Applications of Data Driven Safety Analysis

Exploring the Validity of Combining Predictive Methods

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Agenda

1 Background Motivation

2 Literature and Case Study Review

3 Recommended Approach

4 Example Case Study

5 Questions

Background Motivation

Research Questions

❏ HSM promotes Empirical Bayes (EB) method for analyzing project alternatives

- HSM supplement clarifies EB method cannot be used for any alternatives if it is not applicable for all alternatives

- This has led agencies to avoid EB method in general, including "future no-build" scenarios

- Considering only predicted crash frequency treats locations as "average" locations

❏ Task 2 research questions

- Is there an effective approach to consistently and reliably incorporate observed crash history?

- What is the appropriate traffic volume (projected versus existing) for alternative analysis?

- What role does calibration play in safety analysis?

Key Terminology

- ❑ Predicted Crash Frequency
- ❑ Observed Crash Frequency
- ❑ Expected Crash frequency
- ❑ Local Calibration
- ❑ Single-State Calibration
- ❑ Jurisdiction-Specific SPFs
- ❑ CMFs
- ❑ AFs
- ❑ Pseudo-CMFs
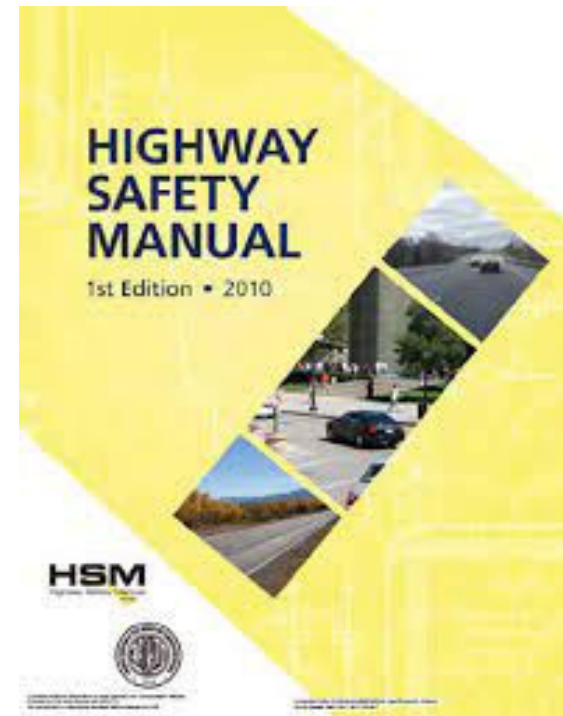
Literature Review and Case Studies

Literature Review

Safety Performance Function Sources

- ❑ National models – Highway Safety Manual

$$N_{predicted} = N_{spf,x} \times \left(\prod AF_{n,x} \right) \times C_x$$
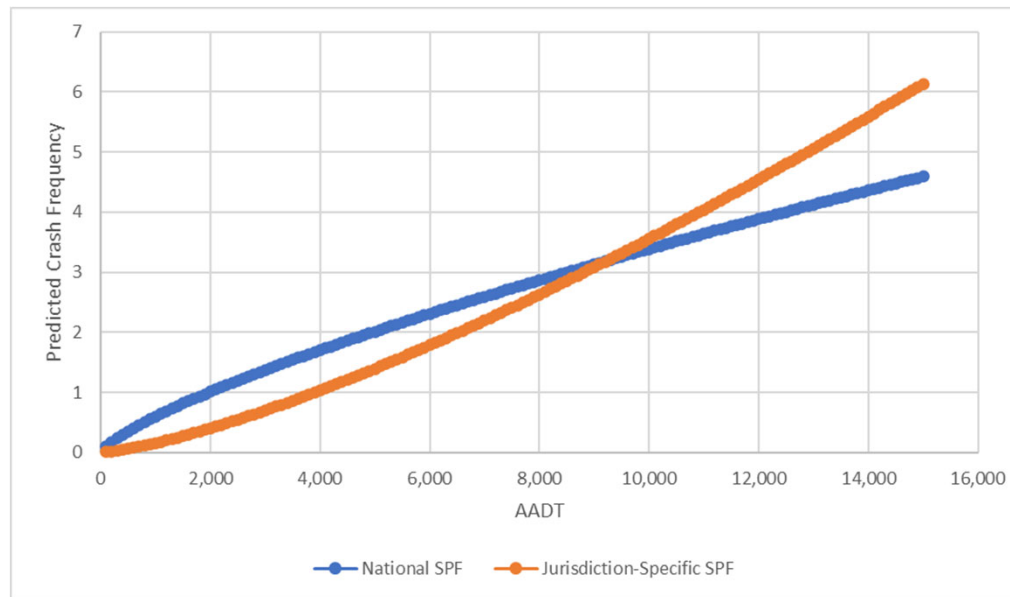
- ❑ Jurisdiction-specific development
  - Substitute for HSM base SPFs
  - Jurisdiction-specific base SPF and adjustment factors

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HSM

Literature Review

Local Calibration

❑ Accounts for differences from one jurisdiction to another, or changes over time

❑ Factors the SPF up or down depending on the average crash frequency

Literature Review

HSM Single-State Calibration

❑ Prior to the release of HSM1, intersections calibrated to California and segments calibrated to Washington

- The intention was to provide support for comparative analysis using predictive method across facility types
- For example, widening a roadway from two-lanes to four-lanes

Image: Town of Morrisville

SPF Calibration

❑ Research has shown need for calibration of HSM or jurisdiction-specific SPFs

❑ Calibration factors may not adequately address relationships

❑ Calibration factors can vary substantially by facility type

- HSM single-State calibration may not be appropriate for many agencies
- Having calibration for each facility type can help overcome this

R2U	0.6956
RM4U	2.3408
RM4D	0.5838
U2U	0.6814
U3T	1.0785
U4U	0.8788
U4D	0.8269
U5T	1.1891

Literature Review Findings

Application of EB Method

❑ Much research has focused on the merits of the EB method at reducing bias

❑ Guidance is unclear on what constitutes a substantial change

- Change in facility type is clear

- How much proposed change within a facility type reduces the validity of historic crash data?

  ◦ Widening shoulders from 0 ft to 10 ft

  ◦ Reducing roadside hazard rating from 7 to 1

  ◦ Installing centerline and shoulder rumble strips

❑ No research has focused on implications of using observed, predicted, or expected crash frequency among alternatives and alignment of methods to long-term project implementation

Literature Review Findings

Role of traffic volume in alternatives analysis

- ❑ HSM guidance suggests using AADT forecast estimates for future periods
- ❑ Part C explains practitioners should predict crash frequency under past or future traffic volumes, including for alternative designs
- ❑ Example applications are typically simplified – same AADT used in all alternatives
- ❑ The implication is that alternative-specific analysis year AADTs should be used; however, the full extent of the project trade-offs should be considered
  - ▪ Does the alternative generate changes in AADT on other facilities, and should those be considered?
  - ▪ Does the crash modification factor already account for the expected change in traffic volume?

Case Studies

❑ Project team solicited data and case study examples from pooled fund States

❑ Three primary case study examples identified

- NCDOT: Conversion of three-leg unsignalized intersection to Continuous Green-T

- WisDOT: Conversion of four-leg unsignalized intersection to roundabout

- HSM User Guide: Alternatives analysis of rural two-lane highway

Case Studies – NCDOT Example

❑ Existing three-leg unsignalized and proposed Continuous Green-T

❑ Alternatives considered signalized intersection – no HSM SPF available

❑ Convenience store at the intersection impacts operations and safety

❑ Analysis methodology

- Used historic crash data as baseline

- Disaggregated crashes by type and severity

- Applied crash type/severity CMFs

- Used signal alternative as baseline for Continuous Green-T intersection

- Future performance scaled based on a linear growth in AADT
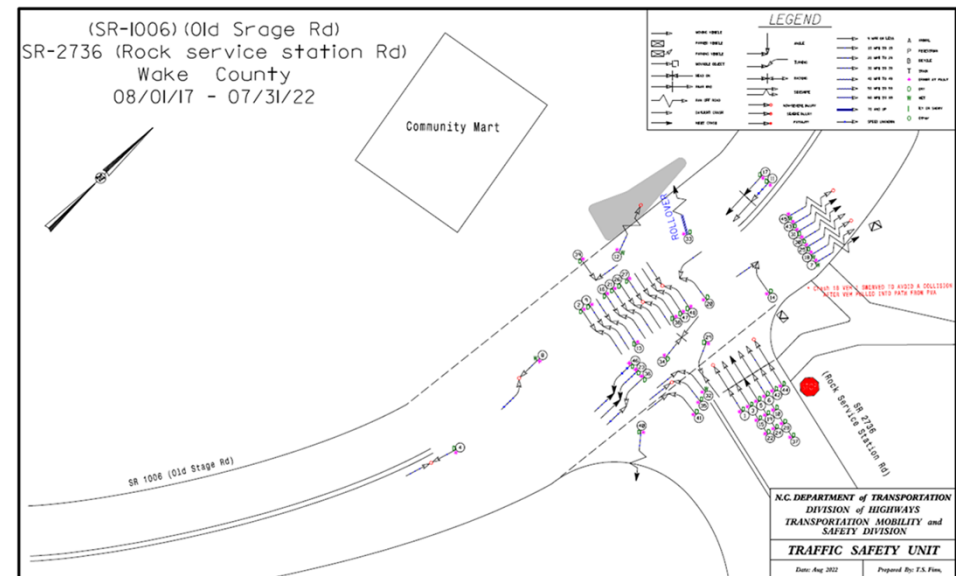
Case Studies – WisDOT Example

- ❑ Existing four-leg unsignalized intersection identified in network screening

- ❑ Roundabout preferred alternative based on right-angle failure to yield crashes

- ❑ Crash data remained high for two years after screening with 65 percent FI

- ❑ WisDOT used calibrated HSM predictive models for comparative analysis (EB not applicable due to change in facility type)

- ❑ Calibrated models suggested 0.6 annual FI and 1.4 annual PDO crashes

- ❑ Observed data suggested 3.0 annual FI and 1.6 annual PDO crashes

- ❑ Analysis suggests that ignoring historic crash data, which may be high at this location for a specific reason, may undervalue the potential benefits, suggesting the project would not be economically justified

Case Studies – HSM User Guide

❑ Existing rural two-lane highway section (three segments)

❑ Project alternative 1 includes widening shoulder from 1 ft to 6 ft

❑ Project alternative 2 includes widening shoulder from 1 ft to 6 ft, installing roadway lighting, improving roadside hazard rating, and automated speed enforcement

Alternative	Segment	Predicted Crash Frequency	Observed Crash Frequency	Overdispersion Parameter	Weighted Adjustment	Expected Crash Frequency
No Build	1	4.94	11	0.202	0.167	9.99
No Build	2	3.58	40	0.303	0.156	34.32
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No Build	Total	16.76	62	N/A	N/A	54.85
1	1	4.02	11	0.202	0.198	9.62
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1	3	6.70	11	0.121	0.198	10.15
1	Total	13.63	62	N/A	N/A	52.91
2	1	3.01	11	0.202	0.248	9.02
2	2	2.18	40	0.303	0.232	31.21
2	3	5.02	11	0.121	0.248	9.52
2	Total	10.21	62	N/A	N/A	49.75

▪ 10.21 predicted crashes is 39 percent reduction

▪ 49.75 expected crashes is 9 percent reduction

Additional Review

- ❑ Project team reviewed State guidance on project alternative safety analysis
  - ▪ FDOT Safety Analysis Guidebook for PD&E Studies highlighted the importance of considering alternative-specific volumes and applicable study area
  - ▪ MassDOT Safety Alternatives Analysis Guide identified two-stage approach
    - ▪ Establish ~~predicted~~ crash frequency for no-build condition in the design year
    - ▪ Apply CMFs to no-build condition for project alternatives

Literature Review and Case Study Summary

❑ There is a demonstrated need for understanding potential biases, including when and how to use historic crash data when evaluating alternatives

- Site specific attributes may contribute to higher crash counts, which may not be accounted for in predicted crash frequency which is a measure of "average"

- Examples highlighted that higher crash counts, or higher proportion of severe crashes can hold over time (i.e., may not necessarily be regression-to-mean)

❑ There is no clear guidance on when historic crash data may no longer be applicable and may introduce bias when employing EB method

❑ There is a demonstrated need for a consistent and reliable approach for conducting project alternatives analysis

Literature Review and Case Study Summary

❑ Project alternatives analysis should consider alternative-specific traffic volumes and should consider the spatial and temporal impacts of the project alternative

❑ The HSM single-State calibration is a useful concept for estimating predicted crash frequency and severity for alternatives when facility types change

❑ However, State calibration efforts have shown that the HSM single-State calibration may not provide valid relationships from State to State

❑ Additionally, the single-State calibration may not capture the interactive influences of traffic volumes and geometric characteristics

❑ Jurisdiction-specific calibrations and utilizing calibration functions can support improved decision-making particularly when considering project alternatives of different facility types

Recommended Approach

Project Alternative Analysis Approach

1. Establish baseline estimated average crash frequency for future no-build condition

2. Determine alternative-specific baseline average crash frequency

3. Identify the applicable method for estimating the safety effectiveness of project alternatives

4. Calculate the project alternative estimated crash frequency

5. Calculate expected change in crash frequency
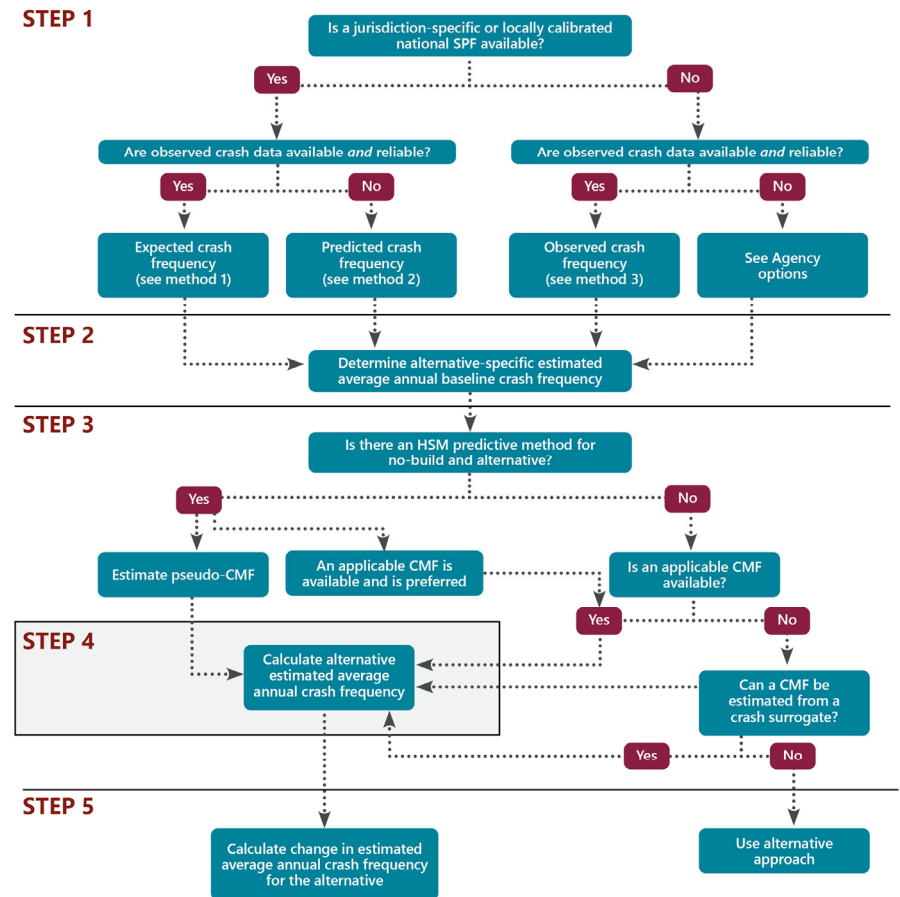
Step 1: Baseline Average Crash Frequency

Establish baseline estimated average crash frequency for future no-build condition

  a) Expected crash frequency
  b) Predicted crash frequency
  c) Observed crash frequency
  d) Identify other options
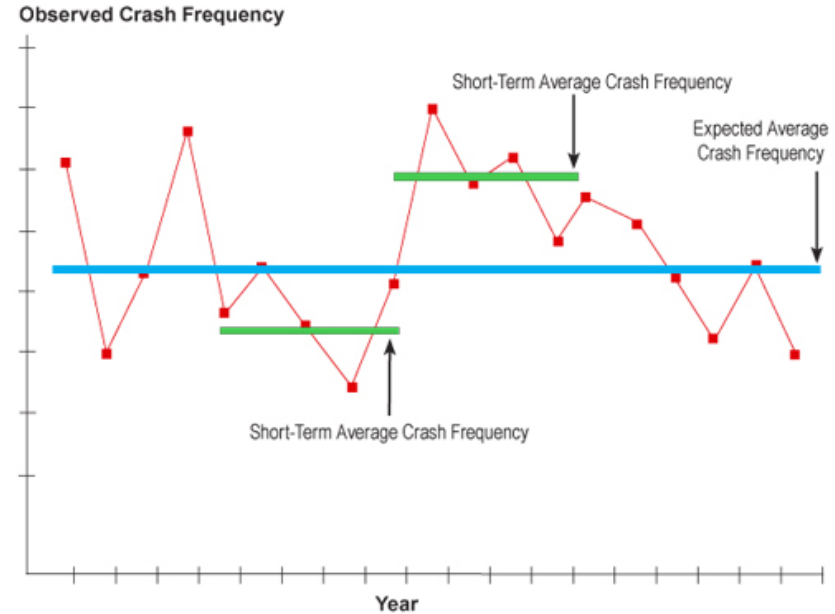
Step 1: Expected Crash Frequency

❑ Calculated using EB Method

❑ At least two years of reliable observed crash data needed

❑ Requires locally calibrated SPFs or jurisdiction-specific SPFs

❑ Study period expected crash frequency adjusted to future no-build in the design year

$$N_{baseline,design,nobuild} = N_{exp,study} \times \frac{N_{pr,design}}{N_{pr,study}}$$

Step 1: Predicted Crash Frequency

❑ At least two years of reliable observed crash data may not be available

❑ Requires locally calibrated SPFs or jurisdiction-specific SPFs

❑ SPF can directly be applied to predict crash frequency for the design year under no-build conditions

Worksheet 1A -- General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments							
General Information			**Location Information**				
Analyst		Scott Himes	Roadway		Route 36		
Agency or Company		vhb	Roadway Section		Sigel Curve		
Date Performed		11/21/23	Jurisdiction		Eldred Township		
			Analysis Year		2033		
Input Data			**Base Conditions**	**Site Conditions**			
Length of segment, L (mi)			--	0.27			
AADT (veh/day)	AADT$_{MAX}$ =	17,800 (veh/day)	--	2,500			
Lane width (ft)			12	10.5			
Shoulder width (ft)			6	Right Shld:	4	Left Shld:	4
Shoulder type			Paved	Right Shld:	Paved	Left Shld:	Paved
Length of horizontal curve (mi)			0	0.3			
Radius of curvature (ft)			0	457			
Spiral transition curve (present/not present)			Not Present	Not Present			
Superelevation variance (ft/ft)			< 0.01	0			
Grade (%)			0	0			
Driveway density (driveways/mile)			5	6.50			
Centerline rumble strips (present/not present)			Not Present	Present			
Passing lanes [present (1 lane) /present (2 lane) / not present)]			Not Present	Not Present			
Two-way left-turn lane (present/not present)			Not Present	Not Present			
Roadside hazard rating (1-7 scale)			3	5			
Segment lighting (present/not present)			Not Present	Not Present			
Auto speed enforcement (present/not present)			Not Present	Not Present			
Calibration Factor, Cr			1	1.14			

Step 1: Observed Crash Frequency

❑ At least two years of reliable observed crash data needed; more years will improve estimate of long-term crash frequency

❑ Locally calibrated SPFs or jurisdiction-specific SPFs may not be available

❑ Study period observed crash frequency adjusted to future no-build in the design year using facility type SPF coefficients for AADT

$$N_{baseline,design,nobuild} = N_{obs,study} \times \frac{AADT_{design}^{a}}{AADT_{study}^{a}}$$

$$N_{baseline,design,nobuild} = N_{obs,study} \times \frac{AADT_{maj,design}^{b} \times AADT_{min,design}^{c}}{AADT_{maj,study}^{b} \times AADT_{min,study}^{c}}$$

Step 1: Identify Other Options

- ❑ At least two years of reliable observed crash data may not be available

- ❑ Locally calibrated SPFs or jurisdiction-specific SPFs may not be available

- ❑ Example options
  - Use one year of crash data if available
  - Identify a group of similar locations with reliable crash data
  - Use a predictive method for a similar facility type if available

Step 2: Alternative-Specific Baseline

❑ No-build condition may not serve as an applicable baseline for a project alternative

- ▪ Example: Existing three-leg signalized intersection for a Continuous Green-T
- ▪ An alternative-specific baseline (three-leg signalized intersection) may be required

❑ Alternative may require adjustment to baseline crash frequency if design year traffic volume differs

- ▪ CMF may account for difference in traffic volume already
- ▪ Example: road diet CMF may already account for change in traffic volume

❑ In most cases no adjustment is needed and results of Step 1 are used for Step 2

Step 3: Safety Effectiveness of Alternatives

❑ Several options exist for assessing project alternatives

❑ Each option has advantages and limitations

❑ Options are not considered as a hierarchy

  ▪ Application of preferred CMFs

  ▪ Application of pseudo-CMF

  ▪ Application of safety surrogates

Step 3: Application of Preferred CMFs

- ❑ CMFs represent the relative effects of proposed countermeasures or enhancements

- ❑ HSM and CMF Clearinghouse contain CMFs to serve this purpose; however, context, crash type, and crash severity should be considered

- ❑ State agencies have developed preferred lists for consistent application

- ❑ HSM AFs can be applied together for multiple countermeasures

- ❑ NCHRP Report 991 should be considered when combining independent CMFs

- ❑ CMFs may not provide nuance for the complexity of proposed improvements
  - ▪ Example: CMF for widening rural two-lane to multilane roadway may be one CMF
  - ▪ Practitioner may wish to further consider the balance of median width, inside shoulder width, lane width, and outside shoulder width on safety performance

Step 3: Application of Pseudo-CMFs

❑ Relative comparison of predicted crash frequency from no-build to alternative

$$CMF_{pseudo} = \frac{N_{Alternative}}{N_{NoBuild}}$$

❑ May involve geometric changes within a facility type

$$CMF_{PM1} = \frac{AF_{i,A} \times \ldots \times AF_{n,A}}{AF_{i,NB} \times \ldots \times AF_{n,NB}}$$

❑ May involve geometric changes and traffic volume difference within a facility type

$$CMF_{PM2} = \frac{AADT_A^{\beta} \times AF_{i,A} \times \ldots \times AF_{n,A}}{AADT_{NB}^{\beta} \times AF_{i,NB} \times \ldots \times AF_{n,NB}}$$

❑ May involve a change in facility type

$$CMF_{pseudo} = \frac{N_{Alternative}}{N_{NoBuild}}$$

Step 3: Application of Pseudo-CMFs

- ❑ Allows for more nuanced assessment of geometric changes

- ❑ Allows for use of the predictive method when a CMF may not exist

- ❑ Assumes the predictive method for different facility types can be compared

  - ▪ Local calibration or jurisdiction-specific for all SPFs considered is required

  - ▪ Assumes single-State calibration is valid and applicable to jurisdiction if HSM models are directly applied

Step 4: Alternative Estimated Annual Crash Frequency

❑ Project alternative-specific estimated annual crash frequency

$$N_{estimated,design,alternative} = N_{baseline,design,alternative} \times CMF_{alternative}$$

❑ Can be compared to baseline crash frequency for the no-build condition or to other alternatives in the design year

Step 5: Change in Estimated Annual Crash Frequency

❑ Calculate the change in estimated annual crash frequency from the baseline in the design year under no-build conditions

$$N_{change,design,alternative} = N_{baseline,design} - N_{estimated,design,alterantive}$$

Example: HSM User Guide Case Study

Case Study – HSM User Guide

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Case Study – Steps 1 and 2

❑ Method 1 can be used since there is reliable crash data and locally calibrated HSM SPF

❑ No change in traffic volume anticipated

❑ Expected crash frequency calculated as shown in the original case study

❑ These serve as the estimated average annual baseline crash frequency for the no-build alternative

❑ No adjustments are needed in Step 2

Alternative	Segment	Predicted Crash Frequency	Observed Crash Frequency	Overdispersion Parameter	Weighted Adjustment	Expected Crash Frequency
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No Build	Total	16.76	62	N/A	N/A	54.85

Case Study – Step 3

❑ Alternative 1: Shoulder widening from 1 ft to 6 ft: Pseudo-CMF = (1.0/1.23) = 0.81

❑ Alternative 2: Pseudo-CMF = (1.00 x 0.92 x 9.83 x 1.00) / (1.23 x 1.00 x 1.00 x 1.14) = 0.61

Feature	Conditions		Adjustment Factors	
	No-Build	**Alternative 2**	**No-Build**	**Alternative 2**
Shoulder Width	1 ft	6 ft	1.23	1.00
Lighting	Not Present	Present	1.00	0.92
Speed Enforcement	Not Present	Present	1.00	0.93
Roadside Rating	5	3	1.14	1.00

Case Study – Steps 4 and 5

❑ Estimated average annual crash frequency

Segment	No-Build	Alternative 1	Alternative 2
1	9.99	8.12	6.09
2	34.32	27.90	20.94
3	10.54	8.57	6.43
Total	54.85	44.59	33.46

❑ Change in estimated average annual crash frequency

- Alternative 1: Reduction of 10.26 crashes

- Alternative 2: Reduction of 21.39 crashes

Summary

- ❑ Recommended approach provides consistent method for project alternatives analysis

- ❑ Recommended approach prioritizes using EB method, when data are available

- ❑ Consistent application of relative effects of safety improvements

- ❑ Flexible to demands of analysis and availability of evaluation methods

- ❑ Can be accomplished without local calibration, but calibration is recommended

- ❑ Flexible to incorporate alternative-specific traffic volumes

- ❑ More research is needed to identify the extent to which local calibration supports assessment of alternatives across facility types compared to a single-State calibration

Questions?

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Thank You!