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

Course Notes
Product 0-4703-P8

SAFETY BY DESIGN

Multilane Highways and Freeways Workshop
Published: December 2008
INCORPORATING SAFETY INTO THE HIGHWAY DESIGN PROCESS:
MULTILANE HIGHWAYS AND FREEWAYS WORKSHOP

Date: __________________
Location: __________________
Contact: Jim Bonneson, (979) 845-9906, j-bonneson@tamu.edu

Agenda

9:30 Introduction

9:45 Session 1: Review of Highway Safety Issues

10:00 Session 2: Overview of Safety Evaluation

10:25 Break

10:40 Session 2: Overview of Safety Evaluation

11:00 Session 3: Procedure for Multilane Highway Segments

11:55 Lunch Break

1:10 Session 4: Procedure for Freeway Segments

1:40 Session 5: Procedure for Interchange Ramps

2:05 Break

2:20 Session 6: Multilane Highway Section Evaluation

2:55 Session 7: Alternatives Analysis

4:05 Wrap-Up, Complete Course Review Form

4:15 Adjourn

Course Materials: Course Workbook
Interim 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
- Instructor
  - Jim Bontrager
  - Researcher 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
Background

- Safety Information Development Process
  - Past TxDOT Research
  - National Research (FMWA, TII)
  - Synthesize
  - Roadway Safety Design Synthesis
  - Roadway Safety Design Workbook

More Information

- Safety Resources from Project 0-4703
  - Roadway Safety Design Synthesis
  - Procedures Guide
  - Texas Roadway Safety Design software

- Web Address
  - http://tdd.lamar.edu/documents/sd.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
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
  - Bridge width
  - Structural capacity
  - Horizontal alignment
  - Vertical curvature
  - Grade
  - Stopping sight distance

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."
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
Analysis Procedures

- Safety Prediction Procedure
- Segmentation Process

Safety Prediction Procedure

- Overview
  - Six steps
  - Use base model and AMP's in Workbook
  - Evaluate a specific roadway segment or intersection (i.e., facility component)
- Output
  - Estimate of crash frequency for segment or intersection

Step 1

- Identify Roadway Section
  - Define limits of roadway section of interest
    - Limits of design project
    - Portion of highway with safety issue or concern
    - May include one or more components
Segmentation Process

- Overview
  -- Use to identify homogeneous roadway segments
  -- Intersections and interchange ramps are not segments

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
    - Horizontal curvature begins or ends
    - Two-way left-turn lane begins or ends
    - Median begins or ends
  - Intersections or ramp terminals are not necessarily segment end points
  - Curve length includes spirals if present
Questions – Comments?

TRSD Worksheet
• Texas Roadway Safety Design Worksheet
  - Overview
  - Navigation
  - Input
  - Output

TRSD Worksheet
• Welcome Screen
  - Tab for introduction (User's Guide)
  - Tabs for selecting specific worksheets

Texas Roadway Safety Design

Developed by James A. Bennett, Kurt Dowsmoor, and Mike Post

FORWARD
The software is designed to estimate the approach-safety influence on design components and roadway safety. It's a tool for engineers and safety professionals to evaluate the actual costs of various design alternatives and to improve the safety and efficiency of roadways. The software is a valuable resource for anyone involved in highway design and safety evaluation.

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3. Highway Segments

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

Safety Prediction Model

- Components
  - Base model
    - \( C_b = \text{base crash rate} \times \text{volume} \times \text{length} \)
  - Accident modification factors

- Relationship

\[
C = C_b \times AMF_{tw} \times AMF_{dd} \ldots
\]

where:
- \( C \) = expected severe crash frequency, crashes/yr;
- \( C_b \) = expected severe base crash frequency, crashes/yr;
- \( AMF_{tw} \) = lane width accident modification factor; and
- \( AMF_{dd} \) = driveway density accident modification factor.

Base Model

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

Page 3-6

\[
C_b = 0.000255 \text{ Base ADT L f}
\]

where:
- \( C_b \) = expected severe base crash frequency, crashes/yr;
- \( ADT \) = average daily traffic volume, veh/day;
- \( L \) = highway segment length, mi; and
- \( f \) = local calibration factor.

<table>
<thead>
<tr>
<th>Median Type</th>
<th>Attributes</th>
<th>Base Crash Rate, severe crash/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Through Lanes</td>
<td>2</td>
</tr>
<tr>
<td>Unidentified or Undetected</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>Capped</td>
<td>0.21</td>
<td>0.23</td>
</tr>
</tbody>
</table>
**Curve Radius**

- **Base Condition**
  - No curvature
- **Limits**
  - Radius ≥ 500 ft
- **Notes**
  - If spirals present, include their length in curve length
  - If no spirals, measure PC to PF

**Example**

- **Questions**
  - What is the AADT for a 2100-ft radius curve?
    - Multilane highway
    - Deflection angle = 30°

**Grade**

- **Base Condition**
  - No grade
- **Limits**
  - Grade ≤ 3%?
- **Notes**
  - "Upgrade" and "Downgrade" have some effect on safety
Example

- Question
  - If a multilane rural highway's outside shoulders are widened from 2 to 4 ft, what would be the expected crash reduction?
  - Surfaced median, 4 lanes

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

Median Width

- Base Condition
  - 10 ft (surfaced)
  - 7.5 ft (depressed)
- Limits
  - Surfaced medians between 4 and 30 ft
  - Depressed medians between 30 and 80 ft
- Notes
  - Not for highways that have a TW/LT.
**Driveway Density**

- **Base Condition**
  - 5 driveways/mi

- **Notes**
  - Count driveways on both sides of roadway
  - Full-access driveways (all minima) count as 1.6 toward total
  - Partial-access driveways count as 0.3 toward total

**Example**

- **Question**
  - What is the AMF for the 0.25 mi road?

- **Answer**
  - Density = \((0.5 + 2.0 + 0.5)/0.25\) = 12 driveways/ft

**Exercise 1: Rural Highway**

- **Given**
  - Rural multilane highway segment
  - Length: 4 mi
  - Volume: 22,000 veh/ld
  - No curvature
  - No grade
  - Lane width: 11 ft
  - Shoulder width: 8 ft
  - 10 ft flush-paved median
  - No rumble strips
  - 3 driveways/mi
  - Horiz. clearance: 30 ft
  - Side slope: 1:6
  - 23 jobs/mi at 20 ft off
  - No bridges

- **Question**
  - What is the expected crash frequency?
Exercise 1: Rural Highway

- Additional Questions
  - What does the combined AMP 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?

- Now it's your turn...

Exercise 2: Rural Highway

- Given
  - Rural midlame highway segment
    - Lanes: 4
    - Length: 2 mi
    - Volume: 17,000 ve/hd
    - No curvature
    - 1 percent grade
    - Lane width: 12 ft
    - Shoulder width: 6 ft outside, 2 ft inside
    - 30-ft depressed median
    - No rumble strips
    - 2 driveways/ni
    - Horiz. clearance: 30 ft
    - Side slope: 1:6
    - 25 poles/ni at 30 ft off
    - No bridges

- Question
  - What is the expected crash frequency?

Exercise 2

- Answer
4. Freeway Segments

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

Safety Prediction Model

- Components
  - Base model
    - \( C_b \) = base crash rate × volume × length
  - Accident modification factors

- Relationship

\[
C = C_b \times AMF_{lw} \times AMF_{mw}
\]  

(2-3)

where:
\( C \) = expected severe crash frequency, crashes/yr;
\( C_b \) = expected severe base crash frequency, crashes/yr;
\( AMF_{lw} \) = lane width accident modification factor; and
\( AMF_{mw} \) = median width accident modification factor.
**Accident Modification Factors**

- Freeway
  - Grade
  - Lane width
  - Outside shoulder width
  - Inside shoulder width
  - Median width
  - Shoulder rumble strips
  - Utility pole offset

---

**Exercise 3: Freeway**

- **Given**
  - Freeway segment
    - Lanes: 6
    - Area type: Urban
    - Length: 1 mi
    - Volume: 82,000 vpd
    - No grade
    - Lane width: 11 ft
  - Shoulder width: 6 ft outside, 4 ft inside
  - No HOV lanes
  - Dugressed median
  - Median width: 50 ft
  - Rumble strips on outside and inside shoulders
  - 25 polesini at 15 ft off

- **Question**
  - What is the expected crash frequency?
Exercise 4: Freeway

- **Given**
  - Freeway segment
    - Lanes: 4
    - Area type: Rural
    - Length: 5 mi
    - Volume: 27,000 veh/d
    - Grade: 2 percent
    - Lane width: 12 ft
  - Shoulder width:
    - 10 ft outside, 4 ft inside
  - No HOV lanes
  - Depressed median
  - Median width: 40 ft
  - No rumble strips
  - 23 poles/mi at 15 ft off

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

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Exercise 4: Freeway

- **Answer**

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Exercise 4: Freeway

- **Question**
  - What is the expected crash frequency if the poles are relocated?
    - 23 poles/mi at 30 ft offset

- **Answer**

---
Ramp Types

- Non-Frontage Road Ramps

- Frontage Road Ramps

Base Model

- Ramp Proper
  - Exit arm 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

<table>
<thead>
<tr>
<th>Output (all crashes)</th>
<th>Ramp crashes</th>
<th>Speed-change lane crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected crash frequency for ramp and adjacent lanes (Rear + Q)</td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Expected speed change frequency (Rear)</td>
<td>0.5%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Expected speed change frequency (Q)</td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Expected speed change frequency for speed change lane</td>
<td>0.1%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

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...
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
  - Rural highway
  - Input data to follow
- Question
  - What is the expected crash frequency for the highway?
Exercise 7: Section Evaluation

• Given
  - Highway segment “a”
    - Lanes: 4
    - Length: 0.13 mi
    - Volume: 4000 veh/d
    - No curvature
    - No grade
    - Lane width: 12 ft
    - Shoulder width: 9 ft
  - TWILTL median
  - No rumble strips
  - 11 driveways/mi
  - Horiz. clearance: 30 ft
  - Sides slope: 1:4
  - 25 poles/mi at 20 ft off

• Question
  - What is the expected crash frequency?

Exercise 7: Section Evaluation

• Answers
  - Segment “a”
  - Segment “b”
  - Segment “c”
  - Entire highway section

Exercise 7: Section Evaluation

• Observations

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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...

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Exercise 9: Alternatives Analysis

- **Current Design**
  - Two intersecting rural highways
    - Northsouth highway
      - 4-lane divided median
    - Eastwest highway
      - 4-lane TWTL
    - Intersection
      - Stop-controlled
      - 35-degree skew angle
  - *From Exercise 6*
    - Crash frequency = 6.63 crashes/yr

Exercise 9: Alternatives Analysis

- **Analysis Process**
  1) Identify components that have a combined AADT > 1.0
    - Northsouth road (Ex. 2-a): 1.27
    - Intersection (Ex-8): 1.19
    - Eastwest road (Ex. 7 "a"): 1.01
  2) Rank them in order of crash frequency
    - Northsouth road: 3.32 crashes/yr
    - Intersection: 2.79 crashes/yr
    - Eastwest road: 0.52 crashes/yr
  3) Identify potential design changes at those components with a larger crash frequency

Exercise 9a: Alternatives Analysis

- **Alternative A**
  - Treatment
    - Increase shoulder width for northsouth road
  - Repeat the analysis for Exercise 2, but
    - Outside shoulder: increase from 6 to 10 ft
    - Inside shoulder: increase from 2 to 6 ft
    - Side slope: decrease from 1:0 to 1:4
Exercise 9b: Alternatives Analysis

- **Alternative B**
  - **Treatment**
    - Realign east/west road to eliminate skew
    - Requires addition of two 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+...h"): 
    - Intersection:
    - Facility:

---

Exercise 9b: Alternatives Analysis

- **Question**
  - Given:
    - $1,009,600 construction cost
    - 25-year life span
    - $100,000 benefit per crash prevented
  - Is this alternative viable?

- **Answer**
Exercise 9c: Alternatives Analysis

- Analysis
  - Northbound exit ramp
    - Area type: Rural
    - Ramp volume: 1000 veh/d
    - Adjacent mainline volume: 8500 veh/d
    - Ramp type: Exit
    - Ramp configuration: Diagonal
- Question
  - What is the expected crash frequency?
- Answer

Exercise 9c: Alternatives Analysis

- Analysis
  - Southbound entrance ramp
    - Area type: Rural
    - Ramp volume: 1000 veh/d
    - Adjacent mainline volume: 8500 veh/d
    - Ramp type: Entrance
    - Ramp configuration: Diagonal
- Question
  - What is the expected crash frequency?
- Answer

Exercise 9c: Alternatives Analysis

- Analysis

<table>
<thead>
<tr>
<th>Crashes/yr</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Ex. 6)</td>
<td></td>
</tr>
<tr>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>0.20 (given)</td>
<td></td>
</tr>
<tr>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>0.12 (given)</td>
<td></td>
</tr>
</tbody>
</table>
Exercise 9c: Alternatives Analysis

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Cost</td>
<td>$1000</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 if the net benefit for Alt. B was $34,000 and the B/C ratio = 1.75?

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
EXERCISE 1: RURAL MULTILANE HIGHWAY SEGMENT

INPUT DATA

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

Traffic Data
  Average daily traffic: 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: Flush paved
  Median width: 10 ft
  Presence of shoulder rumble strips: None

Access Control Data
  Driveway density: 3 driveways/mi

Roadside Data
  Horizontal clearance: 30 ft
  Side slope: 1:6
  Utility pole density: 25 poles/mi
  Utility pole offset: 20 ft

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?
EXERCISE 3: FREEWAY SEGMENT

INPUT DATA

**Basic Roadway Data**
- Number of through lanes: 6
- Area type: Urban
- Segment length: 1 mi

**Traffic Data**
- Average daily traffic: 82,000 veh/d

**Geometric Data**
- Grade: 0 percent

**Cross Section Data**
- Lane width: 11 ft
- Outside shoulder width: 6 ft
- Inside shoulder width: 4 ft
- HOV lane presence: No HOV lane present
- Median type: Depressed
- Median width: 50 ft
- Presence of shoulder rumble strips: Both sides

**Roadside Data**
- Utility pole density: 25 poles/mi
- Utility pole offset: 15 ft

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
- Inside shoulder width: 6 ft
- Median width: 36 ft

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

What is the combined AMF? ............................................................. .
EXERCISE 5: INTERCHANGE RAMP

INPUT DATA

Basic Roadway Data
Area type: Urban

Traffic Data
Average daily traffic on ramp: 2500 veh/d
Average one-way daily traffic on the adjacent mainlanes: 41,000 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 7: SECTION EVALUATION

Location: Rural multilane highway segment “a”

INPUT DATA

Basic Roadway Data
- Number of through lanes: 4
- Segment length: 1.18 mi

Traffic Data
- Average daily traffic: 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: TWLTL
- Presence of shoulder rumble strips: None

Access Control Data
- Driveway density: 4 driveways/mi

Roadside Data
- Horizontal clearance: 30 ft
- Side slope: 1:4
- Utility pole density: 25 poles/mi
- Utility pole offset: 20 ft

OUTPUT SUMMARY

Record your results in the table on the last page for Exercise 7.
EXERCISE 7: SECTION EVALUATION

Location: Rural multilane highway segment “c”

INPUT DATA

Basic Roadway Data
  Number of through lanes: 4
  Segment length: 0.18 mi

Traffic Data
  Average daily traffic: 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: TWLTL
  Presence of shoulder rumble strips: None

Access Control Data
  Driveway density: 11 driveways/mi

Roadside Data
  Horizontal clearance: 30 ft
  Side slope: 1:4
  Utility pole density: 25 poles/mi
  Utility pole offset: 20 ft

OUTPUT SUMMARY

Record all results for segments “a,” “b,” and “c” into 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>Segment “c”</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 “h”? ..................
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>2.48</td>
<td>1.19</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 9c: ALTERNATIVE C

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

INPUT DATA

**Basic Roadway Data**
- Area type: Rural

**Traffic Data**
- Average daily traffic on ramp: 1000 veh/d
- Average one-way daily traffic on the adjacent mainlanes: 8500 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? ................................................. 

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

Date: ______________
Location: ______________

Your Agency: ____________________________________________________________
Your Position: __________________________________________________________

Course Content (circle one)

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Did the course meet your expectations?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Comments:</td>
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<td>2. Was the material presented at the correct level of difficulty?</td>
<td>1</td>
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<td>Comments:</td>
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<td>3. Was the topic of the course covered adequately (nothing left out, no one topic overemphasized)?</td>
<td>1</td>
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<td>Comments:</td>
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<tr>
<td>4. Was the software easy to use?</td>
<td>1</td>
<td>2</td>
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<td>Comments:</td>
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