Module C3:
Evaluation of Safety Effects of Design Decisions and Countermeasures

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Overview

- Relevance to EU directive
- North American practice –safety evaluation of design decisions
  - Highway Safety Manual
  - Interactive Highway Safety Design Model
- Basics of treatment evaluation
- Examples from recent research
- Future directions

Relevance to EU directive

- *Article 5:* ***Safety ranking and management of the road network in operation***
  - **Item** 3. *Member States shall ensure that remedial treatment is targeted at the road sections referred to in paragraph 2 (high ranked sites). Priority shall be given to those measures referred to in point 3(e) of Annex III paying attention to those presenting the highest benefit-cost ratio*.

Point 3e of Annex III: 3. *Elements of evaluation for expert teams' site visits: (e) a set of potential remedial measures for realisation within different timescales considering for example:*

- removing or protecting fixed roadside obstacles,
- reducing speed limits and intensifying local speed enforcement,
- improving visibility under different weather and light conditions,
- improving safety of roadside equipment such as restraint systems,
- improving coherence, visibility, readability and position of road markings (incl. rumble strips),
- signs and signals,
- protecting against rocks falling, landslips and avalanches,
- improving grip/roughness of pavements,
- redesigning road restraint systems,
- providing and improving median protection
- changing the overtaking layout,
- improving junctions, including road/rail level crossings,
- changing the alignment,
- changing width of road, adding hard shoulders,
- installing traffic management and control systems,
- reducing potential conflict with vulnerable road users,
- upgrading the road to current design standards,
- restoring or replacing pavements,
- using intelligent road signs,
- improving intelligent transport systems and telematics services for interoperability, emergency and signage purposes.

Article 4: Road safety audits for infrastructure projects

- 1. Member States shall ensure that road safety audits are carried out for all infrastructure projects.
- 3. Road safety audits shall form an integral part of the design process of the infrastructure project at the stage of draft design, detailed design, pre-opening and early operation.
- …. ***North American practice complements audits with explicit evaluation of the safety consequences of design decisions***

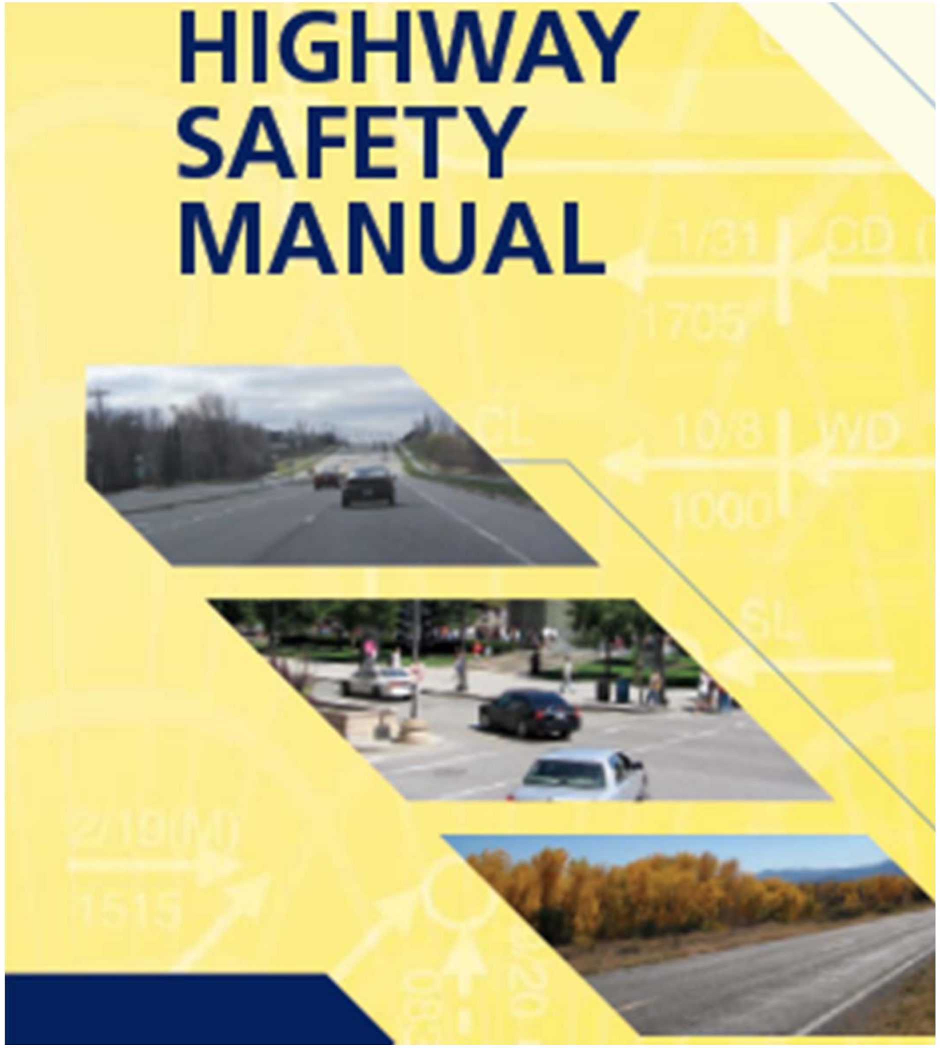
Engaged discussion (or homework)

HOW IMPORTANT IS EXPLICIT CONSIDERATION OF SAFETY COVERED VIS A VIS THE EU DIRECTIVE?

Why evaluate safety?

- Evaluate safety effects of changes to a design
- Evaluate safety effects of *contemplated* changes to a roadway
- Evaluate safety effects of *implemented* changes to a roadway

- *… requires safety performance functions and crash modification factors*



North American practice – safety evaluation of design decisions

Principles of Safety Design

- Since crashes occur on all highways in use, it is inappropriate to say that any highway is safe. However, it is correct to say that highways can be built safer or less safe.

- To consciously build safety into a road requires:
  - explicit attention to safety
  - professional know how

Application of professional know-how

- It is incompatible with the extant knowledge to maintain that obstacles farther than 10m from the edge of the travelled lane will never be hit.

- Nor may one legitimately assume that narrowing the median from 15m to 8.5m will not affect the frequency of accidents

Lessons learned in Canada – Explicit Consideration of Safety

- In road design, standards are often no more than a limit
- One must not provide less than the standard stipulates, but to provide more is usually better.
- Just meeting the standard does not mean that an appropriate amount of safety has been provided.
- In short, implicit attention to safety by meeting design standards is insufficient.

EXPLICIT CONSIDERATION OF SAFETY: HIGHWAY SAFETY MANUAL, IHSDM METHODOLOGY

Interactive Highway Safety Design Model (IHSDM) 2010 Release

IHSDM

What is IHSDM?

- A product of FHWA's Safety Research and Development Program
- A suite of software tools that support project-level geometric design decisions by providing quantitative information on the expected safety and operational performance

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IHSDM

What Benefits does IHSDM Provide?

- IHSDM results help project developers make design decisions that improve the expected safety performance of designs

- IHSDM helps project planners, designers, and reviewers justify and defend geometric design decisions

IHSDM

Evaluation Modules

- Crash Prediction (CPM)
- Policy Review (PRM)
- Design Consistency (DCM)
- Intersection Review (IRM)
- Traffic Analysis (TAM)
- Driver/Vehicle (DVM)

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IHSDM

Crash Prediction Module

Scope

- Estimates expected crash frequency (i.e., Substantive Safety) based upon roadway geometry and traffic volumes

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IHSDM/HSM crash prediction algorithm

- $N = C \times N_b \times CMF_1 \times CMF_2 \times CMF_3 \times \ldots..$

- where N_b is the number of crashes per year predicted by a SPF for specific base conditions.
- CMF_1, CMF_2, CMF_3 …. are crash modification factors for differences from the base conditions,
- C is a calibration factor for applying a base model from a different jurisdiction and/or time period.

- *For an existing road with X collisions in y years*
  $N_{MOD} = w*N*y + (1-w)*X$

Example algorithm -- two lane rural road segments

$$N = C \times N_b \times CMF_1 \times CMF_2 \times CMF_3 \times \ldots..$$

N_b = constant (segment length) (AADT)

for:

- 6 ft (1.8 m) shoulders
- 12 ft (3.6 m) lane width
- No horizontal curvature or grade
- Average roadside
- 5 driveways per mile
- Other CMFs for passing lanes, two-way left turn lanes, rumble strips, lighting, automated speed enforcement

ENGAGED DISCUSSION

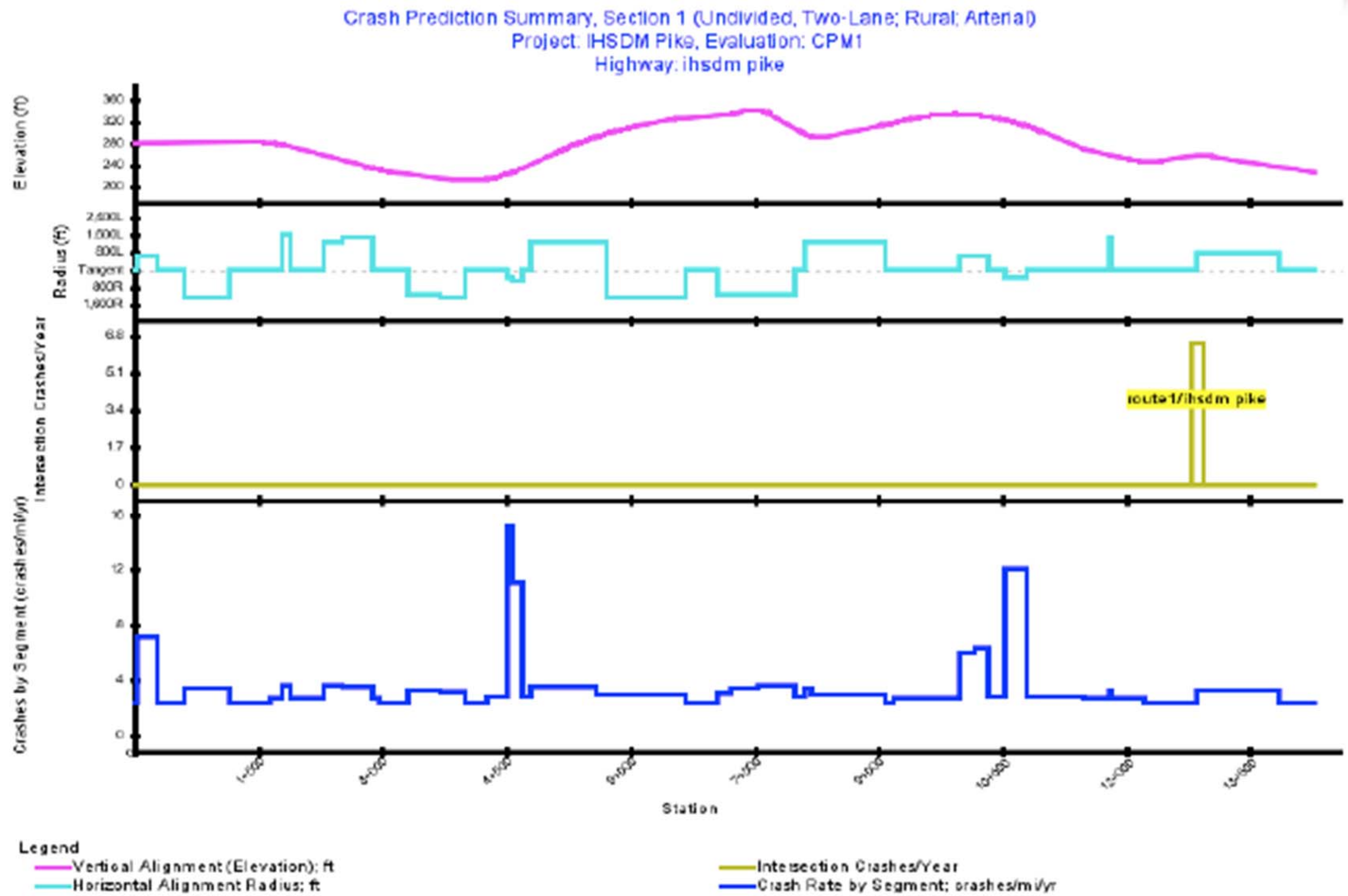
$$N = C \times N_b \times CMF_1 \times CMF_2 \times CMF_3 \times \ldots\ldots$$

- assumes independence of CMFs

IHSDM

CPM Evaluation Report

Expected Crashes Graphs



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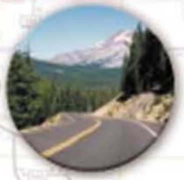

Policy Review Module

Scope

- Checks roadway segment geometry against relevant design policy and "flags" variations (i.e., evaluates Nominal Safety)

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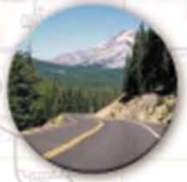

Policy Review Module

- 16 policy checks, organized by category:
  - Cross Section
  - Horizontal Alignment
  - Vertical Alignment
  - Sight Distance

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Policy Review Module

- Horizontal Alignment checks:
  - Radius of Curvature
  - Length of Horizontal Curve
  - Superelevation
  - Compound Curve Ratio
- Vertical Alignment Checks:
  - Tangent Grade
  - Vertical Curvature

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Policy Review Module
Evaluation Report

Radius of Curve

[Radius of Curve Check in the Engineer's Manual]
Evaluation Start Location: 0.000
Evaluation End Location: 14+281.693
e_{max}: 8
Min Policy Speed: 10
Max Policy Speed: 80

Table 3. Radius of Curve

Start Location	End Location	Road Radius (ft)	Policy Radius (ft)	Effective Design Speed (mph)	Speed (mph)	Functional Class	Surface Type	Comment
32.808	273.307	656.17	758.00	47	50	Arterial		Road value varies from controlling criteria
601.391	1+155.538	1,295.93	758.00	61	50	Arterial		Road value is within controlling criteria
1+647.671	2+017.493	1,640.42	758.00	66	50	Arterial		Road value is within controlling criteria
2+283.481	2+512.523	1,312.34	758.00	61	50	Arterial		Road value is within controlling criteria
2+512.523	2+874.898	1,476.38	758.00	65	50	Arterial		Road value is within controlling criteria
3+301.391	3+703.461	1,148.29	758.00	58	50	Arterial		Road value is within controlling criteria
3+703.461	3+994.938	1,301.18	758.00	61	50	Arterial		Road value is within controlling criteria
4+507.470	4+564.731	328.08	758.00	35	50	Arterial		Road value varies from controlling criteria

The Upshot

- Designing Safety into roads requires knowledge on the safety implications of design decisions
  - Crash modification (or reduction) factors

- Problem is: knowledge is incomplete
  - Initiatives to acquire knowledge
    - AASHTO SHSP
    - FHWA Evaluation of Low Cost Treatment Pooled Fund Study
  - Barriers to acquiring sound knowledge
    - Institutional
    - Methodological
    - Data
  - Issues in transferability of knowledge

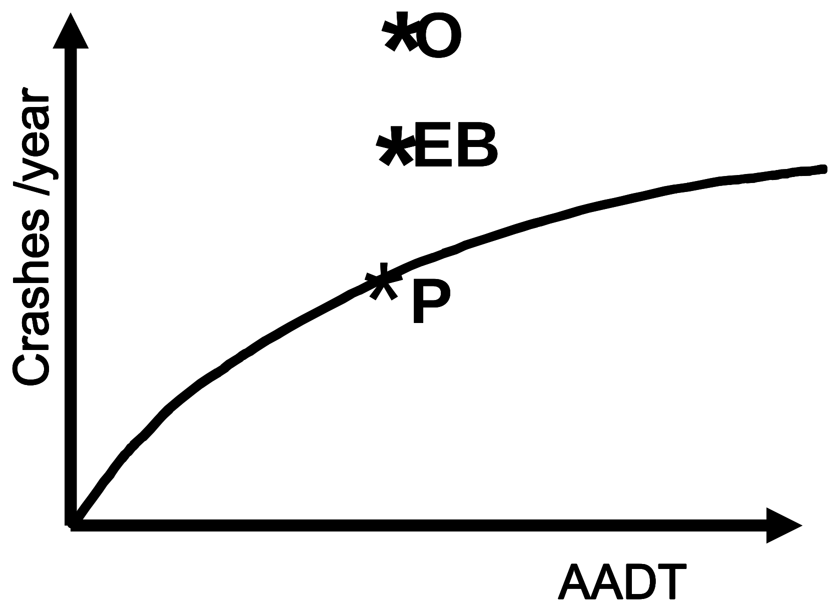
Issues related to the development of CMFs – before-after design

- Observed change in crashes after a treatment may be due not only to the treatment, but to other factors:
  - Changes in traffic volume, crash reporting or weather,
  - Regression-to-the-mean (RTM)
    - Treatment effects are overestimated
- Empirical Bayes methodology resolves the RTM problem with safety performance functions (SPFs)
- SPFs can account for changes in traffic, etc.
- With before-after design samples usually insufficient to investigate how a CMF varies with various factors
  - Cross-section design can overcome this limitation.

EB Before-After Approach Fundamentals

- Compares the crash frequency in the "after" period to an estimate of what it would have been in the absence of the treatment (E*B*).
- *EB* is a weighted average of the counts in the "before period" (O) and the number of crashes expected to occur at similar sites (*P*).
- *P* is estimated from a SPF that links crashes to traffic volumes and characteristics from reference sites "similar" to the treatment sites.
- Adjustments made through the SPF to control for traffic volume and other changes unrelated to the treatment

EB method basics



Issues related to the development of CMFs -- Cross-sectional Design

- Ratio of crash frequencies for sites with and without a feature is an estimate of the CMF related to the feature.
  - Problem: differences in crash frequencies between two groups may be due to factors other than feature of interest.
- Confounding effects of other factors may be controlled for in a multiple regression model, whereby the coefficient of a variable is indicative of the CMF
  - Problem: Coefficients will be inaccurate, even have the incorrect sign, due to correlated or omitted variables.
- CMFs from cross-sectional designs indicate smaller crash reductions than those from before-after studies.

Illustrative recent application examples in CMF development

- Empirical Bayes before-after methodology
  - Develop crash modification factors
- Cross-sectional methodology to develop
  - Develop crash modification *functions*

Change from permissive to protected permissive left turn phasing

Before Phasing	Crash Type	CMF	s.e
All converted legs had protected in the before period) (29 sites) (56 legs treated)	Total	**1.338**	0.097
	Left Turn	**2.242**	0.276
At least 1 converted leg was permissive in the before period) (9 sites) (20 legs treated)	Total	**0.753**	0.094
	Left Turn	**0.635**	0.126
All converted legs had protected-permissive in the before period) (13 sites) (27 legs treated)	Total	0.922	0.104
	Left Turn	0.806	0.146

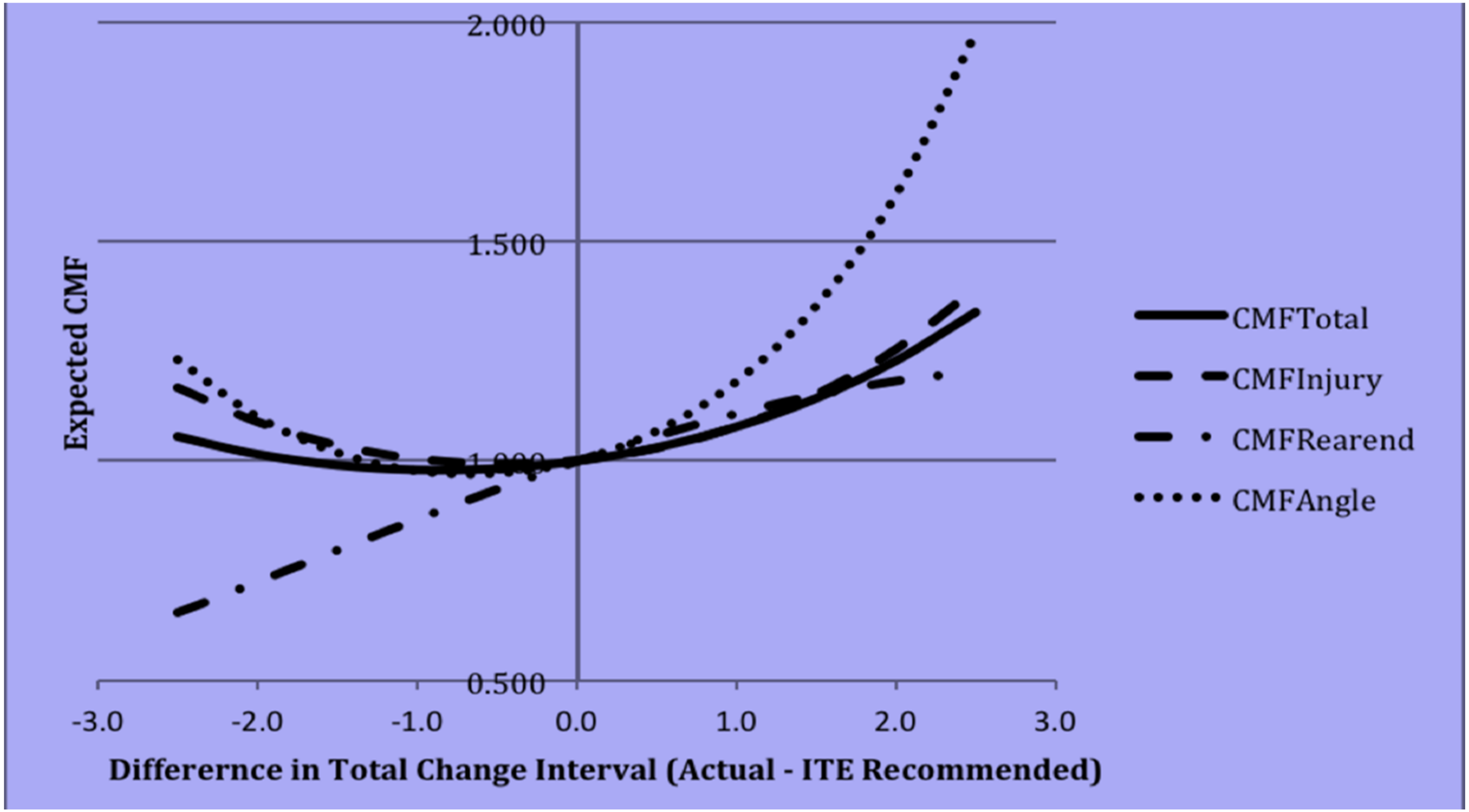
TWO TREATMENTS FOR REDUCING SIGNAL CHANGE INTERVAL RELATED CRASHES

1. Installing dynamic signal warning flashers (DSWF)

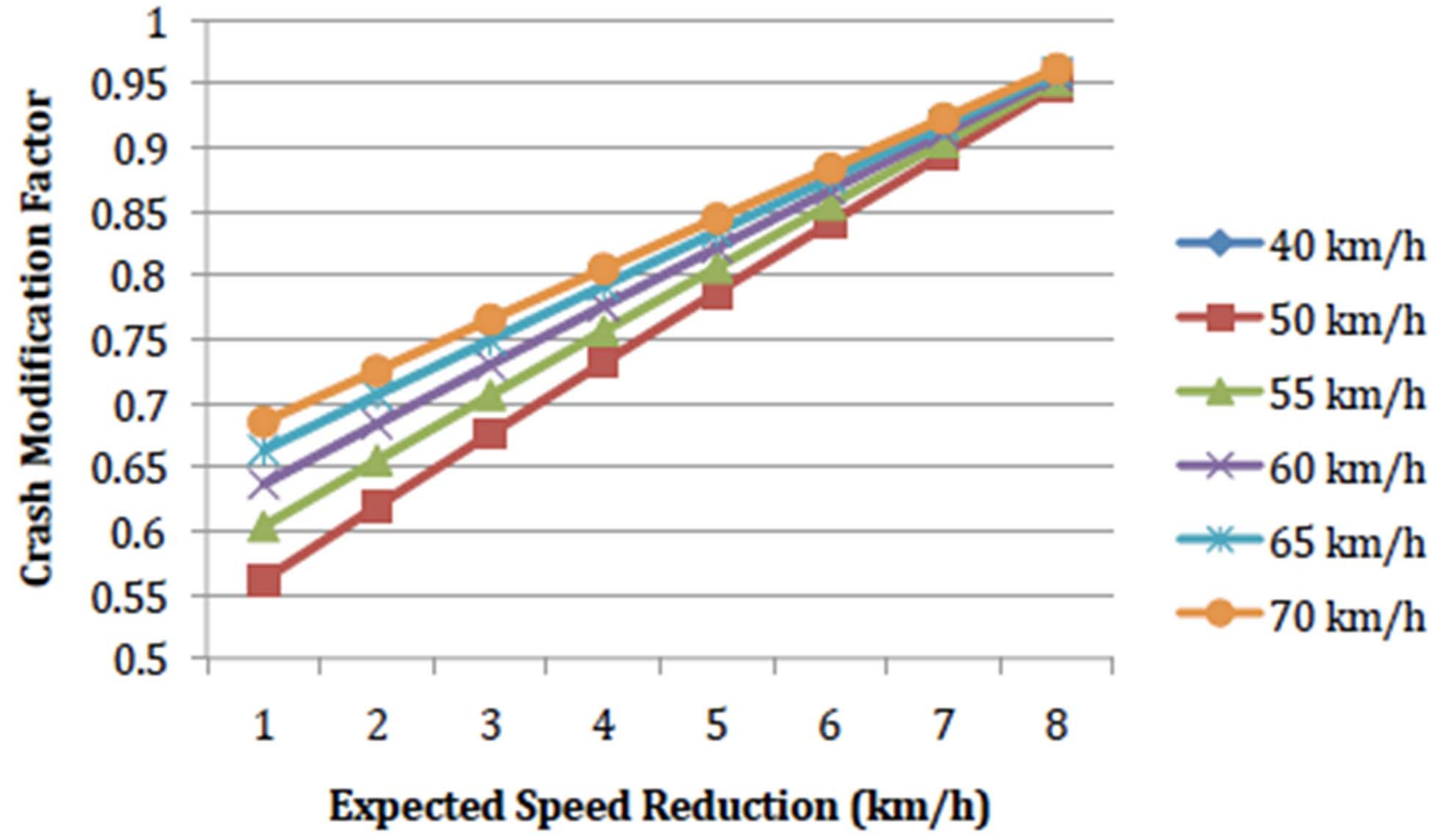
Installing dynamic signal warning flashers (DSWF) – results from cross-sectional regression model

Crash Group	Total	Rear-end	Angle	Injury	Heavy Vehicle
CMF	0.814	0.792	0.745	0.820	0.956
Standard Error	0.062	0.079	0.086	0.083	0.177
Sample Size (crashes)	4425	2651	961	1450	267

2. Modifying change interval: CMF trend for difference between acutal and recommended ITE change interval



CMF for speed reduction -- derived from data from international studies (NCHRP 617)



Safety Evaluation of Offset Left-turn Lanes

FHWA Low Cost Safety Improvements Pooled Funds Study

Evaluation Results – Offset left turn lanes

% reduction in crashes

Total	Injury	Left-Turn Opposing	Rear-End
33.8	35.6	38.0	31.7

SAFETY EVALUATION OF PAVEMENT MARKERS

% Reduction in crashes

	Night	Wet
New Jersey Non-Selective 174 miles	0.9	3.2
New York Selective 82 miles	12.7	20.2

Pavement markers: disaggregate effects (% reduction in crashes)

- Two Lane roads

	Flatter curves	**Sharper curves**
ADT <5000	-16%	-43%
5001-15000	No change	-26%
15001-20000	24%	-3%

Improved curve delineation

- Improve retro-reflectivity of existing signs
- Post-mounted delineators, chevrons, raised pavement markers, edge-lines

Estimate of % Reduction
Improved curve delineation

	Total	Lane Departure	Injury and Fatal (K, A, B, C)	Crashes During Dark	Lane Departure During Dark
CT	**17.8%**	**17.7%**	**25.2%**	**35.3%**	**34.2%**
WA	4.3%	5.9%	16.4%	**24.5%**	**22.1%**

Estimate of % Reduction
Improved curve delineation

	Total	Lane Departure	Injury and Fatal (K, A, B, C)	Crashes During Dark	Lane Departure During Dark
Connecticut (2-lane)	**17.8%**	**17.7%**	**25.2%**	**35.3%**	**34.2%**
Washington (2-lane)	4.3%	5.9%	16.4%	**24.5%**	**22.1%**
ITALY (Motorway)		**31.8%**	**28.2%**	**33.7%**	

Addition of TWLTL to 2-Lane Road

Rural and urban locations in NC, IL, CA and AK

Percent reduction in crashes (significant at the 5% level)		
Rear-end	Injury	Total
38.7	26.1	20.3

Safety Evaluation of US Roundabouts % Reduction in crashes

CONTROL BEFORE	*All*	*Injury*
SIGNALS (9)	*48%*	*78%*
TWO WAY STOP (34)	*44%*	*82%*
ALL-WAY STOP (10)	*No effect*	

- Safety benefit decreases with increasing traffic

Engaged discussion

Lessons that can be learned from North American practice – Transferability of methods and knowledge

Future directions

- Development of crash modification *functions*
- CMFs when multiple treatments are applied
- Full Bayes methods
- Structural models for modeling crash causation
- Surrogate measures
- Bayesian model averaging