP 1.3 to MP 1.33	0.03	OK	11		0.01
3			OK			
	Sum1:	0.08			**Sum2:**	0.04

Outside Clearance (some barrier)

Proportion of segment length with barrier on roadside (P_{ob}):	0.05	Width from edge of shoulder to barrier face (W_{ocb}), ft:	2.0

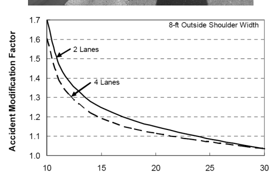
Example

- **Given**
  - *Outside shoulder width: 8 ft*
  - *Horizontal clearance: 20 ft*
- **Find:**
  - AMF_{ocsb} *= 1.07*



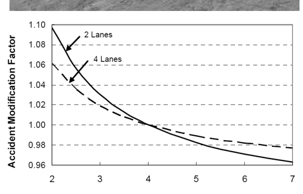
Outside Clearance

- **Full Barrier**
- **Base Conditions**
  - *30-ft clearance*
  - *8-ft shoulder*
- **Limits**
  - *Clearance ≤ 30 ft*
- **Notes**
  - *Use Outside Barrier worksheet*
  - *Not for justifying addition or removal*



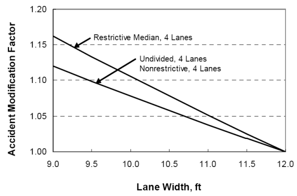
Side Slope

- **Base Condition**
  - *1:4 side slope*
- **Limits**
  - *Slopes between 1:2 and 1:7*



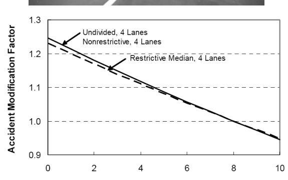
Lane Width

- **Base Condition**
  - *12-ft lanes*
- **Limits**
  - *Lane width between 9 and 12 ft*
- **Notes**
  - *If lane width > 12 ft, use AMF for 12 ft*



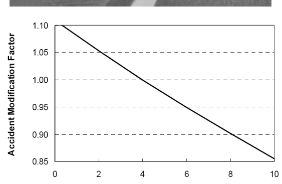
Outside Shoulder Width

- **Base Condition**
  - *8-ft outside shoulder*
- **Limits**
  - *Shoulder widths between 0 and 10 ft*
- **Notes**
  - *If width > 10 ft, use AMF for 10 ft*



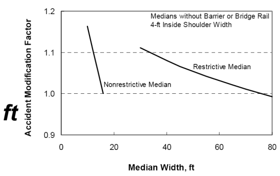
Inside Shoulder Width

- **Base Condition**
  - *4-ft inside shoulder*
- **Limits**
  - *Shoulder widths between 0 and 10 ft*
- **Notes**
  - *If width > 10 ft, use AMF for 10 ft*
  - *Applies to restrictive median*



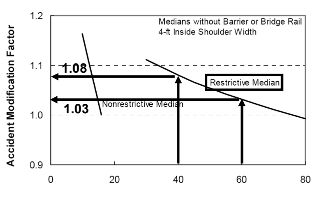
Median Width

- No Barrier
- Base Condition
  - *16-ft median (nonrestrictive)*
  - *76-ft median & 4-ft inside shoulders (restrictive)*
- Limits
  - *Nonrestrictive: 10 - 16 ft*
  - *Restrictive: 30 - 80 ft*



Example

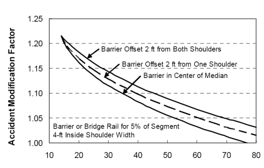
- **Question**
  - ***If a multilane highway's median is widened from 40 to 60 ft, what would be the expected crash reduction?***
    - **Restrictive median, 4-ft inside shoulder, no barrier**



40-ft median: AMF = 1.08
60-ft median: AMF = 1.03
Crash reduction:
100 × (1 - 1.03/1.08) = 4.6 %

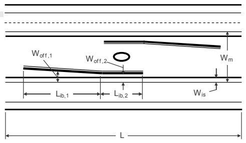
Median Width

- Some Barrier
- Base Condition
  - *76-ft median & 4-ft inside shoulders*
- Limits
  - *Median width ≥ 14 ft*
- Notes
  - *Use Inside Barrier worksheet*
  - *Not for justifying addition or removal*



Example

- **Given**
  - *Segment length: 1.4 mi*
  - *In. shoulder width: 4 ft*
  - *Median width: 40 ft*
  - *Two sections of barrier in median*
    - Long angled element to protect wide area of concern
    - So, break each section into two barrier segments



1. Length ($L_{ib,1}$) = 0.05 mi, offset ($W_{off,1}$) 13.67 ft
2. Length ($L_{ib,2}$) = 0.02 mi, offset ($W_{off,2}$) 4.67 ft

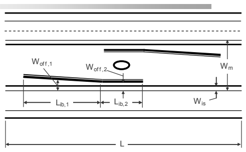
} Direction 1

1. Length ($L_{ib,3}$) = 0.02 mi, offset ($W_{off,3}$) 4.67 ft
2. Length ($L_{ib,4}$) = 0.05 mi, offset ($W_{off,4}$) 13.67 ft

} Direction 2

- **Question**
  - *What is the median width AMF?*

Example



- **Solution**
  - *Equations on p. 3-33*
  - *What is the average barrier offset from edge of shoulder (W_{icb})?*
  - *What proportion of the segment has barrier (P_{ib})?*
  - *Use Inside Barrier sheet to compute*
    - Crash Period (fill out if crash data available)
    - Analysis Year (always fill out)

Example

- **Solution**
  - *Assume no crash data*

Inside Barrier Data Calculation Worksheet for Freeways and Rural Highways

Crash Period *(fill out this section only if crash data are available)*

Input Data				***Messages***
Median barrier present in center of median				Enter additional, short barrier elements below.
Segment length (L), mi:		Inside shoulder width (W_{is}), ft:		Increase median width or decrease shoulder width.
Median width (W_m), ft:		Inside barrier width (W_{ib}), ft:		OK

Analysis Year *(always fill out this section when barrier is present on, or planned for, the segment)*

Input Data				***Messages***
Some barrier present in median				Enter barrier elements below.
Segment length (L), mi:	1.4	Inside shoulder width (W_{is}), ft:	4	
Median width (W_m), ft:		Inside barrier width (W_{ib}), ft:		OK

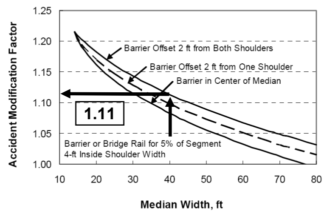
Barrier Segment	Location	Length ($L_{ib,off}$), mi	Width from Edge of Traveled Way to Face of Barrier (W_{off}), ft			Ratio ($L_{ib,off}$ / [W_{off} - W_{is}])
1	MP 11.25 to MP 11.30	0.05	OK	13.67		0.01
2	MP 11.30 to MP 11.32	0.02	OK	4.67		0.03
3	MP 11.30 to MP 11.32	0.02	OK	4.67		0.03
4	MP 11.32 to MP 11.37	0.05	OK	13.67		0.01
	Sum1:	0.14			**Sum2:**	0.07

Median Width (some barrier)

Proportion of segment length with barrier in median (P_{ib}):	0.05	Width from edge of shoulder to barrier face (W_{icb}), ft:	2.0

Example

- **Given**
  - *In. shoulder width: 4 ft*
  - *Median width: 40 ft*
- **Find:**
  - *AMF_{mwsb} = 1.11*



  - *Now it's your turn…*

Example

- **Given**
  - *Segment length: 2.0 mi*
  - *Inside shoulder width: 2 ft*
  - *Median width: 20 ft*
  - *Median barrier*
    - Full length of segment
    - Centered in median, 2.5 ft wide
  - *No crash data*
- **Question**
  - *What is the median width AMF?*

Example

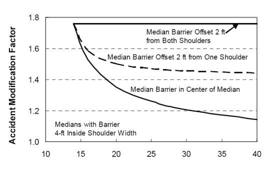
- **Solution**
  - *Step 1. Fill out the Inside Barrier worksheet*

Example

- **Solution**
  - *Step 2. Go to segment worksheet and indicate barrier presence*

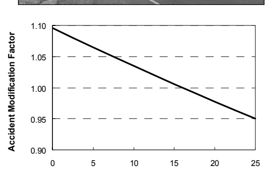
Median Width

- **Full Barrier**
- **Base Condition**
  - *76-ft median & 4-ft inside shoulders*
- **Limits**
  - *Median width ≥ 14 ft*
- **Notes**
  - *Use Inside Barrier worksheet*
  - *Not for justifying addition or removal*



Truck Presence

- **Base Condition**
  - *16 percent trucks*
- **Limits**
  - *Truck presence ≤ 25 percent of ADT*



Exercise 1: Rural Highway

- **Given**
  - ***Rural four-lane highway segment***
    - **No crash data available**
    - **Length: 2 mi**
    - **Driveways: 2 res, 4 bus**
    - **Speed limit: 60 mph**
    - **Percent trucks: 10**
    - **Volume: 22,000 veh/d**
    - **No curvature**
    - **Grade: 0%**
    - **Lane width: 11 ft**
    - **Out. shoulder width: 8 ft**
    - **In. shoulder width: n.a.**
    - **Nonrestrictive median**
    - **Median width: 16 ft**
    - **No roadside barrier**
    - **Horiz. clearance: 30 ft**
    - **Side slope: 6 (=1:6)**
- **Question**
  - ***What is the expected crash frequency?***

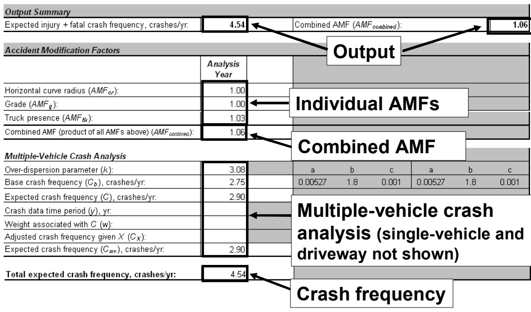
Exercise 1: Rural Highway

Basic Roadway Data		
Segment length (L), mi:	2	**Length**
Number of residential driveways (n_{res}):	2	**Driveways**
Number of industrial driveways (n_{ind}):	0	**Driveways**
Number of business driveways (n_{bus}):	4	**Driveways**
Number of office driveways (n_{off}):	0	**Driveways**
Traffic Data		
Speed limit (V), mph:	60	
Percent trucks represented in A	10	**Volume**
Average daily traffic (ADT), veh/	22,000	**Volume**
Geometric Data		
Presence of horizontal curve:	No	**Curvature**
Curve radius (R), ft:		**Curvature**
Curve length (L_c), mi:		**Curvature**
Percent grade (g), %:	0	**Grade**

Exercise 1: Rural Highway

Cross Section Data		
Lane width (W_l), ft:	11	**Lane width**
Outside shoulder width (W_s), ft:	8	**Shoulder width**
Inside shoulder width (W_{is}), ft:		
Median type:	Nonrestric	**Median**
Median width (W_m), ft:	16	**Median**
Presence of barrier in median:		
Width from edge of shoulder to barrier face (W_{icb}), ft:		
Proportion of segment length with barrier in median (P_{ib}):		
Roadside Data		
Horizontal clearance (W_{hc}), ft	30	**Clearance**
Presence of barrier on roadsid	None	**Roadside barrier**
Width from edge of shoulder t), ft:		
Proportion of segment length with barrier on roadside (P_{ob}):		
Side slope (S_s), ft:	6	**Side slope**

Exercise 1: Rural Highway



Output Summary			
Expected injury + fatal crash frequency, crashes/yr:	4.54	Combined AMF ($AMF_{combined}$):	1.06

Accident Modification Factors	Analysis Year
Horizontal curve radius (AMF_{cr}):	1.00
Grade (AMF_g):	1.00
Truck presence (AMF_{tk}):	1.03
Combined AMF (product of all AMFs above) ($AMF_{combined}$):	1.06

Multiple-Vehicle Crash Analysis		a	b	c	a	b	c
Over-dispersion parameter (k):	3.08						
Base crash frequency (C_b), crashes/yr:	2.75	0.00527	1.8	0.001	0.00527	1.8	0.001
Expected crash frequency (C), crashes/yr:	2.90						
Crash data time period (y), yr:							
Weight associated with C (w):							
Adjusted crash frequency given X (C_X):							
Expected crash frequency (C_{mv}), crashes/yr:	2.90						

Total expected crash frequency, crashes/yr:	4.54

Exercise 1: Rural Highway

- Additional Questions
  - *What does the combined AMF say about this segment, relative to the typical segment?*
  - *Which attributes tend to increase crashes on this segment, relative to the typical segment?*

Exercise 1: Rural Highway

- Additional Questions
  - *From 1/1/1999 to 12/31/2001, the following injury (+ fatal) crashes were reported:*
    - 11 multiple-vehicle, 6 single-vehicle, 1 driveway
  - *What is the expected crash frequency (ECF) for these years?*
    - 6.00 cr/yr (= [11 + 6 + 1]/3), or
    - 4.54 cr/yr, or
    - 5.20 cr/yr

Exercise 1: Rural Highway

- **Additional Questions**
  - ***The crash data are a little old. It is currently 2009 and the ADT is 25,000; what is the ECF?***
- **Now it's your turn. . .**
  - ***Exit sheet without saving, and then re-load it***

Exercise 2: Rural Highway

- **Given**
  - ***Rural four-lane highway segment***
    - **No crash data available**
    - **Length: 2 mi**
    - **Residential driveways: 4**
    - **Speed limit: 60 mph**
    - **Percent trucks: 15**
    - **Volume: 17,000 veh/d**
    - **Curvature: none**
    - **Grade: 1%**
    - **Lane width: 12 ft**
    - **Out. shoulder width: 6 ft**
    - **In. shoulder width: 2 ft**
    - **Median**
      - **Restrictive, 20 ft wide**
      - **Barrier: centered, 2.5 ft wide, full length of seg.**
      - **No short barrier elements**
    - **Horiz. clearance: 30 ft**
    - **Side slope: 1:6**
    - **Outside barrier: no**
- **Question**
  - ***What is the expected crash frequency?***

Exercise 2: Rural Highway

- **Answer**

Exercise 2

- **Answer**

Exercise 2

- **Question**
  - ***If the shoulders are widened to:***
    - **Outside: 10 ft**
    - **Inside: 4 ft**
    - **Side slope: 1:4**
  - ***What is the expected crash frequency?***
    - **Hint: change inside shoulder width on both sheets**
- **Answer**

Questions?

- **How about a break for lunch?**

Incorporating Safety into the Highway Design Process

Part II. Rural Multilane Highways and Freeways

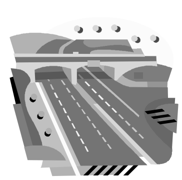
Texas Department of Transportation

Agenda

- **Session 4:**
  - ***Procedure for freeway segments***
- **Session 5:**
  - ***Procedure for interchange ramps***
- **Session 6:**
  - ***Section evaluation***
- **Session 7:**
  - ***Alternatives analysis***

4. Freeway Segments

- **Overview**
  - ***Safety prediction model***
  - ***Accident modification factors***
  - ***Exercises***



Safety Prediction Model

- **Components**
  - ***Base model, C_b***
  - ***Accident modification factors, AMF_i***
- **Relationship**

Page 2-8

$$C = C_b \times AMF_{lw} \times AMF_{cr} \ldots \qquad \textbf{(2-23)}$$

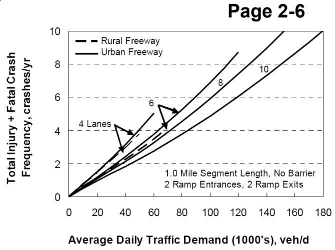
where:

C = expected injury (plus fatal) crash frequency, crashes/yr;
C_b = base injury (plus fatal) crash frequency, crashes/yr;
AMF_{lw} = lane width accident modification factor; and
AMF_{cr} = horizontal curve radius accident modification factor.

Base Model

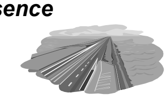
- **Base Model**
  - ***Equations in Workbook***
    - **Based on typical conditions**
    - **Injury (plus fatal) crashes**
    - **All crash types**

Page 2-6



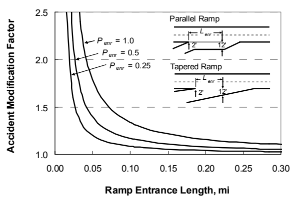
Accident Modification Factors

- **Freeway**
  - ***Curve radius***
  - ***Grade***
  - ***Lane width***
  - ***Shoulder width***
    - **Outside**
    - **Inside**
  - ***Median width***
    - **No barrier**
    - **Some barrier**
    - **Full barrier**
  - ***Shoulder rumble strips***
  - ***Outside clearance***
    - **No barrier**
    - **Some barrier**
    - **Full barrier**
  - ***Ramp entrance***
  - ***Weaving section***
  - ***Truck presence***



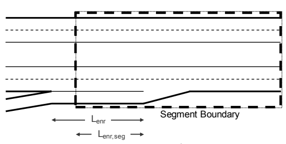
Ramp Entrance

- **Base Condition**
  - ***No ramp entrance***
- **Limits**
  - ***Length ≤ 0.3 mi***
- **Notes**
  - ***Length based on marked pavement***

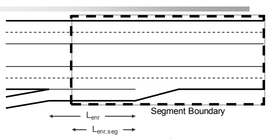


Example

- **Given**
  - ***Segment length, L: 0.20 mi***
  - ***Ramp length, L_{enr}: 0.15 mi***
  - ***Length of ramp <u>in segment</u>, $L_{enr,seg}$: 0.10 mi***
- **Question**
  - ***What is the ramp entrance AMF?***



Example



- **Solution**
  - ***Equations on p. 2-22***
  - ***What is the average ramp entrance length (l_{enr})?***
  - ***What proportion of the segment is adjacent to a ramp entrance (P_{enr})?***
  - ➔ ***Use Ramp Entrance sheet to compute*** ⬅
    - **Crash Period (fill out if crash data available)**
    - **Analysis Year (always fill out)**

Example

- **Solution**
  - ***Assume no crash data***

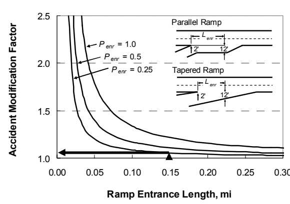
Ramp Entrance Data Calculation Worksheet for Freeways

Crash Period	***(fill out this section only if crash data are available)***			
Input Data			***Messages***	
Segment length (L), mi:			Ramp lengths exceed segment length.	
Ramp Entrance	**Location**	**Length of Ramp Entrance in Segment ($L_{enr,seg}$), mi**	**Length of Ramp Entrance (L_{enr}), mi**	**Ratio ($L_{enr,seg}/L_{enr}$)**
1				

Analysis Year	***(always fill out this section when ramp entrances are present on, or planned for, the segment)***			
Input Data			***Messages***	
Segment length (L), mi:	0.2		OK	
Ramp Entrance	**Location**	**Length of Ramp Entrance in Segment ($L_{enr,seg}$), mi**	**Length of Ramp Entrance (L_{enr}), mi**	**Ratio ($L_{enr,seg}/L_{enr}$)**
1	MP 1.2 to MP 1.3	0.1	0.15 OK	0.67
2				
		Sum1: 0.10	**Sum2:**	0.67
Proportion of segment length adjacent to a ramp entrance (P_{enr}):		0.25	Average ramp entrance length (l_{enr}), ft:	792

Example

- **Solution**
  - ***Average ramp entrance length (l_{enr}) = 792 ft (0.15 mi)***
  - ***Proportion of the segment adjacent to a ramp entrance (P_{enr}) = 0.25***
- **Answer**
  - ***$AMF_{enr/agg}$ = 1.05***



  - ***Now it's your turn…***

Example

- **Given**
  - ***Segment length, L: 2.1 mi***
  - ***Length of ramp 1 in segment, $L_{enr,seg}$: 0.2 mi***
  - ***Ramp 1 length, L_{enr}: 0.2 mi***
  - ***Length of ramp 2 in segment, $L_{enr,seg}$: 0.3 mi***
  - ***Ramp 2 length, L_{enr}: 0.3 mi***
  - ***Crash data are available***
- **Question**
  - ***What is the ramp entrance AMF?***

Example

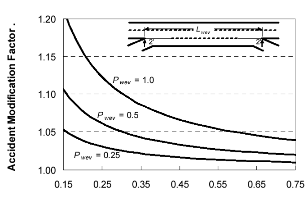
- **Solution**
  - *Step 1. Fill out the Ramp Entrance worksheet*

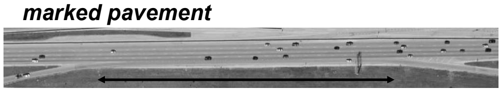
Example

- **Solution**
  - *Step 2. Go to segment worksheet and indicate ramp entrance presence*

Weaving Section

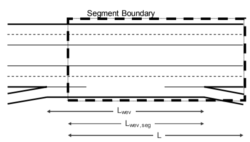
- **Base Conditions**
  - *No weaving section*
- **Limits**
  - *Length between 0.15 and 0.75 mi*
- **Notes**
  - *Length based on marked pavement*



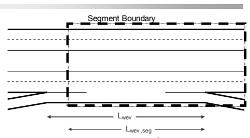


Example

- **Given**
  - *Segment length, L: 0.25 mi*
  - *Length of weaving in segment, $L_{wev,seg}$: 0.2 mi*
  - *Weaving section length, L_{wev}: 0.25 mi*
- **Question**
  - *What is the weaving section AMF?*



Example



- **Solution**
  - *Equations on p. 2-23*
  - *What is the average weaving section length (l_{wev})?*
  - *What proportion of the segment is adjacent to a weaving section (P_{wev})?*
  - ➔ *Use Weaving Section sheet to compute* ⬅
    - Crash Period (fill out if crash data available)
    - Analysis Year (always fill out)

Example

- **Solution**
  - *Assume no crash data*

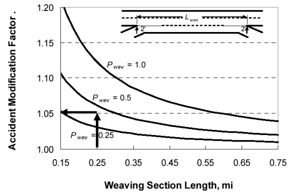
Weaving Section Data Calculation Worksheet for Freeways

Crash Period	*(fill out this section only if crash data are available)*			
Input Data			*Messages*	
Segment length (L), mi:			Weaving section lengths exceed segment length.	
Weaving Section	**Location**	**Length of Weaving Section in Segment ($L_{wev,seg}$), mi**	**Length of Weaving Section (L_{wev}), mi**	**Ratio ($L_{wev,seg}/L_{wev}$)**
1				

Analysis Year	*(always fill out this section when weaving sections are present on, or planned for, the segment)*			
Input Data			*Messages*	
Segment length (L), mi: 0.25			OK	
Weaving Section	**Location**	**Length of Weaving Section in Segment ($L_{wev,seg}$), mi**	**Length of Weaving Section (L_{wev}), mi**	**Ratio ($L_{wev,seg}/L_{wev}$)**
1	MP 1.2 to MP 1.4	0.2	0.25 OK	0.80
2				
	Sum1:	0.20	**Sum2:**	0.80
Proportion of segment length adjacent to a weaving section (P_{wev}):		0.40	Average weaving section length (l_{wev}), ft:	1320

Example

- **Solution**
  - *Average weaving section length (l_{wev}) = 1320 ft (0.25 mi)*
  - *Proportion of the segment adjacent to a weaving section (P_{wev}) = 0.40*
- **Answer**
  - *$AMF_{wev/agg}$ = 1.05*



  - *Now it's your turn…*

Example

- **Given**
  - *Segment length, L: 1.0 mi*
  - *Weaving section 1*
    - Length of weaving in segment, $L_{wev,seg}$: 0.5 mi
    - Weaving section length, L_{wev}: 0.5 mi
  - *Weaving section 2*
    - Length of weaving in segment, $L_{wev,seg}$: 0.4 mi
    - Weaving section length, L_{wev}: 0.4 mi
  - *Crash data are available*
- **Question**
  - *What is the weaving section AMF?*

Example

- **Solution**
  - *Step 1. Fill out the Weaving Section worksheet*

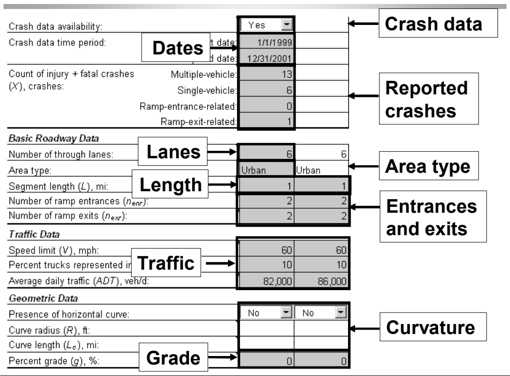
Example

- **Solution**
  - ***Step 2. Go to segment worksheet and indicate weaving section presence***

Exercise 3: Freeway

- **Given**
  - **Crashes:**
    - **1/1/1999 to 12/31/2001**
    - **13 mv, 6 sv, 1 exit ramp**
  - **Lanes: 6**
  - **Area type: Urban**
  - **Length: 1 mi**
  - **2 entrances and 2 exits**
  - **Speed limit: 60 mph**
  - **Percent trucks: 10**
  - **Volume, veh/d:**
    - **Crash period: 82,000**
    - **Analysis year: 86,000**
  - **No curve or grade**
  - **Lane width: 11 ft**
  - **Out. shoulder width: 6 ft**
  - **In. shoulder width: 4 ft**
  - **Median**
    - **50-ft wide, no barrier**
  - **Rumble strips present**
  - **Horiz. clearance: 15 ft**
  - **Outside barrier: some**
    - **0.8 mi length, 8 ft offset**
  - **Two weaving sections:**
    - **0.5 mi and 0.4 mi, entire length on segment**
    - **Ramp ent. in weave section**
- **Question**
  - ***What is the expected crash frequency?***

Exercise 3: Freeway



Exercise 3: Freeway

- **Solution**

Cross Section Data		
Lane width (W_l), ft:	11	11
Outside shoulder width (W_s), ft:	6	6
Inside shoulder width …	4	4
Median width (W_m), …	50	50
Presence of barrier in median:	None	None
Width from edge of shoulder to barrier face (W_{icb}), ft:		
Proportion of segment le…		
Presence of shoulde…	Yes	Yes
Roadside Data		
Horizontal clearance (W_{hc}), ft:	15	15
Presence of barrier on roads…	Some	Some
Width from edge of shoulder …	2.00	2.00
Proportion of segment length with …	0.40	0.40

Lane width
Median width
Rumble strips
Roadside barrier
Shoulder widths
Median barrier
Clearance

Exercise 3: Freeway

- **Solution**
  - ***Outside Barrier worksheet***

Crash Period *(fill out this section only if crash data are available)*

Input Data — Some barrier present on roadside

Messages — Enter barrier elements below.

Segment length (L), mi: 1 — Outside shoulder width (W_s), ft: 6

Barrier Segment	Location	Length ($L_{ob,off}$), mi		Width from Edge of Traveled Way to Face of Barrier (W_{off}), ft	Ratio ($L_{ob,off}$ / [W_{off} - W_s])
1	MP 0.6 to MP 1.4	0.8	OK	8	0.40
	Sum1:	0.80		Sum2:	0.40

Outside Clearance (some barrier)

Proportion of segment length with barrier on roadside (P_{ob}): 0.40 — Width from edge of shoulder to barrier face (W_{ocb}), ft: 2.0

Analysis Year *(always fill out this section when barrier is present on, or planned for, the segment)*

Input Data — Some barrier present on roadside

Messages — Enter barrier elements below.

Segment length (L), mi: 1 — Outside shoulder width (W_s), ft: 6

Barrier Segment	Location	Length ($L_{ob,off}$), mi		Width from Edge of Traveled Way to Face of Barrier (W_{off}), ft	Ratio ($L_{ob,off}$ / [W_{off} - W_s])
1	MP 0.6 to MP 1.4	0.8	OK	8	0.40
	Sum1:	0.80		Sum2:	0.40

Outside Clearance (some barrier)

Proportion of segment length with barrier on roadside (P_{ob}): 0.40 — Width from edge of shoulder to barrier face (W_{ocb}), ft: 2.0

Exercise 3: Freeway

- **Solution**

Access Data		
Presence of one or more ramp entrances:	No	No
Average ramp entrance length (l_{enr}), ft:		
Proportion of length adjacent to a ramp entrance (P_{enr}):		
Presence of one or more weaving sections:	Yes	Yes
Average weaving section length (l_{wev}), ft:	2376	2376
Proportion of length adjacent to a weaving section (P_{wev}):	0.45	0.45

Ramp entrances
Weaving sections

Exercise 3: Freeway

- **Solution**
  - *Weaving Section worksheet*

Crash Period *(fill out this section only if crash data are available)*

Input Data				*Messages*	
Segment length (L), mi:	1			OK	
Weaving Section	**Location**	**Length of Weaving Section in Segment ($L_{wev,seg}$), mi**	**Length of Weaving Section (L_{wev}), mi**		**Ratio ($L_{wev,seg}/L_{wev}$)**
1	MP 10.2 to MP 10.7	0.5	0.5	OK	1.00
2	MP 10.3 to MP 10.7	0.4	0.4	OK	1.00
	Sum1:	0.90		**Sum2:**	2.00
Proportion of segment length adjacent to a weaving section (P_{wev}):		0.45	Average weaving section length (l_{wev}), ft:		2376

Analysis Year *(always fill out this section when weaving sections are present on, or planned for, the segment)*

Input Data				*Messages*	
Segment length (L), mi:	1			OK	
Weaving Section	**Location**	**Length of Weaving Section in Segment ($L_{wev,seg}$), mi**	**Length of Weaving Section (L_{wev}), mi**		**Ratio ($L_{wev,seg}/L_{wev}$)**
1	MP 10.2 to MP 10.7	0.5	0.5	OK	1.00
2	MP 10.3 to MP 10.7	0.4	0.4	OK	1.00
	Sum1:	0.90		**Sum2:**	2.00
Proportion of segment length adjacent to a weaving section (P_{wev}):		0.45	Average weaving section length (l_{wev}), ft:		2376

Exercise 3: Freeway

Output Summary

Expected injury + fatal crash frequency, crashes/yr:	**7.78**	
Combined AMF ($AMF_{combined}$):	**1.59**	

Accident Modification Factors

	Crash Period	*Analysis Year*
Horizontal curve radius (AMF_{cr}):	1.00	1.00
Grade (AMF_g):	1.00	1.00
Truck presence (AMF_{tk}):	1.11	1.11
Combined AMF (product of all AMFs above) ($AMF_{combined}$):	1.59	1.59

Expected Crash Frequency

	Crash Period	Analysis Year	a	b	c	a	b	c
Calibration factor (f):	1.00	1.00						
Multiple-Vehicle Crash Analysis								
Over-dispersion parameter (k):	4.4							
Base crash frequency (C_b), crashes/yr:	3.26	3.51	0.00352					0.001
Expected crash frequency (C), crashes/yr:	5.17	5.56						
Crash data time period (y), yr:	3.00							
Weight associated with C (w):	0.22							
Adjusted crash frequency given X (C_X):	4.52							
Expected crash frequency (C_{mv}), crashes/yr:	4.52	4.86						
Total expected crash frequency, crashes/yr:	7.34	7.78						

C_b x $AMF_{combined}$

Weighted average C_{mv}

$C_{mv} + C_{sv} + C_{enr} + C_{exr}$

Exercise 3: Freeway

- **Additional Question**
  - ***What is the crash frequency if the cross section is changed?***
    - **Lane width: 12 ft**
    - **Outside shoulder width: 10 ft**
    - **Outside barrier offset: 12 ft**
    - **Horizontal clearance: 19 ft**
  - ***Hint: change only the "Analysis Year" data***
- **Now it's your turn. . .**
  - ***Exit sheet without saving, and then re-load it***

Exercise 4: Freeway

- **Given**
  - Crashes:
    - 4/1/2003 to 3/31/2006
    - 5 mv, 10 sv, 1 ent. ramp
  - Lanes: 4
  - Area type: Rural
  - Length: 2.1 mi
  - 2 entrances and 2 exits
  - Speed limit: 60 mph
  - Percent trucks: 20
  - Volume, veh/d:
    - Crash period: 27,000
    - Analysis year: 29,000
  - No curve or grade
  - Lane width: 12 ft
  - Out. shoulder width: 10 ft
  - In. shoulder width: 4 ft
  - Median width: 40 ft
  - No median barrier
  - No rumble strips
  - Horiz. clearance: 20 ft
  - No roadside barrier
  - Two ramp entrances:
    - 0.2 mi and 0.3 mi, entire length on segment
  - No weaving sections
- **Question**
  - *What is the expected crash frequency?*

Exercise 4: Freeway

- **Solution**

Exercise 4: Freeway

- **Solution**

Exercise 4: Freeway

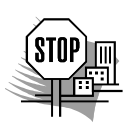
- **Answer**

- **Question**
  - *What is the expected crash frequency if six 0.06-mi lengths of barrier are installed along the roadside (three lengths per side)?*
    - Width from traveled way to face of barrier: 12 ft
  - *Hint: use the Analysis Year column and the Outside Barrier worksheet*

Exercise 4: Freeway

- **Answer**

Questions – Comments?



5. Interchange Ramps

- Overview
  - *Safety prediction model*
  - *Exercises*

Safety Prediction Model

- Components
  - *Base models*
    - $C_{b,r}$ = base rate × ramp volume
  - *No accident modification factors*

Ramp Types

- Non-Frontage Road Ramps

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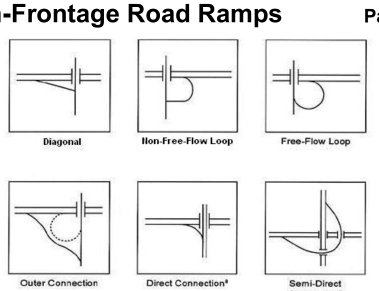

a – when used in directional interchanges

Ramp Types

- **Frontage Road Ramps**

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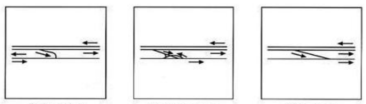

Base Model

- **Ramp Proper**
  - ***Base crash rate***
    - **Ramp type**
    - **Ramp configuration**
  - ***Crash definition***
    - **Injury (plus fatal) crashes**
    - **All crash types**
  - ***Observations***
    - **Higher rates for exit ramps**
    - **Free-flow loops have low rates**

Interchange Setting	Ramp Type	Ramp Configuration	Base Crash Rate, cr/mv [1]
Non-frontage road	Exit	Diagonal	0.28
		Non-free-flow loop	0.51
		Free-flow loop	0.20
		Outer connection	0.33
		Semi-direct conn.	0.25
		Direct connection	0.21
	Entrance	Diagonal	0.17
		Non-free-flow loop	0.31
		Free-flow loop	0.12
		Outer connection	0.20
		Semi-direct conn.	0.15
		Direct connection	0.13
Frontage road	Exit	Button hook	0.57
		Scissor	0.48
		Slip	0.36
	Entrance	Button hook	0.28
		Scissor	0.21
		Slip	0.23

Note:
1 - cr/mv: injury (plus fatal) crashes per million vehicles.

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Exercise 5: Ramp

- **Given**
  - ***Freeway ramp***
    - **Volume: 2500 veh/d**
    - **Type: Entrance**
    - **Configuration: Slip**
- **Question**
  - ***What is the expected crash frequency?***

Exercise 5: Ramp

Input Data	
Traffic Data	
Average daily traffic volume on ramp (*ADT*), veh/d:	2,500 ← **Volume**
Geometric Data	
Ramp type: **Type** →	Entrance
Ramp configuration:	Slip ← **Configuration**

Exercise 5: Ramp

Output Summary	
Expected injury + fatal crash frequency, crashes/yr:	**0.21**

Expected Crash Frequency	*Analysis Year*
Base crash rate (*Base*), crashes/mv:	0.23
Calibration factor (*f*):	1.00
Base crash frequency (C_b), crashes/yr:	0.21
Expected crash frequency (*C*), crashes/yr:	0.21

Crash frequency (points to the two outlined cells: 0.21 crashes/yr expected injury + fatal crash frequency and 0.21 crashes/yr expected crash frequency)

Exercise 5: Ramp

- **Additional Question**
  - ***What is the crash frequency for an exit ramp with similar conditions?***
    - **Ramp type: Exit**
    - **All other data are unchanged**
- **Now it's your turn. . .**

Exercise 6: Ramp

- **Given**
  - *Highway ramp*
    - Volume: 2500 veh/d
    - Type: Exit
    - Configuration: Diagonal
- **Question**
  - *What is the expected crash frequency?*

Exercise 6: Ramp

- **Answer**

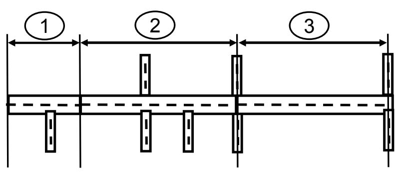
Exercise 6: Ramp

- **Additional Questions**
  - *What is the crash frequency for an entrance ramp with similar conditions?*
    - Ramp type: Entrance
    - All other data are unchanged
  - *What is the crash frequency of the entrance ramp if it is reconfigured?*
    - Ramp type: Entrance
    - Ramp configuration: Non-free-flow loop
    - All other data are unchanged

Questions – Comments?

6. Section Evaluation

- Review Safety Prediction Procedure
- Road Section Evaluation
- Project Evaluation

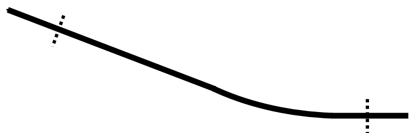


Safety Prediction Procedure

- **Six Steps**
  1. *Identify roadway section*
  2. *Divide section into facility components*
  3. *Gather data for subject component*
  4. *Compute expected crash frequency*
  5. *Repeat steps 3 and 4 for each additional component*
  6. *Add up results for roadway section*

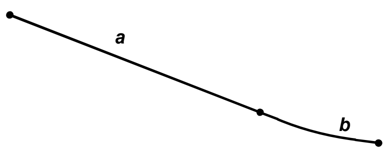
Exercise 7: Section Evaluation

- **Given**
  - *Four-lane rural highway*
  - *Input data to follow*
- **Question**
  - *What is the expected crash frequency for the highway?*



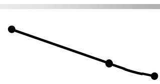
Exercise 7: Section Evaluation

- **Procedure**
  - *Split highway into homogeneous segments*



  - *Analyze each segment separately*
  - *Total up crash frequencies for section*

Exercise 7: Section Evaluation



- **Given**
  - *Highway segment "a"*
    - No crash data
    - Length: 1.36 mi
    - Driveways: 5 bus.
    - Speed limit: 60 mph
    - Percent trucks: 13
    - Volume: 4000 veh/d
    - No curve or grade
    - Lane width: 12 ft
    - Out. shoulder width: 8 ft
    - In. shoulder width: n.a.
    - Median:
      - Nonrestrictive
      - Width: 14 ft
      - No barrier
    - Horiz. clearance: 30 ft
    - No roadside barrier
    - Side slope: 1:4
- **Question**
  - *What is the expected crash frequency?*

Exercise 7: Section Evaluation

- **Answers**
  - ***Segment "a"***

Exercise 7: Section Evaluation

- **Given**
  - ***Highway segment "b"***

- **No crash data**
- **Length: 0.34 mi**
- **Driveways: 1 ind, 1 bus**
- **Speed limit: 60 mph**
- **Percent trucks: 13**
- **Volume: 4000 veh/d**
- **Curve radius: 1430 ft**
- **Curve length: 0.16 mi**
- **No grade**
- **Lane width: 12 ft**
- **Out. shoulder width: 8 ft**
- **Median:**
  - **Nonrestrictive**
  - **Width: 14 ft**
  - **No barrier**
- **Horiz. clearance: 30 ft**
- **No roadside barrier**
- **Side slope: 1:4**

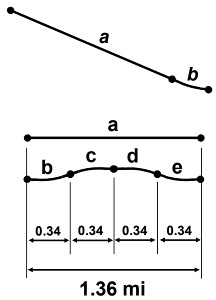
- **Question**
  - ***What is the expected crash frequency?***

Exercise 7: Section Evaluation

- **Answers**
  - ***Segment "b"***
  - ***Entire highway section***

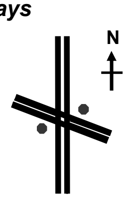
Exercise 7: Section Evaluation

- **Observations**



Exercise 8: Project Evaluation

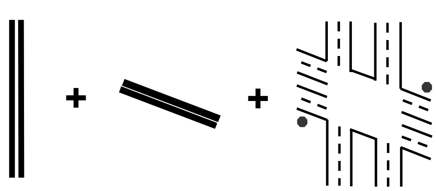
- **Given**
  - *Two intersecting rural highways*
    - North/south highway
      - 4-lane depressed median
      - 2-mi segment
    - East/west highway
      - 4-lane TWLTL
      - 1.36-mi segment
    - Intersection
      - Stop controlled



- **Question**
  - *What is the expected crash frequency?*

Exercise 8: Project Evaluation

- **Procedure**
  - *Split facility into components*
    - North/south road
    - East/west road
    - Intersection (discussed in previous workshop)



Exercise 8: Project Evaluation

- Procedure
  - *Analyze each component separately*
    - Crash frequency
    - Combined AMF
  - *Total up crash frequencies for facility*

Exercise 8: Project Evaluation

- Answers
  - *North/south road (Ex. 2-a)*
  - *East/west road (Ex. 7 "a")*
  - *Intersection (given)*
  - *Entire facility*

Exercise 8: Project Evaluation

- Additional Questions
  - *What is the best measure of safety benefit?*
  - *Which facility component(s) may yield the most benefit through design change?*
- Answers
  - *Expected number of crashes reduced is the best measure of safety benefit*
  - *Segments or intersections with many crashes have more potential for a large safety benefit through a design change, so. . .*

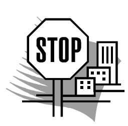
Exercise 8: Project Evaluation

- **Additional Questions**
  - *What does the combined AMF tell us?*
  - *What does it mean when the combined AMF is greater than 1.0?*
- **Answers**
  - *The combined AMF tells us about "relative risk"*
  - *Values larger than 1.0 indicate the component is potentially less safe than the "typical" one*
  - *So. . .*

Exercise 8: Project Evaluation

- **Additional Question**
  - *How do we use both crash frequency and combined AMF to make design decisions?*
- **Answer**
  1) *Identify components that have a combined AMF > 1.0*
  2) *Rank them in order of crash frequency*
  3) *Identify potential design changes at those components with a larger crash frequency*

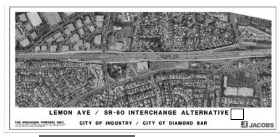
Questions – Comments?



7. Alternatives Analysis

- **Analysis Questions**
  - ***How do you incorporate safety considerations in the design process?***
  - ***Which alternative is the best?***

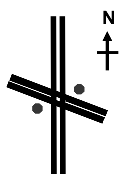
Alternative 1



Alternative 2

Exercise 9: Alternatives Analysis

- **Current Design**
  - ***Two intersecting rural highways***
    - **North/south highway**
      - **4-lane restrictive median**
    - **East/west highway**
      - **4-lane TWLTL**
    - **Intersection**
      - **Stop controlled**
      - **25-degree skew angle**
  - ***From Exercise 8***



Exercise 9: Alternatives Analysis

- **Analysis Process**

  1) Identify components that have a combined AMF > 1.0

  2) Rank them in order of crash frequency

  3) Identify potential design changes at those components with a larger crash frequency

Exercise 9a: Alternatives Analysis

- **Alternative A**
  - *Treatment*
    - Increase shoulder width for north/south road
  - *Repeat the analysis for Exercise 2, but:*
    - Outside shoulder: increase from 6 to 10 ft
    - Inside shoulder: increase from 2 to 4 ft
    - Side slope: increase from 1:6 to 1:4

Exercise 9a: Alternatives Analysis

- **Question**
  - *Is this alternative safer than the current configuration?*
- **Answer**
  - *Expected crash frequencies:*
    - North/south road (Ex. 2-b):
    - East/west road (Ex. 7 "a"):
    - Intersection:
    - Facility:

Exercise 9a: Alternatives Analysis

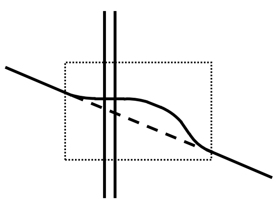
- **Question**
  - *Given*
    - $750,000 construction cost
    - 25-year life span
    - $100,000 benefit per crash prevented
  - *Is this alternative viable?*
- **Answer**

Exercise 9a: Alternatives Analysis

- Discussion
  - *Requires increase in side slope*
  - *Increase in shoulder width likely to provide offsetting benefit*

Exercise 9b: Alternatives Analysis

- Alternative B
  - *Treatment*
    - Realign east/west road to eliminate skew
    - Requires addition of four curves
    - Crash estimates from Exercises 2 and 7



Exercise 9b: Alternatives Analysis

- Question
  - *Is this alternative safer than the current configuration?*
- Answer
  - *Expected crash frequencies:*
    - North/south road (Ex. 2-a):
    - East/west road (Ex. 7 “b”+…+ “e”):
    - Intersection:
    - Facility:

Exercise 9b: Alternatives Analysis

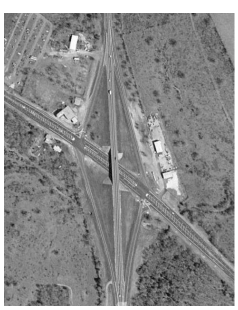
- **Question**
  - *Given*
    - $1,800,000 construction cost
    - 25-year life span
    - $100,000 benefit per crash prevented
  - *Is this alternative viable?*
- **Answer**

Exercise 9b: Alternatives Analysis

- **Discussion**
  - *Requires some right-of-way acquisition*
  - *Addition of curves increases crashes*
    - +0.15 crashes/yr (= 0.56 – 0.41)
  - *Eliminating skew reduces crashes*
    - -1.36 crashes/yr (= 3.32 – 1.96)
  - *Observations*
    - If the intersection were signalized, skew would not pose a safety problem
    - Signal warrants are not satisfied

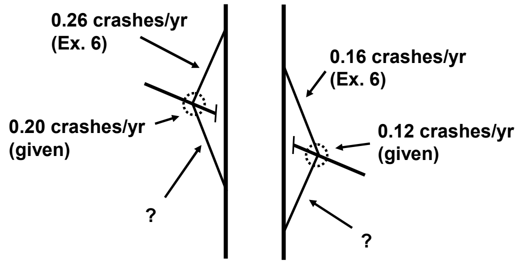
Exercise 9c: Alternatives Analysis

- **Alternative C**
  - *Treatment*
    - Convert to diamond interchange
    - Both ramp terminals are two-way stop controlled



Exercise 9c: Alternatives Analysis

- Analysis



Exercise 9c: Alternatives Analysis

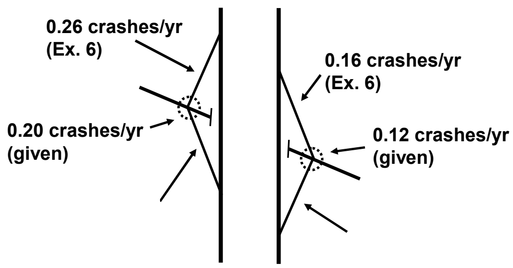
- Analysis
  - *Northbound exit ramp*
    - Volume: 1000 veh/d
    - Type: Exit
    - Configuration: Diagonal
- Question
  - *What is the expected crash frequency?*
- Answer

Exercise 9c: Alternatives Analysis

- Analysis
  - *Southbound entrance ramp*
    - Volume: 1000 veh/d
    - Type: Entrance
    - Configuration: Diagonal
- Question
  - *What is the expected crash frequency?*
- Answer

Exercise 9c: Alternatives Analysis

- **Analysis**



Exercise 9c: Alternatives Analysis

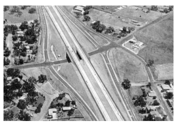
- **Question**
  - ***Is this alternative safer than the current configuration?***
- **Answer**
  - ***Expected crash frequencies:***
    - **North/south road (Ex. 2-a):**
    - **East/west road (Ex. 7 "a"):**
    - **Ramps + terminals:**
    - **Facility:**

Exercise 9c: Alternatives Analysis

- **Question**
  - ***Given***
    - **$6,500,000 construction cost**
    - **25-year life span**
    - **$100,000 benefit per crash prevented**
  - ***Is this alternative viable?***
- **Answer**

Exercise 9c: Alternatives Analysis

- Discussion
  - *Operational benefits (not computed) may still justify the project*
  - *Analysis does not consider rate of traffic growth over time at this location*



Exercise 9c: Alternatives Analysis

Finding	Current	Alt. A	Alt. B	Alt. C
Construction Cost, $1000				
Safety benefit, $1000/yr				
Capital cost, $1000/yr				
Benefit-cost ratio				
Net benefit, $1000/yr				

- Questions
  - *Which alternative is best based on safety benefit and cost?*
  - *What does the larger net benefit for Alt. B tell us?*

Exercise 9: Alternatives Analysis

- Alternative Selection Summary
  - *Establish a goal of reducing total crash frequency by some amount*
  - *Exclude projects that do not provide minimum benefit*
  - *Exclude projects that exceed available funds*
  - *If funds are earmarked for this project:*
    - Use net benefit to select project
  - *If unspent funds can be used for other projects:*
    - Use benefit-cost ratio to select projects

Exercise 9: Alternatives Analysis

- Observations
  - *Our computations reflect only safety impact*
    - Different conclusions may be reached if other impacts are considered
  - *Final decision must consider all impacts*
    - Safety
    - Environment
    - Traffic operations
    - Right-of-way
    - Construction costs
  - *Choose the most cost-effective alternative*

Questions – Comments?

Summary

- Main Points
  1. *Large variability in crash data makes it difficult to observe a change in crash frequency due to change in geometry at one site*
  2. *Statistical evaluation of many crashes at many treated sites is needed to quantify true effect of a change*
  3. *Adherence to design controls does not ensure safety*
  4. *Many geometric design elements influence safety*
  5. *Evaluation should focus on key design elements*
  6. *Evaluation is most helpful in complex or atypical situations*
  7. *Engineer should weigh all impacts when deciding*

Wrap-Up

- **Questions or Comments?**
- **A Request**
  - ***Please fill out the course review form***
  - ***Training course coordinators***
    - **Return course evaluations and sign-in sheets to Rory Meza in Design Division**
- **Thank You!**

SAFETY BY DESIGN

EXERCISES

1. RURAL MULTILANE HIGHWAY SEGMENT
2. RURAL MULTILANE HIGHWAY SEGMENT
3. FREEWAY SEGMENT
4. FREEWAY SEGMENT
5. INTERCHANGE RAMP
6. INTERCHANGE RAMP
7. SECTION EVALUATION
8. PROJECT EVALUATION
9a. ALTERNATIVE A
9b. ALTERNATIVE B
9c. ALTERNATIVE C

EXERCISE 1: RURAL MULTILANE HIGHWAY SEGMENT

INPUT DATA

Basic Roadway Data
- Number of through lanes: 4
- Segment length: 2 mi
- Number of driveways: 2 residential, 4 business

Traffic Data
- Speed limit: 60 mph
- Percent trucks represented in ADT: 10 percent
- Average daily traffic (ADT): 22,000 veh/d

Geometric Data
- Presence of horizontal curve: No
- Grade: 0 percent

Cross Section Data
- Lane width: 11 ft
- Outside shoulder width: 8 ft
- Median type: Nonrestrictive
- Median width: 16 ft
- Presence of barrier in median: None

Roadside Data
- Horizontal clearance: 30 ft
- Presence of barrier on roadside: None
- Side slope: 1:6

OUTPUT SUMMARY

What is the expected crash frequency? ………………………………………….. [ ]

What is the combined AMF? …………………………………………………. [ ]

What does the combined AMF say about this segment, relative to the typical segment? _______

____

Which attribute(s) tend to increase the crash rate of this segment, relative to the typical segment?

____

If the following injury + fatal crashes were reported from 1/1/1999 to 12/31/2001:
- Multiple-vehicle: 11
- Single-vehicle: 6
- Driveway: 1

What is the expected crash frequency? ………………………………………….. [ ]

If the ADT increases to 25,000 veh/d, what is the expected crash frequency? ..... [ ]

EXERCISE 2: RURAL MULTILANE HIGHWAY SEGMENT

INPUT DATA

Basic Roadway Data
- Number of through lanes: 4
- Segment length: 2 mi
- Number of driveways: 4 residential

Traffic Data
- Speed limit: 60 mph
- Percent trucks represented in ADT: 15 percent
- Average daily traffic (ADT): 17,000 veh/d

Geometric Data
- Presence of horizontal curve: No
- Grade: 1 percent

Cross Section Data
- Lane width: 12 ft
- Outside shoulder width: 6 ft
- Inside shoulder width: 2 ft
- Median type: Restrictive
- Median width: 20 ft
- Presence of barrier in median: Full
  - In center of median
  - Inside barrier width: 2.5 ft
  - No short barrier elements present

Roadside Data
- Horizontal clearance: 30 ft
- Presence of barrier on roadside: None
- Side slope: 1:6

OUTPUT SUMMARY

What is the expected crash frequency? …………………………………………….. [ ]

What is the combined AMF? ……………………………………………………. [ ]

If the shoulders are widened to:
- Outside shoulder width: 10 ft
- Inside shoulder width: 4 ft
- Side slope: 1:4

What is the expected crash frequency? …………………………………………….. [ ]

What is the combined AMF? ……………………………………………………. [ ]

EXERCISE 3: FREEWAY SEGMENT

INPUT DATA

Crash Data

Time period: 1/1/1999 to 12/31/2001

Count of injury + fatal crashes:

- 13 multiple-vehicle
- 6 single-vehicle
- 1 ramp-exit-related

Basic Roadway Data

Number of through lanes: 6

Area type: Urban

Segment length: 1 mi

Number of ramp entrances: 2

Number of ramp exits: 2

Traffic Data

Speed limit: 60 mph

Percent trucks represented in ADT: 10 percent

Average daily traffic: 82,000 veh/d (crash period); 86,000 veh/d (analysis year)

Geometric Data

Presence of horizontal curve: No

Grade: 0 percent

Cross Section Data

Lane width: 11 ft

Outside shoulder width: 6 ft

Inside shoulder width: 4 ft

Median type: Nonrestrictive

Presence of barrier in median: None

Median width: 50 ft

Presence of shoulder rumble strips: Yes

Roadside Data

Horizontal clearance: 15 ft

Presence of barrier on roadside: Some

- Length = 0.8 mi, offset = 8 ft

Access Data

Presence of one or more ramp entrances: No

Presence of one or more weaving sections: Yes

- Weaving section 1: length = 0.5 mi, entire length on segment
- Weaving section 2: length = 0.4 mi, entire length on segment

OUTPUT SUMMARY

What is the expected crash frequency? …………………………………………..	
What is the combined AMF? …………………………………………………….	

If the cross section is changed to:

- Lane width: 12 ft
- Outside shoulder width: 10 ft
- Outside barrier offset: 12 ft
- Horizontal clearance: 19 ft

What is the expected crash frequency? …………………………………………..	
What is the combined AMF? …………………………………………………….	

EXERCISE 4: FREEWAY SEGMENT

INPUT DATA

Crash Data

Time period: 4/1/2003 to 3/31/2006

Count of injury + fatal crashes:

- 5 multiple-vehicle
- 10 single-vehicle
- 1 ramp-entrance-related

Basic Roadway Data

Number of through lanes: 4

Area type: Rural

Segment length: 2.1 mi

Number of ramp entrances: 2

Number of ramp exits: 2

Traffic Data

Speed limit: 60 mph

Percent trucks represented in ADT: 20 percent

Average daily traffic: 27,000 veh/d (crash period); 29,000 veh/d (analysis year)

Geometric Data

Presence of horizontal curve: No

Grade: 0 percent

Cross Section Data

Lane width: 12 ft

Outside shoulder width: 10 ft

Inside shoulder width: 4 ft

Median type: Nonrestrictive

Presence of barrier in median: None

Median width: 40 ft

Presence of shoulder rumble strips: No

Roadside Data

Horizontal clearance: 20 ft

Presence of barrier on roadside: None

Access Data

Presence of one or more ramp entrances: Yes

- Ramp entrance 1: length = 0.2 mi, entire length on segment
- Ramp entrance 2: length = 0.3 mi, entire length on segment

Presence of one or more weaving sections: No

OUTPUT SUMMARY

What is the expected crash frequency? …………………………………………..

What is the combined AMF? …………………………………………………….

If the following roadside barrier pieces are added:
Six identical pieces (three pieces per side)
Length: 0.06 mi
Width from traveled way to face of barrier: 12 ft

What is the expected crash frequency? …………………………………………..

What is the combined AMF? …………………………………………………….

EXERCISE 5: INTERCHANGE RAMP

INPUT DATA

Traffic Data

Average daily traffic on ramp: 2500 veh/d

Geometric Data

Ramp type: Entrance

Ramp configuration: Slip

OUTPUT SUMMARY

What is the expected crash frequency? ………………………………………….. [ ]

For an exit ramp with similar conditions:

Ramp type: Exit

All other input data are unchanged

What is the expected crash frequency? ………………………………………….. [ ]

EXERCISE 6: INTERCHANGE RAMP

INPUT DATA

Traffic Data

Average daily traffic on ramp: 2500 veh/d

Geometric Data

Ramp type: Exit

Ramp configuration: Diagonal

OUTPUT SUMMARY

What is the expected crash frequency? ………………………………………….. [ ]

For an entrance ramp with similar conditions:

Ramp type: Entrance

All other input data are unchanged

What is the expected crash frequency? ………………………………………….. [ ]

If the entrance ramp is reconfigured:

Ramp configuration: Non-free-flow loop

All other input data are unchanged

What is the expected crash frequency? ………………………………………….. [ ]

EXERCISE 7: SECTION EVALUATION

Location: Rural multilane highway segment "a"

INPUT DATA

Basic Roadway Data
Number of through lanes: 4
Segment length: 1.36 mi
Number of driveways: 5 business

Traffic Data
Speed limit: 60 mph
Percent trucks represented in ADT: 13 percent
Average daily traffic (ADT): 4000 veh/d

Geometric Data
Presence of horizontal curve: No
Grade: 0 percent

Cross Section Data
Lane width: 12 ft
Outside shoulder width: 8 ft
Median type: Nonrestrictive
Median width: 14 ft
Presence of barrier in median: None

Roadside Data
Horizontal clearance: 30 ft
Presence of barrier on roadside: None
Side slope: 1:4

OUTPUT SUMMARY

Record your results in the table on the next page.

EXERCISE 7: SECTION EVALUATION (continued)

Location: Rural multilane highway segment "b"

INPUT DATA

Basic Roadway Data
- Number of through lanes: 4
- Segment length: 0.34 mi
- Number of driveways: 1 industrial, 1 business

Traffic Data
- Speed limit: 60 mph
- Percent trucks represented in ADT: 13 percent
- Average daily traffic (ADT): 4000 veh/d

Geometric Data
- Presence of horizontal curve: Yes
  - Curve radius: 1430 ft
  - Curve length: 0.16 mi
- Grade: 0 percent

Cross Section Data
- Lane width: 12 ft
- Outside shoulder width: 8 ft
- Median type: Nonrestrictive
- Median width: 14 ft
- Presence of barrier in median: None

Roadside Data
- Horizontal clearance: 30 ft
- Presence of barrier on roadside: None
- Side slope: 1:4

OUTPUT SUMMARY

Record all results for segments "a" and "b" in this table.

Facility Component	Expected Crash Frequency (crashes/yr)	Combined AMF
Segment "a"		
Segment "b"		
Total for roadway section		

What is the expected crash frequency for segments "b" through "e"?…………….. [ ]

EXERCISE 8: PROJECT EVALUATION (CURRENT CONFIGURATION)

Location: Two intersecting rural multilane highways

Please complete the table and answer the questions below.

Facility Component	Exercise Number	Expected Crash Frequency (crashes/yr)	Combined AMF
North-south road	2-a (before change)		
East-west road	7 “a”		
Intersection	Given	3.32	1.12
Total for facility			

What is the best measure of safety benefit? ______________________________

Which facility component(s) may yield the most benefit through design change? ____________

____

What does the combined AMF tell us? ______________________________

____

What does it mean when the combined AMF is greater than 1.0? __________________

____

How do we use both crash frequency and combined AMF to make design decisions? _________

____

____

____

EXERCISE 9a: ALTERNATIVE A

Description: Widen the inside and outside shoulders on the north-south road. To provide the increased width while remaining within the right-of-way, it is necessary to reduce the side slope.

Please complete the table and answer the questions below.

Facility Component	Exercise Number	Expected Crash Frequency (crashes/yr)	Combined AMF
North-south road	2-b (after change)		
East-west road	7 “a”		
Intersection	Given	2.95	1.05
Total for facility			

Is this alternative safer than the current configuration (see Exercise 8)? ____________________

How many crashes are reduced per year, relative to the current configuration? ______________

Given the following assumptions:

$750,000 construction cost to widen the shoulders on the north-south road
25-year life span for the project
$100,000 benefit per crash reduced

Benefit: [ ] crashes/yr reduced x $100,000/crash reduced = $ [ ] / yr

Cost: $ [ ] construction cost ÷ [ ] yr life span = $ [ ] / yr

Is this alternative viable? ____

What is the net benefit for Alternative A, relative to the current configuration? ______________

EXERCISE 9b: ALTERNATIVE B

Description: Realign the east-west road to eliminate the intersection skew. The realignment requires the addition of two curves on the east-west road.

Please complete the table and answer the questions below.

Facility Component	Exercise Number	Expected Crash Frequency (crashes/yr)	Combined AMF
North-south road	2-a (before change)		
East-west road	7 "b" through "e"		
Intersection	Given	1.96	0.72
Total for facility			

Is this alternative safer than the current configuration (see Exercise 8)? ____________________

How many crashes are reduced per year, relative to the current configuration? ______________

Given the following assumptions:

- $1,800,000 construction cost to realign the east-west road
- 25-year life span for the project
- $100,000 benefit per crash reduced

Benefit: [ ] crashes/yr reduced x $100,000/crash reduced = $ [ ] / yr

Cost: $ [ ] construction cost ÷ [ ] yr life span = $ [ ] / yr

Is this alternative viable? ____

What is the net benefit for Alternative B, relative to the current configuration? ______________

EXERCISE 9c: ALTERNATIVE C

Description: Grade-separate the roads. Use a diamond interchange with four diagonal ramps.

INPUT DATA

Traffic Data

Average daily traffic on ramp: 1000 veh/d

Geometric Data

Ramp type: Exit

Ramp configuration: Diagonal

OUTPUT SUMMARY

What is the expected crash frequency? ………………………………………….. [ ]

For an entrance ramp with similar conditions:

Ramp type: Entrance

All other input data are unchanged

What is the expected crash frequency? ………………………………………….. [ ]

EXERCISE 9c: ALTERNATIVE C (continued)

Description: Grade-separate the roads. Use a diamond interchange with four diagonal ramps.

Please complete the table and answer the questions below.

Interchange Component	Exercise Number	Expected Crash Frequency (crashes/yr)	Combined AMF
Western ramp terminal	Given	0.20	0.40
Eastern ramp terminal	Given	0.12	0.40
Southbound exit	6-a		
Northbound entrance	6-b		
Northbound exit	9c		
Southbound entrance	9c		
Total for interchange			

Facility Component	Exercise Number	Expected Crash Frequency (crashes/yr)	Combined AMF
North-south road	2-a (before change)		
East-west road	7 "a"		
Total for interchange	from table above		
Total for facility			

Is this alternative safer than the current configuration (see Exercise 8)? ____________________

How many crashes are reduced per year, relative to the current configuration? ______________

Given the following assumptions:

- $6,500,000 construction cost to grade-separate the roads
- 25-year life span for the project
- $100,000 benefit per crash reduced

Benefit: [ ] crashes/yr reduced x $100,000/crash reduced = $ [ ] / yr

Cost: $ [ ] construction cost ÷ [ ] yr life span = $ [ ] / yr

Is this alternative viable? ____

What is the net benefit for Alternative C, relative to the current configuration? ______________

INCORPORATING SAFETY INTO THE HIGHWAY DESIGN PROCESS: MULTILANE HIGHWAYS AND FREEWAYS WORKSHOP

COURSE REVIEW FORM

Date:
Location:

Your Agency:____

Your Position:____

Course Content (circle one)

		Yes				No
1.	Did the course meet your expectations? Comments: ______________________________ ______________________________	1	2	3	4	5
2.	Was the material presented at the correct level of difficulty? Comments: ______________________________ ______________________________	1	2	3	4	5
3.	Was the topic of the course covered adequately (nothing left out, no one topic overemphasized)? Comments: ______________________________ ______________________________	1	2	3	4	5
4.	Was the software easy to use? Comments: ______________________________ ______________________________	1	2	3	4	5

General Observations

5. What did you like most about the course?

6. What did you like least about the course?

7. What can we do to improve this workshop?

8. Other Comments:

Thank you for taking the time to complete this course evaluation form. Please make sure the course instructor receives it before you leave.