Focused Training Course
**HSM Focused Training Agenda**

<table>
<thead>
<tr>
<th>Section</th>
<th>Topic</th>
<th>Duration</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Introductions (15 min)</td>
<td></td>
<td>9:00 to 9:15</td>
</tr>
<tr>
<td>II.</td>
<td>Intro and Fundamentals of AASHTO HSM (60 min)</td>
<td></td>
<td>9:15 to 10:15</td>
</tr>
<tr>
<td></td>
<td>Break</td>
<td></td>
<td>10:15 to 10:30</td>
</tr>
<tr>
<td>III.</td>
<td>Safety Prediction for ODOT (30 min)</td>
<td></td>
<td>10:30 to 11:00</td>
</tr>
<tr>
<td>IV.</td>
<td>HSM Predictive Methods for Rural Highways Example (60 min)</td>
<td></td>
<td>11:00 to 12:00</td>
</tr>
<tr>
<td></td>
<td>Lunch</td>
<td></td>
<td>12:00 to 1:00</td>
</tr>
<tr>
<td>V.</td>
<td>HSM Predict Methods for Urban Streets and Arterials (60 min)</td>
<td></td>
<td>1:00 to 2:00</td>
</tr>
<tr>
<td>VI.</td>
<td>HSM Predictive Methods for Freeways/Interchanges (45 min)</td>
<td></td>
<td>2:00 to 2:45</td>
</tr>
<tr>
<td></td>
<td>Break</td>
<td></td>
<td>2:45 to 3:00</td>
</tr>
<tr>
<td>VII.</td>
<td>Workshop Problem Using ODOT Data and Tools (ECAT)</td>
<td></td>
<td>3:00 to 3:45</td>
</tr>
<tr>
<td>VIII.</td>
<td>Final Questions and Course Summary</td>
<td></td>
<td>3:45 to 4:00</td>
</tr>
</tbody>
</table>

Appendix A: Urban Streets and Arterials Handouts

Appendix B: ODOT Data and Data Systems

Appendix C: Interpretation and Documentation of Safety Analysis
Ohio Department of Transportation

Highway Safety Manual
Focused Training Course

www.transportation.ohio.gov

ODOT HSM Training

Introduction and Agenda
ODOT HSM Focused Training Course
Housekeeping

- Cell phones
- Breaks
  - Authorized Areas
  - Restroom Locations
  - Lunch
- Emergency Exits

CPD/PDH

- HSM Training Course is equivalent to 6 hours of CPD credits
- Please sign-in; this workshop will be recorded in your training record
Agenda

Course Introduction 9:00 - 9:15
Break 10:15 - 10:30
Safety Prediction for ODOT 10:30 - 11:00
HSM Predictive Methods for Rural Highways 11:00 - 12:00
Lunch 12:00 - 1:00
HSM Predictive Methods for Urban Arterials 1:00 - 2:00
HSM Predictive Methods for Freeways and Interchanges 2:00 - 2:45
Break 2:45 - 3:00
Example Problems - Using ODOT ECAT Tool 3:00 - 3:45
Final Questions and Course Summary 3:45 - 4:00
Fundamentals of Safety
ODOT HSM Focused Training Course

- HSM Part A: Chapters 2 & 3 (Volume 1)
  - The two dimensions of safety
  - Crashes as the substantive safety metric of interest
  - Contributing factors to crashes
- Highway Safety Manual Predictive Methods (Volumes 2 & 3)
  - Estimating crashes -- Parts C and D
  - Incorporating crash history
  - Interpreting and communicating results
The two dimensions of safety*

**Nominal Safety**
Examined in reference to compliance with standards, warrants, guidelines and sanctioned design procedures.

**Substantive Safety**
The expected or actual crash frequency and severity for a highway or roadway.

*Ezra Hauer, ITE Traffic Safety Toolbox, 1999

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The two dimensions of safety produce different outlooks

- **Nominal Safety** is an *Abstraction*.
- **Substantive Safety** is a *Continuum*.

DESIGN DIMENSION
(Lane Width, Radius of Curve, Stopping Sight Distance, etc.)
Substantive safety is “context sensitive”

What types and severity of crashes would you expect at each of these locations?

What is Safety in the HSM?

- The HSM uses crashes as a measure of safety
- Objective, data-driven and measurable
- Substantive
As long as humans operate cars............. there is no such thing as a zero-risk road
## A tool for understanding crashes – The Haddon Matrix

<table>
<thead>
<tr>
<th>Crash Timeline</th>
<th>Contributing Factor</th>
<th>Human</th>
<th>Vehicle</th>
<th>Roadway Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before Crash</strong></td>
<td>Driver capabilities, condition (Sober? Alert? Distracted?), skills</td>
<td></td>
<td>Type, condition (brakes, tires, etc.), safety equipment</td>
<td>Alignment and cross section, road type, prevailing speed, presence of signs, markings, etc.</td>
</tr>
<tr>
<td><strong>During Crash</strong></td>
<td>Restrained? Location of occupants</td>
<td>Type, reaction to impact (absorbing energy), center of gravity</td>
<td></td>
<td>Pavement condition (wet, skid resistance), presence and type of fixed objects, roadside</td>
</tr>
<tr>
<td><strong>After Crash</strong></td>
<td>Age and physical condition (survivability)</td>
<td>Extraction of victims from vehicles</td>
<td></td>
<td>Detection and dispatch of EMS access to site, proximity to trauma care</td>
</tr>
</tbody>
</table>

## Crash Severity (‘KABCO’ Scale)

- **Crashes are rated by the most severe injury occurring in the crash**
  - **K** – One or more persons died within 30 days of the crash
  - **A** – Incapacitating injury
  - **B** – Non-incapacitating but evident injury
  - **C** – Possible injury
  - **O** – No injury, but property damage exceeding the state’s threshold for reporting
Crash types differ by highway type, and road segment

- Highway Type
- Roadway Element
  - Segments
  - Intersections
- Crash type
- Severity

Crash Benchmarks

- Crash rate has traditionally been the method by which we compare locations and judge relative safety

\[
CR_{rs} = \frac{\text{No. crashes per year}}{(\text{annual traffic volume} \times \text{length})} = \text{Crashes per MVMT}
\]

\[
CR_{int} = \frac{\text{No. crashes per year}}{(\sum \text{annual entering volumes})} = \text{Crashes per MEV}
\]
Crash Frequency

- The basic measure of crashes in the HSM is crash frequency per unit of time (typically one year)

\[ N_c = \text{Number of crashes per year}^* \]

*expressed for a location or site; or per mile depending on the context

HSM Part C – Methods for predicting crash frequency

- Safety Performance Functions (SPF)
- Crash Modification Factors (CMF)
- Calibration (C)
- Incorporating Observed Crashes -- Weighting with Empirical Bayes
Predictive Method Analysis Process

**PREPARATION**

1. Determine data needs: Homogeneous segments & intersections
2. Calculate predicted number of crashes for base condition
3. Calculate predicted number of crashes for the site condition
4. Calculate expected number of crashes for the site condition*

*In some cases, we can incorporate crash history using the Empirical Bayes (E.B.) process to get to expected...

---

Data Collection/Preparation

Roadway segments and intersections are modeled separately

**Segment Length**

(Center of Intersection to Center of Intersection)
General form of the predictive method for roadway segments or intersections

Predicted Crash Frequency $=>$ SPF x (CMF₁ x CMF₂ x ...) x C

'Safety Performance Function'

'Crash Modification Factors'

'Local Calibration Factor'

Safety Performance Functions (SPF)

- Mathematical expression used to estimate the expected average crash frequency for a base condition
- Product of a statistical modeling process
Example SPF – Single vehicle crashes on 3-leg signalized intersections of urban and suburban arterials

SPFs are unique to basic highway types

Chapter 10 for 2-lane Rural Highway SPFs

Chapter 12 for Urban Arterial SPFs

Chapter 11 for Multilane Rural Highway SPFs
### SPFs - Facility Type and Site Type

<table>
<thead>
<tr>
<th></th>
<th>Chapter 10 Rural 2-Lane 2-Way Roads</th>
<th>Chapter 11 Rural Multilane Highways</th>
<th>Chapter 12 Urban and Suburban Arterials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undivided Roadway Segments</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Divided Roadway Segments</td>
<td></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Intersections – Stop Control 3-Leg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intersections – Stop Control 4-Leg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intersections – Signalized 3-Leg</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Intersections – Signalized 4-Leg</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>

**SPFs predict crashes for Base Conditions**

- Include variables that statistically explain crash frequency (e.g., cross section elements, alignment)
- Base conditions are established in the SPF modeling process
- CMFs derived from the same research effort; describe effect of differences in variables for site vs. base conditions
**Base Conditions for 2-lane Rural Arterials (Ch. 10)**

**Intersections**
- 90° angle (0° skew)
- No left turn lanes
- No right turn lanes
- No lighting

**Road segments**
- 12-ft lane widths
- 6-ft shoulder widths
- ‘Roadside Hazard Rating’- 3
- 5 driveways per mile
- Tangent, flat alignment (0% grade)
- No centerline rumble strips
- No passing lanes
- No two-way left turn lanes
- No lighting
- No automated speed enforcement

*CMFs are applied for each condition when it differs from the base condition*

---

**Base Conditions for Multilane Rural Arterials (Ch. 11)**

**Intersections**
- 90° angle (0° skew)
- No left turn lanes
- No right turn lanes
- No lighting

**Road segments**
- 12-ft lane widths
- 6-ft shoulder widths
- 30-ft median (4D)
- No lighting
- No automated speed enforcement

*CMFs are applied for each condition when it differs from the base condition*
Base Conditions for Urban and Suburban Arterial SPFs (Ch. 12)

**Intersections**
- No left-turn lanes
- Permissive left-turn signal phasing
- No right-turn lanes
- Right-turn on red permitted
- No lighting
- No automated enforcement
- No bus stops, schools, alcohol sales establishments near intersection

**Road segments**
- No on-street parking
- No roadside fixed objects
- 15-ft median (4D)
- No lighting
- No automated speed enforcement

CMFs are applied for each condition when it differs from the base condition.

Part C CMFs
- Some are a single value, others are a function
- Understand each one – do they make sense to you?
- Some apply to all crashes, others to specific crash types
- Absence of a CMF means the modeling process either did not consider the variable or did so and found it not to be significant
Rural 2-Lane Segments -- Lane Width CMF

Be careful!!

Calibration -- C

- SPF's and CMF's developed from selected state databases
- Calibration is required for applications in other states
- Relative comparisons are still possible using uncalibrated models
What about observed crash history? Don’t we use that in our analysis?

Regression to the mean bias exists when only crash history is used.
Site-Specific Empirical Bayes (EB) Method
- Reduces effects of regression-to-the-mean
- Improves the crash frequency estimate
- *Both SPF and crash data must be available*

EB Method
- Combines actual site crash history with predicted average crash frequency
- Weights the two values based on the strength of the model (SPF)
- ‘Overdispersion Parameter’ – k is the measure of the model’s strength
- Result is referred to as the *Expected Crash Frequency*
EB Method
Application and Formula

\[ N_{expected} = w \times N_{predicted} + (1.00 - w) \times N_{observed} \]

Weighted Adjustment \((w)\):

\[ w = \frac{1}{1 + k \times (\sum N_{predicted})} \]

where

- \( k \) is over-dispersion parameter (unique to each SPF) and
- \( \sum N_{predicted} \) is predictive model estimate for all study yrs


Weighting reflects strength and reliability of the model used

Reliability of a model is function of:
- Fit of original data
- Variance
- How well model was calibrated for local data

33 34
EB Method Applications

- Existing crash history is relevant
  - Only existing locations
  - Site is not being significantly changed
- Existing crash data are available and can be relied upon

Crash Modification Factors in Part D -- CMF

CMF is a value which quantifies the change in crash frequency at a site as a result of implementing a specific countermeasure or treatment.
HSM Part D Contents
Research on CMFs reviewed and vetted; only the highest quality research was included

CMF knowledge base in Part D
- Ch. 13 - Roadway Segments
- Ch. 14 - Intersections
- Ch. 15 - Interchanges
- Ch. 16 - Special Facilities and Geometric Situations

Part D CMF Applications

- **Infrastructure Treatments**
  - Widening lanes or shoulders
  - Flattening curves
  - Improving roadside (barrier, slope treatments, etc.)
  - Install rumble strips
- **Traffic Control**
  - Signing, pavement marking applications
  - Signalization
- **Operational Strategies**
  - On-street parking prohibition, regulation
  - Changeable message advance warning signing on freeways
  - Access management
  - Left turn signalization, clearance intervals
- **Maintenance Strategies**
  - Winter maintenance, anti-icing strategies
  - Work zone duration
- **Enforcement Strategies**
  - Automated enforcement
Example Format and Description of CMFs in Part D

Table 13-32. Potential Crash Effects of Installing Changeable “Queue Ahead” Warning Signs (8)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Setting (Road Type)</th>
<th>Traffic Volume</th>
<th>Crash Type (Severity)</th>
<th>CMF</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install Changeable “Queue Ahead” warning Signs</td>
<td>Urban Freeways</td>
<td>Unspecified</td>
<td>Rear-end (Injury)</td>
<td>0.84</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rear-end (Non-injury)</td>
<td>1.16</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Base Condition: Absence of changeable “Queue Ahead” warning signs

NOTE: Based on international studies: Erke and Gottlieb 1980; Cooper, Sawyer and Rutley 1992; Persaud, Musci and Ugge 1995.
Bold text is used for the most reliable CMFs. These CMFs have a standard error of 0.1 or less.
Italic text is used for less reliable CMFs. These CMFs have standard errors between 0.2 to 0.3.
* Treatment results in a decrease in injury crashes and an increase in non-injury crashes. See Part D – Introduction and Application Guidance.

Table 13-32, p. 13-31

Important concepts about CMFs

- May apply to all crashes, or specific subsets of crashes (e.g., run-off-road, night, wet weather, multi-vehicle, etc.)
- Same treatment in different contexts or highway types may have differing effects and resultant differing CMF values
- Multiple CMFs may be applied to same location
Important concepts about CMFs

- CMF is one value, but our knowledge of effects suggests we expect a distribution of results (variance when applied in multiple locations)
- A crash modification function may apply

Crash Modification Function (example – ‘Modify Horizontal Curve’)

\[
CMF_{hc(3r^*)} = \frac{(1.55 \times L_C) + \left(\frac{80.2}{R}\right) - (0.012 \times S)}{(1.55 \times L_C)}
\]

Where:
- \( L_C \) is length of curve (mi)
- \( R \) is radius of curve in ft
- \( S = 1.0 \) if spiral curve present; 0 if no spiral
Guidance in applying CMFs

- Use engineering judgment to diagnose the problem and select appropriate countermeasures
- Where possible use CMFs targeted to specific crash types
- Focus on low cost countermeasures first
- Understand what the countermeasure is intended to do
- Stay within the parameters of the underlying research
Use of multiple Part D CMFs

\[ N_{\text{after}} = N_{\text{before}} \times [CMF_1 \times CMF_2 \times \ldots] \]

- Effect of each CMF is assumed to be independent of other effects
- Caution against using a large number of CMFs
- Must account for specific crash types for which each CMF applies

Methods for estimating safety effectiveness

- Part C Predictive Method with Part C CMFs, Crash History using EB method, & Part D CMFs (ODOT)
- Part C Predictive Method with Part C CMFs
- Part C Predictive Method with Part D CMFs
- SPF only & Part D CMFs
- Observed crash frequency & Part D CMFs
Cautions and caveats in using the HSM

- Don’t forget – you’re using a model
  - Data quality and other limitations
  - Human element and randomness
- Apply judgment
  - Type of decision
  - Understand strength of model and methods

Questions and Discussion
Learning Outcomes

- Introduction and use of SPFs, CMFs, Cs
- Predictive method/analysis process
- Identify required data
- Discuss approach, appropriate use, and limitations
- Illustrate predictive method with an example
Determine data needs
Homogeneous segments & intersections

1. Calculate predicted number of crashes for base condition
2. Calculate predicted number of crashes for the site condition
3. Calculate expected number of crashes for the site condition

In some cases, we can incorporate crash history using the Empirical Bayes (E.B.) process to get to expected

Preparation

- Determine Data Needs
  - Study limits
  - Facility type
  - Study period
  - Site conditions (geometry, traffic control, etc.)
  - Traffic volumes (vehicles/day)
Preparation
Divide locations into homogeneous segments or intersections

- Presence (and type) of intersections
- Number of lanes
- Cross section dimensions (LW, SW)
- Alignment change (Horiz, Vertical)
- Change in roadside conditions
- Change in traffic volume

Creating Homogeneous Segments

*A new roadway segment begins where:*

- Base conditions* change
- Major changes in
  - Traffic volume
  - Geometric alignment*
- Presence of an intersection

* Homogeneous sections will vary based on the facility type (SPF and CMFs)
Example: Homogeneous Segments
Rural Two-Lane

A new roadway segment begins at/where:

- Center of each intersection
- Horizontal curves (PC)
- End of grade (VPI)
- Limits of passing lanes or short 4-lane sections
- Limits of two-way left-turn lane
- Average daily traffic volume change
- Lane or shoulder width or type
- Change in driveway density (per mile)
- Roadside hazard rating change
- Presence of centerline rumble strip, lighting, or automated speed enforcement

Calculate the predicted # of crashes for SPF base condition

Identify & apply the appropriate SPF

Chapter 10 for 2-lane Rural Highway SPFs
Chapter 12 for Urban Arterial SPFs
Chapter 11 for Multilane Rural Highway SPFs
Calculate the predicted number of crashes

1. Predicted crashes for the base condition
2. Adjust for site conditions that are different from the SPF base condition
3. Apply Calibration Factor

\[ SPF \times (CMF_1 \times \ldots \times CMF_i) \times C \]

Apply CMFs to Calculated SPF Values

- Review applicable SPF “base case” or typical features
- Determine how study site differs from “base case”
- Select CMFs for road type and atypical features from Part C
- Multiply SPF value by applicable CMFs
Apply Local Calibration Factor (C)

- “C” adjusts HSM SPF-derived crash estimates to reflect local conditions
  - Reporting levels
  - Weather and other similar factors
- Each SPF requires its unique “C”
- “C” values would be provided to you by Program Management

Apply Site-Specific Empirical Bayes (EB) Method

- Reduces effects of RTM
- Improves the crash frequency estimate
- Requires SPF & historic crash data
- Steps: HSM Part C Appendix
**EB Method**

**Application and Formula**

\[ N_{expected} = w \times N_{predicted} + (1.00 - w) \times N_{observed} \]

**Weighted Adjustment \( w \):**

\[ w = \frac{1}{1 + k \times (\sum N_{predicted})} \]

where

- \( k \) is over-dispersion parameter (unique to each SPF) and
- \( \sum N_{predicted} \) is predictive model estimate for all study yrs

**Site-EB Method**

1. **Apply method for each segment & intersection**
2. **Sum expected average # crashes across all segments & intersections**
3. **Repeat for each alternative**
4. **Evaluate alternate designs: compare expected average # of crashes**

\[ N_{(total)_expected} = \sum N_{(all\ segments)} + \sum N_{(all\ intersections)} \]
What is the benefit of the EB step?

- Incorporate the site crash history to
  - improve our estimate,
  - reduce effects of RTM,
  - understand the unbiased potential for safety improvement.
When is the EB method applicable?

- **No-build option**
  - Sites at which the roadway geometrics and traffic control are not being changed (e.g., the “do-nothing” alternative);

- **# through lanes consistent**
  - Projects in which the roadway cross section is modified but the basic number of through lanes remains the same (e.g., projects for which lanes or shoulders were widened or the roadside was improved, but the roadway remained a rural two-lane highway);

- **Minor alignment changes**
  - Projects in which minor changes in alignment are made, such as flattening individual horizontal curves while leaving most of the alignment intact;

- **Passing lanes**
  - Projects in which a passing lane or a short four-lane section is added to a rural two-lane, two-way road to increase passing opportunities; and

- **Any combination of the above improvements**

When is the EB method NOT applicable?

- **New alignment and/or cross section**
  - Across substantial proportion of the project length; major change in facility type (e.g., 2 lane to multilane road)

- **Intersections where**
  - Change in # intersection legs
  - Change in traffic control
Apply site-specific EB method

**STEP 1:** Calculate weight *w*

\[ W = \frac{1}{1 + k \times (\sum N_{\text{predicted}})} \]

**STEP 2:** Combine observed and predicted crash #

\[ N_{\text{expected}} = w \times N_{\text{predicted}} + (1-w) \times N_{\text{observed}} \]

**STEP 3:** Adjust estimated value of expected average crash frequency to future time period (if needed)

\[ N_f = N_p \times N_{bf} \times \text{CMF}_{1f} \times \text{CMF}_{2f} \times \ldots \times \text{CMF}_{nf} \]

Methods for estimating safety effectiveness

- Part C Predictive Method with Part C CMFs, Crash History using EB method, & Part D CMFs (ODOT)
- Part C Predictive Method with Part C CMFs
- Part C Predictive Method with Part D CMFs
- SPF only & Part D CMFs
- Observed crash frequency & Part D CMFs
Predictive Method Considerations

- Impact of potential geometric or traffic control features may not be mentioned (assume impact unknown RATHER than no impact!)
- Non-geometric factors *only in a general sense*
- Climate conditions *not explicitly considered*
- Potential interactions between geometric & traffic control features

General Observations

- **Estimates**
  - Predicted crash frequency *when we use SPF, CMFs and C*
  - Expected crash frequency *when we apply EB method to predicted crashes*
- Can be applied to past or future
- Can estimate total crashes, KABC, and in some cases KAB crashes
- Estimation incorporates effects to specific collision types
Default crash & severity distributions

Table 12-13 (excerpt) Distribution of Single-Vehicle Crashes for Intersection by Collision Type (Proportion of Crashes by Severity Level)

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>4SG</th>
<th>4SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision with parked vehicle</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Collision with animal</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Collision with fixed object</td>
<td>0.744</td>
<td>0.870</td>
</tr>
<tr>
<td>Collision with other object</td>
<td>0.072</td>
<td>0.070</td>
</tr>
<tr>
<td>Other single-vehicle collision</td>
<td>0.040</td>
<td>0.023</td>
</tr>
<tr>
<td>Noncollision</td>
<td>0.141</td>
<td>0.034</td>
</tr>
</tbody>
</table>

HSM provides default distributions if local tables are not available.

Ohio Proportional Tables: http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/ECAT.aspx

Up Next: Work Problems

- We keep all the digits until the end.
- Round CMFs to two digits and crash counts to 1 digit.
- When reporting to the public, we’ll round to whole numbers.
Learning Outcomes

- Introduction and use of SPFs, CMFs, and Cs
- Predictive method/analysis process
- Identify required data
- Discuss approach, appropriate use, and limitations
- Illustrate predictive method with an example
Topics/Examples Presented Today

- **Rural Two-Lane and Multilane**
  - Chapter 10 – Rural Two-Lane, Two-Way Roads
  - Chapter 11 – Rural Multilane Highways
- **Urban/Suburban Arterials**
  - Chapter 12 – Urban and Suburban Arterials

*Ohio Department of Transportation*

Rural two-lane and multilane roadways
### Base Conditions for rural two-lane two-way roads (Ch 10)

**Intersections**
- 90° angle (0° skew)
- No left turn lanes
- No right turn lanes
- No lighting

**Road segments**
- 12-ft lane widths
- 6-ft shoulder widths
- Roadside Hazard Rating -- 3
- 5 driveways per mile
- Tangent, flat alignment (No vertical grade)
- No centerline rumble strips
- No passing lanes
- No two-way left turn lanes
- No lighting
- No automated speed enforcement

### Base Conditions for rural multilane highways (Ch 11)

**Intersections**
- 90° angle (0° skew)
- No left turn lanes
- No right turn lanes
- No lighting

**Road segments**
- 12-ft lane widths
- 6-ft shoulder widths
- 30-ft median (4D)
- No lighting
- No automated speed enforcement
Study Site, Ohio

INTERSECTION PROJECT
Two-lane rural highway intersection

Analysis Period: 2006 – 2010
60 Total Crashes (12 crashes/year):
  59 R.E.
  1 Angle
  25% Injury, 75% PDO
  33% occurred between 2:00 – 4:00 PM.
  40.4% snow/rain
  17% dark/dusk

The opportunity?
Address the frequency of crashes at this intersection
But how do we quantify the potential for improvement?
Our Task

Perform predictive analysis for Rural Intersection on a Two-Lane Two-Way Facility

- What is the predicted performance of this location as compared to the predicted performance of similar two-lane two-way rural intersections that look exactly like the segments in our project area?

- What is the expected safety performance of this intersection given adjustment for actual site conditions and observed crash performance as compared to the predicted? => our opportunity for improvement!

Given Site Data - Intersection

Intersection Input Data

| ADT Major Street | 19,900 |
| ADT Minor Street | 1,070  |
| Left-turn lanes on approaches without stop control | None |
| Right-turn lanes on approaches without stop control | None |
| Lighting (present/not present) | Not Present |
| Skew (absolute value of deviation from 90 degrees) | 35 |
| Observed Crashes 2006-2010 (avg. crashes per year) | 60 (12) |
| Observe Fatal (avg. crashes per year) | 15(3) |
| Observed PDO (avg. crashes per year) | 45(9) |
| Calibration factor (C) | 1.00* |

*SPFs used in the predictive method are developed with data from specific jurisdictions and time periods. Calibration of SPFs to local conditions is necessary to account for the differences. ODOT is currently in the process of developing calibration factors for use in HSM analysis. For the purposes of this analysis calibration factors of 1.0 have been assumed for all SPFs.
Chapter 10 for 2-lane Rural Highway SPFs

Identify & apply the appropriate SPF

Calculate the predicted # of crashes for SPF base condition

Calculate the predicted average crash frequency for the base condition of

Identify and apply the appropriate SPF

a) Urban arterial?
b) 2-lane rural highway?
c) Rural multilane highway?

i. Segment?
ii. Intersection?

Find the SPF for each collision type
Calculate the predicted average crash frequency for the base condition of:

1. Identify and apply the appropriate SPF
2. Find the SPF for each collision type

### SPF for 2-lane rural three-leg stop controlled intersection

**Figure 10-4**

Equation 10-8:

\[ N_{spf3ST} = \exp[-9.86 + 0.79 \times \ln(AADT_{maj}) + 0.49 \times \ln(AADT_{min})] \]

Note! Should be natural log (ln)

Equation 10-8, page 10-18; Figure 10-4, page 10-19.
Predicted average crash frequency for a 2-lane rural three-leg stop controlled intersection

\[ N_{spf3ST} = \]
\[ = \exp[-9.86 + 0.79 \times \ln(AADT_{maj}) + 0.49 \times \ln(AADT_{min})] \]
\[ = \exp[-9.86 + 0.79 \times \ln(19,900) + 0.49 \times \ln(1,070)] \]
\[ = \exp[-9.86 + 7.8198 + 3.4179] = 3.9658 \text{ crashes/year} \]

Equation 10-8, page 10-18.

What does this value mean?

3.9658 predicted average number of crashes

If we reviewed a 1000 similar intersections (two-lane rural three-leg intersection SPF base conditions) for the given AADT we would have found that there are, on average, 4 crashes per year for all 1000 intersections.
Adjust for site conditions

1. Predicted crashes for the base condition
2. Adjust for site conditions that are different from the SPF base condition
3. Apply Calibration Factor

SPF \times (\text{CMF}_1 \times \ldots \times \text{CMF}_i) \times C

Calculate the predicted average crash frequency for the base (site) condition

2. Calculate predicted number of crashes for each element (similar sites)

a) Identify appropriate CMFs
b) Calculate CMFs based on site specific conditions
c) Combine segment CMFs
d) Combine intersection CMFs
e) Apply CMFs by segment/intersection
f) Apply local calibration factor ‘C’*

*SPFs used in the predictive method have been developed with data from specific jurisdictions and time periods. Calibration of SPFs to local conditions is necessary to account for the differences. ODOT has calibration factors for use in HSM analysis. These calibration factors are already included in ODOT HSM analysis tools, or are available upon request from ODOT.
Review base conditions & identify how the intersection differs

Base Conditions
- Left-turn lanes on approaches without stop control: None
- Right-turn lanes on approaches without stop control: None
- Lighting (present/not present): Not Present
- Skew (absolute value of deviation from 90 degrees): 0

Intersection Data
- Left-turn lanes on approaches without stop control: None
- Right-turn lanes on approaches without stop control: None
- Lighting (present/not present): Not Present
- Skew (absolute value of deviation from 90 degrees): 35
- Calibration factor (C): 1.45

Table 10-7, page 10-23
CMF for Intersection Skew Angle (CMF_{1i})

Equation 10-22 *

$$CMF_{1i} = e^{(0.004 \times \text{skew})}$$

$$= e^{(0.004 \times 35^\circ)}$$

$$= e^{(0.14)}$$

$$= 1.1503$$

*Equation 10-22 is the CMF for the effect of intersection skew on total crashes for three-leg intersections with stop-control on the minor approach; equation 10-23 is the corresponding CMF for four-leg intersections with stop-control on the minor approaches.

Calculate the predicted average number of crashes for site conditions

$$SPF \times (CMF_1 \times \ldots \times CMF_i) \times C$$

$$N_{\text{predicted \ int}} = N_{\text{spf 3ST}} \times CMF_{1i} \times C$$

$$= 3.9658 \times 1.1503 \times 1.45$$

$$= 6.6147 \text{average crashes}$$

Ohio Calibration Factors:
http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/ECAT.aspx
We calculated predicted average number of crashes per year

If we reviewed 1000 similar two-lane two-way rural intersections that look exactly like the intersection in our project area, (characteristics, traffic volume), we would have found that there are, on average 6.6 crashes/year on all such similar intersections.

NOTE: we have not net incorporated crash history so the predicted average # crashes/yr gives a baseline for the performance of intersections like this intersection.

The next step will tell us how our site is performing relative to its peers (i.e., other intersections like it).
We’ve calculated the predicted average number of crashes for similar sites (intersection types).

A supplementary step 3 in Part C is to calculate the **Expected Average Number of Crashes for the Site**

Calculate the expected average crash frequency for the base condition

Site specific EB method combines the predictive model estimate with observed crash frequency for the specific site, by segment and intersection.
**Apply site-specific EB method**

**STEP 1:** Calculate weight, \( w \)

**STEP 2:** Combine observed and predicted crash #

**STEP 3:** Adjust estimated value of expected average crash frequency to future time period (if needed)

---

**Equation A-5** (page A-19)

\[
 w = \frac{1}{1 + 0.54 \times 6.6147} 
\]

\( w = 0.2187 \)

For rural three-leg stop controlled intersections (\( k \)) is ? (hint: p. 10-18)

\( k = 0.54 \)

---

**Equation A-4** (page A-19)

\[
 N_{\text{expected}} = w \times N_{\text{predicted}} + (1-w) \times N_{\text{observed}}
\]

<table>
<thead>
<tr>
<th>Intersection</th>
<th>( w )</th>
<th>( N_{\text{pred}} )</th>
<th>( N_{\text{obs}} )</th>
<th>( N_{\text{exp}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2187</td>
<td>6.6147</td>
<td>12.0</td>
<td>10.8222</td>
</tr>
</tbody>
</table>
Apply site-specific EB method

**STEP 1:** Calculate weight, \( w \)

Eq A-5 (p.A-19)

**STEP 2:** Combine observed and predicted crash #

Eq A-4 (p.A-19)

**STEP 3:** Adjust estimated value of expected average crash frequency to future time period (if needed)

Eq A-15

\[
N_f = N_p \times \frac{N_{bf}}{N_{bp}} \times CMF_{1f} \times CMF_{1p} \times CMF_{2f} \times ... \times CMF_{nf}
\]

Equation A-15 (page A-23)

Predicted Average Crash Frequency for the site = 6.6

Expected average crash frequency for the site = N/A

Site is expected to have more crashes per year on average than its peers → Potential for improvement!

'expected excess crashes' = 10.8222 - 6.6147 = 4.2075 crashes per year

Expected average crash frequency for the site = 10.8

Site is expected to have fewer more crashes per year on average than its peers

Crashes Years

\( x \)
What does this mean?

Given
- the site conditions,
- the site crash history, and
- what we know about the crash performance of sites such as our own.

We estimate that the site will on average experience **10.8 total crashes per year**; and an excess of **4.2 crashes per year** (which is based on what the site’s peers experience on average: **6.6 crashes per year**). This 4.2 excess crashes translate into an opportunity for the potential for long term safety improvement.

What treatments might we apply in this situation?
Potential Treatments/Countermeasures?

?Correct for skew? – CMF in Part C
  = 1.0 for 90 degrees
  vs. 1.15 for site condition

?Lighting? – CMF in Part C
  = 0.9012

?Turn Lane? – CMF in Part C
  0.56 for single left-turn lane from major street

All of these would be expected to improve safety performance to varying degrees

?Others not in Part C? – See Part D and/or CMF Clearinghouse
Next Step:

Calculate the change in expected number of crashes for project conditions

This is the expected performance ‘after’ the construction of the selected treatment/countermeasure

Review existing conditions & identify how the intersection differs

**Existing Condition**
- Left-turn lanes on approaches without stop control: None
- Right-turn lanes on approaches without stop control: None
- Lighting (present/not present): Not Present
- Skew (absolute value of deviation from 90 degrees): 35

**Project Condition**
- Left-turn lanes on approaches without stop control: Present
- Right-turn lanes on approaches without stop control: None
- Lighting (present/not present): Not Present
- Skew (absolute value of deviation from 90 degrees): 35
- Calibration factor (C): 1.45

Table 10-7, page 10-23
What is the Expected Crash Performance of the project with selected treatment?

\[
N_{\text{expected(project)}} = N_{\text{expected(existing)}} \times \left(\frac{\text{CMF}_{2i}}{\text{CMF}_{1i}}\right)
\]

\[
= 10.8222 \times \left(\frac{0.56}{1.00}\right)
\]

\[
= 6.0604
\]
What is the change in expected number of crashes for project conditions

\[ N_\Delta = N_{\text{expected(existing)}} - N_{\text{expected(project)}} \]

\[ = 10.8222 - 6.0604 \]

\[ = 4.7618 \]

What does this mean?

With the construction of the left turn lane there is expected to be 5.0 crash per year benefit at this intersection.

Considerations in the application of CMFs to expected crash performance

- CMFs can be applied to existing conditions to estimate post construction conditions assuming there is little expected change in other conditions (AADT, geometry)
- Where significant changes in volume or site conditions are anticipated, this may not apply
Considerations in the application of CMFs to expected crash performance

Where long time frames are expected between the existing and future (completed project condition) and no other major site changes are expected, the expected crash performance may be adjusted to the future time period using equation A-15.

\[
N_f = N_p \times \frac{N_{bf}}{N_{bp}} \times CMF_{1f} \times CMF_{2f} \times \ldots \times CMF_{nf}
\]

What about the observed crash history the predicted crash performance?

Where:
Observed benefit = $12 - 12(0.56) = 5.3$
Predicted benefit = $6.6-6.6(0.56) = 2.9$

Why wouldn’t we consider these calculations?
Cautions to using Comparison to Observed and Predicted Crash Performance

- **Using Crash History:**
  - Ignores regression to the mean
  - Results in over predicting crash benefit
  - → will not get the return we expect or plan on

- **Using Predicted Crash Performance:**
  - Under predicts effectiveness
  - Is OK in that it is conservative and at least money is not wasted
  - → may mean missed opportunity

Rural Two-Lane Vs. Rural Multilane

For rural multi-lane facilities we model intersections & segments using CMFs similar to rural two-lane.

Analysis may be performed by collision type such as Run-off Road, Head-on, Sideswipe, and Nighttime or by severity level – Fatal/Injury, PDO, etc.
Rural Multilane

- Multilane analysis is similar to Two-lane Two-way – differences are in types of conditions that CMFs address and that CMFs are more frequently developed/applied by crash type.

- Additional example problem (#2) will be provided for Urban/Suburban Arterial Intersection and includes more detailed examples of analysis by crash type.

Questions and Discussion
UP NEXT:
Predictive Method for Urban and Suburban Arterial Example Problem #2
Ohio Department of Transportation

ODOT HSM Training

Safety Prediction for ODOT
Example Problems – Part 2

Urban and Suburban Arterials
Base Conditions for urban & suburban arterial SPFs (Ch 12)

**Intersections**
- No left-turn lanes
- Permissive left-turn signal phasing
- No right-turn lanes
- Right-turn on red permitted
- No lighting
- No red-light cameras
- No bus stops, schools or alcohol sales establishments near intersection

**Road segments**
- No on-street parking
- No roadside fixed objects
- 15-ft median (4D)
- No lighting
- No automated speed enforcement

For urban arterials projects we model intersections & segments separately by collision type:

**Intersections**
- MV collisions
- SV collisions
- *Vehicle-pedestrian* collisions
- *Vehicle-bicycle* collisions

**Roadway Segments**
- MV non-driveway collisions
- MV driveway related collisions
- SV collisions
- *Vehicle-pedestrian* collisions
- *Vehicle-bicycle* collisions
Study Site, Ohio

INTERSECTION
Urban/Suburban Multilane Arterial Intersection

Note: Some assumptions were made for training purposes, may not reflect real on-site conditions or ODOT findings or recommendations

Site:  Four-leg Urban Arterial Intersection

The facts:
- Intersection of two four-lane undivided Urban-Principal Arterials
- Major ADT – 25,340, Minor ADT – 24,390
- Signal controlled intersection
- Left-turn lanes and protected left-turn phases on all approaches
- Right-turn lanes on two approaches
- Right-turns on red permitted on all approaches
- All lanes are 12 feet wide
- No pedestrian facilities and minimal/no pedestrian traffic
- Intersection lighted
- Observed Crash Performance: 53 crashes over 3 year period

Crash types:
- 31 rear end
- 6 angle
- 7 left-turn
- 6 sideswipe
- 1 fixed object
- 1 overturn
- 1 head-on

Crash Characteristics:
- 19 crashes at night
- 6 crashes – ran red light
- 2 single vehicle crashes
- 1 fixed object crash
- 18 Injury, 35 PDO
Session 4.2

Step 1 in the process

Calculate the predicted number of crashes for the base condition of a 4-leg urban arterial signalized intersection

\[ N_{\text{predicted base}} = \text{SPF} \]

<table>
<thead>
<tr>
<th>Input Data</th>
<th>Base Conditions</th>
<th>Site Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection Type (3ST, 3SG, 4ST, 4SG)</td>
<td>---</td>
<td>4SG</td>
</tr>
<tr>
<td>AADT_{maj}(veh/day)</td>
<td>---</td>
<td>25340</td>
</tr>
<tr>
<td>AADT_{min}(veh/day)</td>
<td>---</td>
<td>24390</td>
</tr>
<tr>
<td>Intersection lighting (present/not present)</td>
<td>not present</td>
<td>present</td>
</tr>
<tr>
<td>Calibration factor, CI</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Data for unsignalized intersections only</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Number of major-road approaches with left-turn lanes (0, 1, 2)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Number of minor-road approaches with left-turn lanes (0, 1, 2)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Data for signalized intersections only</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Number of approaches with left-turn lanes (0, 1, 2, 3, 4)</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Number of approaches with right-turn lanes (0, 1, 2, 3, 4)</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Number of approaches with left-turn phasing (0, 1, 2, 3, 4)</td>
<td>---</td>
<td>4</td>
</tr>
<tr>
<td>Number of approaches with right-turn on-red-prohibited (0, 1, 2, 3, 4)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Type of left-turn signal phasing (each approach)</td>
<td>permissive</td>
<td>protected(all)</td>
</tr>
<tr>
<td>Intersection red light cameras (present/not present)</td>
<td>not present</td>
<td>not present</td>
</tr>
<tr>
<td>Sum of all pedestrian crossing volumes (PedVol)</td>
<td>---</td>
<td>0</td>
</tr>
<tr>
<td>Maximum number of lanes crossed by a pedestrian (nlanes)</td>
<td>---</td>
<td>6</td>
</tr>
<tr>
<td>Number of Bus stops within 300 m (1000 ft) of the intersection</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>Schools within 300 m (1000 feet) of the intersection (present/non present)</td>
<td>not present</td>
<td>Not present</td>
</tr>
<tr>
<td>Number of alcohol sales establishments within 300 m (1000ft) of the intersection</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Our task

Calculate the predicted average crash frequency for the base condition of a 4-leg signalized urban arterial intersection

Identify and apply the Appropriate SPF

a) Urban arterial?
b) 2-lane rural highway?
c) Rural multilane highway?
   i. Segment?
   ii. Intersection?

Find the SPF for each collision type
Our task

Calculate the predicted average crash frequency for the base condition of the 4SG on urban and suburban arterials

1. Identify and apply the appropriate SPF

   a) Urban arterial
   b) 2-lane rural highway
   c) Rural multilane highway

   i. Segment
   ii. Intersection

   Find the SPF for each collision type

SPF for each collision type

Total Crashes =

- Multiple-vehicle collisions
- Single-vehicle collisions
- Veh-pedestrian collisions
- Veh-bicycle collisions
Multiple-vehicle collisions

\[ N_{\text{binv}} = \exp(a + b \times \ln(AADT_{\text{maj}}) + c \times \ln(AADT_{\text{min}})) \]

Eq. 12-21 (p.12-29), Fig. 12-13 (p.12-32)

Multiple-vehicle collisions (cont)

Table 12-10. SPF Coefficients for Multiple-Vehicle Collisions at Intersections

<table>
<thead>
<tr>
<th>Intersection Type</th>
<th>Intercept (a)</th>
<th>AADT_{maj} (b)</th>
<th>AADT_{min} (c)</th>
<th>Overdispersion Parameter (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Crashes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3ST</td>
<td>-13.36</td>
<td>1.11</td>
<td>0.41</td>
<td>0.80</td>
</tr>
<tr>
<td>JSG</td>
<td>-12.13</td>
<td>1.11</td>
<td>0.26</td>
<td>0.33</td>
</tr>
<tr>
<td>45T</td>
<td>-8.50</td>
<td>0.52</td>
<td>0.25</td>
<td>0.40</td>
</tr>
<tr>
<td>4SG</td>
<td>-10.99</td>
<td>1.07</td>
<td>0.23</td>
<td>0.39</td>
</tr>
</tbody>
</table>

\[ N_{\text{binv}} = \exp(a + b \times \ln(AADT_{\text{maj}}) + c \times \ln(AADT_{\text{min}})) \]

\[ = \exp[-10.99 + 1.07 \times \ln(45T_{\text{maj}}) + 0.23 \times \ln(45T_{\text{min}})] \]

Eq. 12-21 (p.12-29) & Table 12-10 (p.12-30)
Multiple-vehicle collisions (cont)

\[ N_{\text{inv}} = \exp(a + b \times \ln(AADT_{\text{maj}}) + c \times \ln(AADT_{\text{min}})) \]

\[ = \exp[-10.99 + 1.07 \times \ln(25,340) + 0.23 \times \ln(24,390)] \]

\[ = 8.8463 \times \text{crashes/year} \]

* predicted average # multiple vehicle collisions/yr for the base condition

What does this value mean?

Our calculation shows 8.9 multiple vehicle crashes

If we reviewed a 1000 similar 4SG (base conditions) for the given entering volumes, we would have found that there are, on average, 8.9 multiple vehicle crashes.
Calculate the predicted single vehicle collisions for base conditions using the SPF

Initial \( N_{biv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \)

\[
= \exp[-10.21 + 0.68 \times \ln(25,340) + 0.27 \times \ln(24,390)]
\]

\( = 0.5599 \) predicted single-vehicle crashes/yr

*initial predicted average # single vehicle collisions for the base condition

Eq. 12-24 (p.12-32) Table 12-12 (p. 12-33)
The SPF for vehicle-pedestrian collisions ($N_{\text{pedbase}}$):

$$N_{\text{pedbase}} = \exp\left(a + b \times \ln(AADT_{\text{total}}) + c \times \ln\left(\frac{AADT_{\text{min}}}{AADT_{\text{maj}}}\right) + d \times \ln(PedVol) + e \times n_{\text{lanes}}\right)$$

= predicted average # vehicle-pedestrian crashes for the base condition of the intersection

Where:

- $N_{\text{pedbase}}$ = predicted number of vehicle-pedestrian collisions per year for base conditions at signalized intersections
- $AADT_{\text{total}}$ = the sum of the ADT volumes for major and minor roads
- $PedVol$ = sum of daily pedestrian volumes crossing the intersection (ped/day)
- $n_{\text{lanes}}$ = maximum number of traffic lanes crossed by a pedestrian in any crossing maneuver at the intersection
- $a, b, c, d, e$ = regression coefficients

Why calculate pedestrian collisions if we have no observed pedestrian crashes?

1. Site may not represent performance of similar sites
2. Study period may be too short to capture pedestrian-vehicle collisions at this intersection

The HSM provides estimates of pedestrian volumes based on general level of pedestrian activity.

What is the estimate of PedVol for a 4 leg signal controlled intersection with a LOW general level of pedestrian activity?

$PedVol = 50$
Vehicle-pedestrian collisions

\[ N_{\text{pedbase}} = \exp[a + b \times \ln(AADT_{\text{total}}) + c \times \ln(AADT_{\text{min}}/AADT_{\text{maj}}) + d \times \ln(\text{PedVol}) + e \times N_{\text{lanesx}}] \]

\[ = \exp[-9.53 + 0.40 \times \ln(25,340 + 24,390) + 0.26 \times \ln(24,390/25,340) + 0.45 \times \ln(50) + 0.04 \times 6] \]

\[ = 0.0403 \] predicted average # vehicle-pedestrian crashes/year for the base condition of the intersection or approximately 1 pedestrian crash every 25 years *

* All vehicle-pedestrian crashes are considered to be fatal-and-injury type crashes

---

Vehicle-bicycle collisions

SPF for vehicle-bicycle collisions?
No, we apply a bicycle factor to the sum of the MV and SV predicted crash frequency

Predicted number of bicycle crashes:

\[ N_{\text{bikei_base}} = (N_{\text{bimv}} + N_{\text{bisv}}) \times f_{\text{bikei}} \]

After adjusting base condition to site condition
### Summary Results for the *Base Conditions* of our intersection

**Summary:** Initial Predicted Average Number of Crashes for the Base Condition

<table>
<thead>
<tr>
<th>Collision Type</th>
<th>Total Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-vehicle collisions</td>
<td>8.8463</td>
</tr>
<tr>
<td>Single-vehicle collisions</td>
<td>0.5599</td>
</tr>
<tr>
<td>Vehicle-pedestrian collisions</td>
<td>0.0403</td>
</tr>
<tr>
<td>Vehicle-bicyclist collisions</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note: Vehicle-bicycle collisions not included – we can only calculate that once we've adjusted our MV and SV collision SPF's for our site conditions*

### Summary Results for the *Base Conditions* of our intersection

<table>
<thead>
<tr>
<th>Crash severity level</th>
<th>Predicted average crash frequency, N&lt;sub&gt;predicted int&lt;/sub&gt; (crashes/year)</th>
<th>Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (MV+SV)</td>
<td>9.4</td>
<td>Predicted MV + SV</td>
</tr>
<tr>
<td>Fatal and injury (FI)</td>
<td>3.1</td>
<td>For both FI and PDO:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MV: Equation 12-21, Table 12-10 coefficients for FI and PDO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equation 12-22, Equation 12-23 to correct for imbalances in sum</td>
</tr>
<tr>
<td>Property damage only (PDO)</td>
<td>6.3</td>
<td>SV: Equation 12-25, Table 12-12 coefficients for FI and PDO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equation 12-25, Equation 12-26 to correct for imbalances in sum</td>
</tr>
</tbody>
</table>

*Note: Vehicle-bicycle collisions not included – we can only calculate that once we've adjusted our MV and SV collision SPF's for our site conditions*
Handout 1
Calculation of FI and PDO Crashes for Base Conditions

Reminder...

We only applied the SPF
So the results are for the base condition of our signalized intersection.
Our task

Calculate the predicted average crash frequency for our signalized urban arterial intersection

4SG Base Conditions

* No left-turn lanes
* Permissive left-turn phasing
* No right-turn lanes
* No lighting
* No bus stops, schools or alcohol sales establishments near intersection
* Right-turn on red permitted
* No automated enforcement

Our Site

What’s Different?

VS.
The predicted average number of MV crashes for the base condition is 8.8463

CMFs for MV SPF site conditions:
- Presence of left turn lanes
- Presence of left-turn signal phasing
- Presence of right-turn lanes
- Right-turn on red permitted
- Lighting present
- Red-light cameras/automated enforcement present
### Table 12-24. Crash Modification Factors for Left Turn Lanes

<table>
<thead>
<tr>
<th></th>
<th>Minor-rd STOP control</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 approach</td>
<td>2 approaches</td>
<td>3 approaches</td>
</tr>
<tr>
<td>3-leg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor-rd STOP control</td>
<td>0.67</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Traffic Signal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 approach</td>
<td>0.93</td>
<td>0.86</td>
<td>0.80</td>
</tr>
<tr>
<td>2 approaches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 approaches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-leg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor-rd STOP control</td>
<td>0.73</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>Traffic Signal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 approach</td>
<td>0.90</td>
<td>0.81</td>
<td>0.73</td>
</tr>
<tr>
<td>2 approaches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 approaches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 approaches</td>
<td>0.66</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12-24 (p. 12-43)
Our intersection has a protected left-turn phase on four approaches.

CMF for left-turn signal phasing

<table>
<thead>
<tr>
<th>Type of Left-Turn Signal Phasing</th>
<th>CMF_{2i}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permissive</td>
<td>1.00</td>
</tr>
<tr>
<td>Protected/permisive or permissive/protected</td>
<td>0.99</td>
</tr>
<tr>
<td>Protected</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Note: Use CMF_{2i} = 1.00 for all unsignalized intersections. If several approaches to a signalized intersection have left-turn phasing, the values of CMF_{2i} for each approach are multiplied together.

Note: Because the protected/permisive phasing is used on 4 approaches, the answer is computed by:

\[ CMF_{2i} = (0.94)^4 = 0.7807 \]

Table 12-25 (p.12-44)
### CMF for Right-Turn Lanes

**Table 12-26 (p. 12-44)**

<table>
<thead>
<tr>
<th></th>
<th>Minor-rd STOP control</th>
<th>1 approach</th>
<th>2 approaches</th>
<th>Traffic Signal</th>
<th>1 approach</th>
<th>2 approaches</th>
<th>3 approaches</th>
<th>4 approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-leg</td>
<td></td>
<td>0.86</td>
<td>0.74</td>
<td></td>
<td>0.96</td>
<td>0.92</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-leg</td>
<td></td>
<td>0.86</td>
<td>0.74</td>
<td></td>
<td>0.96</td>
<td>0.92</td>
<td>0.88</td>
<td>0.85</td>
</tr>
</tbody>
</table>
CMF for Right-Turn-on-Red

If we allow RTOR and the base condition is allowing RTOR, what is the CMF?

CMF = 1.0
i.e. NO change

CMF for lighting

Our intersection has lighting and the base condition is no lighting
CMF for Lighting

Table 12-27, p.12-45 (default values in absence of locally derived values)

<table>
<thead>
<tr>
<th>Intersection Type</th>
<th>Proportion of Crashes that Occur at Night (Pn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3ST</td>
<td>0.238</td>
</tr>
<tr>
<td>4ST</td>
<td>0.229</td>
</tr>
<tr>
<td>3SG and 4SG</td>
<td>0.235</td>
</tr>
</tbody>
</table>

NOTE. CMF applies to all crash types

\[
CMF_{ji} = 1 - 0.38 \times P_{ni} = 1 - 0.38(0.235) = 0.9107
\]

Therefore, the predicted average number of MV crashes will be:

\[
N_{MV\ predicted\ intersection} = SPF_{MV} \times CMFs = 8.8463 \times [0.6600 \times 0.7807 \times 0.9200 \times 0.9107] = 8.8463 \times [0.4317] = 3.8190\ predicted\ MV\ crashes/yr
\]
**Next steps:**
calculate the predicted average number of crashes for the other three collision types

---

**Single-vehicle collisions**

Determine whether any CMF’s are needed to adjust the base condition to match the site condition

The CMF’s for the single-vehicle collisions will be the same as the combined CMF for the multiple-vehicle collisions (0.4317).
Determine the predicted average number of single vehicle collisions

**Predicted SV Crashes**

\[ \text{Predicted SV Crashes} = N_{\text{bisv}} \times \text{CMFs} \]

\[ = 0.5599 \times 0.4317 \]

\[ = 0.2417 \text{ predicted SV crashes/yr} \]

---

Determine whether any CMF’s are needed to adjust the base condition to match the site condition

Three CMF’s are usually considered when adjusting \( N_{\text{pedbase}} \) to match site conditions:

- CMF for Bus Stops,
- CMF for Schools,
- and CMF for Alcohol Sales Establishments.

Based on the given information, none of these CMFs are applicable.
Vehicle-ped collisions (cont)

<table>
<thead>
<tr>
<th>CMF for bus stops</th>
<th>Crash Modification Factors (CMF_{bp}) for the Presence of Bus Stops near the Intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Stops within 1000 ft of the intersection</td>
<td>CMF_{bp}</td>
</tr>
<tr>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>1 or 2</td>
<td>2.78</td>
</tr>
<tr>
<td>3 or more</td>
<td>4.15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CMF for proximity to schools</th>
<th>Crash Modification Factors (CMF_{sp}) for the Presence of Schools near the Intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Stops within 1000 ft of the intersection</td>
<td>CMF_{sp}</td>
</tr>
<tr>
<td>No School Present</td>
<td>1.00</td>
</tr>
<tr>
<td>School Present</td>
<td>1.35</td>
</tr>
</tbody>
</table>

Includes any alcohol sales establishment (e.g. liquor stores, bars, restaurants, grocery stores.)

Tables 12-28, 12-29 (p. 12-46)
Why Alcohol Sales Establishments in particular?

- Intersections near to alcohol sales establishments are likely to experience more veh-ped collisions than those that are not.
- Alcohol Sales establishments are identified within state database (liquor license)
- Surrogate for density of development

---

Vehicle-ped collisions *(cont)*

CMF for alcohol sales establishments

<table>
<thead>
<tr>
<th>Number of Alcohol Sales Establishments within 1,000 ft of the Intersection</th>
<th>CMF (3p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>1–8</td>
<td>1.12</td>
</tr>
<tr>
<td>9 or more</td>
<td>1.56</td>
</tr>
</tbody>
</table>

Table 12-30 (p.12-47)
Determine the predicted average number of vehicle-pedestrian collisions

Predicted # of pedestrian crashes

\[ N_{pedi} = N_{pedbase} \times CMFs \]
\[ = 0.0403 \times 1.00 \]
\[ = 0.0403 \text{ predicted vehicle-ped crashes/yr} \]

SPF for vehicle-bicycle collisions?

No, we apply a bicycle factor to the sum of the MV and SV predicted crash frequency

Predicted number of bicycle crashes:

\[ N_{bikei} = (N_{bimv} + N_{bisv}) \times f_{bikei} \]

Already adjusted with CMFs
Vehicle-bicycle collisions

Table 12-17. Bicycle Crash Adjustment Factors for Intersections

<table>
<thead>
<tr>
<th>Intersection Type</th>
<th>Bicycle Crash Adjustment Factor ($f_{bikei}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3ST</td>
<td>0.016</td>
</tr>
<tr>
<td>3SG</td>
<td>0.011</td>
</tr>
<tr>
<td>4ST</td>
<td>0.018</td>
</tr>
<tr>
<td>4SG</td>
<td>0.015</td>
</tr>
</tbody>
</table>

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All bicycle collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes. Source: HSTS data for California (2002–2006)

$N_{bikei}$

$= (N_{bimv} + N_{bisv}) \times f_{bikei} \times C$

$= (3.8190 + 0.2417) \times 0.015$

$= 0.0609$ predicted veh-bicycle crashes/yr

i.e. approximately 1 every 17 years...

Note: $N_{bimv} + N_{pisv}$ are both the predicted # crashes (i.e. adjusted with CMFs, not just the base condition)
We combine all the different collision types at our intersection:

\[ N_{\text{predicted int}} = (N_{\text{bimv}} + N_{\text{bisv}} + N_{\text{pedi}} + N_{\text{bikei}}) \times C^* \]

\[ = (3.8190 + 0.2417 + 0.0403 + 0.0609) \times 1.0 \]

\[ = 4.1619 \text{ predicted crashes/yr} \]

Note: round to 4 crashes when discussing results with the public

*SPFs used in the predictive method have been developed with data from specific jurisdictions and time periods. Calibration of SPFs to local conditions is necessary to account for the differences. ODOT has calibration factors for use in HSM analysis. These calibration factors are already included in ODOT HSM analysis tools, or are available upon request from ODOT. For the purposes of this analysis the calibration factor was assumed to be 1.0.

What does this mean?

\[ N_{\text{predicted int}} = 4.2 \text{ crashes/year} \]

If we reviewed the crash experience of 1,000 other 4SG sites with exactly the same conditions as our intersection (i.e. volumes and site-specific characteristics), we can expect that we will, on average, observe 4 crashes at these intersections per year.
Our task

Calculate the expected average crash frequency for our signalized urban arterial intersection
Calculate the expected average crash frequency

- Use over dispersion parameter (k) and observed crashes for each collision type
- Predicted = Expected
- Total expected average crash frequency

Multiple-vehicle collisions

Single-vehicle collisions

Veh-pedestrian collisions

Veh-bicycle collisions

Multiple-vehicle collisions

Single-vehicle collisions

\[
 w = \frac{1}{1 + k \times \left( \sum N_{\text{predicted}} \right)}
\]

\[
 N_{\text{expected}} = w \times N_{\text{predicted}} + (1 - w) \times N_{\text{observed}}
\]

### Average Crash History by Collision Type

<table>
<thead>
<tr>
<th>Collision Type</th>
<th>Fatal &amp; Injury</th>
<th>PDO</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-vehicle collisions</td>
<td>5.7</td>
<td>11.3</td>
<td>17.0</td>
</tr>
<tr>
<td>Single-vehicle collisions</td>
<td>0.3</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Vehicle-pedestrian collisions</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Vehicle-bicycle collisions</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6.0</strong></td>
<td><strong>11.7</strong></td>
<td><strong>17.7</strong></td>
</tr>
</tbody>
</table>

What is the overdispersion parameter \(k\) for this 4SG intersection?

With the overdispersion parameter \(k\) of 0.39 we calculate \(w\):

\[
\begin{align*}
    w &= 1/[1+k \times (3.819)] \\
    &= 1/[1+0.39(3.819)] \\
    &= 0.4017
\end{align*}
\]

\(k\) from table 12-10, p.12-30 for MV

#### Multiple-vehicle crashes

**What is the overdispersion parameter \(k\) for this 4SG intersection?**

- **Calculate \(w\)**, the weighted adjustment for observed crashes

  \[
  w = 1/[1+k \times (3.819)]
  \]

  \[
  = 1/[1+0.39(3.819)]
  \]

  \[
  = 0.4017
  \]

\(k\) from table 12-10, p.12-30 for MV
Multiple-vehicle crashes (continued)

\[ N_{\text{expected}} = w \times N_{\text{predicted}} + (1 - w) \times N_{\text{observed}} \]

\[ = (0.4017 \times 3.8190) + (1 - 0.4017) \times (17.0) \]
\[ = 11.7052 \text{ expected average MV crashes} \]

Eq. A-4 (p.A-19)

Multiple-vehicle crashes (continued)

\[ N_{i\text{MV\_expected TOTAL}} = 11.7 \]

In other words, *given our site conditions* and what we know about the *crash performance of sites such as our own*, along with *crash history*, we estimate that we will on average experience 11.7 multiple vehicle crashes/yr.
Handout 2
Calculation of Expected Single Vehicle Crashes

<table>
<thead>
<tr>
<th>Collision Type</th>
<th>Expected average # of crashes per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-vehicle</td>
<td>11.7052</td>
</tr>
<tr>
<td>Single-vehicle</td>
<td>0.2417</td>
</tr>
<tr>
<td>Vehicle-ped</td>
<td>0.0403</td>
</tr>
<tr>
<td>Vehicle-bicycle</td>
<td>0.0609</td>
</tr>
<tr>
<td><strong>All</strong></td>
<td><strong>12.0481</strong></td>
</tr>
</tbody>
</table>
Summary Results

Average number of crashes per year by severity:

<table>
<thead>
<tr>
<th></th>
<th>( N_{\text{predicted}} )</th>
<th>( N_{\text{expected}}^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>4.2</td>
<td>12.1</td>
</tr>
<tr>
<td>Fatal and injury (FI)</td>
<td>1.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Property damage only (PDO)</td>
<td>2.7</td>
<td>7.9</td>
</tr>
</tbody>
</table>

* Note: differences in total and FI+PDO due to rounding
Handout 3
Calculation of Expected FI and PDO Crashes for Site Conditions

Interpretation

Given
- the site conditions,
- the site crash history, and
- what we know about the crash performance of sites such as our own,

We estimate that we will on average experience 12.2 crashes per year.
Questions and Discussion
Freeway and Interchange Crash Prediction -- ISATe
Challenges for ODOT

Interchange and freeway corridor projects are the most complex and expensive of all ODOT projects.

We should understand the expected safety performance of a $250 million investment.

Would you expect these three alternatives to experience the same number of crashes over a 30 year project life?

If not, would it be helpful to understand the potential differences when selecting a preferred alternative?
Interchange and Corridor Planning and Design Issues

- Configuration (service and system)
- Design geometry (e.g., design speed of ramps)
- Interchange spacing
- Weaving vs. CD roads vs. ramp braids
- Design Level of Service (number of lanes and amount of traffic for which design should accommodate)
- Design exceptions

HSM Chapter on Freeways and Interchanges

- NCHRP Project 17-45 – ‘ISATe’ – Interchange Safety Analysis Tool Enhanced
  - Texas Transportation Institute (Jim Bonneson, PI)
  - CH2M HILL subcontractor (Tim Neuman)
  - Research completed in later 2011 and approved in September 2012
  - ISATe Tool Released for use in 2012
  - TRB Highway Safety Performance Committee recommended adoption into the HSM – published as HSM 2014 Supplement
  - ECAT Tool has been updated to add Freeway Analysis (2016/2017)
Potential HSM Freeway Applications

- Predict crashes before and after reconstruction of a corridor
- Evaluate affect of adding new interchange
- Predict interchange configuration alternatives
- Evaluate and refine geometry

Crash Prediction for Freeway Segments and Interchanges

- Statistical modeling process similar to other chapters was used
  - SPF, CMF, C
  - Data from California, Maine and Washington states
- ‘Google earth’ used to obtain horizontal and cross sectional data on hundreds of miles of freeways and interchanges
Freeway Crash Prediction Components

- Freeway Segments
- Ramps
- Ramp Terminal Intersections with Crossroad

Freeway Segments

- Geometric Data
  - Basic Roadway Data – Length, number of lanes, area type
  - Alignment – horizontal curve
  - Cross Section – lane width, inside/outside shoulder widths, rumble strips, median barrier
  - Roadside data – clear zone, roadside barrier
  - Ramp Access – presence, side, length of speed-change area

- Traffic Data
  - AADT - Segment, entrance ramp, exit ramp
  - Proportion of AADT during high-volume hours
Ramp Segments

Geometric Data
- Basic Roadway Data – Length, number of lanes, Average Speed on Freeway, type of traffic control at ramp terminal, area type
- Alignment – horizontal curve
- Cross Section – lane width, left/right shoulder widths, lane add/drop in segment
- Roadside data – barrier
- Ramp Access – length of speed-change area, length of weaving section

Traffic Data
- AADT - segment

Ramp Terminal Intersections

Geometric Data
- Basic Intersection Data – area type, terminal configuration, presence of non-ramp public street
- Alignment – skew, distance to nearest public street intersection on outside crossroad leg, distance to adjacent ramp terminal
- Traffic Control – presence of protected left/right turn control on crossroad
- Cross Section – crossroad median width, number of lanes crossroad and ramp, right-turn channelization on crossroad, left-turn and right-turn lanes/bays on crossroad
- Access data – number of drives, public street approaches
- Ramp Access – presence, side, length of speed-change area

Traffic Data
- AADT – ramp, crossroad
HSM Freeway Analysis

**Segmentation**
- Divide facility (freeway/ramps) into homogenous segments and intersections (ramp terminal)
- Most time-intensive part of analysis
- Most important part of analysis
- The more homogenous a section, the more accurate your results!

**Both Directions of Freeway Analyzed**
- May require averaging of values - see comments/notes in tools
- Situations with significantly different cross section or differing number of lanes by direction requires special analysis approach – ASK ODOT !!!

Limitations

**Site types not addressed**
- Facilities with HOV lanes
- Ramp metering
- Frontage roads
- Speed change lanes at crossroads

**Geometric elements not addressed**
- Vertical geometry
- > 10-lane freeway segments
- > 2-lane ramp segments
- Differing barrier types (i.e. cable vs. guardrail vs. jersey barrier)

**Freeways with Barrier Separated Managed Lanes or Toll Facilities**
- Can be analyzed for some conditions - special considerations described in HSM
Special Conditions

Freeways with Barrier Separated Managed Lanes
- Managed Lanes (Express, HOT, HOV) are considered part of median
- Analysis is performed for General Purpose lanes with managed lane entry/exit points treated as entrance or exit ramps

Toll Facilities
- Can be analyzed provided the section is sufficiently distance from toll facility so that the facility does not influence vehicle operations
- Areas in immediate vicinity of a toll plaza, where widened to accommodate vehicles through a toll plaza, or areas that experience toll-related traffic queues or speed changes cannot be analyzed via HSM

Calibration

Model derived from multiple state databases

Reporting thresholds vary state-by-state

Uses of an calibrated vs. uncalibrated model
- Calibrated - preferred
  - ODOT has calibration factors for use in Ohio analysis for many conditions – included in ECAT
- Uncalibrated - still a good analysis tool
  - Compare multiple alternatives against one another
  - K/A reporting is fairly consistent state-by-state
  - Compare predicted crash pattern against observed crash pattern
  - Meaningful for work outside Ohio or where calibration factors don’t exist (for conditions not covered by HSM models there will be no calibration factors - ASK ODOT !!!)
Predictive Methods for Freeway Segments (HSM Ch. 18)

- Safety Performance Functions
  - Rural vs. Urban
  - Number of Lanes
  - Single Vehicle
  - Multiple Vehicle
  - Fatal and Injury
  - Property Damage Only

<table>
<thead>
<tr>
<th>Freeway Segments</th>
<th>Crash Type</th>
<th>Crash Severity</th>
<th>SPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four lane divided</td>
<td>Multiple vehicle (rev)</td>
<td>Fatal and injury (R)</td>
<td>SPF</td>
</tr>
<tr>
<td>Single vehicle (s)</td>
<td>Fatal and injury (R)</td>
<td>Property damage only (pol)</td>
<td></td>
</tr>
<tr>
<td>Eight lane divided</td>
<td>Multiple vehicle (rev)</td>
<td>Fatal and injury (R)</td>
<td>SPF</td>
</tr>
<tr>
<td>Single vehicle (s)</td>
<td>Fatal and injury (R)</td>
<td>Property damage only (pol)</td>
<td></td>
</tr>
</tbody>
</table>

Freeway Segments

- Safety Performance Functions

[AADT vs. Multiple-Vehicle Crash Frequency Graph]
Freeway Segment CMFs

- **Crash Modification Factors**
  - Developed to work with SPFs
  - Most are functions of geometric variables
  - May affect single vehicle vs. multiple vehicles

  - Horizontal Curve
  - Lane Width
  - Inside Shoulder Width
  - Median Width
  - Median Barrier
  - High Volume
  - Lane Change
  - Outside Shoulder Width
  - Shoulder Rumble Strip
  - Outside Clearance
  - Outside Barrier
  - Ramp Entrance Ramp Exit

Freeway Segment CMFs

- **Median Barrier**
  - Data requirements include:
    - length and offset to median and roadside barrier
    - width of continuous median barrier
  - Requires consideration of preliminary barrier layout at earlier point in project development
Freeway Segment CMFs

High Volume

Volume Variation During Average Day

- Proportion of AADT during hours where volume exceeds 1,000 veh/h/ln:
  - Hourly volumes may be continuously high, or
  - May represent a few high peak hours
- Use nearest traffic count station (ATR) data

Ramp spacing and taper lengths

- Ramp spacing impacts lane change CMF
- Useful metric during design phase:
  - How does the CMF change as ramps are spaced closer and closer to one another or removed entirely?
  - What happens if a ramp is removed entirely?
Type B Weaving

- Presence of Type B weave adds a “bonus” CMF to analysis
- Other types of weaving accounted for by generic lane change CMF

Useful metric during design phase:
- How does this CMF affect predicted number of crashes as the Type B weave gets shorter?

Ramp spacing and taper lengths

- **Ramp in segment**
  - Define type (lane add or speed change lane)
  - Define length of entrance/exit between taper point and 2’ separation
  - Define side (left or right)

- **Ramp outside of segment**
  - Entrance: Define distance from begin milepost of the current segment to ramp gore (2’ separation point) of previous upstream entrance ramp
  - Exit: Define distance from end milepost of the current segment to ramp gore (2’ separation point) of next downstream exit ramp
Predictive Methods for Ramps or C-D Roads (HSM Ch. 19)

- **Ramp Analysis:**
  - Entrance Ramp Segment (one or two lanes)
  - Exit Ramp Segment (one or two lanes)
  - Crossroad Ramp Terminal Intersection

- **Ramp:** Roadway between the freeway speed change lane and either the cross road ramp terminal or crossroad speed-change lane.

- **C-D Road:** is the roadway between the freeway ramp exit speed-change lane and the freeway ramp entrance speed-change lane.

- HSM methods cannot evaluate frontage roads unless they can be considered a roadway type covered in Chapters 10, 22, 12!

---

Freeway Ramp Segments

- **Segment-based evaluation**
  - Works for all ramp configurations up to 2 lanes
  - Similar to freeway segment analysis
  - Can also analyze C-D roads
Freeway Ramp Segments

Safety Performance Functions
- Defined by whether ramp segment is Exit, Entrance, C-D
- Area Type
- Number of Lanes

Crash Modification Factors
- Ramp or C-D Road
  - Horizontal Curve
  - Lane Width
  - Shoulder width
    - Right
    - Left
  - Barrier
    - Right
    - Left
- Lane add or drop
- Ramp speed change Lane
- C-D Road
- Weaving section
Ramp Segments - Mileposting

- Used to model the speed of a vehicle along the ramp
- Establishes ramp horizontal curve CMF
- Milepost = distance along ramp to start of curve
- Establish one milepost 0.0 for all segments on ramp
- Establish one milepost 0.0 for all ramps with a common entrance or exit location

Some ramps have two possible milepost 0.0 locations
- Goal is to estimate average curve entry speed on these segments
Predictive Methods for Ramp Terminal Analysis (HSM Ch. 19)

- Most detailed part of Freeway/Ramp analysis
- Method addresses seven configurations

Ramp Terminal Analysis

- Safety Performance Functions
- Characteristics
  - Traffic Control
  - Cross Section
  - Area Type
  - AADT Volume
Ramp Terminal Analysis

Crash Modification Factors

- Exit Ramp Capacity
- Cross Road Turn Lane
  - Right turn
  - Left turn
- Access point frequency
- Segment length
- Median width
- Stop
  - Skew angle
- Signal
  - Protected-only left-turn phase
  - Channelized right-turn phase
    - Crossroad
    - Exit ramp
  - Non-ramp leg

The ISATe Model and Tool

Excel Spreadsheet

- Input
  - Individual site
  - Freeway segment
  - Ramp or CD road segment
  - Crossroad ramp terminal
  - Freeway facility
  - Segmentation is key!
- Output
  - Crashes for entire facility
  - Crashes by component
  - Distribution of crashes
### ECAT Input Ramp Segments Tab

<table>
<thead>
<tr>
<th>Ramp Segments</th>
<th>Existing Conditions</th>
<th>Ramp Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Information</td>
<td>Location Information</td>
<td></td>
</tr>
<tr>
<td>Route</td>
<td>Agency &amp; Company</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ODOT</td>
<td></td>
</tr>
<tr>
<td>Site Number</td>
<td>County</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>Cuyahoga</td>
<td></td>
</tr>
<tr>
<td>Project Title</td>
<td>Federal Aid</td>
<td></td>
</tr>
<tr>
<td>State Route 218 Bypass</td>
<td>Federal Aid</td>
<td></td>
</tr>
</tbody>
</table>

### ECAT Input Ramp Terminals Tab

<table>
<thead>
<tr>
<th>Ramp Terminals</th>
<th>Existing Conditions</th>
<th>Ramp Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Information</td>
<td>Location Information</td>
<td></td>
</tr>
<tr>
<td>Route</td>
<td>Agency &amp; Company</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ODOT</td>
<td></td>
</tr>
<tr>
<td>Site Number</td>
<td>County</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>Cuyahoga</td>
<td></td>
</tr>
<tr>
<td>Project Title</td>
<td>Federal Aid</td>
<td></td>
</tr>
<tr>
<td>State Route 218 Bypass</td>
<td>Federal Aid</td>
<td></td>
</tr>
</tbody>
</table>
Reviewing Results

- **Crashes for Entire Facility**

<table>
<thead>
<tr>
<th>Estimated Crash Statistics</th>
<th>Total</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated number of crashes during Study Period, crashes:</td>
<td>776.0</td>
<td>3.1</td>
<td>8.4</td>
<td>53.9</td>
<td>152.6</td>
<td>558.0</td>
</tr>
<tr>
<td>Estimated average crash freq. during Study Period, crashes/yr</td>
<td>155.2</td>
<td>0.6</td>
<td>1.7</td>
<td>10.8</td>
<td>30.5</td>
<td>111.6</td>
</tr>
</tbody>
</table>

- Multiple-vehicle (head-on, right-angle, side-swipe, other)
- Single-vehicle (fixed-object, animal, parked vehicle)

**Distribution of Crashes for Entire Facility**

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Number of Expected Crashes During the Study Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-vehicle</td>
<td></td>
</tr>
<tr>
<td>Head-on crashes</td>
<td>1.6</td>
</tr>
<tr>
<td>Right-angle crashes</td>
<td>33.6</td>
</tr>
<tr>
<td>Side-swipe crashes</td>
<td>90.7</td>
</tr>
<tr>
<td>Fixed-object crashes</td>
<td>13.0</td>
</tr>
<tr>
<td>Animal crashes</td>
<td>2.0</td>
</tr>
<tr>
<td>Other multiple-vehicle</td>
<td>106.9</td>
</tr>
<tr>
<td>Total multiple-vehicle</td>
<td>1.1</td>
</tr>
<tr>
<td>Single-vehicle</td>
<td></td>
</tr>
<tr>
<td>Crashes with animal</td>
<td>0.7</td>
</tr>
<tr>
<td>Crashes with fixed object</td>
<td>15.5</td>
</tr>
<tr>
<td>Crashes with other object</td>
<td>1.9</td>
</tr>
<tr>
<td>Crashes with parked vehicle</td>
<td>1.4</td>
</tr>
<tr>
<td>Total single-vehicle</td>
<td>22.5</td>
</tr>
<tr>
<td>Total crashes</td>
<td>155.7</td>
</tr>
</tbody>
</table>

**Crashes by Facility Component**

<table>
<thead>
<tr>
<th>Crashes by Facility Component</th>
<th>Nbr. Sites</th>
<th>Total</th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway segments, crashes</td>
<td>6</td>
<td>55.6</td>
<td>3.2</td>
<td>0.6</td>
<td>3.8</td>
<td>7.0</td>
<td>21.5</td>
</tr>
<tr>
<td>Ramp segments, crashes</td>
<td>5</td>
<td>4.6</td>
<td>0.5</td>
<td>0.1</td>
<td>0.7</td>
<td>1.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Crossroad ramp terminals, crashes</td>
<td>9</td>
<td>91.1</td>
<td>9.1</td>
<td>7.2</td>
<td>6.0</td>
<td>34.9</td>
<td>48.5</td>
</tr>
</tbody>
</table>
I-270/US 33 Improvements: Dublin, OH

- Interchange is unique
  - Operates as a service interchange to the east as it approaches the Frantz Road/Post Road intersection
  - Operates as system interchange to the west

Project Application – I-270/US 33 Interchange

- **Goals**
  - Improve Safety
  - Address Traffic Congestion
  - Resolve Obsolete Geometric Designs
  - Fiscal responsibility - Develop phased plan to meet funding constraints
- **Three alternatives further studied and developed**
  - Alternative 4
  - Alternative 7
  - Alternative 8
I-270/US 33 Improvements: Alternative 4

I-270/US 33 Improvements: Alternative 7
I-270/US 33 Improvements: Alternative 8

Crash Analysis, 2015-2035 Crash Predictions

- ISATe for the I-270/US 33 Interchange
  - The model was uncalibrated as used
  - The results used for comparisons are relative
  - Focused on KAB type crashes from 2015-2035
    - Most important crash types
    - Reliability of data is greater
  - Safety was one of many criteria used to determine the preferred alternative
Results

- **Total KAB predicted crashes 2015-2035**
  - Existing: 308 crashes
  - Alt. 4: 323 crashes
  - Alt. 7: 360 crashes
  - Alt. 8: 320 crashes

- **Societal costs 2015-2035**
  - Existing: $97M
  - Alt. 4: $90M
  - Alt. 7: $102M
  - Alt. 8: $88M

Interpretation

- **Trade-off of reconfiguring interchanges with high speed ramp designs**
  - Increases VMT

<table>
<thead>
<tr>
<th>Alternative</th>
<th>2015 VMT</th>
<th>2035 VMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td>646,908</td>
<td>849,555</td>
</tr>
<tr>
<td>Alt 4</td>
<td>910,494</td>
<td>1,198,120</td>
</tr>
<tr>
<td>Alt 7</td>
<td>907,212</td>
<td>1,194,732</td>
</tr>
<tr>
<td>Alt 8</td>
<td>906,375</td>
<td>1,193,947</td>
</tr>
</tbody>
</table>

- **‘Higher quality’ design**
  - Safety performance is better even though VMT is 30% greater than existing
Alternative 8 – Preferred Alternative (Phase 2)

Loop Ramp Crash Prediction

- ISATe used to predict ramp KAB type crashes from 2015 to 2025
- Option 1 – Maintain existing ramp with a 230’ radius
- Option 2 – Reconstruct ramp with a 200’ radius
- Option 3 – Reconstruct ramp with a 185’ radius

<table>
<thead>
<tr>
<th>Option</th>
<th>Crash Type: K</th>
<th>Crash Type: A</th>
<th>Crash Type: B</th>
<th>Total KAB Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>0.4</td>
<td>1.1</td>
<td>7.1</td>
<td>9</td>
</tr>
<tr>
<td>Option 2</td>
<td>0.4</td>
<td>1.2</td>
<td>7.7</td>
<td>10</td>
</tr>
<tr>
<td>Option 3</td>
<td>0.4</td>
<td>1.3</td>
<td>8.2</td>
<td>10</td>
</tr>
</tbody>
</table>
Loop Ramp Crash Prediction

- Per the HSM, comparing the predicted crashes is the appropriate approach for the analysis
- Using an uncalibrated model is an accepted analysis method
- From HSM work in Ohio, the KAB crashes are very close to model predictions

Summary

- Model predicts that the KAB crashes for the options are anywhere from 9-10 crashes on the ramp proper over a 10 year period
- Little difference between the options as far as crash performance
- Because weaving movements are removed, the main issue will be the speed entering the ramp curve
- Speed will have a significant influence on safety performance regardless of option
Summary

- **Existing ramp radius will be maintained for the project**
- Treatments will be implemented to slow traffic on the approach
- These countermeasures (or lack thereof) would be expected to have a more appreciable influence on expected crash performance than the ramp radius

Questions and Discussion
Example Problem Using ECAT

ODOT HSM Focused Training Course

ECAT has the ability to:
- calculate predicted crash frequencies,
- complete empirical bayes calculations,
- predict crash frequencies for proposed conditions,
- conduct alternatives analyses, and
- complete benefit-cost analysis.

http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/ECAT.aspx
ECAT – Where to Find It?

http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/ECAT.aspx

Project Sample Analysis

Project Description:
- Rural Two Lane Two way Intersection
- SR 117/Spencerville Rd. and SR 501/ S. Wapakoneta/Wapak Rd.
- Lima Allen County, OHIO

Note: Some assumptions were made for training purposes, may not reflect real on-site conditions or ODOT findings or recommendations
Background

- Important route for school buses, commuter traffic, commercial traffic, fire and other emergency vehicles.
- Ranked #1 crash location in Shawnee Township, 13th highest crash intersection in Allen County.
- While not ranked statewide, meets state safety program of at least 10 crashes over 3 years – eligible for funding consideration.
- Intersection had more injury (~60%) than PDO crashes.
- Due to skew and other factors driver’s sight distance is reduced at the intersection, 84% accidents during 2004-2007 were rear-end or angle, attributable to sight distance flaws.
- Intersection meets left-turn lane warrant for WB direction; sufficient traffic gaps for left-turns are missing increasing risk of crash and affecting traffic operations.

Project Purpose

Correct the intersection design deficiencies and provide a safe and operationally efficient facility for left turn movements from SR117 to SR501/ Wapakoneta Road and through traffic.
Existing Conditions

- Number of Lanes - 2, undivided
- Major Road AADT (2011) - 5650
- Minor Road AADT (2011) - 3170
- Intersection Skew Angle - 45
- Intersection control type - Un-signalized four-leg stop control on minor road
- Number of uncontrolled approaches with a left-turn lane - 0
- Number of uncontrolled approaches with a right-turn lane - 0
- Intersection Lighting - No lighting
Proposed Conditions

Features:
- Add 11’ wide left turn lanes, offset at 4.5’
- Widen pavement to south of existing SR 117 to accommodate LT lanes
- Correct skew

Benefits:
- Reduces rear-end conflict points
- Improves radii
- Location and angle of Intersection is improved

Addressing Purpose & Need:
- Separates left-turning vehicles from through vehicles, reducing potential for rear-end crashes
- Corrects sub-standard intersection angle
- Sight obstructions removed (church, house, trees)
- Removes obstructions in clear zone (church)
- While LOS remains F, signal is not warranted
Proposed Conditions

- Number of Lanes - 2, undivided
- Major Road AADT (2011) - 5650
- Minor Road AADT (2011) - 3170
- Intersection Skew Angle - 0
- Intersection control type - Un-signalized four-leg stop control on minor road
- Number of uncontrolled approaches with a left-turn lane - 2
- Number of uncontrolled approaches with a right-turn lane - 0
- Intersection Lighting - No lighting

Work Problem

What does the HSM Analysis tell us about the predicted safety performance of the proposed condition as compared to existing?

Our Task:
Calculate the average number of crashes for both of the existing and proposed conditions of the intersection.
Compare two analyses.
Using the Spreadsheet Tool

HSM Toolbox:

- Follow the steps in the “Analysis Processing” box.
- Can open toolbox at any time by clicking toolbox icon.
Given Site Data – Project Information

Load crash data from CAM spreadsheet: 2009~2011 years of crashes are applied.

Assign crashes to locations using Toolbox- “Assign crashes to elements automatically”
Given Site Data – Existing Conditions

Segments & Intersections

Given Site Data – Proposed Conditions

Segments & Intersections
Using ECAT – Follow the Steps

Basic Analysis Steps:
- Create a project file
- Enter general project data
- Load crash data from CAM tool (black box)
- Assign crashes to each location ID (red box)
- Generate analysis tabs for the segments and intersections (blue box)
- Generate the summary report and benefit cost (yellow box)

Demonstration of HSM Calculations Using ECAT Spreadsheet Tool
Existing & Proposed Conditions
## Analysis Results – Existing Condition

### Existing Conditions: Predicted Number of Crashes by Severity Level and Collision Type

<table>
<thead>
<tr>
<th>Collision Type</th>
<th>( N_{\text{predicted}} ) (KABCO) (crashes/year)</th>
<th>( N_{\text{predicted}} ) (KA) (crashes/year)</th>
<th>( N_{\text{predicted}} ) (B) (crashes/year)</th>
<th>( N_{\text{predicted}} ) (C) (crashes/year)</th>
<th>( N_{\text{predicted}} ) (O) (crashes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.374683</td>
<td>0.428683</td>
<td>1.063027</td>
<td>0.707947</td>
<td>3.804509</td>
</tr>
</tbody>
</table>

### Existing Conditions: Expected Number of Crashes by Severity Level and Collision Type

<table>
<thead>
<tr>
<th>Collision Type</th>
<th>( N_{\text{expected}} ) (KABCO) (crashes/year)</th>
<th>( N_{\text{expected}} ) (KA) (crashes/year)</th>
<th>( N_{\text{expected}} ) (B) (crashes/year)</th>
<th>( N_{\text{expected}} ) (C) (crashes/year)</th>
<th>( N_{\text{expected}} ) (O) (crashes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>6.2170</td>
<td>0.4827</td>
<td>1.2319</td>
<td>0.6900</td>
<td>3.8124</td>
</tr>
</tbody>
</table>

### Potential for Safety Improvement (PSI)

<table>
<thead>
<tr>
<th>Collision Type</th>
<th>( N_{\text{excess}} ) (KABCO) (crashes/year)</th>
<th>( N_{\text{excess}} ) (KA) (crashes/year)</th>
<th>( N_{\text{excess}} ) (B) (crashes/year)</th>
<th>( N_{\text{excess}} ) (C) (crashes/year)</th>
<th>( N_{\text{excess}} ) (O) (crashes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.2026</td>
<td>-0.0439</td>
<td>0.1688</td>
<td>-0.0180</td>
<td>0.0079</td>
</tr>
</tbody>
</table>

## Analysis Results – Proposed Condition

### Proposed Conditions: Expected Number of Crashes by Severity Level and Collision Type

<table>
<thead>
<tr>
<th>Collision Type</th>
<th>( N_{\text{expected}} ) (KABCO) (crashes/year)</th>
<th>( N_{\text{expected}} ) (KA) (crashes/year)</th>
<th>( N_{\text{expected}} ) (B) (crashes/year)</th>
<th>( N_{\text{expected}} ) (C) (crashes/year)</th>
<th>( N_{\text{expected}} ) (O) (crashes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2.5354</td>
<td>0.1969</td>
<td>0.5024</td>
<td>0.2814</td>
<td>1.5548</td>
</tr>
</tbody>
</table>
Project Safety Performance Report

Summary by Crash Type

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Existing</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>0.0238</td>
<td>0.0237</td>
</tr>
<tr>
<td>Head On</td>
<td>0.0517</td>
<td>0.0515</td>
</tr>
<tr>
<td>Rear End</td>
<td>1.2652</td>
<td>1.2618</td>
</tr>
<tr>
<td>Backing</td>
<td>0.2419</td>
<td>0.2299</td>
</tr>
<tr>
<td>Sideslip-Meeting</td>
<td>0.1747</td>
<td>0.1718</td>
</tr>
<tr>
<td>Sideslip-Passing</td>
<td>0.2719</td>
<td>0.2616</td>
</tr>
<tr>
<td>Angle</td>
<td>2.2949</td>
<td>2.6635</td>
</tr>
<tr>
<td>Parked Vehicle</td>
<td>0.2140</td>
<td>0.2565</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>0.0293</td>
<td>0.0292</td>
</tr>
<tr>
<td>Animal</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Train</td>
<td>0.0010</td>
<td>0.0011</td>
</tr>
<tr>
<td>Pedalcyclist</td>
<td>0.0221</td>
<td>0.0221</td>
</tr>
<tr>
<td>Other Non-Vehicle</td>
<td>0.0004</td>
<td>0.0004</td>
</tr>
<tr>
<td>Fixed Object</td>
<td>1.0085</td>
<td>0.8847</td>
</tr>
<tr>
<td>Other Object</td>
<td>0.0352</td>
<td>0.0350</td>
</tr>
<tr>
<td>Overturning</td>
<td>0.0036</td>
<td>0.0022</td>
</tr>
<tr>
<td>Other Non-Collision</td>
<td>0.0756</td>
<td>0.0787</td>
</tr>
<tr>
<td>Left Turn</td>
<td>0.2186</td>
<td>0.2233</td>
</tr>
<tr>
<td>Right Turn</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Summary of Anticipated Safety Performance of the Project (average crashes/year)

- Existing Conditions:
  - Predicted Average Crash Frequency
  - Expected Average Crash Frequency
- Existing Conditions Potential for Safety Improvement
- Proposed Conditions:
  - Expected Average Crash Frequency
Site is expected to have more crashes per year on average than its peers → Potential for improvement!

“expected excess crashes” = 6.2-6.0 = 0.2 crashes per year

Site is expected to have fewer more crashes per year on average than its peers

Expected average crash frequency for the site = 6.2

Predicted Average Crash Frequency for the site = 6.0

Expected average crash frequency for the site = N/A

**KABC Results Compare**

- Benefit – Cost Analysis
  - Compare the estimated future safety benefits of the proposed improvements to the cost of constructing the same improvements.
  - Benefit-Cost Ratio > 1.0 means that the present value of the safety benefits exceeds the present value of the construction costs
  - Benefit-Cost Ratio < 1.0 means that the present value of the safety benefits are less than the present value of the construction costs.
## Benefit – Cost Analysis

<table>
<thead>
<tr>
<th>Countermeasure</th>
<th>Initial Cost of Countermeasure</th>
<th>Annual Maintenance &amp; Energy Costs</th>
<th>Salvage Value</th>
<th>Net Present Cost of Countermeasure</th>
<th>Total Cost of Countermeasure</th>
<th>Summary of Annual Crash Modifications</th>
<th>Net Present Value of Safety Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Characteristic Improvements (Please add description about improvements i.e. Lane widening)</td>
<td>$500,000.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$500,000.00</td>
<td>$500,000.00</td>
<td>-0.00</td>
<td>$2,271,000</td>
</tr>
<tr>
<td>Site Characteristic Improvements (Please add description about improvements i.e. Lighting)</td>
<td>$500,000.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$500,000.00</td>
<td>$500,000.00</td>
<td>-0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Site Characteristic Improvements (Please add description about improvements i.e. Signal Phasing)</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>-0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Site Characteristic Improvements (Please add description about improvements i.e. Added Right Turn Lane)</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>-0.00</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

## Questions and Discussion
ODOT HSM Training

Course Summary and Closing

How is Safety Important in Your Job?

- Programming and prioritization
- System planning
- Program administration
- Policy development

- Project development
- Planning
- Design
- Construction
- Operations and maintenance
- Public affairs
- Interagency coordination
Safety in Project Development Decisions

How you do account for safety now?

- “Our design standards tell us what to do.”
- “I don’t because I have no basis for doing so.”
- “I don’t know how.”
- “I do sometimes but frankly I don’t trust the results.”
- “I don’t because I don’t believe you can predict safety.”
- “I don’t because I don’t have to and there are too many other things that are required of me.”
- “I don’t because if I do, I will get sued if something goes wrong.”
- “That statistical stuff is too complicated for me.”

The two dimensions of safety produce different outlooks
Nominal and Substantive Safety Are Not the Same Thing

**Nominal Safety**
- Standards and models not related to safety performance
- Standards and criteria common across highway types and contexts
- Standards and models exclude traffic volume
- Characterized as ‘Yes/No’

**Substantive Safety**
- Varies by context
- Directly related to traffic volume
- Varies incrementally with incremental changes in conditions

---

**Ever Trade Off Safety?**

Safety

Environmental Right-of-Way

Crisis
How Do You Do Your Job Now?

Capital Costs
- Engineer’s estimate ($) based on detailed design drawings

Right of way
- Acres, no. parcels, $ value of R/W from plans and appraisals

Environmental
- Air quality
- Noise
- Wetlands, steams
- Parks and recreation
- Cultural resources
- Socioeconomics

Traffic operations
- Modeled delay (sec/veh), speeds (mph), queues (ft), fuel consumption (gallons/yr)

Safety
- Jobs created/lost;
- Tax base affected;
- Low or disadvantaged populations affected; etc.

The Value of the HSM

Predictive Method Analysis Process

**PREPARATION**

1. Determine data needs
2. Calculate predicted number of crashes for base condition
3. Calculate predicted number of crashes for each element (similar sites)
4. Calculate expected number of crashes for each element (actual site)

*In some cases, we can incorporate crash history using the Empirical Bayes (E.B.) process to get to expected*
The Value of the HSM

The HSM....

• Provides a proven and vetted science-based approach to quantifying the safety effects of decisions we make and actions we contemplate
• Provides a common knowledge base, language and basis for reasoned judgments about safety
• Allows incorporation of safety to the same level of importance as other factors

It does not force or require you to do anything; but merely helps you do a better job.

Questions and Discussion

Thank You!
Predicted Total Crashes Base Condition:

\[ Nbimv = 8.8764 \] (predicted intersection multivehicle crashes)

\[ Nbiv = 0.5559 \] (predicted intersection single vehicle crashes)

FI & PDO Calculations For multivehicle collisions:

1) Use equation 12-21 with FI and PDO SPF Coefficients from Table 12-10

(Eqn. 12-21) \[ N_{bimv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \]

(Table 12-10) FI Crashes \[ a = -13.14, b = 1.18, c = 0.22 \]

PDO Crashes \[ a = -11.02, b = 1.02, c = 0.24 \]

FI Crashes \[ N_{bimv(FI)} = \exp(-13.14 + 1.18 \times \ln(25,340) + 0.22 \times \ln(24,390)) = 2.8513 \]

PDO Crashes \[ N_{bimv(PDO)} = \exp(-11.02 + 1.02 \times \ln(25,340) + 0.24 \times \ln(24,390)) = 5.7397 \]

2) Adjust calculations using equations 12-22 and 12-23 to assure that \( N_{bimv(FI)} \) and \( N_{bimv(PDO)} \) sum to \( N_{bimv} \)

(Eqn. 12-22) \[ N_{bimv(FI)} = N_{bimv(total)} \times \frac{N_{bimv(FI)}}{N_{bimv(FI)} + N_{bimv(PDO)}} \]

\[ = 8.8764 \times \frac{2.8513}{2.8513 + 5.7397} = 2.9460 \]

(Eqn. 12-23) \[ N_{bimv(PDO)} = N_{bimv(total)} - N_{bimv(FI)} \]

\[ = 8.8764 - 2.9460 = 5.9304 \]

FI and PDO Calculations For single vehicle collisions:

1) Use Equation 12-24 with FI and PDO SPF coefficients from table 12-12

(Eqn. 12-24) \[ N_{bisv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \]

(Table 12-12) FI Crashes \[ a = -9.25, b = 0.43, c = 0.29 \]

PDO Crashes \[ a = -11.34, b = 0.78, c = 0.25 \]

FI Crashes \[ N_{bisv(FI)} = 0.1408 \]

PDO Crashes \[ N_{bisv(PDO)} = 0.4045 \]

2) Adjust calculations using equations 12-25 and 12-26 to assure that \( N_{bisv(FI)} \) and \( N_{bisv(PDO)} \) sum to \( N_{bisv} \)

(Eqn. 12-25) \[ N_{bisv(FI)} = N_{bisv(total)} \times \frac{N_{bisv(FI)}}{N_{bisv(FI)} + N_{bisv(PDO)}} = 0.1435 \]

(Eqn. 12-26) \[ N_{bisv(PDO)} = N_{bisv(total)} - N_{bisv(FI)} = 0.4124 \]

Total predicted Fatal and Injury Crashes = \( N_{bimv(FI)} + N_{bisv(FI)} = 2.9460 + 0.1435 = \boxed{3.0895} \)

Total predicted Property Damage Only = \( N_{bimv(PDO)} + N_{bisv(PDO)} = 5.9304 + 0.4124 = \boxed{6.3428} \)

Total Predicted Crashes = \( 3.0895 + 6.3428 = \boxed{9.4323} \)
Expected Single Vehicle Crashes

\[ N_{\text{predicted}}^{sv} = 0.240 \] (predicted intersection multivehicle crashes)
\[ N_{\text{observed}}^{sv} = 0.66 \] (predicted intersection single vehicle crashes)

1) Use equation A-4 to calculate the weighted adjustment for observed crashes:

\[ k = 0.36 \] (Table 12-12, page 12-33)

\[ w = \frac{1}{1 + k \left( \sum N_{\text{predicted SV}} \right)} \]
\[ = \frac{1}{1 + 0.36 \times 0.240} \]
\[ = \frac{1}{1 + 0.0864} \]
\[ = 0.9205 \]

2) Use equation A-4 (page A-19) to calculate the expected number of Single Vehicle crashes:

\[ N_{\text{expected}} = w \times N_{\text{predicted}} + (1-w) \times N_{\text{observed}} \]
\[ = 0.9205 \times 0.240 + (1 - 0.9205) \times 0.66 \]
\[ = 0.2209 + 0.05247 \]
\[ = 0.2734 \]
Expected Fatal & Injury and Property Damage Only Crashes

\[ n_{(\text{predicted})\text{total}} = 4.18 \] (total predicted intersection crashes)
\[ n_{(\text{predicted})\text{FI}} = 1.44 \] (fatal and injury predicted intersection crashes)
\[ n_{(\text{predicted})\text{PDO}} = 2.74 \] (property damage only predicted intersection crashes)
\[ n_{(\text{expected})\text{total}} = 12.10 \] (total expected intersection crashes)

1) Use Worksheet 3C to calculate the expected fatal and injury crashes:

\[ n_{(\text{expected})\text{FI}} = n_{(\text{expected})\text{total}} \times \left( \frac{n_{(\text{predicted})\text{FI}}}{n_{(\text{predicted})\text{total}}} \right) \]
\[ n_{(\text{expected})\text{FI}} = 12.10 \times \left( \frac{1.44}{4.18} \right) \]
\[ n_{(\text{expected})\text{FI}} = 4.2 \]

2) Use Worksheet 3C to calculate the expected property damage only crashes:

\[ n_{(\text{expected})\text{PDO}} = n_{(\text{expected})\text{total}} \times \left( \frac{n_{(\text{predicted})\text{PDO}}}{n_{(\text{predicted})\text{total}}} \right) \]
\[ n_{(\text{expected})\text{PDO}} = 12.10 \times \left( \frac{2.74}{4.18} \right) \]
\[ n_{(\text{expected})\text{PDO}} = 7.9 \]
ODOT HSM Training

Appendix B:
Risk Management, Tort Liability and Communicating Safety Concepts

Learning Objectives

- Gain perspective on the issue of safety, risk and trade-offs
- Stakeholder understanding of the two dimensions of safety
- Communicating safety in report writing and stakeholder discussions
- Legal protections for use of safety data
- Risk management, tort liability and professionals' responsibilities
Trading off safety sounds “risky”

Won’t we get sued if we use the HSM and select the ‘wrong’ approach?

“Safety always comes first in everything we do. We can’t trade off or compromise safety or we would get sued!”
The two dimensions of safety*

**Nominal Safety**

Examined in reference to compliance with standards, warrants, guidelines and sanctioned design procedures

Nominal Safety*
is examined in reference to compliance with standards, warrants, guidelines and sanctioned design procedures

The expected or actual crash frequency and severity for a highway or roadway

*Ezra Hauer, ITE Traffic Safety Toolbox, 1999

**Substantive Safety**

The three aspects of nominal safety:

- Roadway design must enable road users to behave legally
- Roadway design should enable the vast majority of users to operate without difficulties
- Owning agency requires protection against claims of moral, professional, and legal liability

*Ezra Hauer, ITE Traffic Safety Toolbox, 1999
The AASHTO Policy and L&D Manual are NOT ‘Safety Manuals’

- Traffic Operations
- Costs and cost effectiveness
- Maintainability
- Constructability
Appendix C: ODOT Data and Data Systems

HSM Data Needs

1. Crash data
2. Facility data
3. Traffic volume data
DATA NEEDS GUIDE

http://onlinepubs.trb.org/onlinepubs/nchp/nchrp_rrd_329.pdf

Data Needs

- Crash data
  - type
  - outcome (severity)
  - location
  - time of day
- Traffic volume
  - AADT

- Facility data
  - horizontal alignment
  - vertical alignment
  - cross section
  - roadside geometry
  - intersection geometry

Integrated via common geographic referencing system
National Efforts

CRASH DATA

MMUCC
www.mmucc.us

ROADWAY DATA

MIRE
www.mireinfo.org

Data Needs

Data Needs Guide Table 1-
Site Characteristic and traffic-volume variables used in HSM Safety Prediction
Highway Safety Data

- Crash data in the study area may be obtained from:
  - ODOT
  - Ohio Department of Public Safety (ODPS)
  - Locality (City, County, etc.) or any other relevant source if needed to show trends or if HSP numbers are low

- Crash data can be downloaded for ease in data sorting using ODOT CAM Tool

- Crash forms (OH-1 Reports) with details for each crash can be obtained from ODPS – available online:
  
  http://www.dps.state.oh.us/OHCrashReports

ODPS Crash Data

https://ext.dps.state.oh.us/crashreports/Default.aspx
OH-1 Traffic Crash Report
### Crash Data

<table>
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<tr>
<th>ACCIDENT'S PORTION</th>
<th>LOCAL REPORT NO.</th>
<th>STREET 1</th>
<th>LOCATION KM</th>
<th>CRASH ID</th>
<th>STREET 2</th>
<th>STREET 2 REFERENCE</th>
<th>DISTANCE OFF RT</th>
<th>DAY OF WEEK</th>
<th>HOUR OF DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>101516</td>
<td>07-2256</td>
<td>SHAUN 0227/CC</td>
<td>11.64</td>
<td>20000140</td>
<td>RONALD REAGAN CC</td>
<td>1</td>
<td>TUESDAY</td>
<td>6</td>
<td></td>
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<td>11.64</td>
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<td>RONALD REAGAN CC</td>
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<td>101518</td>
<td>07-2258</td>
<td>SHAUN 0227/CC</td>
<td>11.88</td>
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<td>RONALD REAGAN CC</td>
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<td>THURSDAY</td>
<td>20</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPE OF CRASH</th>
<th>NO. OF VEHICLES</th>
<th>CRASH SEVERITY</th>
<th>WEATHER CONDITION</th>
<th>ROAD CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPERTY DAMAGE</td>
<td>2</td>
<td>2</td>
<td>NO ADVERSE WEATHER CONDITION</td>
<td>ROAD - DRY</td>
</tr>
<tr>
<td>PROPERTY DAMAGE</td>
<td>2</td>
<td>2</td>
<td>NO ADVERSE WEATHER CONDITION</td>
<td>ROAD - DRY</td>
</tr>
<tr>
<td>PROPERTY DAMAGE</td>
<td>2</td>
<td>2</td>
<td>NO ADVERSE WEATHER CONDITION</td>
<td>ROAD - DRY</td>
</tr>
</tbody>
</table>

### Observed Crash Data Limitations

1. **Quality and accuracy**
2. **Reporting thresholds**
3. **Frequency-severity indeterminacy**
4. **Differences among jurisdictions**
Traffic Volume Data

- ODOT – maintains database for state system
- Other sources
  - MPOs
  - Counties
  - Local

HSM Implementation Tools

- SafetyAnalyst – Network Screening
- ODOT Analysis Tools (GCAT/CAM Tool/ECAT)
- TIMS
- NCHRP 17-38 Spreadsheets (customized)
  - Developed for each predictive method in Part C
  - Customized for use by states and ODOT
- ISATe
- IHSDM
Safety Analyst

http://www.safetyanalyst.org/

ODOT TIMS/GCAT/CAM Tool/ECAT

- Transportation Information Mapping System (TIMS)
  - Viewer and query capability for roadway feature attributes and information, traffic data, transportation projects, assets
  - Links to ODOT’s data systems including ODOT’s straight line diagrams, PathWeb (video photo-log, etc.)
    http://tims.dot.state.oh.us/tims

- GIS Crash Analysis Tool (GCAT)
  - Includes state and local system data
  - Convenient crash analysis tool for ODOT, MPOs, County Engineers, and consultants (must have safety study prequalification) to query crash data
  - Data pulled into ODOT CAM Tool for summary and analysis
    https://gcat.dot.state.oh.us/SSL/Login.aspx
**ODOT TIMS/GCAT/CAM Tool/ECAT**

- CAM Tool
  - Automates crash data analysis
  - [http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/GCAT/CAMTool.xlsm](http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/GCAT/CAMTool.xlsm)

- ECAT
  - Combination CAM Tool, NCHRP 17-38 spreadsheet methods, and economic analysis tool
  - Has ability to calculate predicted crash frequencies, empirical bayes calculations
  - Can be used to predict crash frequencies for proposed conditions, alternative analyses, and complete benefit-cost analysis
  - [http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/ECAT.aspx](http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/ECAT.aspx)

**Other Spreadsheet Tools**

- Variations from NCHRP 17-38
- Developed for each predictive chapter in Part C
  - Rural Two-Lane, Two-Way Roads
  - Rural Multilane Highways
  - Predictive Method for Urban and Suburban Arterials
  - [http://www.highwaysafetymanual.org/Pages/tools_sub.aspx](http://www.highwaysafetymanual.org/Pages/tools_sub.aspx)
Crash, volume, roadway feature data is entered in subsequent worksheets for individual elements (segments, intersections).
Interchange Safety Analysis Tool ‘Enhanced’ (ISATe)

- Perform Predictive Methods Analyses for Freeways/Ramps
  - Basic Freeway Segments
  - Freeway speed-change lane
  - Basic ramp segment (including collector-distributor road segments)
  - Crossroad ramp terminal

http://www.highwaysafetymanual.org/Pages/tools_sub.aspx

Interactive Highway Safety Design Model (IHSDM)

- Perform Predictive Methods Analyses for HSM Predictive Chapters (10, 11, 12) and Freeways/Ramps
- Suite of software tools
- The IHSDM currently includes six evaluation modules - Crash Prediction, Design Consistency, Intersection Review, Policy Review, Traffic Analysis, and Driver/Vehicle

http://www.ihsdm.org