Roadway Safety Design
An Engineer’s Guide to Evaluating the Safety of Design Alternatives

Course Notes
Product 5-4703-01-P3

Multilane Highways and Freeways Workshop
July 2009
Published: February 2010
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

Welcome

• Introductory Session
  – Objectives, outcomes, scope, main points
  – Background
  – Agenda

• Instructors
  – Jim Bonneson
  – Mike Pratt

• Researchers with TTI
• College Station

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”

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
- 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

- 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, \( C = C_0 \times AMF_{lw} \times AMF_{sw} \ldots \)

- **Model Components**
  - Base model, \( C_0 \)
  - 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

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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

• 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)

- 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

<table>
<thead>
<tr>
<th>Blue cells: input data</th>
<th>White &amp; gray cells: protected</th>
<th>Notes provide info.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Messages and range checks for input data</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

15
## Input Data

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

### Close-Up View

<table>
<thead>
<tr>
<th>Geometric Data</th>
<th>Presence of horizontal curve</th>
<th>0.0</th>
<th>20.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Curve radius (ft)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Curve length (ft)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Percent grade (%)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

## Calculations

### Individual AMFs
- Roadway curvature (AMP<sub>cur</sub>)
- Grade (AMP<sub>grd</sub>)
- fascle curvature (no barrier) (AMP<sub>cur</sub>)
- fascle curvature (full barrier) (AMP<sub>cur</sub>)
- Side hills (AMP<sub>shl</sub>)
- Lane width (AMP<sub>lw</sub>)
- Curbside shoulder width (AMP<sub>sw</sub>)
- Med save w/b (AMP<sub>ms</sub>)
- Med save w/o (AMP<sub>ms</sub>)

### Combined AMF

<table>
<thead>
<tr>
<th>Combined AMF</th>
<th>Analyzed Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined AMF</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Calculations

Calibration factor

Crash analysis

Crash frequency

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

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

<table>
<thead>
<tr>
<th>Analysis Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types 1 and 2</td>
</tr>
<tr>
<td>- Type 1 – No Crash Data</td>
</tr>
<tr>
<td>- Provide geometry and traffic for analysis year</td>
</tr>
<tr>
<td>- Type 2 – With Crash Data</td>
</tr>
<tr>
<td>- Provide geometry and traffic for both analysis year and crash period</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRSD Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Analysis year</td>
</tr>
<tr>
<td>- Year for which expected crash frequency estimate is desired</td>
</tr>
<tr>
<td>- Crash period</td>
</tr>
<tr>
<td>- Time period representing crash data</td>
</tr>
</tbody>
</table>

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 and crash data
    • Use EB analysis to get weighted average of both

<table>
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<td>- Type 2 – With Crash Data</td>
</tr>
<tr>
<td>- Provide geometry and traffic for both analysis year and crash period</td>
</tr>
</tbody>
</table>
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)

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

$$C = C_b \times AMF_i \times AMF_g$$

(3-15)

where:
- $C$ = expected injury (plus fatal) crash frequency, crashes/yr;
- $C_b$ = base injury (plus fatal) crash frequency, crashes/yr;
- $AMF_i$ = 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

——
### Base Model

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

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Base Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural Highways — Two or Four Lanes</td>
<td></td>
</tr>
<tr>
<td>Horizontal curve radius</td>
<td>tangent (6 in lanes)</td>
</tr>
<tr>
<td>Grade</td>
<td>flat (0% grade)</td>
</tr>
<tr>
<td>Lanes width</td>
<td>12 ft</td>
</tr>
<tr>
<td>Outside shoulder width</td>
<td>8 ft</td>
</tr>
<tr>
<td>Presence or absence barrier</td>
<td>not present</td>
</tr>
<tr>
<td>Median resistance</td>
<td>50 ft</td>
</tr>
<tr>
<td>Side slope</td>
<td>1% max</td>
</tr>
<tr>
<td>Rural Highways — Four Lanes</td>
<td></td>
</tr>
<tr>
<td>Inside shoulder width</td>
<td>4 ft</td>
</tr>
<tr>
<td>Median width</td>
<td>5 ft for non-protective median, 7.5 ft for protective median</td>
</tr>
<tr>
<td>Truck presence</td>
<td>10% trucks</td>
</tr>
</tbody>
</table>

**Notes:**
1. Applies to highways with a restrictor median.
2. Non-protective median: This T1 is for a barrier on the side of the highway, but no barrier on the inside.

### 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)

- **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_{ocb})?
  – 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
    | Segment length (0.75 mi) | Crash Period (if crash data available) | Analysis Year (always fill out) |
|-------------------------|---------------------------------------|---------------------------------|
|                         |                                      |                                 |

W_{ocb}  W_{off}
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 (\(L_{b1,1}\)) = 0.05 mi, offset (\(W_{off,1}\)) 13.67 ft
      2. Length (\(L_{b2,1}\)) = 0.02 mi, offset (\(W_{off,2}\)) 4.67 ft
      1. Length (\(L_{b1,2}\)) = 0.02 mi, offset (\(W_{off,3}\)) 4.67 ft
      2. Length (\(L_{b2,2}\)) = 0.05 mi, offset (\(W_{off,4}\)) 13.67 ft
  - **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
  - Assuming that a traffic study is performed, the crash period can be calculated.
  - Use Inside Barrier sheet to compute
    - Crash Period (fill out if crash data available)
    - Analysis Year (always fill out)
Example

Given
- In. shoulder width: 4 ft
- Median width: 40 ft

Find:
- \( AMF_{\text{mswb}} = 1.11 \)

- 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/day
  - No curvature
  - Grade: 0%

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

---

<table>
<thead>
<tr>
<th>Basic Roadway Data</th>
<th>Length (L, mi)</th>
<th>Driveways</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic Data</th>
<th>Speed limit (V, mph)</th>
<th>Volume (V, veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60</td>
<td>22,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Geometric Data</th>
<th>Presence of horizontal curve</th>
<th>Grade (G, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>0</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Cross Section Data</th>
<th>Lane width (Wl, ft)</th>
<th>Shoulder width (Ws, ft)</th>
<th>Median width (Wm, ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Presence of barrier on inside</th>
<th>Width from edge of shoulder to barrier (Wba, ft)</th>
<th>Proportion of segment length with barrier (Pba)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n.a.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Presence of barrier on median | Width from edge of shoulder to barrier (Wmb, ft) | Proportion of segment length with barrier (Pmb) |
| n.a.                         |                                                  |                                               |

<table>
<thead>
<tr>
<th>Roadside barrier</th>
<th>Clearance (C, ft)</th>
<th>Side slope (S, ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

---

31
Exercise 1: Rural Highway

Output

Individual AMFs

Combined AMF

Multiple-vehicle crash analysis (single-vehicle and driveway not shown)

Crash frequency

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?

• 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%

• Question
  – What is the expected crash frequency?

Exercise 2: Rural Highway

• 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

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

\[ C = C_b \times AMF_{i1} \times AMF_{i2} \ldots \]  
Page 2-8

where:
- \( C \) = expected injury (plus fatal) crash frequency, crashes/yr;
- \( C_b \) = base injury (plus fatal) crash frequency, crashes/yr;
- \( AMF_{i1} \) = lane width accident modification factor; and
- \( AMF_{i2} \) = horizontal curve radius accident modification factor.

Base Model

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

![Graph](image)

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, Lenr: 0.15 mi
  - Length of ramp in segment, Lenr,seg: 0.10 mi
- Question
  - What is the ramp entrance AMF?

- Solution
  - Equations on p. 2-22
  - What is the average ramp entrance length (Lenr)?
  - What proportion of the segment is adjacent to a ramp entrance (Penr)?
  - 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
    - 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
  – $AMF_{enr,seg} = 1.05$

– Now it’s your turn…

Example

• Solution
  – 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

• Solution
  – Assume no crash data

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

- **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
- **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

Exercise 3: Freeway

<table>
<thead>
<tr>
<th>Crash data availability</th>
<th>Dates</th>
<th>Reported crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash data for period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of injury and fatal crashes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple or single-vehicle crashes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramp ent. or exit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crash frequency data</th>
<th>Dates</th>
<th>Reported crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of crashes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of injury and fatal crashes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of ramp ent. or exit crashes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Dates</th>
<th>Reported crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (mi/h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent trucks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent single-vehicle crashes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Geometric Data</th>
<th>Dates</th>
<th>Reported crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent left to right</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curve radius (ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent vertical grade</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Exercise 3: Freeway

**Solution**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width</td>
<td>10 ft</td>
</tr>
<tr>
<td>Inside shoulder width</td>
<td>5 ft</td>
</tr>
<tr>
<td>Outside shoulder width</td>
<td>5 ft</td>
</tr>
<tr>
<td>Median width</td>
<td>40 ft</td>
</tr>
<tr>
<td>Presence of barrier in median</td>
<td>Yes</td>
</tr>
<tr>
<td>Presence of rumble strips</td>
<td>Yes</td>
</tr>
<tr>
<td>Presence of shoulder barrier</td>
<td>Yes</td>
</tr>
<tr>
<td>Clearance</td>
<td>30 ft</td>
</tr>
</tbody>
</table>

**Outside Barrier worksheet**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp entrances</td>
<td>No</td>
</tr>
<tr>
<td>Average ramp entrance length (Lr)</td>
<td>200 ft</td>
</tr>
<tr>
<td>Proportion length to ramp entrance (Lr)</td>
<td>0.5</td>
</tr>
<tr>
<td>Average weaving section length (Lw)</td>
<td>200 ft</td>
</tr>
<tr>
<td>Proportion length to weaving section (Lw)</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Roadside barrier clearance**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal clearance (Hc)</td>
<td>35 ft</td>
</tr>
<tr>
<td>Median barrier width</td>
<td>40 ft</td>
</tr>
<tr>
<td>Shoulder widths</td>
<td>30 ft</td>
</tr>
</tbody>
</table>

**Inside Barrier worksheet**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp entrances</td>
<td>No</td>
</tr>
<tr>
<td>Average ramp entrance length (Lr)</td>
<td>200 ft</td>
</tr>
<tr>
<td>Proportion length to ramp entrance (Lr)</td>
<td>0.5</td>
</tr>
<tr>
<td>Average weaving section length (Lw)</td>
<td>200 ft</td>
</tr>
<tr>
<td>Proportion length to weaving section (Lw)</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Exercise 3: Freeway

Solution

- Weaving Section worksheet

<table>
<thead>
<tr>
<th>Segment</th>
<th>Location</th>
<th>Length of Weaving Section (m)</th>
<th>Length of Departing Section (m)</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP 40-200</td>
<td>0-200</td>
<td>100</td>
<td>150</td>
<td>0.2</td>
</tr>
<tr>
<td>IP 200-400</td>
<td>200-400</td>
<td>150</td>
<td>200</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Total weighted average Cmv

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

- **Solution**
  - 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
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
    • \( C_{ct} = \text{base rate} \times \text{ramp volume} \)
  – No accident modification factors

Ramp Types

• Non-Frontage Road Ramps

- Beige
- Split
- Free Flow Loop
- Outer Connection
- Direct Connection
- Semi-Circular Connection

a – when used in directional interchanges
Ramp Types

- Frontage Road Ramps

<table>
<thead>
<tr>
<th>Ramp Type</th>
<th>Configuration</th>
<th>Crash Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buttress</td>
<td>Slip Road</td>
<td>Low rates</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Slip Road</td>
<td>Low rates</td>
</tr>
<tr>
<td>Ramp</td>
<td>Slip Road</td>
<td>Low rates</td>
</tr>
</tbody>
</table>

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

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/day: 3,000

Geometric Data
Ramp type: Type
Ramp configuration: Length

Volume

Exercise 5: Ramp

Output Summary

Expected injury + fatal crash frequency, crash/yr

Expected Crash Frequency

Analysis Year

Base crash rate (Base): crash/yr
Calibration factor (C): 1.00
Base crash frequency (F): crash/yr
Expected crash frequency (E): crash/yr

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
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”

• 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

  • Question
    – What is the expected crash frequency?

• 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?

Exercise 9: Alternatives Analysis

• Current Design
  – Two intersecting rural highways
    • North/south highway
      – 4-lane restrictive median
    • East/west highway
      – 4-lane TWI-TRL
    • 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:

7.12 – 5.91 = 1.21 crashes/yr prevented
**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
  – 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

0.26 crashes/yr (Ex. 6)

0.20 crashes/yr (given)

0.16 crashes/yr (Ex. 6)

0.12 crashes/yr (given)

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Cost, $1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety benefit, $1000/yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital cost, $1000/yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefit-cost ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net benefit, $1000/yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 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**
- 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.

<table>
<thead>
<tr>
<th>Facility Component</th>
<th>Expected Crash Frequency (crashes/yr)</th>
<th>Combined AMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment “a”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segment “b”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total for roadway section</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

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

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.

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

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.

<table>
<thead>
<tr>
<th>Facility Component</th>
<th>Exercise Number</th>
<th>Expected Crash Frequency (crashes/yr)</th>
<th>Combined AMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-south road</td>
<td>2-a (before change)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>East-west road</td>
<td>7 “b” through “e”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intersection</td>
<td>Given</td>
<td>1.96</td>
<td>0.72</td>
</tr>
<tr>
<td>Total for facility</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

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

<table>
<thead>
<tr>
<th>Facility Component</th>
<th>Exercise Number</th>
<th>Expected Crash Frequency (crashes/yr)</th>
<th>Combined AMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-south road</td>
<td>2-a (before change)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>East-west road</td>
<td>7 “a”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total for interchange</td>
<td>from table above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total for facility</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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: | $100,000/crash reduced x crashes/yr 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)

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.