NCHRP Project 17-45

Enhanced Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges

March 2012

Overview

• Background on HSM
• Project Overview
• Safety Evaluation Overview
• Freeway Predictive Method
• Ramp Predictive Method
• Closure
Background on HSM

• HSM Purpose
  – To provide tools and techniques for quantifying the relationship between infrastructure element presence or dimension on safety
  – These tools and techniques can be used to quantify the potential change in safety resulting from a change in geometric design or control feature
  – Safety is explicitly described in terms of expected crash frequency and severity

• History
  – 10-year research program funded by NCHRP and FHWA
    • Renamed Highway Safety Performance committee
  – Kittelson & Associates, Inc. was prime contractor responsible for producing the document
  – Published by AASHTO
Background on HSM

- Part C – Predictive Method
  - Used to estimate the expected crash frequency and severity for a facility, or portion of a facility
  - The estimate can describe existing conditions or a proposed design
  - Methods provided in Part C
    - Chapter 10 – Rural two-lane roads
    - Chapter 11 – Rural multilane highways
    - Chapter 12 – Urban and suburban arterials

- Part C – Predictive Method
  - Application
    - Facility is decomposed into individual road segments and intersections → called “sites”
    - Method is used to evaluate individual sites
    - Results are added to describe facility performance
  - Performance Measures
    - Crash severity (K, A, B, C, and PDO)
    - Crash type
      - Fixed object, parked vehicle, animal, other
      - Head on, right angle, rear end, sideswipe, other
Project Overview

• Objectives
  – Develop predictive methods
    • Freeways
    • Interchanges
  – Develop a software tool that implements the methods
  – Document in a chapter for a future HSM
  – Develop algorithm documentation for IHSDM

Project Overview

• Schedule
  – Begin: May 2009
  – End: August 2012

• Status
  – NCHRP Panel has reviewed and approved
  – Draft final report and products under review by TRB’s Highway Safety Performance committee
  – Final report and products due May 2012
Safety Evaluation Overview

• Predictive Model
• Predictive Method
• Segmentation Process

Safety Evaluation Overview

• Predictive Model
  – Crash frequency, \( N_p = N_{spf} \times CMF_{lw} \times CMF_{sw} \ldots \times C \)
• Model Components
  – Safety performance function (SPF), \( N_{spf} \)
  – Crash modification factors (CMF), \( CMF_i \)
  – Calibration factor, \( C \)
Safety Evaluation Overview

• Safety Performance Function
  – Crash frequency for segment with base conditions
  – Typical: 12 ft lanes, 10 ft outside shoulder, etc.
  – \( N_{spf} = a \times (AADT)^b \times L \)
    • \( AADT \) = annual average daily traffic volume
    • \( L \) = segment length
  – May be sensitive to...
    • Crash severity: fatal-and-inj. (FI), prop.-damage-only (PDO)
    • Crash type: multiple-vehicle (MV), single-vehicle (SV)
    • Area type: urban, rural
    • Number of lanes

Safety Evaluation Overview

• Crash Modification Factor
  – Change in crash frequency for a specific change in geometry (or the application of a treatment)
  – Adapts SPF to non-base conditions
  – One CMF per design element (e.g., lane width)
  – CMF = 1.00 for base condition value

• Project 17-45 CMFs
  – 13 CMFs for freeways
  – 9 CMFs for ramps
  – 11 CMFs for crossroad ramp terminals
Safety Evaluation Overview

- Example Crash Modification Factor
  - Existing 4-lane freeway
  - Base condition
    - 12 ft lanes
    - $CMF_{base} = 1.00$
  - Existing roadway
    - 11 ft lanes
    - $CMF_{11\, ft} = 1.04$

Safety Evaluation Overview

- Predictive Method
  - 18 steps in HSM predictive method
  - Use predictive model to evaluate all sites
  - See HSM Part C – Introduction for details
  - Severity distribution
    - HSM Part C – table of typical distribution values (1% K, 5% A, etc.)
    - Project 17-45 - severity distribution functions (SDFs)
- Project 17-45 Software Implementation
  - 7 steps
  - First 6 steps are the same as in HSM method
  - Software automates remaining steps
Safety Evaluation Overview

• Segmentation Process
  – Divide roadway into sites
  – Sites
    • Homogenous segments
    • Intersections

Plan View

Safety Evaluation Overview

• Definition - Homogeneous Segment
  – A homogeneous segment has the same basic character for its full length
    • Number of lanes
    • Lane width
    • Shoulder width
    • Median width
    • Clear zone width
Safety Evaluation Overview

• Example Segmentation
  — Begin segment at gore point

Input Data
1. Number of through lanes: 5
2. Ramp entrance in segment? “Lane Add”
3. Ramp exit in segment? “No”
4. Type B weave in segment? “No”

Freeway Predictive Method

• Safety Performance Function
• Crash Modification Factors
Freeway Predictive Method

• Safety Performance Function
  – \( N_{spf} = a \times (AADT)^b \times L \)
  – Coefficients \( a \) and \( b \) by...
    • Area type
    • Number of lanes
    • Crash type
    • Severity

\[
\begin{array}{c|c|c|c|c}
\hline
\text{Average Daily Traffic Demand (1000s), veh/day} & 0 & 50 & 100 & 150 & 200 & 250 \\
\hline
FI Multiple-Vehicle Crash Frequency, crashes/yr & 0 & 3 & 6 & 9 & 12 & 15 \\
\hline
\text{1.0-mile segment length, no barrier} & 4 lanes & 8 lanes & 8 lanes & 8 lanes & 8 lanes & 8 lanes \\
\hline
\text{Rural Freeway} & \text{Urban Freeway} & \text{Rural Freeway} & \text{Urban Freeway} & \text{Rural Freeway} & \text{Urban Freeway} & \text{Rural Freeway} \\
\hline
\end{array}
\]

Freeway Predictive Method

• Crash Modification Factors
  – Horizontal curve
  – Lane width
  – Paved shoulder width
    • Inside
    • Outside
  – Median width
  – Barrier
    • Median
    • Roadside
  – High volume (congestion)
  – Lane change (ramp related)
  – Shoulder rumble strips
  – Outside clearance
  – Ramp entrance
  – Ramp exit

\[ L_r = \text{ramp entrance length} \]
Freeway Predictive Method

• High Volume CMF
  – Proportion of AADT during hours where volume exceeds 1,000 veh/h/ln
  – Proportion > 0.0 if
    • Hourly volumes continuously high, or
    • A few very high peak hours exist
  – Use nearest traffic count station data

Freeway Predictive Method

• High Volume CMF
  – Base Condition
    • Proportion = 0.0
  – Limits
    • 0.0 to 1.0
  – Notes
    • Default values available
Freeway Predictive Method

- Lane Change CMF
  - Ramp Location and AADT
  - Need for upstream entrances and downstream exits
    - *Not* upstream exits and downstream entrances

- Not upstream exits and downstream entrances

-- Freeway Predictive Method

- Lane Change CMF
  - Base condition
    - Ramps > 0.5 mi
  - Notes
    - Includes adjustment for weaving sections

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**Average CMF for 0.5-mi road section = 1.10**

- Distance from Left-Side Gore (x), mi

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**AADTb,ent**

**AADTb,ext**

**AADTe,ent**

**AADTe,ext**

**AADTb,ent**

**AADTb,ext**

**AADTe,ent**

**AADTe,ext**

---

**All measurements are to the marked gore point.**

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**Increasing mile post**

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**Segment**

---

**Begin milepost**

---

**End milepost**

---

**Freeway Predictive Method**

- Lane Change CMF
  - Ramp Location and AADT
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**AADTb,ent**

**AADTb,ext**

**AADTe,ent**

**AADTe,ext**

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**Segment**

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**Begin milepost**

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**Freeway Predictive Method**

- Lane Change CMF
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Ramp Predictive Method

- Ramp and C-D Road Segments
  - Ramp configurations
  - Safety performance function
  - Crash modification factors
- Crossroad Ramp Terminals
  - Terminal configurations
  - Safety performance function
  - Crash modification factors

Ramp Predictive Method

- Ramp Configurations
  - Segment based, works for all ramp configurations
  - Diamond (Diagonal)
  - Parclo Loop (Non-Free-Flow)
  - Free-Flow Loop
  - Buttonhook
  - Outer Connection
  - Direct Connection (used at directional interchanges)
  - Semi-Direct Connection (used at directional interchanges)
  - Collector-Distributor
Ramp Predictive Method

- SPF
  - \( N_{spf} = a \times (AADT)^b \times L \)
  - Coefficients \( a \) and \( b \) by...
    - Exit, entrance, C-D road
    - Area type
    - Number of lanes
    - Crash type
    - Severity

Ramp Predictive Method

- CMFs
  - Horizontal curve
  - Lane width
  - Right shoulder width
  - Left shoulder width
Ramp Predictive Method

• CMFs
  – Right side barrier
  – Left side barrier
  – Lane add, lane drop
  – Ramp speed-change lane
  – Weaving section (C-D road only)

• Supplemental Models
  – Ramp curve speed prediction model

Ramp Predictive Method

• Horizontal Curve CMF

![Graph showing Crash Modification Factor vs. Curve Radius for different speeds and curve types.]
Ramp Predictive Method

- Ramp and C-D Road Segments
  - Ramp configurations
  - Safety performance function
  - Crash modification factors

- Crossroad Ramp Terminals
  - Terminal configurations
  - Safety performance function
  - Crash modification factors

Ramp Predictive Method

- Ramp Terminal Configurations
  - Terminal-configuration based
  - 7 configurations

Diagonal, Exit

Diagonal, Entrance

Diagonal, 4-Leg
Ramp Predictive Method

• Ramp Terminal Configurations (continued)
  – 7 configurations

- 4-quad Parclo A
  - Type: A4

- 4-quad Parclo B
  - Type: B4

- 2-quad Parclo A
  - Type: A2

- 2-quad Parclo B
  - Type: B2

Ramp Predictive Method

• Safety Performance Function
  – \( N_{spt} = a \times (AADT_{xrd})^b \times (AADT_{ex} + AADT_{en})^d \)
  – AADT_{xrd} = crossroad traffic = (AADT_{in} + AADT_{out})/2
  – AADT_{en} = entrance ramp traffic
  – AADT_{ex} = exit ramp traffic
  – Coefficients \( a, b, d \) by...
    • Configuration
    • Type of control (signal, stop)
    • Area type
    • Number of crossroad lanes
    • Severity
Ramp Predictive Method

- **SPFs**
  - D4 Configuration
    - One-way stop
    - Signal

- **CMFs**
  - Signal or Stop
    - Exit ramp capacity
    - Crossroad turn lane
      - Left turn
      - Right turn
    - Access point frequency
    - Segment length
    - Median width

- **Signal**
  - Protected-only left-turn phase
  - Channelized right turn
    - Crossroad
    - Exit ramp
  - Non-ramp leg

- **Stop**
  - Skew angle
Ramp Predictive Method

- Median Width CMF
  - Stop Control

<table>
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<tr>
<th>Median Width, ft</th>
<th>Crash Modification Factor</th>
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<tr>
<td>20</td>
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<tr>
<td>50</td>
<td>2.0</td>
</tr>
<tr>
<td>60</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Ramp Terminal, 14,000 veh/d, proposed
Urban, 4 Legs (Highway, 2010)
Ramp Terminal, 5000 veh/d, proposed
Rural, 4 Legs (Highway, 2010)

Closure

- Methods Do Not Address the Following
  - Freeways with continuous access HOV lanes
  - Freeways with buffer-separated managed lanes
  - Use of safety shoulders as travel lanes
  - Ramp meters
  - HOV by-pass lanes on ramps
  - Crossroad segments
  - Frontage road segments or terminals

Buffer (ok) Barrier (ok)
Closure

• Safety Evaluation Scenarios
  – Freeway
    • Interchange spacing
    • Weaving section length
    • Reallocation of cross section width
  – Interchange
    • System interchange configuration
    • Service interchange configuration (parclo, diamond)
  – Analysis Scale
    • Single year analysis or design life analysis
    • Freeway system analysis or individual section

Closure

• Implementation Plan
  – Practitioner-Oriented Products
    • ISATe software
    • ISATe User Manual
    • HSM draft chapters
    • Training course content
  – User Evaluation Procedure
    • Detailed evaluation by freeway design experts
    • Two, one-day practitioner workshops
Closure

• Questions or Comments?