TRB ACS20
Safety Performance and Analysis Standing Technical Committee

Transportation Research Board 2023 Annual Meeting

Washington, D.C.

Attendance

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TRB ACS20 Wednesday Meeting

Chair: Karen Dixon

Agenda

1:30 pm **Call to Order and Introductions** Karen Dixon

1:45 pm – 3:45 pm
Update on Second Edition of AASHTO Highway Safety Manual and Related NCHRP Research:

- NCHRP 17-71A, Proposed AASHTO Highway Safety Manual (HSM) Second Edition, Stephen Read and Darren Torbic (60 minutes)
- Implementation of NCHRP Research, Waseem Dekelbab (NAS) (30 minutes)
- Practical Applications of the HSM, Bonnie Polin, Kelly Hardy, Stephen Read (30 minutes)

3:45 pm – 4:00 pm Break

Agenda (2)

4:00 pm – 5:30 pm **Presentations on Safety Related NCHRP Research**:

- NCHRP 07-29, Development of the 8th Edition of AASHTO's A Policy on the Geometric Design of Highways and Streets, Ingrid Potts (30 minutes)
- NCHRP 17-104, Enhancement of Roadside Design Safety Prediction Models for the Highway Safety Manual, Jeff Gooch (20 minutes)
- NCHRP 22-48, Development of Crash Prediction Models for Short-Term Durations, Mohamed Abdel-Aty (20 minutes)
- Development of Freeway Crash Modification Functions for Italian Freeways, Alfonso Montella (The University of Naples Frederico II) (20 minutes)

Thank you!

trbacs20.org → meetings

NCHRP Project 17-71A

Proposed AASHTO Highway Safety Manual, Second Edition

2023 TRB Annual Meeting
ACS20

Texas A&M Transportation Institute

HDR

Exponent®

Harwood Road Safety, LLC

Mr. Brelend C. Gowan

Ogle Research, LLC

Agenda

- Project objective and outline of HSM2
- Status of draft chapters
- Schedule
- Remaining major activities
- Questions
- AASHTO update

Project Objective And HSM2 Outline

Project Objective

- Complete work initiated as part of NCHRP Project 17-71 to develop and prepare a proposed HSM2 in a format suitable for adoption as an AASHTO publication
  - Proposed HSM2 will synthesize and incorporate relevant ongoing and completed research including completed NCHRP Project 17-71 deliverables, related documents, and user feedback to expand the scope and quality of HSM2 to increase application and improve its usability

The HSM2 Will…

- **Expand** upon the methodologies in HSM1

- **Incorporate** new models and research completed since HSM1

Outline of HSM2

HSM2 (Ch.)	HSM1 (Ch.)	Chapter Title
		Preface
1	1	Introduction and Overview to the Highway Safety Manual
Part A- Fundamentals		
		Introduction to Part A
2	3	Road Safety Principles **(Previously titled "Fundamentals")**
3	2	Human Factors
4		**Pedestrians and Bicyclists (NEW)**
Part B – Roadway Safety Management Process		
		Introduction to Part B
5		**Areawide Evaluation (NEW)**
6	4	Network Screening
7	5	Diagnosis
8	6	Countermeasure Selection
9	7	Economic Appraisal
10	8	Project Prioritization
11	9	Countermeasure Effectiveness Evaluation
12		**Systemic Evaluation (NEW)**
Part C – Predictive Method		
		Introduction to Part C
13		**Developing, Calibrating, & Using Safety Performance Functions and Crash Prediction Models (NEW)**
14	10	Predictive Method for Rural Two-Lane, Two-Way Roads
15	11	Predictive Method for Rural Multilane Highways
16	12	Predictive Method for Urban and Suburban Arterials
17	18	Predictive Method for Freeways
18	19	Predictive Method for Ramps
Part D – Crash Modification Factors		
		Introduction to Part D
19		**Selecting CMFs (NEW)**
20		**Applying CMFs (NEW)**
		Glossary (Applicable to all Parts)

Status of Draft Chapters

Task 6 – Submission and Review Schedule

HSM2 Chapter	Short Title	Individual Chapter Drafts					Full Draft (all chapters)
		Submit for Review and Comments					
		(12/1/21)	(3/16/22)	(7/15/22)	(10/31/22)	(2/28/23)	(5/31/23)
	Preface	X					X
Chapter 1	Intro & Overview		X				X
Part A—Fundamentals							
	Introduction		X				X
Chapter 2	Road Safety Principles			X			X
Chapter 3	Human Factors			X			X
Chapter 4	Peds & Bikes					X	X
Part B—Roadway Safety Management Process							
	Introduction	X					X
Chapter 5	Areawide Evaluation		X				X
Chapter 6	Network Screening			X			X
Chapter 7	Diagnosis				X		X
Chapter 8	Countermeasure Selection				X		X
Chapter 9	Economic Appraisal	X					X
Chapter 10	Project Prioritization	X					X
Chapter 11	Effectiveness Evaluation			X			X
Chapter 12	Systemic Evaluation				X		X
Part C—Predictive Method							
	Introduction		X				X
Chapter 13	Use of SPFs and CPMs				X		X
Chapter 14	Rural Two-Lane				X		X
Chapter 15	Rural Multilane			X			X
Chapter 16	Urb/Sub Arterials					X	X
Chapter 17	Freeways					X	X
Chapter 18	Ramps		X				X
Part D—Crash Modification Factors							
	Introduction	X					X
Chapter 19	Selecting CMFs		X				X
Chapter 20	Applying CMFs			X			X

HSM2 – Ch.1 Introduction and Overview to the Highway Safety Manual

- Updated content based on revised outline of HSM2

HSM2 – Ch.2 Road Safety Principles

- Changed title from “Fundamentals” to “Road Safety Principles”
- Added section on Safe System approach
- Fundamental safety performance analysis terms have been expanded to be more inclusive for bicycles and pedestrians
- Content previously in Chapter 20 (Application of CMFs) has been moved forward into this chapter
- Content from several appendices in HSM1 has been blended into this chapter

HSM2 – Ch.3 Human Factors

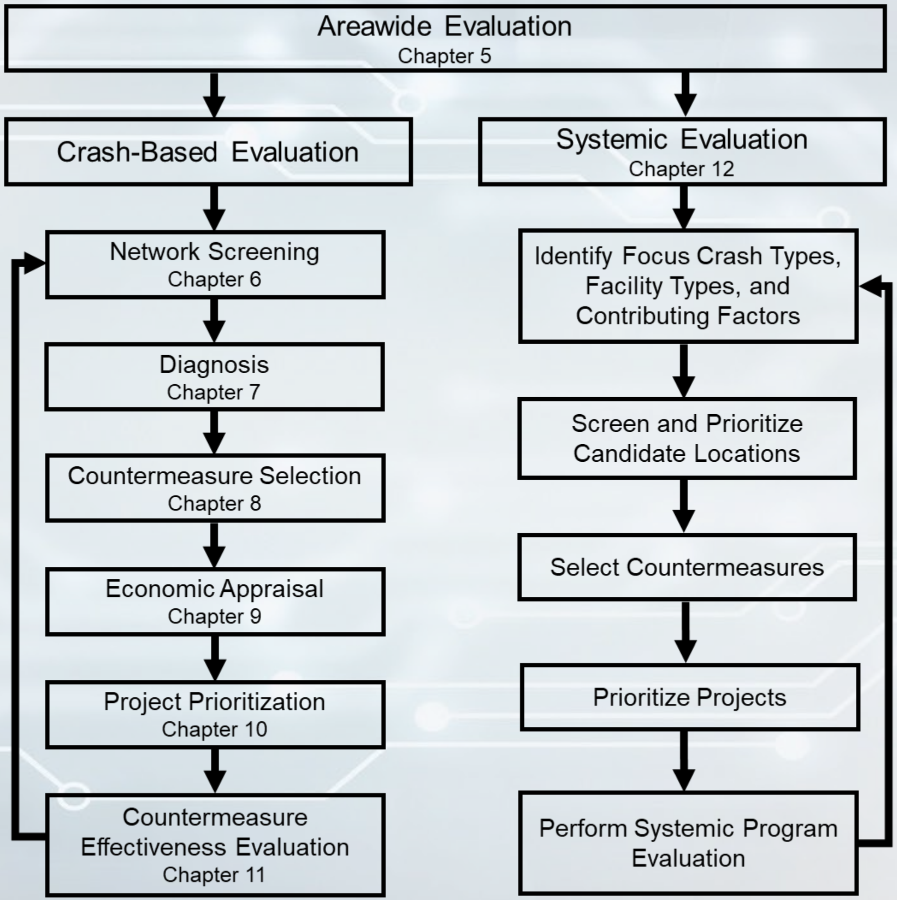
- Added section on Human Factors vs. Driver Behaviors
- Added several new examples
- Revised general discussions of human factors to emphasize practical aspects and to eliminate some of the narrative that seemed too academic
- Replaced section on “User Characteristics and Limitations” with “Human Factors and Crash Diagnostics”
- New section on countermeasure selection emphasizes the need to link countermeasures to the diagnostics process and shows how countermeasures for three specific crash types support road users

HSM2 – Ch.4 Pedestrians and Bicyclists

- Under development soon
- Move some material into systemic chapter
- Add material from NCHRP 17-84 (and other sources)

HSM2 – Part B Roadway Safety Management Process

Roadway Safety Management Process



HSM2 – Ch.5 Areawide Evaluation

- Chapter presents a method to predict areawide crash totals within geographical areas of various sizes, using a predictive method based on macro-level safety performance analysis

- Areawide evaluations can be used to:
  - Compare alternative growth scenarios in a planning process
  - Support analysis of crash frequency and severity performance measures
  - Assess impacts of large-scale developments on crash frequency and severity in different geographical regions

- An areawide evaluation can serve as a first step in the roadway safety management process

HSM2 – Ch.5 Areawide Evaluation

- Provides definitions of the analysis units
- Provides the predictive steps
- Provides macro-level CPMs for Census Block Groups
  - Macro-level CPMs for planning areas inside MPO boundaries
  - Macro-level CPMs for planning areas in a state
- Calibration
- Limitations of models

HSM2 – Ch.6 Network Screening

- Removed several performance measures from the chapter
  - Excess predicted average crash frequency using method of moments
  - Excess predicted average crash frequency using SPFs
- Categorized performance measures
  - Measures used for reporting purposes or other measures
  - Measures used for network screening
- Included additional network screening SPFs
  - Freeways
  - Pedestrians and bicyclists

HSM2 – Ch.7 Diagnosis

- Updated chapter based on 190 outstanding comments from reviews conducted during NCHRP 17-71

- Integrated material from Ch 3 (Human Factors)

HSM2 – Ch.8 Countermeasure Selection

- Integrated material from Ch 3 (Human Factors)

HSM2 – Ch.9 Economic Appraisal

- Updated chapter based on outstanding comments from reviews conducted during NCHRP 17-71
- Updated information on crash costs
- Clarified methods for estimating change in crashes for a proposed project

HSM2 – Ch.10 Project Prioritization

- Updated language based on the style and usage guide to avoid language that might raise tort liability issues for transportation agencies

HSM2 – Ch.11 Countermeasure Effectiveness Evaluation

- Consolidated chapter on “Developing CMFs” (prepared as part of NCHRP 17-63: Guidance for the Development and Application of Crash Modification Factors) with HSM1 Chapter 9- Safety Effectiveness Evaluation

Most of the content from Chapter 21 was integrated into Chapter 11, including

1. Fundamental concepts related to CMFs
2. Relevant statistical concepts and terminology
3. Study design and analysis approaches to develop CMFs
4. Other approaches for developing CMFs
5. Crash modification functions
6. CMF reporting

- Discussion of experimental design was removed from the chapter

HSM2 – Ch.12 Systemic Evaluation

- Updating chapter based on outstanding comments from reviews conducted during NCHRP 17-71

- Incorporating ped/bike systemic material into chapter

Ch. 13 Developing, Calibrating, and Using SPFs and CPMs

- Currently under development
- Incorporated material/text from HSM1 Part C Introduction and appendices into the chapter
- Sections with new material still need to be developed

Ch 14. Predictive Method for Two-Lane, Two-Way Highways

- Added new SPFs for total crashes, KABC crashes, and KAB crashes from NCHRP 17-62 to replace the HSM1 SPFs for two-lane roadway segments and three intersection types
- Added new SPFs for three intersection types (3STT, 3SG, and 4AST) from NCHRP 17-68
- Added roundabout SPFs and AFs from NCHRP 17-70
- Added pedestrian and bicycle predictive methods from NCHRP 17-84
- Updated all materials to agree with HSM2 conventions
  - For example, talks about AFs rather than CMFs; the term CMF remains only when talking about clearinghouse/Part D CMFs

Ch 14. Predictive Method for Two-Lane, Two-Way Highways (cont.)

- Single-state calibration remains to be addressed
  - Roundabout models have not been updated to adjust them so that crash predictions for roundabouts are appropriately less than for comparable conventional intersections

- Sample problems have not been updated

Ch 15. Predictive Method for Rural Multilane Highways

- Added new SPFs for total crashes, KABC crashes, and KAB crashes from NCHRP 17-62 to replace the HSM1 SPFs for undivided roadway segments, divided roadway segments, and three intersection types
- Added new SPFs for one intersection type (3SG) from NCHRP 17-68
- Added roundabout SPFs and AFs from NCHRP 17-70
- Added pedestrian and bicycle predictive methods from NCHRP 17-84
- Updated all materials to agree with HSM2 conventions
  - For example, talks about AFs rather than CMFs; the term CMF remains only when talking about clearinghouse/Part D CMFs

Ch 15. Predictive Method for Rural Multilane Highways (cont.)

- Single-state calibration remains to be addressed
  - Roundabout models have not been updated to adjust them so that crash predictions for roundabouts are appropriately less than for comparable conventional intersections

- Sample problems have not been updated

Ch 16. Predictive Method for Urban and Suburban Arterials

- Under development

- Adding new SPFs from:
  - NCHRP 17-62 (crash type and severity)
  - NCHRP 17-58 (six-lane and one-way facilities)
  - NCHRP 17-68 (intersections)
  - NCHRP 17-70 (roundabouts)
  - NCHRP 17-84 (pedestrian and bikes)

Ch 17. Predictive Method for Freeways

- Under development soon
- Plan to change bidirectional models to directional models
  - Incorporate part-time shoulder use adjustment factor
- Qualitatively address HOV/HOT lanes
- Address rumble strip adjustment factor

Ch 18. Predictive Method for Ramps

- Reorganized chapter according to ramp segments and crossroad ramp terminals

- Added models for single-point diamond interchange and tight diamond interchange from NCHRP Project 17-68

Ch 19. Selecting CMFs

- Updated chapter based on outstanding comments
- Integrated text and tables on new CMF rating system into the chapter (from Appendix D1)
- Integrated text and figure on adjusting CMFs to local conditions into the chapter (from Appendix D2)

Ch 20. Applying CMFs

- Integrated text from Appendix D3 (Combining CMFs for the Same Countermeasure) into the chapter

- Coordinated material and reduced redundancy with other chapters, in particular:
  - Ch 2. Road Safety Principles
  - Ch 11. Countermeasure Effectiveness Evaluation
  - Ch 19. Selecting CMFs

Reviews / Comments

- Received comments from first three rounds of submissions/draft chapters
- Most comments seem reasonable to address
- Have not received any show-stoppers

Scope of Updates to HSM

- Results from the following NCHRP projects will likely be incorporated into one or more chapters of HSM2:
- 15-63: Guidance to Improve Pedestrian and Bicycle Safety at Intersections
- 17-18(3): Guides for Implementation of the AASHTO Strategic Highway Safety Plan
- 17-50: Lead States Initiative for Implementing the HSM
- 17-56: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments
- 17-58: CPMs for Six-Lane and One-Way Urban and Suburban Arterials
- 17-62: Improved Prediction Models for Crash Types & Severities
- 17-63: Guidance for the Development and Application of CMFs
- 17-68: Intersection Crash Prediction Methods for the HSM
- 17-70: Development of Roundabout CPMs and Methods

Scope of Updates to HSM (cont)

- Results from the following NCHRP projects will likely be incorporated into one or more chapters of HSM2:
- 17-71: Proposed AASHTO Highway Safety Manual, 2nd Edition
- 17-72: Update of Crash Modification Factors
- 17-73: Systemic Pedestrian Safety Analyses
- 17-77: Guide for Quantitative Approaches to Systemic Safety Analysis
- 17-78: Understanding and Communicating Reliability of CPMs
- 17-81: Proposed Macro-Level Safety Planning Analysis Chapter for HSM
- 17-84: Pedestrian and Bicycle Safety Performance Functions for the HSM
- 17-89: Safety Performance of Part-Time Shoulder Use on Freeways
- 17-89A: HOV/HOT Freeway CPMs for HSM

Scope of Updates to HSM (cont)

- Results from the following NCHRP projects will likely be incorporated into one or more chapters of HSM2:
- 17-41: Human Factors Guidelines for Road Systems – Phase III
- 17-47: Human Factors Guidelines for Road Systems
- 17-80: Expansion of Human Factors Guidelines for Road Systems, Second Edition
- 20-07(314): Recommended Protocols for Developing Crash Modification Factors
- 20-07(334): Primer on the Joint Use of the Highway Safety Manual (HSM) and the Human Factors Guidelines (HFG) for Road Systems
- 22-46: Human Factors Guidelines for Road Systems, Proposed 4th Edition
- 22-45: Informing the Selection of Countermeasures by Evaluating, Analyzing, and Diagnosing Contributing Factors that Lead to Crashes

Scope of Updates to HSM

- Results from **<u>25 NCHRP projects</u>** will likely be incorporated into one or more chapters of HSM2
- Estimating more than 200 new references will be incorporated into HSM2

Schedule

Schedule

RESEARCH TASK	2023												2024
	J	F	M	A	M	J	J	A	S	O	N	D	J
Task 1: Kickoff Meeting and Project Management													
Task 2: Review Materials from NCHRP Project 17-71													
Task 3: Assessment of Research for Potential Incorporation into HSM2													
Task 4: Develop Glassary of Terms and Phrases to be Used and Avoided in HSM2													
Task 5: Prepare Interim Report													
Task 6: Execute Approved Phase II Work Plan		*			*								
Task 7: Prepare Project Deliverables										*			*

Remaining Major Activities

Remaining Major Activities

- Complete initial drafts of remaining chapters
  - Ch 4. Pedestrians and Bicyclists
  - Ch 12. Systemic Evaluation
  - Ch 13. Developing, Calibrating, and Using Safety Performance Functions and Crash Prediction Models
  - Ch 17. Predictive Model for Urban and Suburban Arterials
  - Ch 18. Predictive Model for Freeways
- Revise chapters in response to comments
- Worksheet development
- Single state calibration
- Sensitivity analysis
- Sample problems
- Equations / figures
- Address consistency issues within and across chapters
- Glossary

Questions
and
AASHTO Update

NATIONAL ACADEMIES *Sciences Engineering Medicine*

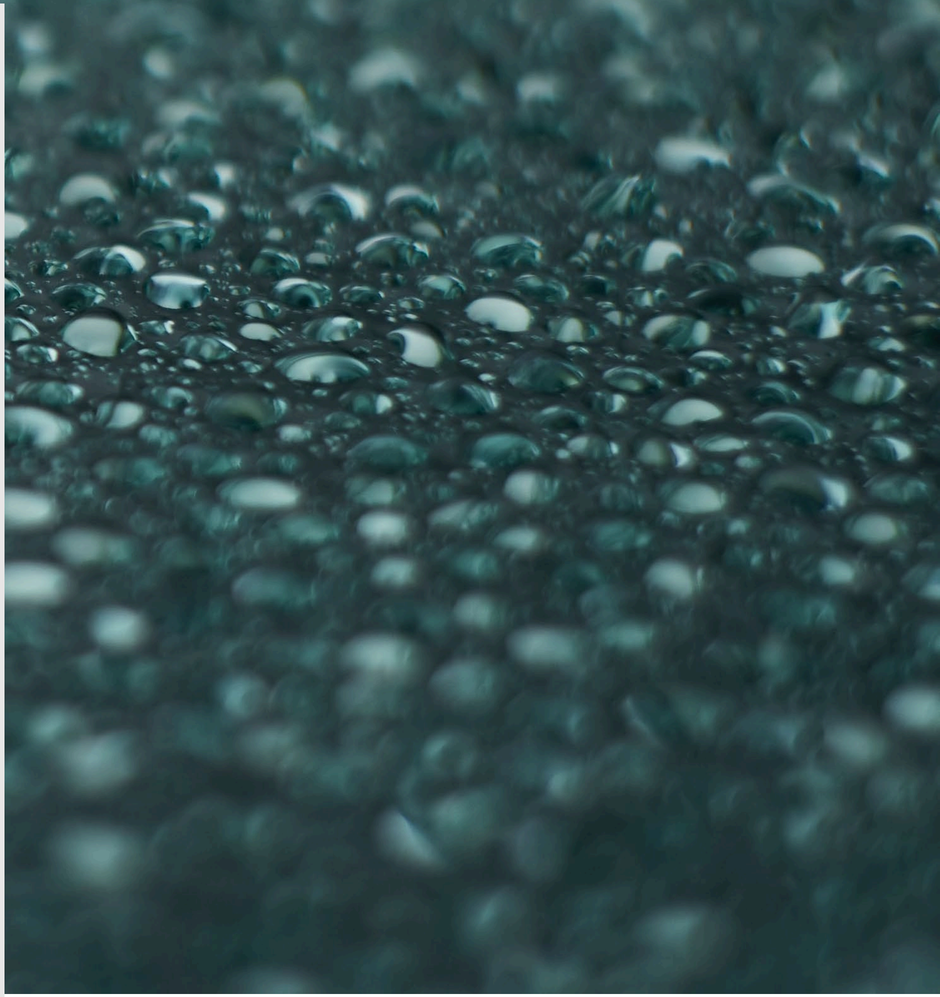
National Cooperative Highway Research Program

NCHRP Active Implementation

102nd TRB Annual Meeting

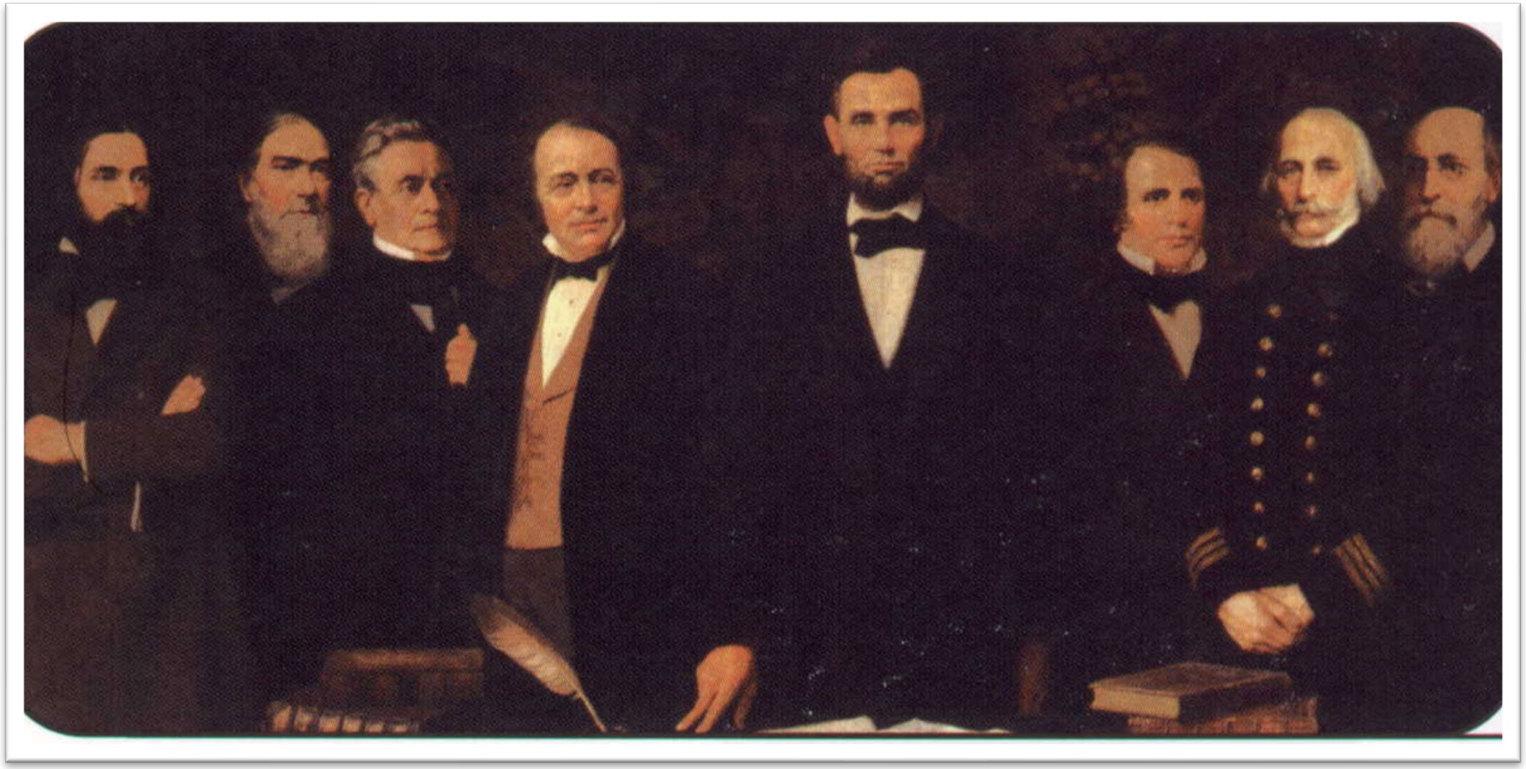
Safety Performance Analysis Committee (ACS20)

Jan 11, 2023

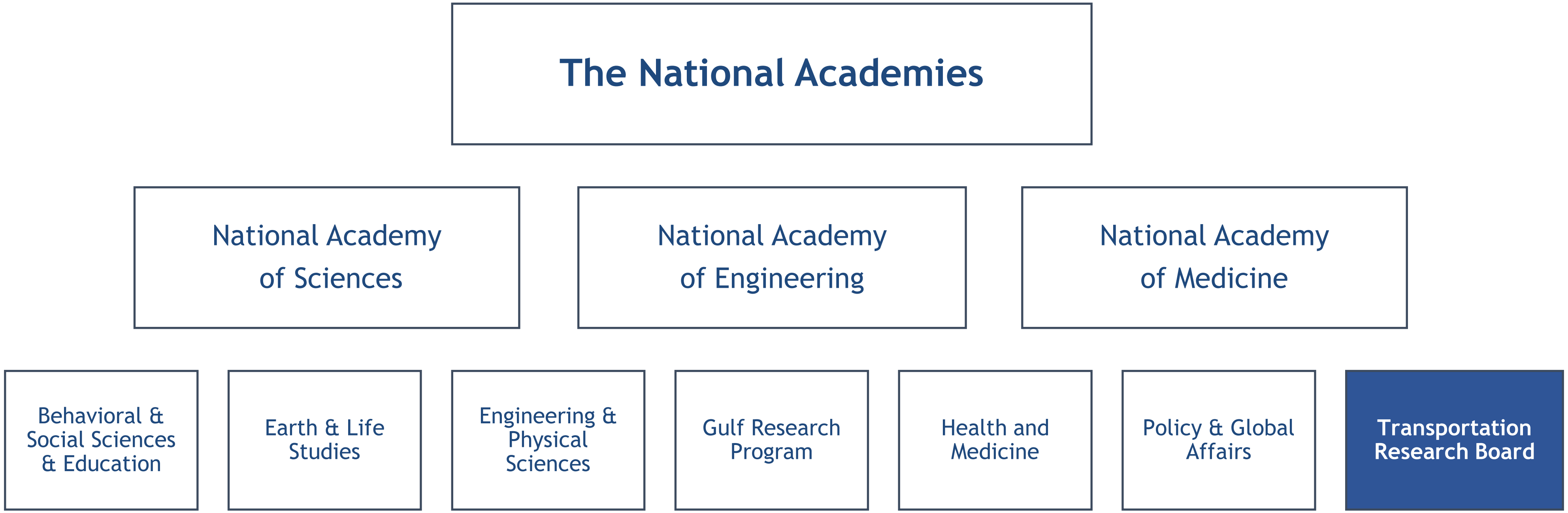


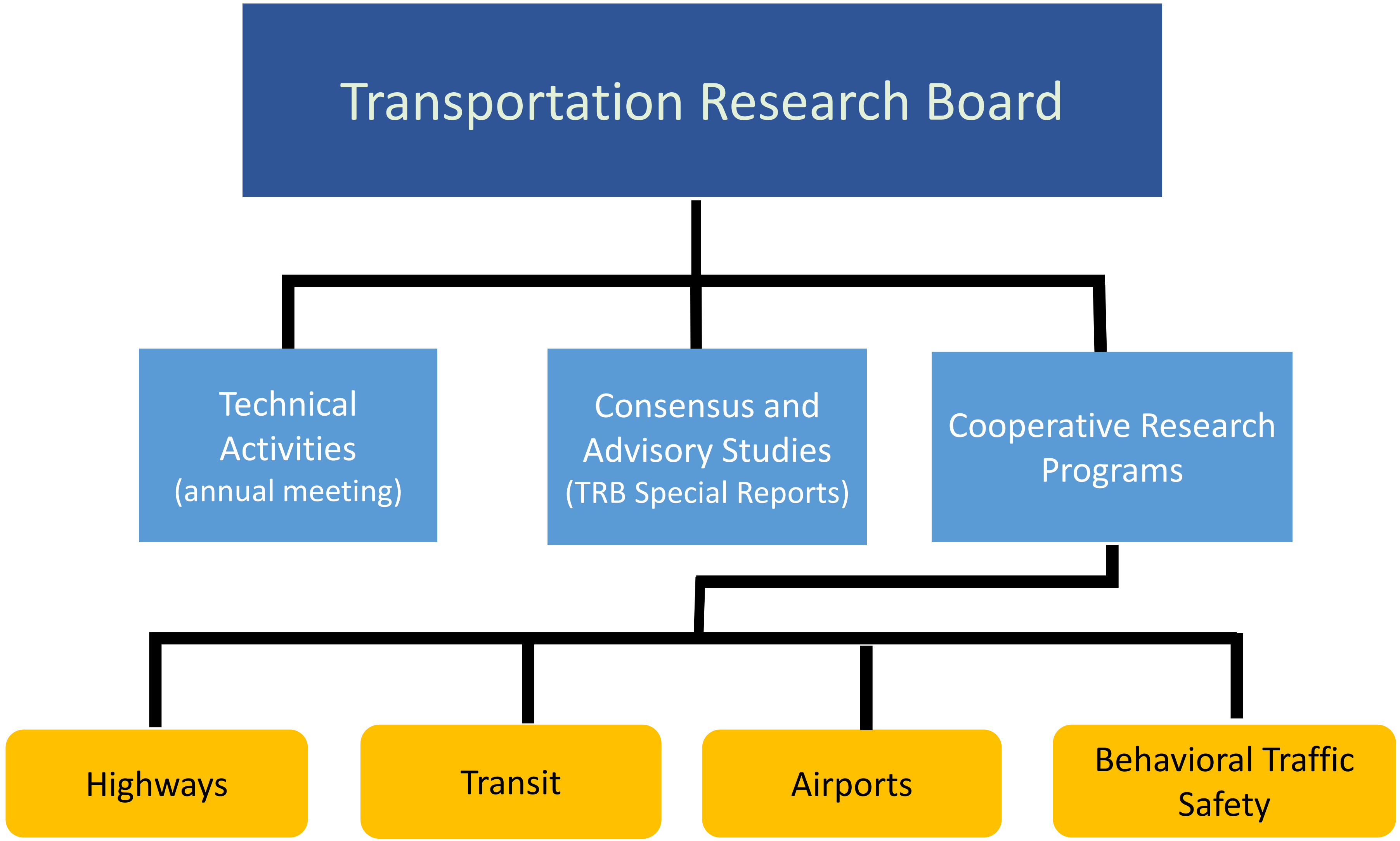
TRB
TRANSPORTATION RESEARCH BOARD

The National Academy of Sciences was established in 1863 to provide scientific advice to the government and to "investigate, examine, experiment, and report upon any subject of science”



Private, Nonprofit Institution
…with a mission of national service




Transportation Research Board
Technical Activities (annual meeting)
Consensus and Advisory Studies (TRB Special Reports)
Cooperative Research Programs
Highways
Transit
Airports
Behavioral Traffic Safety

NCHRP's role

NCHRP does not develop, issue, or publish standards or specifications. NCHRP manages applied research projects which provide the scientific foundation that may be used by TRB sponsors, industry associations, or other organizations as the basis for revised practices, procedures, guides, or specifications.

NCHRP Active Implementation
Moving Research into Practice

- **im·ple·men·ta·tion**
- "A specified set of activities designed to put into practice an activity or products of known dimensions"

- "**Implementation Science:** The systematic study of specified activities designed to put into practice activities or products of known dimensions"

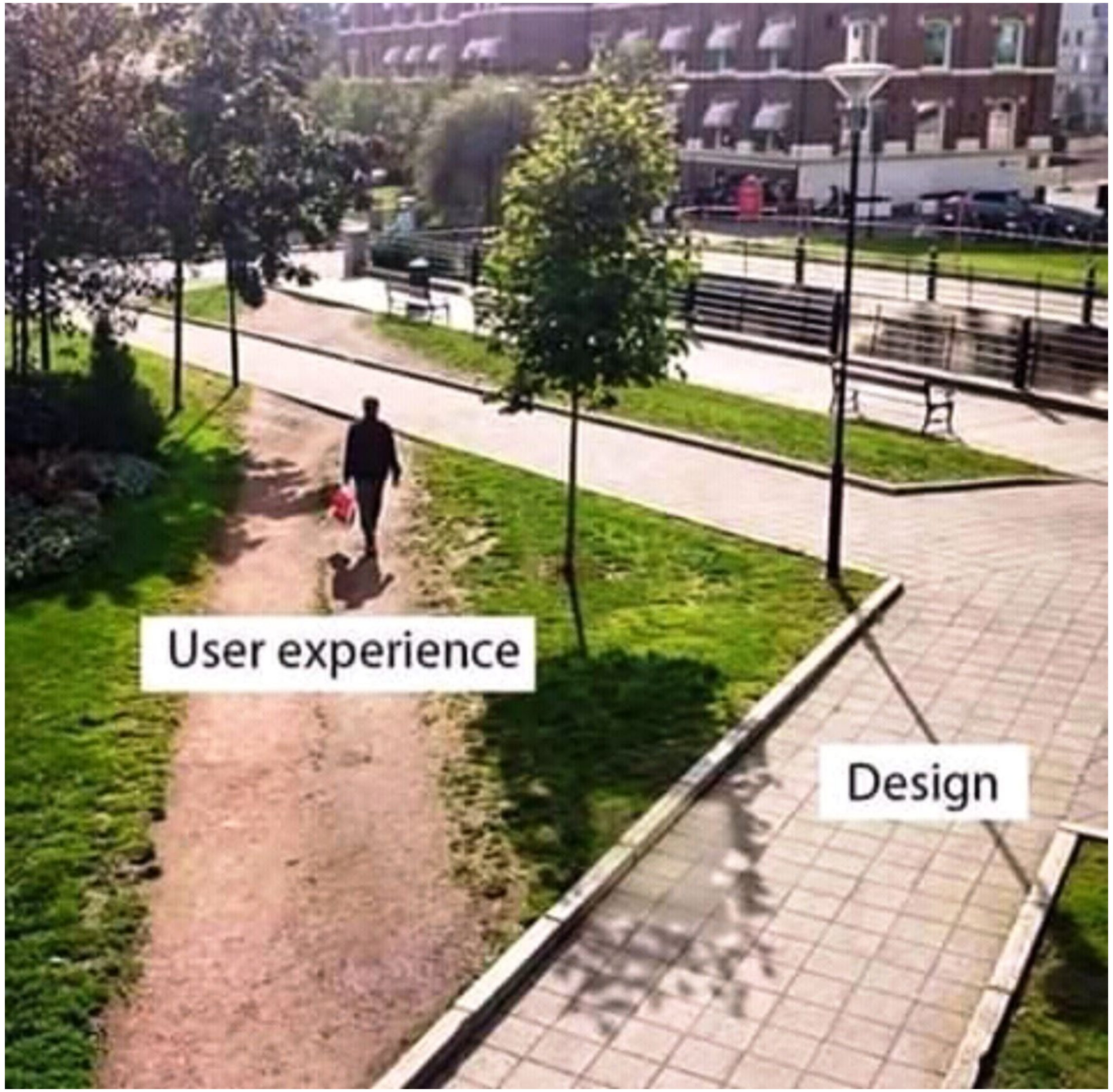
National Implementation Research Network (NIRN): http://nirn.fpg.unc.edu/.

NCHRP Active Implementation

- Increased emphasis on implementation
  - Addressed in the problem statement
  - Addressed in RFP
  - Implementation plan as a deliverable – developed by panel and research team

https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?Projec
tID=588

  - $2.0 million/year to assist DOTs in bringing research results into practice
  - Application process is overseen by NCHRP 20-44 Panel
    - https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=588
    - Sid Mohan (smohan@nas.edu)
  - Variety of activities, from $30k - $300k


User experience
Design

National Implementation Research Network (NIRN)

- In 2005, the National Implementation Research Network released a monograph synthesizing implementation research findings across a range of fields.
- Based on these findings, NIRN developed five overarching frameworks referred to as the Active Implementation Frameworks.
- **The Active Implementation Frameworks presented herein have been modified to implement research outcomes "products" instead of "interventions".**

Fixsen, D., S. Naoom, K. Blase, R. Friedman, and F. Wallace, "Implementation Research: A Synthesis of the Literature," University of South Florida, Tampa, 2005. HTTP://NIRN.FPG.UNC.EDU

Active Implementation

What is Active Implementation?

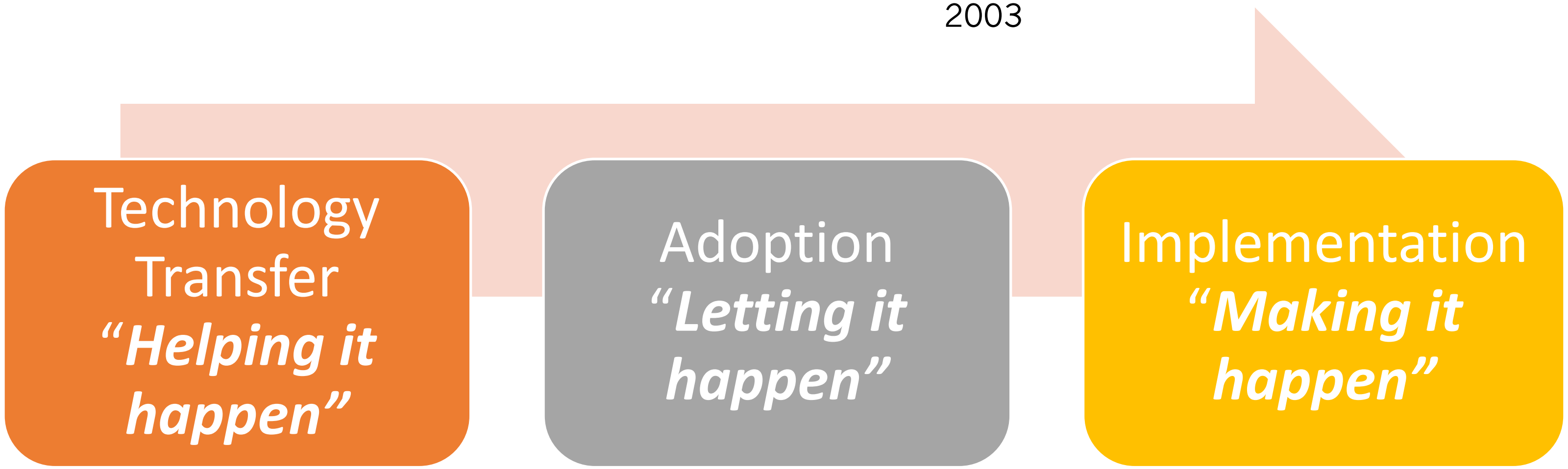
Effective Products X **Effective Implementation** X **Enabling Contexts** = **Intended Outcomes**

- The formula for success involves multiplication. If any component is weak then the intended outcomes will not be achieved, sustained, or used on a socially significant scale.
- Like a serum and a syringe, innovations are one thing and implementation is something else entirely different. Doing more research on a serum will not produce a better syringe; doing more research on an innovation will not produce better implementation methods.

Effective Implementation Process Flow

- Technology transfer—a communications process through which the results of scientific research are put into use; often including implementation strategies and activities
- Adoption—a decision to use an innovation (e.g., AASHTO Ballot Items and adoption of specifications)
- Implementation—putting an innovation to use

Rogers, E., M., *Diffusion of Innovations*, 5th ed., 2003

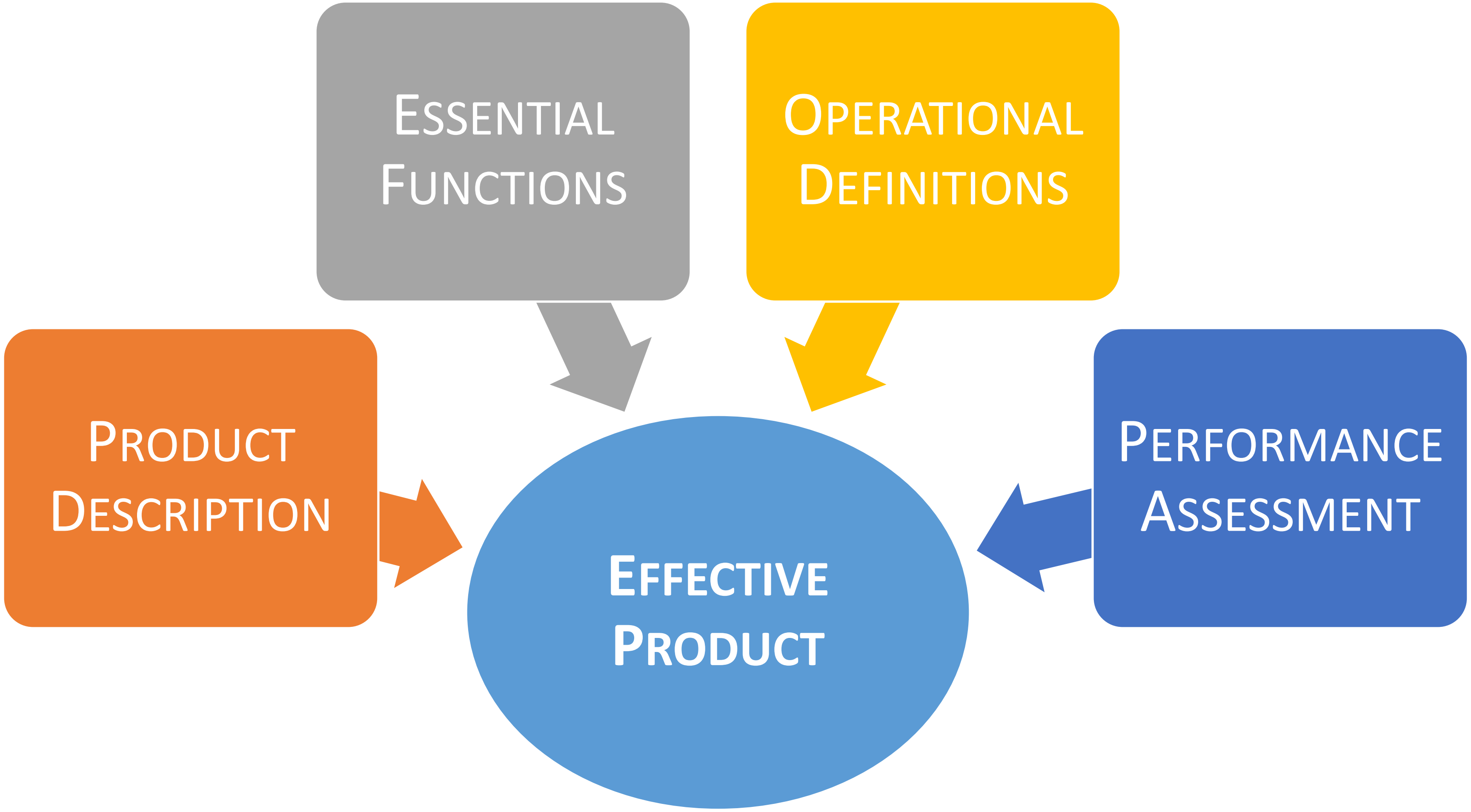


Active Implementation Frameworks

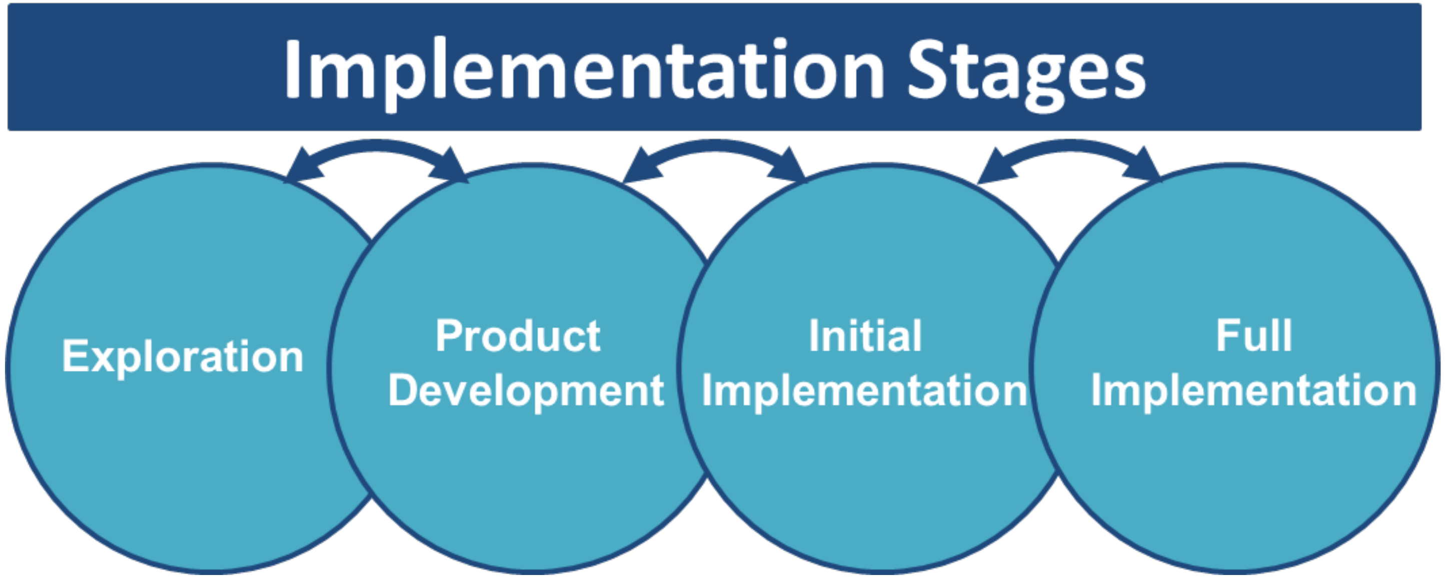
- **Framework 1: Effective Products**
    - *Well defined, effective products that are useable and implementable*
- **Framework 2: Implementation Stages**
    - *Development of implementation guidance specific to research results*
- **Framework 3: Implementation Drivers**
    - *Critical program and organizational support that is needed to implement products*
- **Framework 4: Implementation Teams**
    - *The group that guides and manages the implementation and scale-up process*
- **Framework 5: Product Feedback**
    - *The processes that support teams and organizations efficiently to solve problems and get better*

Adapted from Dean Fixsen and Karen Blase

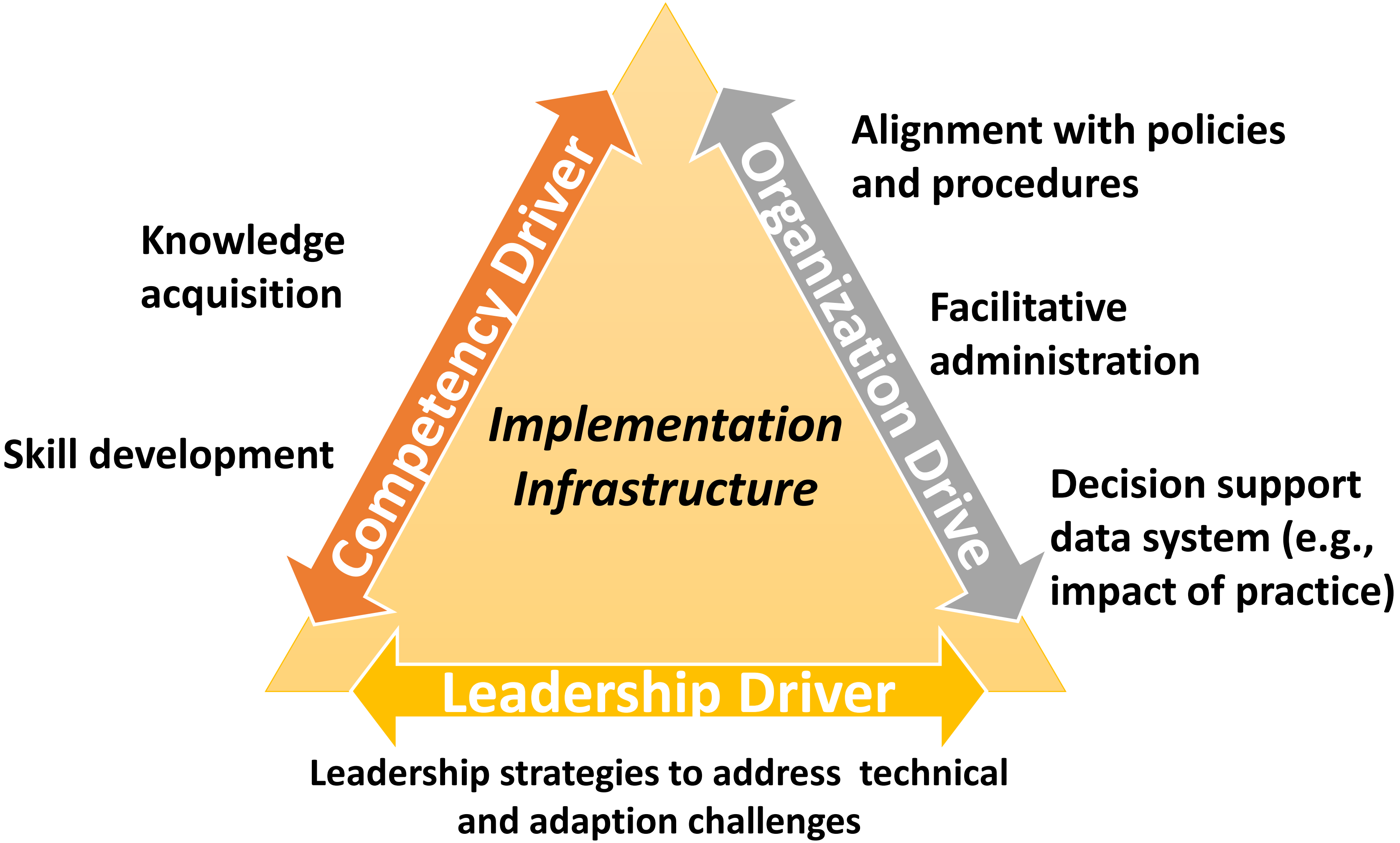
Framework 1: Effective Products



Framework 2: Implementation Stages



Framework 3: Implementation Drivers



Adapted from Dean Fixsen and Karen Blase

Influence of Implementation Drivers on Effective Product Implementation

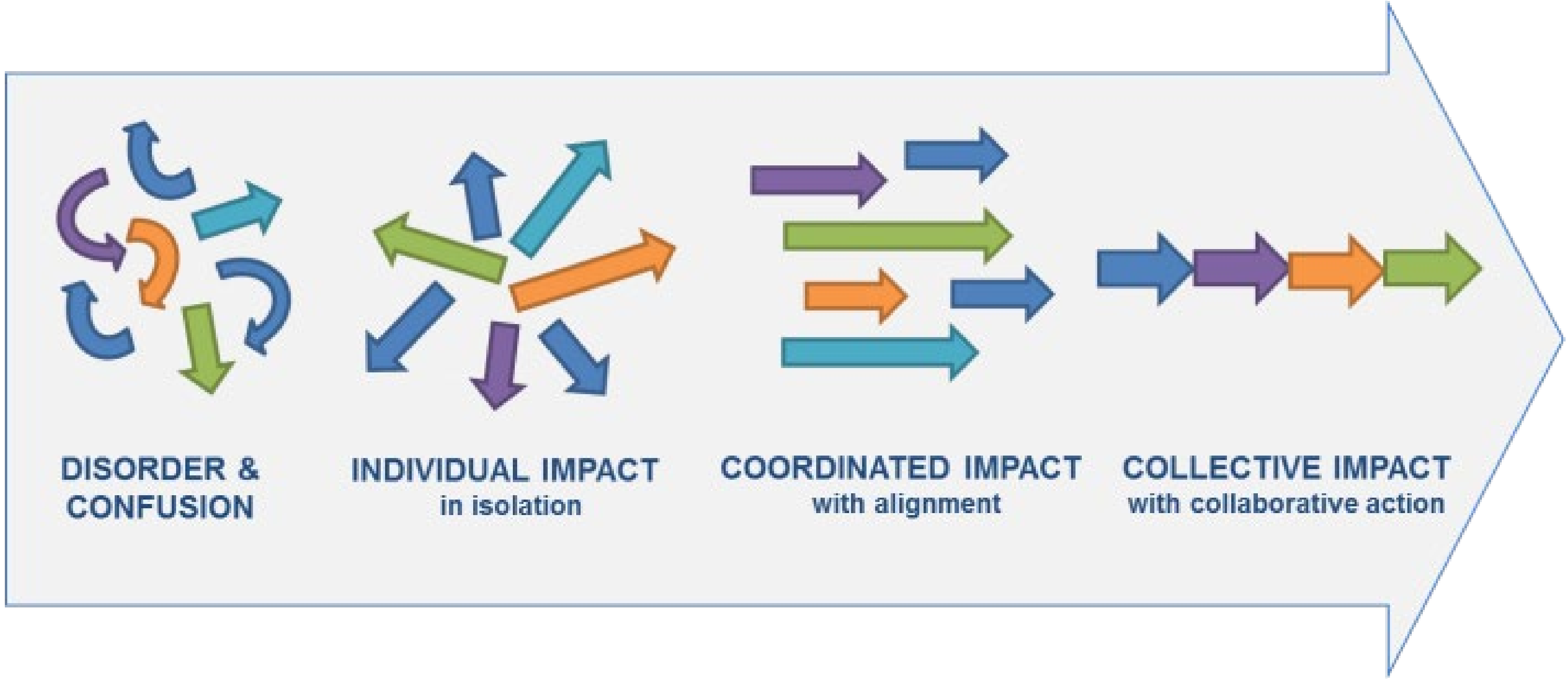
Leadership Driver	Organization Driver	Competency Driver	Effective Product	Possible Implementation Outcome
Generally Enabling	Strong	Strong	Strong	High
		Weak	Weak	Low
	Weak	Strong	Strong	Medium
		Weak	Weak	Low
Generally Hindering	Strong	Strong	Strong	Medium
		Weak	Weak	Low
	Weak	Strong	Strong	Low
		Weak	Weak	N/A

Framework 4: Implementation Teams

Implementation **Teams could be**:

- Developers and purveyors of a product.
- Intermediary organizations that help others implement a variety of products.
- Agency staff with support from groups outside the organization or system.

Framework 4: Implementation Teams



Collective Impact with Collaborative Action

https://www.santafecf.org/birth-to-career

FRAMEWORK 5: PRODUCT FEEDBACK

- Product feedback supports the purposeful process of change.
- Implementation teams use product feedback to maintain and improve products
- Measure product impact on practice and find the return of investment

Technology Transfer—Implementation Strategies

Implementation Approaches

Ad hoc Implementation

- Cumbersome or varying activities
- Lack of funding
- Lack of expertise
- Champions
- Incremental change
- No lasting impact

Systematic Active Implementation

- Implementation infrastructure within the agency (guidance, training, etc.)
- Dedicated funding and expertise
- Implementation team
- Accelerating change
- Lasting change

NATIONAL ACADEMIES *Sciences Engineering Medicine*

NCHRP Active Implementation

https://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP_ActiveImplementation.pdf

Questions?

Waseem Dekelbab, PhD, PE, PMP

CRP Deputy Director and Manager, NCHRP

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NOVEMBER 2022 UPDATE

Highway Safety Manual
Practical Applications

Bonnie Polin, Massachusetts DOT

Transportation Research Board
January 11-12, 2023

Recommendations List

1. Technical assistance contract
2. On-call technical assistance in NCHRP contracts
3. Webinar with users before models are finalized to discuss case studies, sensitivity analysis, and edge cases
4. Discussion in final report on how to handle edge cases, sensitivity analysis, and comparison to existing HSM models
5. Examine transferability of state/location- specific calibrations and SPFs
6. Include factors in model development that allow for transferring to other jurisdictions
7. Practitioners’ application guide for using Part C models on edge cases
8. Develop uniform liability-neutral language and caveats detailing the appropriateness of models
9. Ensure tools require site-specific SPFs or calibration factors or disclaimers regarding use of ‘generic’ models
10. Database of states’ fatal and injury crash data
11. Add data from NCHRP projects to one database for use by others

Implementation of NCHRP Research

- Waseem Dekelbab, Cooperative Research Programs Deputy Director, and NCHRP
- Manager Sid Mohan, NCHRP Associate Program Manager for Implementation and Technology Transfer

Recommendations List - *Research*

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12. Add data from NCHRP projects to one database for use by others

Recommendations List - *Data*

1. Technical assistance contract
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4. Discussion in final report on how to handle edge cases, sensitivity analysis, and comparison to existing HSM models
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11. **Database of states' fatal and injury crash data**
12. **Add data from NCHRP projects to one database for use by others**

Recommendations List – *RPS and RFP Text*

1. Technical assistance contract
2. On-call technical assistance in NCHRP contracts
3. **Webinar with users before models are finalized to discuss case studies, sensitivity analysis, and edge cases**
4. **Discussion in final report on how to handle edge cases, sensitivity analysis, and comparison to existing HSM models**
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7. Include factors in model development that allow for transferring to other jurisdictions
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11. Database of states' fatal and injury crash data
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Recommendations List – *Also underway…*

1. **Technical assistance contract**
2. **On-call technical assistance in NCHRP contracts**
3. Webinar with users before models are finalized to discuss case studies, sensitivity analysis, and edge cases
4. Discussion in final report on how to handle edge cases, sensitivity analysis, and comparison to existing HSM models
5. Examine transferability of state/location- specific calibrations and SPFs
7. Include factors in model development that allow for transferring to other jurisdictions
8. Practitioners' application guide for using Part C models on edge cases
9. Develop uniform liability-neutral language and caveats detailing the appropriateness of models
10. **Ensure tools require site-specific SPFs or calibration factors or disclaimers regarding use of 'generic' models**
11. Database of states' fatal and injury crash data
12. Add data from NCHRP projects to one database for use by others

Discussion: Suggested RPS and RFP Text

- Compatibility with Existing Research:
  - Ensure results/products are consistent and compatible, or document differences and guidance for use.
- Scope, Sensitivity, Edge Cases:
  - Evaluate and document appropriate use cases for the models, sensitivity analysis, and impacts of applying models to outside the intended scope.
- Pilot Tests:
  - Use pilot tests of models and tools prior to finalization of models and refine research products based on inputs from pilots.
- Frequently Asked Questions:
  - Document responses to anticipated frequently asked questions.
- Implementation Planning:
  - Directly engage stakeholders and practitioners prior to finalization of research to raise awareness and obtain input.

Discussion

Bonnie Polin (bonnie.polin@state.ma.us)

NCHRP Project 7-29

Development of an 8th Edition of the AASHTO *Green Book* (GB8)

Incorporating Crash Prediction Methods In Design Decisions

Presentation to TRB SPA Committee
January 2023

Texas A&M Transportation Institute

Ingrid Potts, PI (TTI)

Karen Dixon, Co-PI (TTI)

Doug Harwood
(Harwood Road Safety, LLC)

Project Objective

- Develop a draft 8th Edition *Green Book* (GB8) suitable for balloting through AASHTO processes

GB8 Goals

- Increased design flexibility
- Performance-based approach (in situations where performance measures are available)
- Multimodal considerations
  - address all transportation modes for every project
- Based on context classifications
  - rural and natural context
  - rural town context
  - suburban context
  - urban context
  - urban core context
  - special contexts

Top-Level GB8 Outline

- Part I—Introduction
- Part II—Performance-Based Design Process
- Part III—Design Controls and Criteria
- Part IV—Tailoring Geometric Design to Roadway Context

Outline for Part I—Introduction

- Chapter 1—Overview
- Chapter 2—Key Concepts in Geometric Design
- Chapter 3—Overview of Performance-Based Design
- Chapter 4—Project Needs and Objectives Statement

Outline for Part II—Performance-Based Design Process

- Chapter 5—Performance Analysis Tools
- Chapter 6—Steps in Performance-Based Design

Outline for Part III—Design Controls and Criteria

- Chapter 7—Design Controls
- Chapter 8—Roadway Alignment
- Chapter 9—Cross-Section Elements
- Chapter 10—At-Grade Intersections
- Chapter 11—Freeways
- Chapter 12—Interchanges
- Chapter 13—Other Elements Affecting Geometric Design

Outline for Part IV—Tailoring Geometric Design to Roadway Context

- Chapter 14—Rural and Natural Context
- Chapter 15—Rural Town Context
- Chapter 16—Suburban Context
- Chapter 17—Urban Context
- Chapter 18—Urban Core Context
- Chapter 19—Special Contexts

Outline for Discussion of Specific Geometric Design Elements in Part III Chapters

- Introduction
- Performance Measures
- Basis for Design Guidance and Criteria
- Design Guidance and Criteria
- Project Type Considerations
- Context Considerations

Crash Performance Measures

- Crash frequency (total and by transportation mode)
- Crash severity
- Crash type distribution
  - multiple- and single-vehicle crashes
  - multiple-vehicle collision types
  - single-vehicle collision types

Crash Performance Analysis Tools

- *Highway Safety Manual (second edition)*
    - with encouragement for calibration and/or agency-specific SPFs
- Other relevant CMFs and research results
- Other relevant tools

Where in GB8 Will Crash Prediction Be Addressed?

- Chapter 3—Definition/explanation of performance-based design
- Chapter 5
  - Definition/identification of specific performance measures
  - Discussion of performance analysis tools
- Chapter 6—example of steps in a performance-based design process
- Part III chapters—performance measures applicable to specific individual geometric design elements
- Part IV chapters—“putting it all together”—analysis of design alternatives combining multiple geometric features for a project in a specific context class

Where Does the Work Stand At Present?

- Part I chapters have been drafted and undergone one round of reviews.
- Some Part III chapters have been drafted and are under review; others are currently being drafted.
- Work on Parts II and IV will begin soon.
- Projected completion date: mid-2024
- Formal AASHTO review and balloting will be conducted after the NCHRP project is complete.

Questions?

Part III Overview

- **Objective:** Present the design controls and criteria for geometric design.
- Chapter 7:
  - Presents the road user and vehicle characteristics that are key controls for geometric design.
  - Reviews the role of speed in geometric design.
- Chapters 8 through 13:
  - Present design information for specific geometric design elements.
  - Present a review of applicable performance estimates and a summary of dimensional design criteria that can be used as defaults when performance estimates are lacking.
- Part III has a broad scope, addressing all context classes, functional classes, and roadway types. (Part IV will address specific context classes in separate chapters and will focus on more specific conditions.)

Chapter 9 – Cross Section Elements

Objective:

- Present performance measures and design guidance criteria for cross section elements. In this and other Part III chapters:
  - performance measures (where available) are intended as the primary design decision making tool
  - design guidance and criteria are intended for application where no performance measures are available and as a supplement to the performance measures where they are available
  - design guidance and criteria are a revised/expanded version of what was in GB7

Chapter 9 – Cross Section Elements

- CMFs for individual cross-section elements are presented in the chapter
- Analysis of alternatives with multiple cross-section features should be done with the full HSM procedures which are described, but not presented in detail, in Chapter 5

Chapter 9 – Cross Section Elements

Chapter 9 – Cross Section Elements			
9.1	Traveled Way Surface and Cross Slope	9.9	Pedestrian Facilities
9.2	Lane Width	9.10	Bicycle Facilities
9.3	Shoulders	9.11	Transit Facilities
9.4	Rumble Strips	9.12	On-Street Parking
9.5	Curbs	9.13	Frontage Roads
9.6	Roadside Design	9.14	Roadway Traffic Noise Abatement
9.7	Medians	9.15	Tunnels
9.8	Access Management and Control	9.16	References

Chapter 11 – Freeways

Objective:

- Present performance measures and design guidance and criteria and related performance analysis methods for freeways.
  - Generally based on GB7 Chapter 8 with added information on performance measures.

Chapter 11 – Freeways

Chapter 11 – Freeways			
11.1	Performance Measures	11.10	Structures
11.2	Design Speed	11.11	Vertical Clearance
11.3	Design Traffic Volumes	11.12	Roadside Design
11.4	Levels of Service	11.13	Ramps and Terminals
11.5	Traveled Way and Shoulders	11.14	Outer Separations, Borders, and Frontage Roads
11.6	Curbs	11.15	Freeways in Rural Areas
11.7	Horizontal Alignment	11.16	Freeways in Urban Areas
11.8	Superelevation	11.17	References
11.9	Vertical Alignment		

Chapter 13 – Other Elements Affecting Geometric Design

Objectives:

- This chapter is intended as the home for material that was in GB7 Chapter 3 but is not directly related to the alignment material now being incorporated in GB8 Chapter 8

Chapter 13 – Other Elements Affecting Geometric Design

Chapter 13 – Other Elements Affecting Geometric Design	
13.1	Erosion Control and Landscape Development
13.2	Rest Areas, Information Centers, and Scenic Overlooks
13.3	Lighting
13.4	Utilities
13.5	Traffic Control Devices
13.6	Traffic Management Plans for Construction
13.7	References

Related Material That Will Appear in Other Chapters

- Chapter 1 (Overview)
  - definitions of key terms
- Chapter 5 (Performance-Based Analysis Tools)
  - definition of performance measures
  - description of tools to quantify performance measures
  - interpretation of CMFs
  - more detailed discussion of noise models than in Chapter 9
- Chapter 7
  - motor vehicle, pedestrian, and bicycle characteristics
  - design vehicle dimensions and turning characteristics
  - forecasting design volumes

Related Material That Will Appear in Other Chapters

- Chapter 8 (Alignment)
  - basics if horizontal alignment design
  - basics of vertical alignment design
- Chapter 10 (Intersections)
  - design of cross section features at intersections
  - intersection-related strategies for access management
  - design of frontage roads at intersections
- Chapter 12 (interchanges)
  - design of interchange ramps and speed-change lanes
  - design of ramp terminals

Related Material That Will Appear in Other Chapters

- Part IV will present:
  - design guidance for specific context classes

Figures Not Yet Developed for Chapter 9

- Figure 9-12 (Comparison of Crash Performance Measures for Streets with Various Cross Sections)
  - awaiting completion of urban and suburban arterial chapter for HSM2
- Figure 9-15 (photograph of grade separated facility with pedestrian fencing present)
  - searching for suitable photograph
- Figure 9-22 (Typical Separated Bicycle Lane Cross Section)
  - to be adapted from Figures 8 and 9 of the FHWA separated bicycle lane guide

Questions?

NCHRP 17-104: Enhancement of Roadside Design Safety Prediction Models for the Highway Safety Manual

January 11, 2023

Presenter – Jeff Gooch, VHB

Project Team

- UNC Highway Safety Research Center (HSRC)
  - Raghavan Srinivasan (PI), Taha Saleem, Bo Lan, Mike Vann, Meghna Chakraborty
- Kittelson and Associates (KAI)
  - James Bonneson
- VHB
  - Jeff Gooch, Bhagwant Persaud
- Bucknell University
  - Doug Gabauer

Objectives

- Validate Roadside SPFs and associated CMFs developed in NCHRP Project 17-54
- Develop or enhance roadside SPFs to supplement or replace existing models
- Coordinate the research products with planner content for other manuals such as Green Book and the Roadside Design Guide (RDG)

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Phase 1

- Task 1: Review literature and assess data sources
- Task 2: Assess state of practice
- Task 3: Review project 17-54 SPFs
- Task 4: Develop draft phase II work plan
- Task 5: Develop revised phase II work plan
- Task 6: Prepare interim report

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Phase II

- Task 7: Conduct the approved phase II work plan
- Task 8: Develop implementation guidance
- Task 9: Develop final products

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RESEARCH CENTER

Task 1: Review literature and assess data sources

- Literature review
  - Submitted to panel
- Coordination with other NCHRP projects and committees
  - Ongoing
- Contacted the PIs for relevant NCHRP projects

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Task 1: Preliminary Findings

- Vehicle dynamics data may be useful for assessing the potential severity of collisions between vehicles and roadside features, including fixed objects, barriers, and slopes.
- Object type AND lateral offset both affect the outcome of roadside collisions.
- The research has primarily focused on rural roadways with little to no access control. Research on fixed objects has primarily concerned trees and utility poles, and treated them as groups rather than as individual objects. Research into longitudinal hazards has only concerned barrier. Most research focused solely on severe run-off-road crashes and several failed to validate their results.
- There is a lack of consensus on what the target crash type should be (and if one should even be used, as opposed to crashes of all types). For reliable decision making, research should develop a uniform definition of a target crash for roadside features, and also quantify the effect on non-target crashes.

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Task 2: Assess state of practice

- Conduct survey of States
  - Determine priority of facility types (distributed survey)
    - Rural undivided, Rural divided, Rural freeway, Urban undivided, Urban divided, Urban freeway
  - Data and importance of specific roadside elements
  - Responses provided by 1/6
- Interviewing roadside safety practitioners and analysts

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Task 3: Review Project 17-54 SPFs

- Critical review of project 17-54 CMFs and SPFs
  - Some of it was done as part of NCHRP 17-72
- Compare 17-54 CPM to HSM and other CPMs
  - Determine whether the predicted crash frequency (by severity) is consistent with other CPMs
  - Compare with RSAP predictions for run of road crashes

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Task 3: 17-54 and the HSM

- 17-54 CPMs predict SVROR crash frequency for a user-specified roadside – combine for SVROR crash frequency
- 17-54 CPMs do not include a calibration factor, nor do they recommend a procedure for calibration
- 17-54 CPMs include severity conversion factors – but do not predict PDO crash frequency
- 17-54 narrow object density AF does not
  - Demonstrate a logical increase in value with an increase in object density, or
  - Bound to a value like the barrier CMF as objects become very dense
- 17-54 CPMs generally follow expected shapes, though magnitude of differences with other models varies
- Roadside slope AF produces significantly larger values than other slope CMFs in literature

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Task 3: RSAP and 17-54

Adjustment Factor Feature	RSAPv3	NCHRP 17-54	Conflicting?
Number of Lanes	As the number of lanes increase, encroachment frequency decreases.	For all except undivided rural roads, crash frequency increases as number of lanes increases.	
Posted Speed Limit	Encroachment frequency is higher for roads with a posted speed limit less than 65 MPH.	Crash frequency is increased for roads with a posted speed limit less than 55 MPH and decreased for roads with a posted speed limit greater than 55 MPH.	●
Access Density	Encroachment frequency increases significantly as access density increases linearly.	Access density is not included in the crash prediction model.	N/A
Terrain	Encroachment frequency is highest for rolling terrain and elevated for mountainous terrain.	Terrain is not included in the crash prediction model.	N/A
Grade	Encroachment frequency is increased for segments with a grade steeper than 2 percent.	Crash frequency decreases on urban roads as grade exceeds 3 percent, while it increases on rural roads while grade exceeds 3 percent.	●
Horizontal Curvature	Encroachment frequency increases linearly as curve radii get sharper from 1,910 feet to 955 feet or sharper. The adjustment factor is higher for curves to the left (relative to direction of travel) compared to curves to the right.	Generally, crash frequency increases as degree of curvature increases sharper than 10 degrees, with the relationship much starker on rural roads compared to urban roads. The analysis is directional, so right edge of road crashes are increased for curves to the left relative to the direction of travel.	
Lane Width	Encroachment frequency increases as lane width decreases.	Crash frequency increases as lane width increases.	●
Shoulder Width	Though not included as an adjustment factor, increased shoulder width is associated with decreased crash frequency in RSAPv3 due to the mapping of trajectories.	Crash frequency decreases as shoulder width increases.	

Task 4: Draft Phase II Work Plan

- Revise prioritized list of roadway types and roadside data elements
  - Use a numerical scheme to rank candidate roadside attributes

Roadside attribute	Safety evaluation need based on survey (5 high, 1 low)	Data element availability (5 high, 1 low)	Data element collection effort required (1 high, 5 low)	Total

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Task 4: Draft Phase II Work Plan

- Validation of Project 17-54 CPMs
- Development of new and/or enhanced roadside CPMs
- Data collection and analysis plan

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Task 5: Revised Phase II Work Plan

- Gather existing data
- Assess viability of analytical approaches
- Describe possible modifications to Draft Phase II Work Plan

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Task 6: Prepare Interim Report

- Prepare revised phase II work plan
- Prepare interim report
- Meet with panel

Task 7: Conduct the Phase II Work Plan

- Collect data
- Analyze data and develop roadside CPMs
- Validate CPMs and select proposed CPMs
- Develop draft application spreadsheet
- Develop draft reference guide and training materials

Task 8: Implementation Guidance

- Assess likely implementation outcomes
  - Need for the CPMs
  - Opportunities for the CPMs
  - Limitations of the CPMs
  - Risks of using the CPMs
- Demonstrate Roadside CPM implementation
  - Assistance from States that provided input in Task 2

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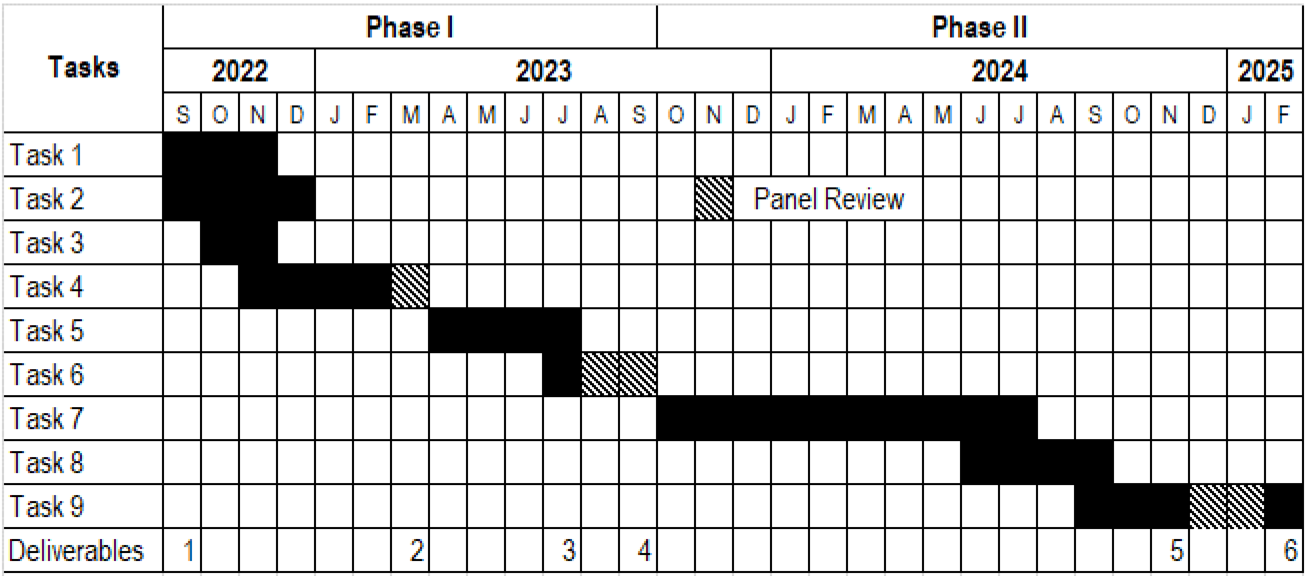
Task 9: Develop Final Products

- Prepare draft HSM text
- Prepare draft final report
- Submit final spreadsheet, guide, and training materials
- Submit final report and HSM text

Timeline



Deliverables

1: Amplified Work Plan

2: Panel review fo Task 4 materials

3: Draft Work Plan for Phase 2

4: Meet with NCHRP Panel to discuss Draft Work Plan for Phase 2

5: Draft final report

6: Revised final report

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Questions?

- Thank you for your time!
  - jgooch@vhb.com
  - Srini (PI) – srini@hsrc.unc.edu

DEVELOPMENT OF CRASH PREDICTION MODELS FOR SHORT-TERM DURATIONS

NCHRP 22-48

PI: Mohamed Abdel-Aty, PhD, PE

Presenter: Nada Mahmoud, PhD

OUTLINE

1) Project Objectives
2) Project Data
3) Project Methodology
4) Project Results
5) Project Conclusions
6) User Guide
7) Implementation Tool

01

PROJECT OBJECTIVES

PROJECT OBJECTIVES

A

IDENTIFY

explanatory variables measured over short durations, including more precise measures of exposure other than AADT, and factors such as speed and speed variability

B

DEVELOP

short-term crash prediction models to estimate the safety performance of roadways, with considerations given to operational and exposure characteristics, and routes that experience short-term capacity changes

C

DEVELOP

an implementation tool suitable for practitioners' use

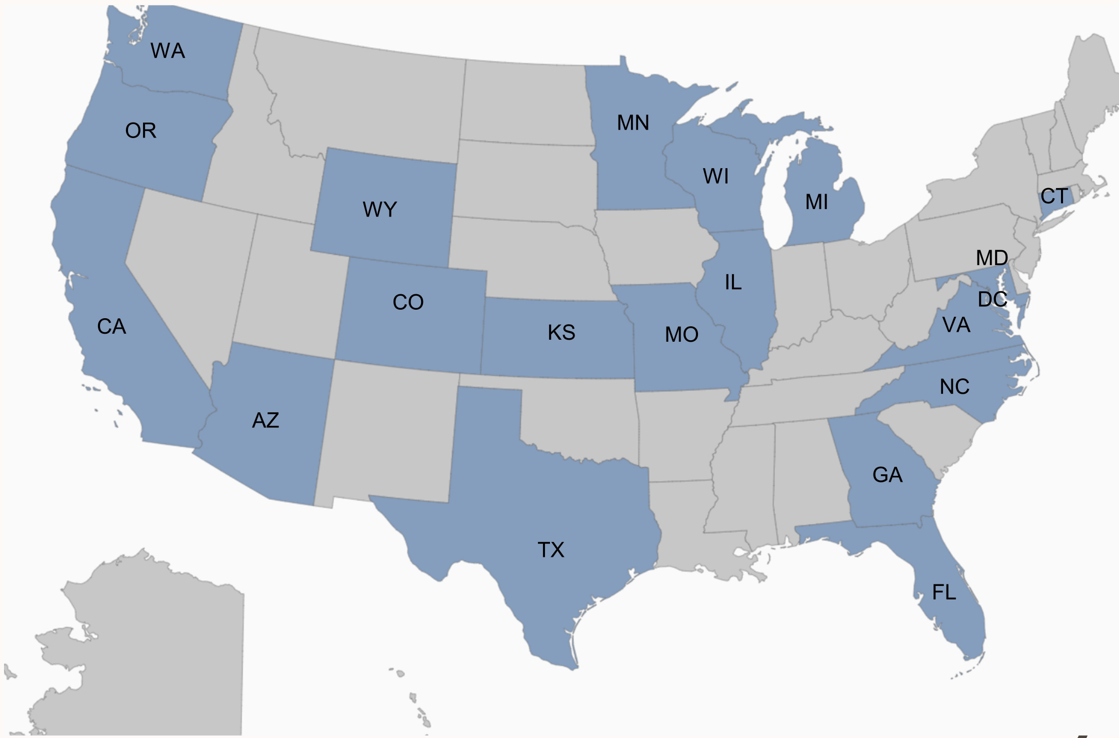
02

PROJECT DATA

COVERAGE OF STATES

- Data from **19 states** and **D.C.** were collected

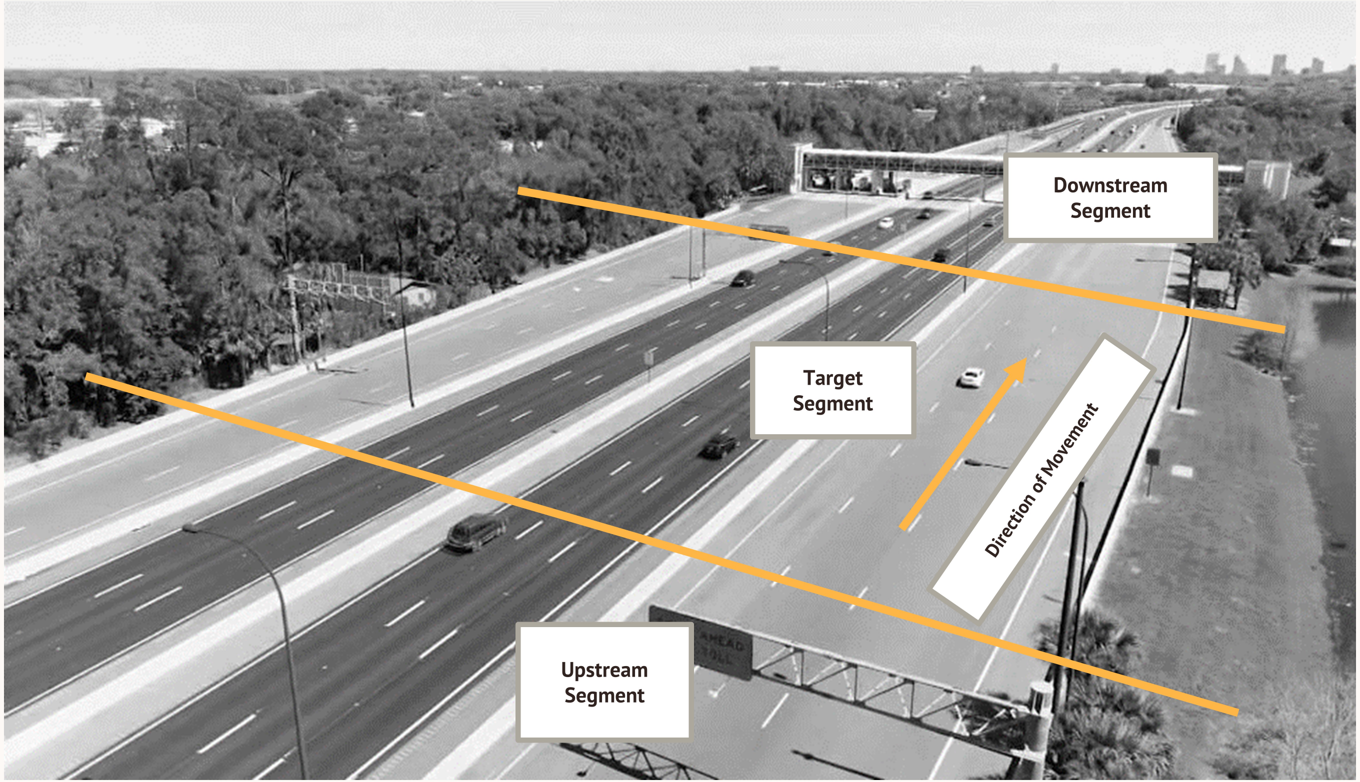
- High resolution data from **16** of them were used for **modeling** or **validation** (excluding CT, MN, and NC)



CLASSES OF DATA

Traffic Data	Crash Data	Geometric Data	Active Traffic Management (ATM) Data
high resolution volume	crash location	route shapefiles	VSL/VAS
high resolution speed	crash time	number of lanes	HOV/HOT
high resolution occupancy	crash severity		HSR
			RM
			WZ

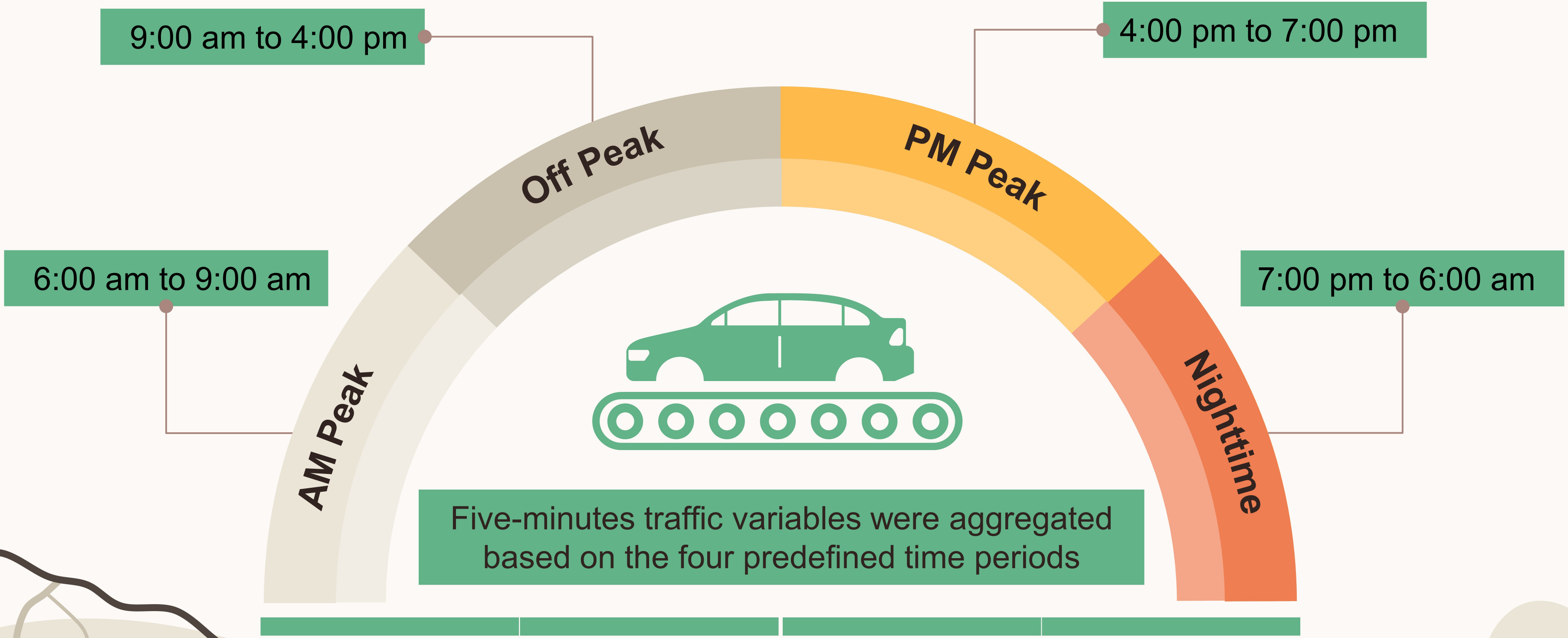
SPATIAL TRAFFIC VARIABLES CONSIDERED



SPATIAL TRAFFIC VARIABLES CONSIDERED

Spatial Variables		Difference in Adjacent Spatial Variables	
Log (Volume) upstream	Std. of speed upstream	Avg. speed target segment – Avg. speed downstream segment	Avg. occupancy downstream segment – Avg. occupancy target segment
Log (Volume) downstream	Std. of speed downstream		
Log (Avg. speed) upstream	Avg. occupancy upstream	Avg. speed upstream segment – Avg. speed target segment	Avg. occupancy target segment – Avg. occupancy upstream segment
Log (Avg. speed) downstream	Avg. occupancy downstream		

TIME PERIODS CONSIDERED



Five-minutes traffic variables were aggregated based on the four predefined time periods

03

PROJECT METHODOLOGY

MODELS CHOSEN

Crash prediction models for different use case scenarios by the predefined time periods and severity levels (KABCO, KABC, KA, and O), i.e., **short-term SPFs**, need to be developed. A variety of statistical and machine learning models were tested and compared; model prediction power and parsimony were considered for choosing the final models.

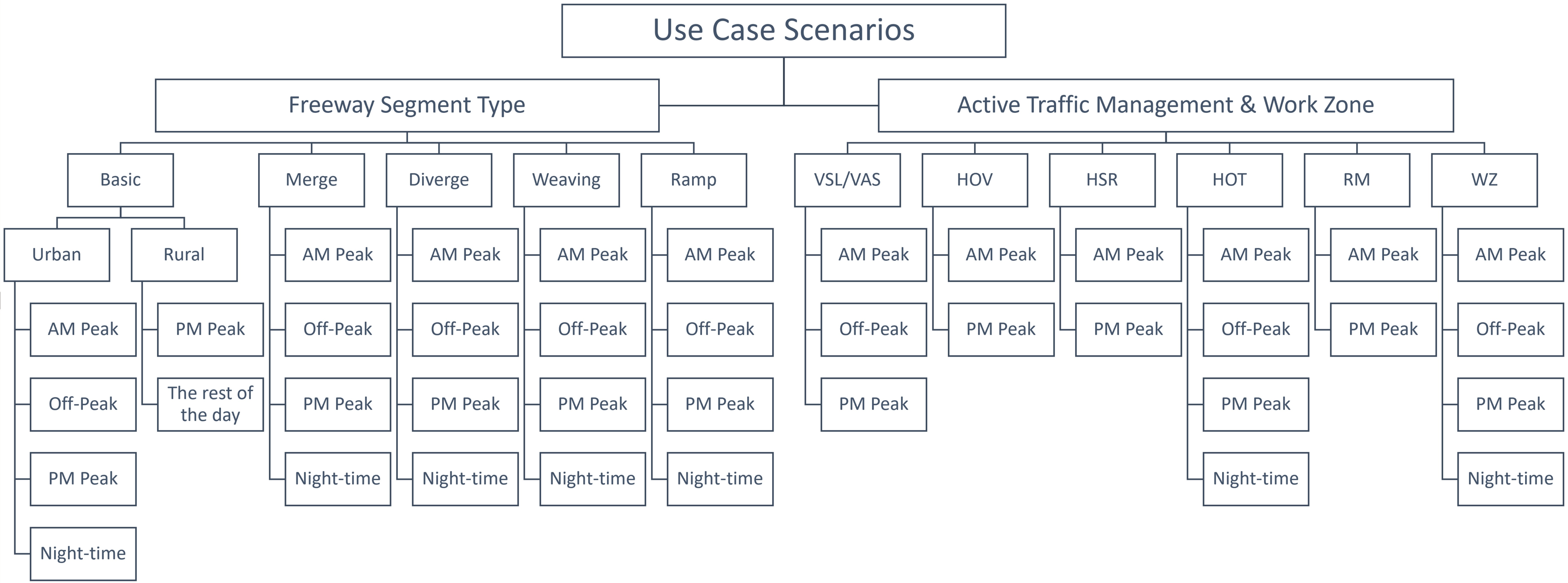
Poisson Lognormal Model for KABCO, KABC, KAB, O

assumes the error term to be lognormal, which makes it appropriate for modeling crash frequencies with a heavier-tailed distribution

Hurdle or Logistic Regression Model for KA

Hurdle model includes two parts, one models the probability of attaining value zero, and the other models the non-zero values, which makes it appropriate for data with excessive zeros

SHORT-TERM CRASH PREDICTION MODELS SCENARIOS



SHORT-TERM CRASH PREDICTION MODELS SCENARIOS

ID	Use Case Scenarios		Detailed Scenarios		Number of Models
1	Freeway Segment Type	Urban Basic	Weekday: AM Peak, Off Peak, PM Peak, Nighttime	KABCO, KABC, KAB, KA, O	4×5= 20
		Rural Basic	Weekday: PM Peak, Non-PM Peak (Rest of the day)	KABCO, KABC, KAB, KA, O	4x5=10
		Weaving (Type A,B)	Weekday: AM Peak, Off Peak, PM Peak, Nighttime	KABCO, KABC, O (Type A) KABCO (Type B)	4x3=12 4x1 = 4
		Merge	Weekday: AM Peak, Off Peak, PM Peak, Nighttime	KABCO, KABC, KAB, KA, O	4×5=20
		Diverge	Weekday: AM Peak, Off Peak, PM Peak, Nighttime	KABCO, KABC, KAB, KA, O	4×5=20
		On-Ramp	Weekday: AM Peak, Off Peak, PM Peak, Nighttime	KABCO, KABC, KAB, O	4×4=16
		Off-Ramp	Weekday: AM Peak, Off Peak, PM Peak, Nighttime	KABCO, KABC, KAB, O	4×4=16
2	High-Occupancy Vehicle Lane (HOV)		HOV Operation Status (AM Peak, PM Peak)	KABCO, KABC, KAB, O	2×4=8
3	Variable/Advisory Speed Limit	Variable Speed Limit	VSL/VAS Operation Status (AM Peak, PM Peak, Off-Peak)	KABCO, KABC, KAB, KA, O	3×5=15
		Advisory Speed Limit			
5	Hard Shoulder Running (HSR)		HSR Operation Status (AM Peak, PM Peak)	KABCO, KABC, KAB, O	2×4=8
6	Work Zone (WZ)		Weekday: AM Peak, Off Peak, PM Peak, Nighttime	KABCO, KABC, KAB, KA, O	4×5=20
7	Ramp Metering (RM)		RM Operation Status (AM Peak, PM Peak)	KABCO, O	2×2=4
8	High Occupancy Toll Lane (HOT)		Weekday: AM Peak, Off Peak, PM Peak, Nighttime	KABCO, KABC, O	4×3=12
Total					**185**

04

PROJECT RESULTS

A GLANCE AT ANALYSIS RESULTS

A

FREEWAY SEGMENT MODELS

B

USE CASE SCENARIOS

C

CALIBRATION

D

CASE STUDY

A GLANCE AT ANALYSIS RESULTS

A

FREEWAY SEGMENT MODELS

B

USE CASE SCENARIOS

C

CALIBRATION

D

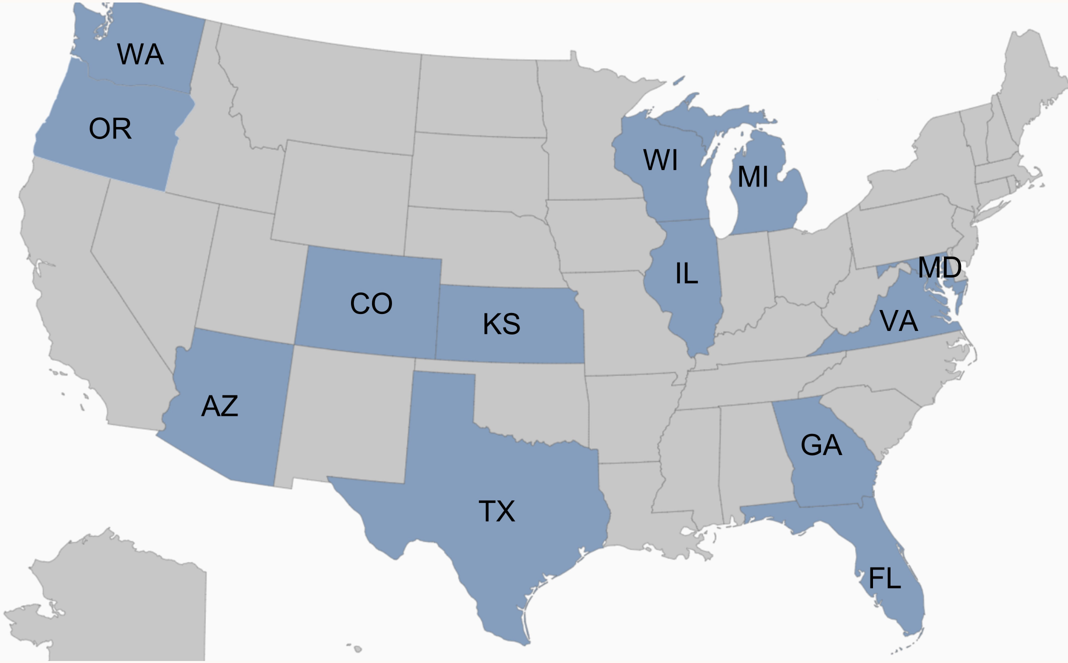
CASE STUDY

1. URBAN BASIC SEGMENT MODELS

Models developed using data from 13 States

The segments with Active Traffic Management (ATM) systems were excluded in these models

Variables from upstream and downstream segments were included while training the models



1. URBAN BASIC SEGMENT MODELS

KABCO

AM Peak

KABCO Crashes											
AM Peak (N: 3741, # of Crashes: 12777)			PM Peak (N: 3745, # of Crashes: 16953)			OFF Peak (N: 3744, # of Crashes: 22059)			Nighttime (N: 3743, # of Crashes: 13957)		
	Estimate	Pr(>|z|)		Estimate	Pr(>|z|)		Estimate	Pr(>|z|)		Estimate	Pr(>|z|)
(Intercept)	-0.481	0.244	(Intercept)	1.304	0.001	(Intercept)	-0.123	0.760	(Intercept)	-2.521	0.000
Ln (Volume)	0.399	0.000	Ln (Volume)	0.283	0.000	Ln (Volume)	0.364	0.000	Ln (Volume)	0.502	0.000
Ln (Average Speed)	-1.020	0.000	Ln (Average Speed)	-1.102	0.000	Ln (Average Speed)	-0.939	0.000	Ln (Average Speed)	-0.555	0.000
Std. Speed	0.094	0.000	Std. Speed	0.107	0.000	Std. Speed	0.114	0.000	Std. Speed	0.023	0.000
Number of Lanes (Ref. 4)			Number of Lanes (Ref. 4)			Number of Lanes (Ref. 4)			Number of Lanes (Ref. 4)		
Num. of Lanes (6-8 lanes)	0.636	0.000	Num. of Lanes (6-8 lanes)	0.669	0.000	Num. of Lanes (6-8 lanes)	0.572	0.000	Num. of Lanes (6-8 lanes)	0.517	0.000
Num. of Lanes (>= 10 lanes)	1.290	0.000	Num. of Lanes (>= 10 lanes)	1.329	0.000	Num. of Lanes (>= 10 lanes)	1.317	0.000	Num. of Lanes (>= 10 lanes)	1.128	0.000
State (Ref. MD_OR_WA_WI)			State (Ref. AZ_FL_KS_OR_WA)			State (Ref. MD_OR_WA_WI)			State (Ref. AZ_FL_WI)		
AZ_FL_TX	0.476	0.000	CO_TX	0.362	0.000	AZ_FL	0.331	0.000	CO_KS_VA	0.664	0.000
CO_VA	1.075	0.000	GA_MI	1.300	0.000	CO_IL_VA	1.061	0.000	GA	1.820	0.000
GA_MI	1.795	0.000	IL_VA	0.748	0.000	GA_MI	1.638	0.000	IL	1.331	0.000
IL_KS	1.342	0.000	MD_WI	-0.390	0.000	KS_TX	0.623	0.000	MD_OR	-0.305	0.002
-			-			-			MI	0.985	0.000
-			-			-			TX_WA	0.399	0.000
AIC	15514.300		AIC	17262.300		AIC	19279.600		AIC	16635.300	
MAE (train)	1.285		MAE (train)	1.637		MAE (train)	2.088		MAE (train)	1.343	
MAE (test)	1.266		MAE (test)	1.600		MAE (test)	2.157		MAE (test)	1.388	
MSE (train)	8.969		MSE (train)	14.372		MSE (train)	25.980		MSE (train)	7.527	
MSE (test)	9.027		MSE (test)	11.474		MSE (test)	26.080		MSE (test)	8.738	
MAD (train)	1.208		MAD (train)	2.352		MAD (train)	2.950		MAD (train)	1.209	
MAD (test)	1.229		MAD (test)	2.301		MAD (test)	2.960		MAD (test)	1.219	

1. URBAN BASIC SEGMENT MODELS

KABCO

AM Peak

$$\textbf{Predicted Crashes} = No.of\ years\ \times\ Segment\ Length\ \times\ \exp(-0.481 + 0.399\ LogVolume\ - 1.020\ Log\ AvgSpeed + 0.094\ Std.Speed + 0.636\ LaneNumber_{6-8} + 1.290 \times LaneNumber_{\geq 10} + 0.476\ (AZ, FL, TX) + 1.075\ (CO, VA) + 1.795\ (GA, MI) + 1.342\ (IL, KS))$$

When calibration is necessary, e.g., for a different time period, or for a state that is not included in the equation above, a calibration factor can be calculated as

$$Calibration\ Factor_{state} = \frac{\sum Observed\ Crashes_{state}}{\sum Predicted\ Crashes_{state}}$$

$$\textbf{Predicted Crashes with Calibration} = No.of\ years\ \times\ Segment\ Length \times \exp(-0.481 + 0.399\ LogVolume\ - 1.020\ Log\ AvgSpeed + 0.094\ Std.Speed + 0.636\ LaneNumber_{6-8} + 1.290\ LaneNumber_{\geq 10}) \times\ Calibration\ Factor_{state}$$

SIGNIFICANT VARIABLES

1. Ln Volume
2. Ln Average Speed
3. Std. of Speed
4. Lane Number (6-8)
5. Lane Number ≥ 10

2. WEAVING SEGMENT MODELS

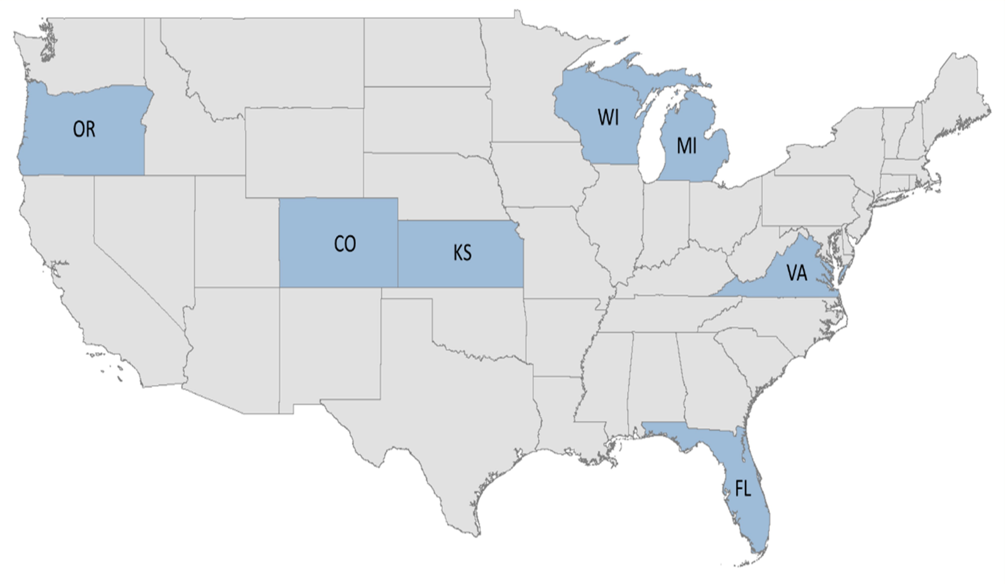
Models were developed for AM peak, PM peak, Off-peak, and Nighttime

Models were developed for KABCO, KABC, and O

Due to sample size, KAB and KA models weren't developed

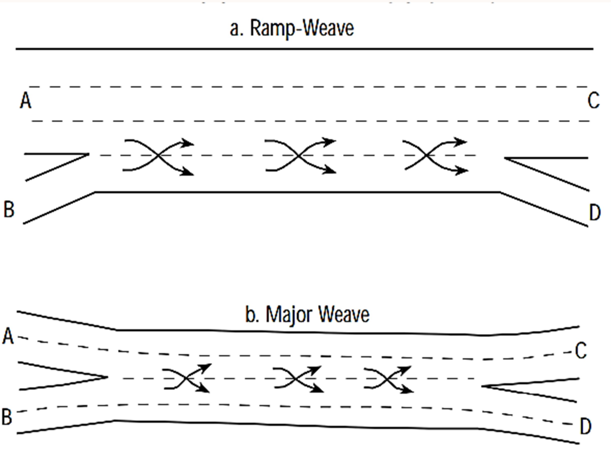
On-Ramp Volume and Off-Ramp ratio were utilized in the developed models

Models developed using data from 7 States

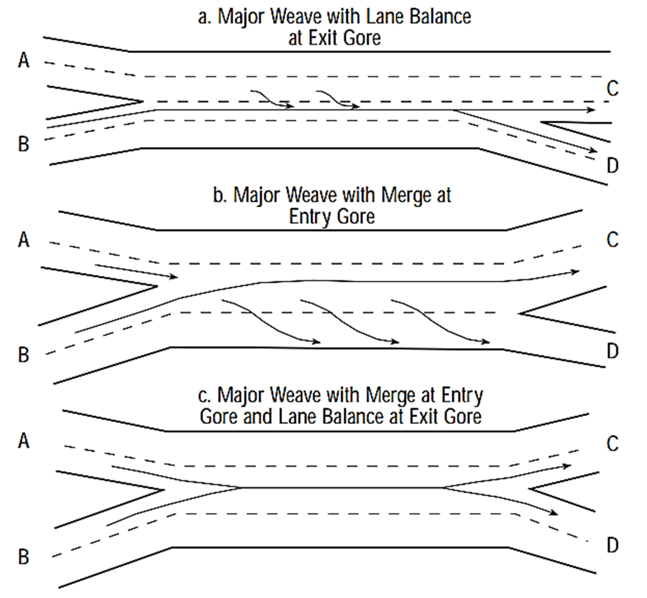


2. WEAVING SEGMENT MODELS

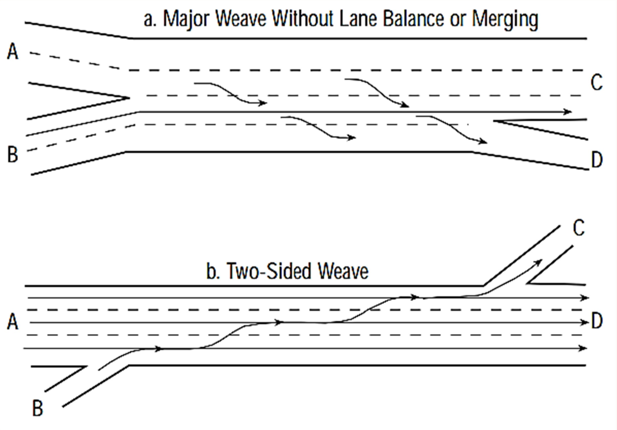
Type “A”



Type “B”

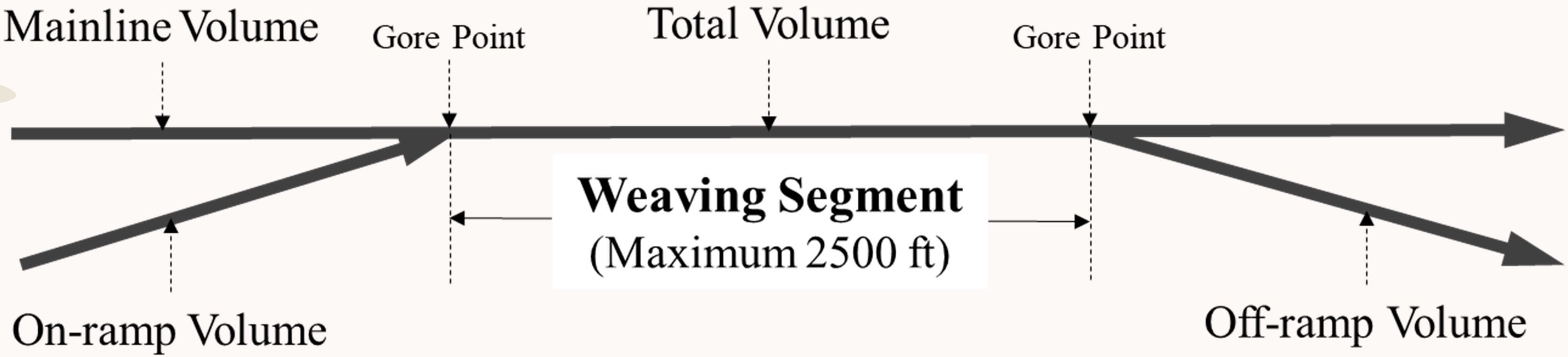


Type “C”



KABCO, KABC, and O models were developed for Type “A” weaving segments
Only KABCO models were developed for Type “B” weaving segments

2. WEAVING SEGMENT MODELS



$$Total\ Volume = Mainline\ Volume + OnRamp\ Volume$$

$$OffRamp\ Volume\ Ratio = OffRamp\ Volume / Mainline\ Volume$$

2. WEAVING SEGMENT MODELS

KABCO

AM Peak

Significant Variables: **1. Ln Volume** **2. Ln Avg. Speed**

$$\textit{Predicted Crashes} = \text{No. of years x Segment Length x exp(-1.559 + 0.833 LnVolume – 1.1 Ln AvgSpeed – 0.452 OR)}$$

When calibration is necessary, e.g., for a different time period, or for a state that is not included in the equation above, a calibration factor can be calculated as

$$Calibration\ Factor_{state} = \frac{\sum Observed\ Crashes_{state}}{\sum Predicted\ Crashes_{state}}$$

$$\textit{Predicted Crashes} = \text{No. of years x Segment Length x exp(−1.559 + 0.833 LnVolume – 1.1 Ln AvgSpeed – 0.452 OR) x Calibration Factor}$$

A GLANCE AT ANALYSIS RESULTS

A

FREEWAY SEGMENT MODELS

B

USE CASE SCENARIOS

C

CALIBRATION

D

CASE STUDY

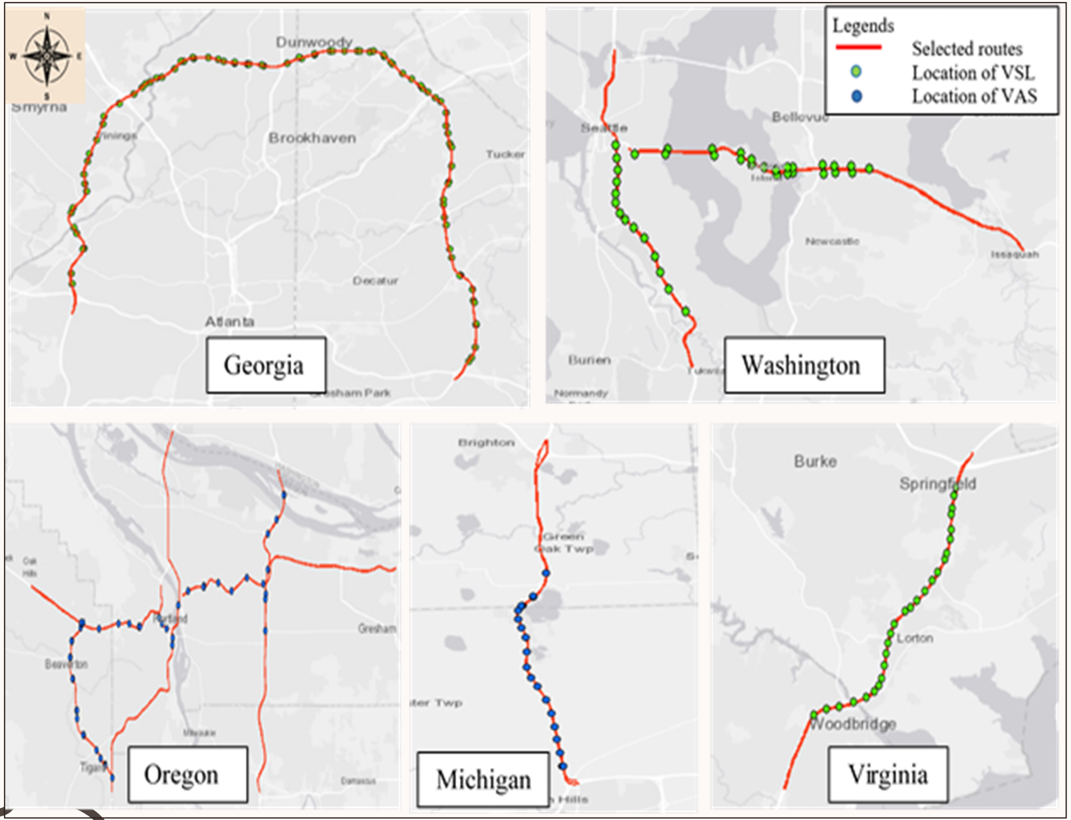
1. VSL/VAS USE CASE SCENARIO

Total Five States

Three States VSL

Two States VAS

- VSL/VAS dummy variable was included in the models
- Models were developed for AM, PM, and Off peak
- Models were developed for KABCO, KABC, KAB, KA, and O



1. VSL/VAS USE CASE SCENARIO

KABCO

AM Peak

Significant Variables:

1. Ln Volume
2. Ln Avg. Speed
3. VAS_VSL Segment
4. Std. Speed Upstream
5. Avg. Occupancy Downstream

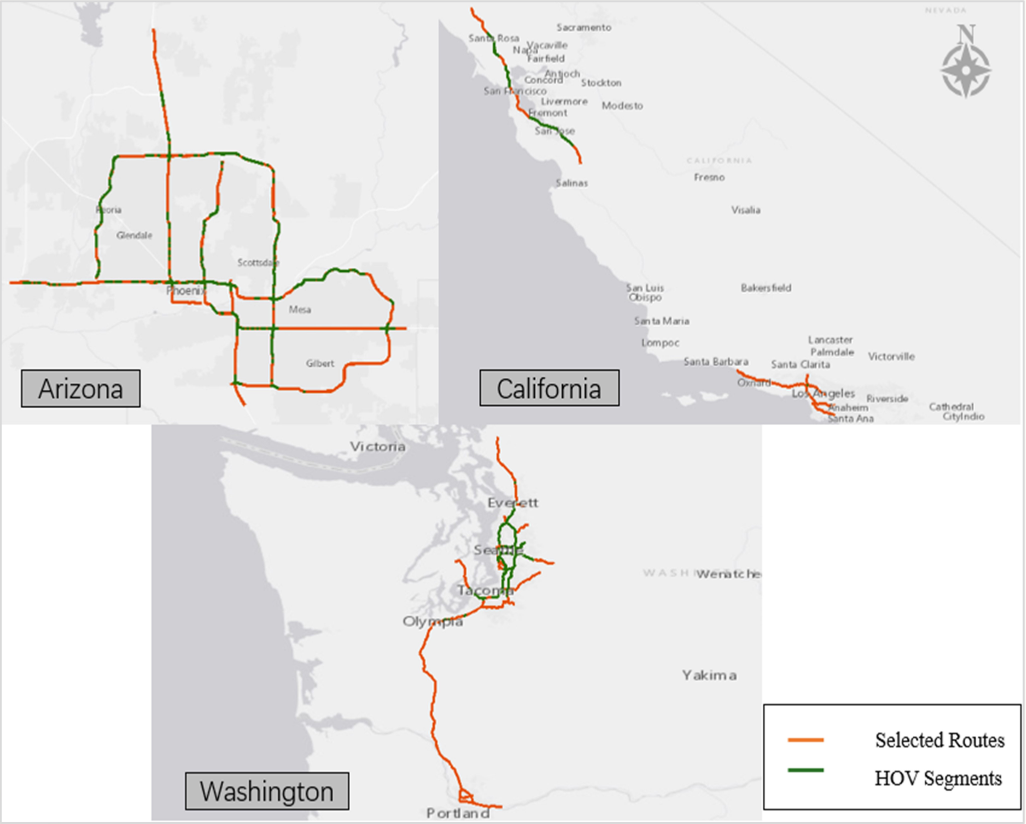
$$\boldsymbol{Predicted\ Crashes} = No.of\ years \times Segment\ Length \times \exp(-0.414 + 0.209\ \text{LogVolume} - 0.472\ \text{LogAvgSpeed} + 0.035\ \text{Std.Speed\_Upstream} + 0.047\ \text{AvgOccupancy\_Downstream} - 0.221\ \text{VAS\_VSL\_Segment} + 2.696\ \text{GA} + 0.876\ \text{VA} + 0.412\ (\text{MI}, \text{WA}))$$

$$\boldsymbol{Predicted\ Crashes\ with\ Calibration} = No.of\ years \times Segment\ Length \times \exp(-0.414 + 0.209\ \text{LogVolume} - 0.472\ \text{LogAvgSpeed} + 0.035\ \text{Std.Speed\_Upstream} + 0.047\ \text{AvgOccupancy\_Downstream} - 0.221\ \text{VAS\_VSL\_Segment}) \times Calibration\ Factor_{state}$$

2. HOV LANES USE CASE SCENARIO

Total Three States

- ❑ Models were developed for AM and PM peaks
- ❑ Models were developed using lane level Data
- ❑ Models were developed for KABCO, KABC, KAB, and O
- ❑ Multiple traffic variables that capture the difference between the HOV lanes and the GP lanes were considered



2. HOV LANES USE CASE SCENARIO

KABCO

AM Peak

Significant Variables: 1. Ln Volume 2. Ln Avg. Speed 3. Avg. Occupancy

4. Avg. Speed HOV Lanes – Avg. Speed General Purpose Lanes

$$\boldsymbol{Predicted\ Crashes} = No.of\ years\ \times\ Segment\ Length\ \times\ \exp(3.854 + 0.247\ LogVolume\ - 1.297\ LogAvgSpeed + 0.021\ (Avg.Speed\ HOV\ Lanes\ - Avg.Speed\ Genreal\ Purpose\ Lanes) + 0.014\ Avg.Occupancy)$$

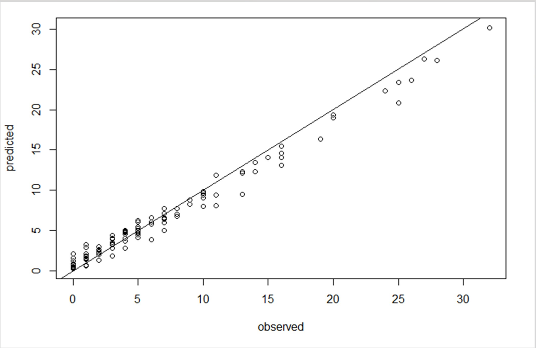
$$\boldsymbol{Predicted\ Crashes\ with\ Calibration} = No.of\ years\ \times\ Segment\ Length\ \times\ \exp(3.854 + 0.247\ LogVolume\ - 1.297\ LogAvgSpeed + 0.021\ (Avg.Speed\ HOV\ Lanes\ - Avg.Speed\ Genreal\ Purpose\ Lanes) + 0.014\ Avg.Occupancy) \times\ Calibration\ Factor_{state}$$

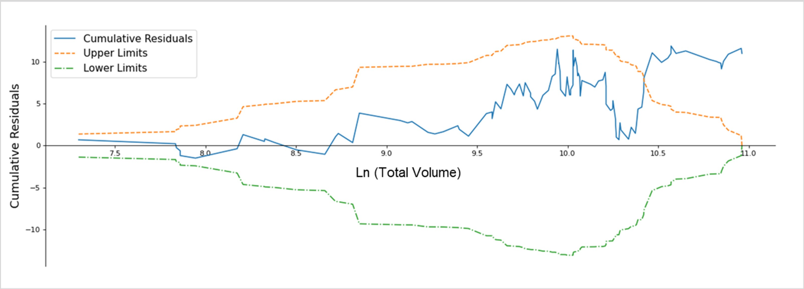
EVALUATION OF THE MODELS

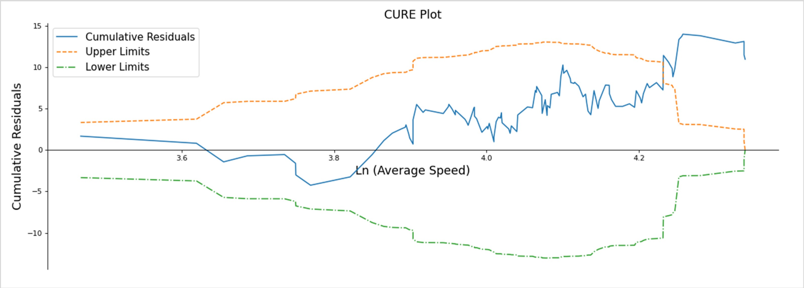
- The developed models were compared considering the Akaike Information Criterion (AIC), the Mean Absolute Error (MAE), the Mean Squared Error (MSE), and the Mean Absolute Deviation (MAD).

- The cumulative residual (CURE) plots to evaluate the selected models. The CURE plot is a visualization estimation measurement that was used in previous research to evaluate the SPFs and to better understand how well the proposed models fit the data

- The observed and the predicted crashes were plotted







Example of the evaluation plots (KABCO Crashes – weaving segments – AM peak)

05

PROJECT CONCLUSIONS

A GLANCE AT ANALYSIS RESULTS

A
FREEWAY SEGMENT MODELS

B
USE CASE SCENARIOS

C
CALIBRATION

D
CASE STUDY

CALIBRATION AND TRANSFERABILITY

Calibration is often needed to adjust the predicted crash counts when the SPF models are applied to a different area or time period.

For states included in the models, **pre-defined state dummies** were utilized to calibrate the total predicted crashes

If the user intends to utilize the developed models to predict the number of crashes for different states or regions, **Calibration factor (CF)**, is calculated as the ratio between total observed crashes and total predicted crashes.

VALIDATION AND TRANSFERABILITY

Validation and transferability were conducted using dataset from new states that were not represented in the models' development:

1. Sample of the remaining Florida data to validate the short-term developed models for the urban basic freeway segments.

2. Data from two states that were not included in the developed models (i.e., Wyoming and Wisconsin) to test the transferability of the developed models.

3. Data from HSR implemented route (US-23) in Michigan was utilized to check the transferability of the HSR models.

A GLANCE AT ANALYSIS RESULTS

A

FREEWAY SEGMENT MODELS

B

USE CASE SCENARIOS

C

CALIBRATION

D

CASE STUDY

CASE STUDY

Purpose

Compare the network screening result using the short-term models with that using the traditional HSM models

Data

Two representative states

- Florida urban sites
- Wisconsin rural sites

Method

- Using EB method to calculate the expected crashes
- Using (Expected – Predicted) as the performance measure for ranking sites and identifying PSI (potential for safety improvement)

Results

More different sites got identified between the short-term models and the HSM models

CONCLUSIONS

1. The high-resolution traffic variables capture much of the driving behavior in response to the geometry

2. Although the selected variables were consistent in the models, the magnitude of estimates, and the state dummy variables varied depending on the crash severity and time period. Therefore, the team would recommend separated SPFs for each crash severity and time period.

3. Some spatial variables (traffic variables for upstream and downstream segments) were found to be significant in the models.

4. The case study showed that the short-term SPFs were able to identify hotspots in more refined way based on the time period.

5. The identified hotspots were consistent with their corresponding that were identified using HSM models. However, different sites were identified in the short-term models and the HSM models.

06

USER GUIDE

USER GUIDE

- **Help** safety analysts to **use** the developed short-term crash prediction models in practice
- **When** and **how** the alternative methods should be selected and implemented
- **Step-by-step** process to **prepare** the dataset

07

IMPLEMENTATION TOOL

WEB-BASED TOOL

A **web-based tool** was developed to help users implement the short-term crash prediction models produced in this project

NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

TRB TRANSPORTATION RESEARCH BOARD

UCF SST UCF UNIVERSITY OF CENTRAL FLORIDA

UCONN UNIVERSITY OF CONNECTICUT

Thank You!

NCHRP 22-48

102nd Annual Meeting ▲ January 8–12, 2023 ▲ Washington, DC
TRB ANNUAL MEETING

Committee on Safety Performance and Analysis ACS20
January 11, 2023

Development of Crash Modification Functions for Italian Freeways

Alfonso Montella

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

Background

- Italian freeways have a total lenght of **13,974 km** (considering separately the carriageways)
- Approximately **90% is toll-operated** and managed by concessionary companies
- The biggest network is managed by "**Autostrade per l'Italia**" (ASPI) who manages **5,709 km of freeways**
  - 3,214 km with 2 lanes, 2,268 km with 3 lanes, 223 km with 4 lanes, 4 km with 5 lanes
- The network is mainly built in terrain with **morphological constraints** and most of the network was built in the 70's
- Italian crash modification factors have been developed only for **P2P speed control system** and **delineation improvements**
- ASPI, Italian Ministry for Transport and Infrastructure and University of Naples Federico II signed an agreement for **safety research on Italian freeways**

Background

50's | 70's | 90's | 2021

ASPI network in red color

Background

Method

- **Cross sectional study**
  - This study calibrated **safety performance functions** (SPFs) for developing CMFs, separately for curves and tangents, for different
    - crash types (total, single-vehicle, and multi-vehicles)
    - pavement conditions (dry and wet)
    - lighting conditions (daytime and nighttime)
    - severity (PDO and injury+fatal)
  - Generalized linear modelling techniques were used to fit the models and a **negative binomial distribution** error structure was assumed
  - The SPFs were used to quantify the effect of a specific variable on the crash occurrence and **CMFs were then derived from the model coefficients**

Model form

$$N_p = e^{a_0} \times L \times AADT^{a_1} \times e^{\sum_{p=1}^{m} b_p \times (x_p - x_{pbase})}$$

$$= N_{base} \times e^{\sum_{p=1}^{m} b_p \times (x_p - x_{pbase})} = N_{base} \times \prod CMF_p$$

where:

- **N_p** is the predicted annual crash frequency
- **L** is the segment length (m)
- **AADT** is the segment annual daily traffic (veh/day)
- **x_p** are the explanatory variables other than AADT and L
- **x_{pbase}** are the base values of the explanatory variables
- **a_0, a_1, b_p** are the model parameters
- **N_{base}** is the predicted annual crash frequency in base conditions
- **CMF_p** are the crash modification functions

Model fit

- The model parameters and the dispersion parameter of the negative binomial distribution were estimated by the **maximum likelihood method** using the Mass and the lme4 packages in R
- The models were developed by the **stepwise forward procedure**, adding one explanatory variable at each step. The decision on whether or not to keep a variable in the model was based on three criteria:
  - t-ratio of the variable's estimated coefficient significant at the 10 % level
  - improvement of the goodness-of-fit measures of the model that includes that variable (AIC and R^2_{α})
  - avoid inclusion of correlated variables in the same model
- The database was split in:
  - **training**, composed by 80% of the data, to estimate the models
  - **validation**, composed by 20% of the data, to validate the models

Explanatory variables

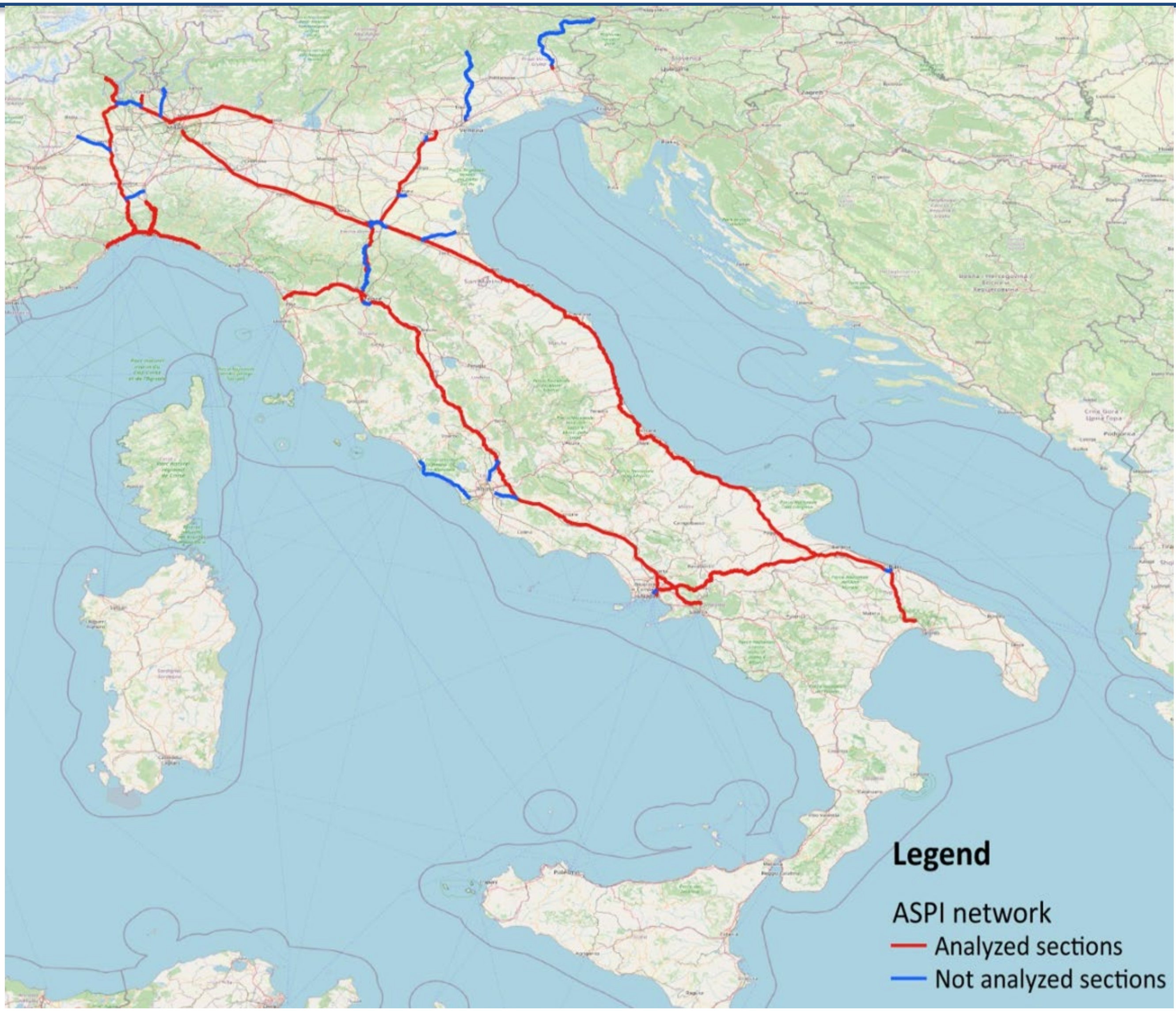
Variable	Description	x_{base}
HGV	Proportion of heavy goods vehicles	0.00
1/R [1/km]	Horizontal curvature	0.00
G_d [%]	Equivalent downgrade, obtained by weighing each gradient in relation to the segment length	0.00
G_u [%]	Equivalent upgrade, obtained by weighing each gradient in relation to the segment length	0.00
SEdef [%]	Superelevation deficiency, equal to the difference between the superelevation required by the Italian geometric design standard and the actual superelevation	0.00
RSW [m]	Right shoulder width	3.00
N_{lanes}	Binary variable, equal to 1 if the number of lanes is greater than 2	0.00

Explanatory variables

Variable	Description	x_{base}
SFC [#/100]	Sideway Force Coefficient (divided by 100)	0.55
TEX [mm]	Texture of the pavement	1.00
IRI [mm/m]	International Roughness Index	2.00
R_{Ledge} [cd/(m^2×lux)]	Coefficient of retroreflected luminance in dry conditions for edge lines (EN 1436:18)	0.20
R_{Llanes} [cd/(m^2×lux)]	Coefficient of retroreflected luminance in dry conditions for edge lines (EN 1436:18)	0.20
P2P	Binary variable, equal to 1 if the point-to-point speed enforcement system is active	0.00
Tunnel	Binary variable, equal to 1 if the segment is on a tunnel	0.00
Entering	Binary variable, equal to 1 if an entering lane is in the segment	0.00
Exit	Binary variable, equal to 1 if an exit lane is in the segment	0.00
Roadwork	Binary variable, equal to 1 if a roadwork with duration more than 7 days was present	0.00

Data

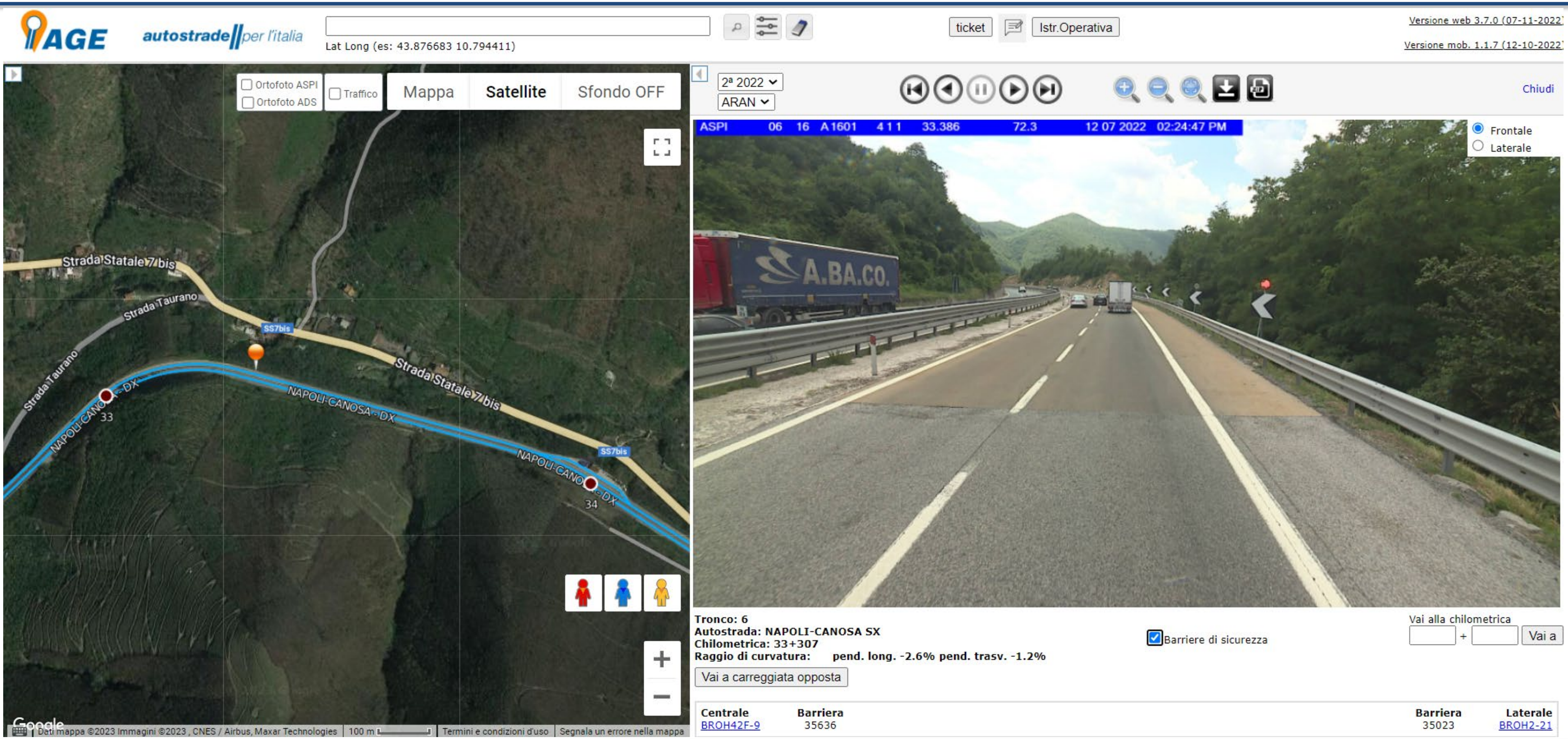
- **Almost all ASPI network was studied**
- The following sections were removed:
  - Ramps
  - Toll gates
  - Sections outside toll gates
- Overall, study network was composed by **4'665 km** with **5,002 homogeneous segments** (as regards alignment, section, and traffic)



Data

- Study data were retrieved from the ASPI database
  - **Crash** data
  - **Traffic** data
  - **Geometric** data
  - **Pavement** data (measures carried out every 6 months by ARAN and SUMMS)
  - **Marking** data (measures carried out every 6 months by Ecodyn)

Data



AGE
autostrade per l'italia
Lat Long (es: 43.876683 10.794411)
ticket
Istr.Operativa
Versione web 3.7.0 (07-11-2022)
Versione mob. 1.1.7 (12-10-2022)
Ortofoto ASPI
Ortofoto ADS
Traffico
Mappa
Satellite
Sfondo OFF
Strada Statale 7 bis
Strada Taurano
SS7bis
NAPOLI-CANOSA - DX
33
34
Dati mappa ©2023 Immagini ©2023 , CNES / Airbus, Maxar Technologies
100 m
Termini e condizioni d'uso
Segnala un errore nella mappa
2ª 2022
ARAN
Chiudi
ASPI 06 16 A1601 4 1 1 33.386 72.3 12 07 2022 02:24:47 PM
Frontale
Laterale
A.BA.CO.
Tronco: 6
Autostrada: NAPOLI-CANOSA SX
Chilometrica: 33+307
Raggio di curvatura: pend. long. -2.6% pend. trasv. -1.2%
Vai a carreggiata opposta
Barriere di sicurezza
Vai alla chilometrica
Vai a
Centrale
BROH42F-9
Barriera
35636
Barriera
35023
Laterale
BROH2-21

Crash data, 2017-2021

Crash type	N	%
Total	43,563	100.00
PDO	33,200	76.21
Injury	9,993	22.94
Fatal	370	0.85
Dry	36,990	84.91
Wet	6,092	13.98
SV	27,165	62.36
MV	16,398	37.64
Day	28,737	65.97
Night	13,773	31.62

Traffic and geometric data

Variable	Mean	Standard deviation	Min	Max
AADT	13,308	7,564	1,710	67,828
HGV [%]	25.71	6.29	0.78	53.54
R [m]	1,072	784	76	6,039
G_d [%]	0.58	0.71	0.00	5.18
G_u [%]	0.53	0.67	0.00	5.41
SEdef [%]	4.08	1.20	0.90	8.33
RSW [m]	2.63	0.93	0.00	4.00
N_{lanes}	0.38	0.49	0.00	1.00
P2P	0.33	0.47	0.00	1.00
Tunnel	0.15	0.35	0.00	1.00
Entering	0.07	0.26	0.00	1.00
Exit	0.07	0.26	0.00	1.00
Roadwork	0.67	0.47	0.00	1.00

Pavement and markings data

Variable	Mean	Standard deviation	Min	Max
SFC [#/100]	0.52	0.07	0.34	1.01
TEX [mm]	0.97	0.33	0.32	2.38
IRI [mm/m]	1.68	0.42	0.70	4.54
R_{Ledge} [cd/(m^2×lux)]	0.23	0.06	0.00	0.51
R_{Llanes}[cd/(m^2×lux)]	0.18	0.05	0.00	0.41

Results, tangents

	Total	Day	Night	Dry	Wet	SV	MV	PDO	Injury
a_0	-15.149 (0.183)	-16.019 (0.234)	-16.855 (0.274)	-15.397 (0.189)	-16.64 (0.453)	-14.126 (0.201)	-18.464 (0.296)	-14.984 (0.209)	-18.72 (0.333)
AADT	0.896 (0.018)	0.945 (0.022)	0.945 (0.027)	0.909 (0.019)	0.835 (0.045)	0.734 (0.02)	1.146 (0.029)	0.836 (0.020)	1.105 (0.032)
HGV	n.s.	0.246 (0.221)	n.s.	n.s.	n.s.	n.s.	n.s.	0.806 (0.200)	n.s.
Gu	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Gd	0.029 (0.017)	0.036 (0.02)	0.053 (0.027)	n.s.	0.135 (0.042)	0.061 (0.019)	n.s.	n.s.	0.070 (0.031)
RSW	-0.03 (0.013)	-0.054 (0.015)	n.s.	-0.026 (0.013)	0.29 (0.176)	n.s.	-0.091 (0.019)	-0.032 (0.014)	-0.036 (-0.022)
N_{lanes}	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SFC	-0.901 (0.189)	-0.927 (0.224)	-0.827 (0.286)	-0.798 (0.197)	-2.349 (0.518)	-0.623 (0.211)	-1.080 (0.296)	-0.848 (0.207)	-1.013 (0.341)
TEX	n.s.	n.s.	n.s.	n.s.	-0.393 (0.106)	n.s.	n.s.	n.s.	n.s.
IRI	0.331 (0.029)	0.556 (0.034)	0.259 (0.046)	0.312 (0.031)	0.475 (0.075)	0.338 (0.034)	0.319 (0.046)	0.386 (0.032)	0.129 (0.054)
R_{Ledge}	-1.215 (0.207)	-1.522 (0.221)	-0.897 (0.284)	-1.473 (0.193)	-0.71 (-0.432)	-0.820 (0.212)	-1.823 (0.323)	-1.096 (0.228)	-1.765 (0.328)
R_{Llanes}	-0.271 (-0.165)	n.s.	n.s.	n.s.	n.s.	n.s.	-0.897 (0.389)	-0.454 (0.275)	n.s.

Results, tangents

	Total	Day	Night	Dry	Wet	SV	MV	PDO	Injury
P2P	-0.099 (0.02)	-0.115 (0.024)	-0.098 (0.029)	-0.089 (0.021)	-0.195 (0.05)	n.s.	-0.252 (0.032)	-0.096 (0.022)	-0.141 (0.035)
Tunnel	0.367 (0.029)	0.415 (0.034)	0.105 (0.046)	0.366 (0.03)	0.182 (0.077)	0.32 (0.032)	0.403 (0.045)	0.364 (0.032)	0.406 (0.052)
Entering	n.s.	n.s.	0.062 (0.038)	n.s.	0.141 (0.074)	n.s.	n.s.	n.s.	n.s.
Exit	0.148 (0.025)	0.158 (0.029)	0.065 (0.04)	0.127 (0.025)	0.105 (0.064)	0.038 (0.027)	0.285 (0.037)	0.121 (0.026)	0.165 (0.040)
Roadwork	0.044 (0.021)	0.112 (0.025)	n.s.	0.05 (0.022)	n.s.	n.s.	0.19 (0.033)	0.037 (0.022)	0.077 (0.036)
1/k	5.039 (0.268)	4.036 (0.234)	6.128 (0.655)	5.179 (0.294)	2.053 (0.213)	6.337 (0.476)	2.465 (0.144)	4.983 (0.296)	3.639 (0.333)
Log-likelihood	-14,247	-11,899	-8,141	-13,357	-4,596	-11,510	-9,300	-12,769	-7,189
AIC	28,520	23,824	16,303	26,736	10,011	23,038	16,240	25,564	14,402
BIC	28,614	23,918	16,383	26,815	10,105	23,104	18,711	25,658	14,489
R^2_a	0.931	0.923	0.957	0.934	0.887	0.942	0.905	0.928	0.938

Results, curves

	Total	Day	Night	Dry	Wet	SV	MV	PDO	Injury
a_0	-16.828 (0.269)	-18.614 (0.332)	-18.568 (0.443)	-17.065 (0.283)	-19.253 (0.656)	-15.576 (0.302)	-22.654 (0.502)	-16.755 (0.302)	-20.752 (0.557)
AADT	1.050 (0.026)	1.182 (0.032)	1.136 (0.043)	1.078 (0.027)	1.041 (0.063)	0.9 (0.029)	1.525 (0.05)	1.018 (0.028)	1.303 (0.053)
HGV	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.306 (0.251)	n.s.
1/R	0.199 (0.011)	0.22 (0.012)	0.141 (0.018)	0.145 (0.012)	0.365 (0.023)	0.186 (0.013)	0.184 (0.018)	0.171 (0.012)	0.241 (0.019)
Gu	n.s.	n.s.	n.s.	-0.034 (0.02)	n.s.	n.s.	n.s.	n.s.	n.s.
Gd	n.s.	n.s.	n.s.	n.s.	0.056 (0.04)	n.s.	n.s.	n.s.	0.057 (0.035)
SEdef	0.089 (0.011)	0.096 (0.013)	0.05 (0.018)	0.062 (0.012)	0.174 (0.027)	0.056 (0.013)	0.129 (0.021)	0.078 (0.012)	0.093 (0.022)
RSW	-0.065 (0.014)	-0.072 (0.017)	-0.059 (0.023)	-0.07 (0.015)	-0.066 (0.032)	-0.036 (0.016)	-0.141 (0.023)	-0.047 (0.016)	-0.179 (0.026)
N_{lanes}	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.056 (0.053)	n.s.	n.s.
SFC	-1.991 (0.172)	-2.284 (0.204)	-2.167 (0.295)	-1.479 (0.181)	-4.892 (0.43)	-2.034 (0.21)	-2.783 (0.311)	-2.148 (0.197)	-2.454 (0.339)
TEX	n.s.	n.s.	-0.25 (0.075)	n.s.	-0.810 (0.109)	-0.206 (0.053)	-0.234 (0.082)	-0.238 (0.051)	n.s.
IRI	0.302 (0.033)	0.444 (0.038)	0.392 (0.052)	0.312 (0.034)	0.195 (0.077)	0.302 (0.038)	0.249 (0.056)	0.306 (0.036)	0.176 (0.064)
R_{Ledge}	-1.360 (0.241)	-1.548 (0.287)	-1.432 (0.38)	-1.651 (0.252)	-0.777 (0.481)	-1.479 (0.238)	-1.712 (0.408)	-1.441 (0.259)	-1.366 (0.411)
R_{Llanes}	-0.495 (0.303)	-0.4 (0.36)	-0.643 (0.482)	-0.679 (0.317)	n.s.	n.s.	-0.856 (0.511)	-0.631 (0.325)	n.s.

Results, curves

	Total	Day	Night	Dry	Wet	SV	MV	PDO	Injury
P2P	n.s.	n.s.	-0.046 (0.042)	-0.034 (0.027)	n.s.	n.s.	-0.144 (0.046)	n.s.	-0.060 (0.051)
Tunnel	0.169 (0.034)	0.164 (0.04)	n.s.	0.215 (0.035)	n.s.	0.114 (0.039)	0.216 (0.056)	0.134 (0.037)	0.214 (0.063)
Entering	0.105 (0.065)	0.076 (0.077)	n.s.	0.139 (0.065)	n.s.	n.s.	0.324 (0.099)	0.143 (0.069)	n.s.
Exit	0.24 (0.059)	0.276 (0.069)	0.134 (0.084)	0.226 (0.06)	0.25 (0.133)	0.147 (0.063)	0.41 (0.09)	0.231 (0.063)	0.281 (0.098)
Roadwork	0.049 (0.027)	0.118 (0.033)	n.s.	n.s.	0.11 (0.067)	n.s.	n.s.	n.s.	n.s.
1/k	2.201 (0.103)	1.835 (0.102)	1.801 (0.176)	2.851 (0.181)	0.369 (0.023)	1.904 (0.104)	1.283 (0.098)	2.223 (0.12)	1.273 (0.135)
Log-likelihood	-13,360	-10,706	-6,925	-11,774	-4,596	-11,317	-6,741	-11,963	-5,380
AIC	26,749	21,439	13,877	23,579	10,246	22,658	13,515	23,956	10,786
BIC	26,850	21,540	13,971	23,687	10,340	22,745	13,630	24,065	10,880
R^2_a	0.578	0.604	0.582	0.675	0.316	0.478	0.674	0.579	0.598

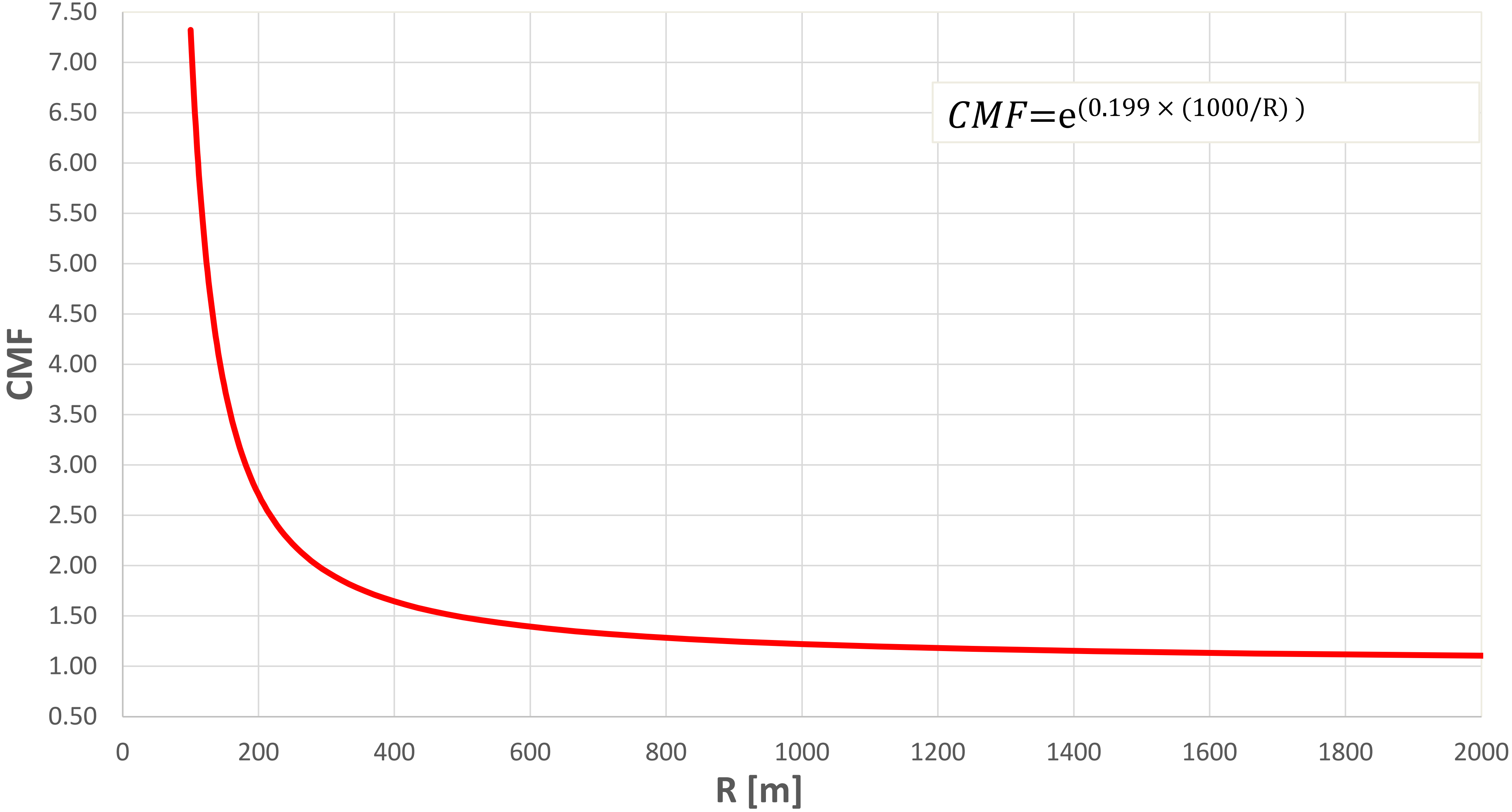
Goodness-of-fit measures, tangents

Measure	Sample	Total	Day	Night	Dry	Wet	Sv	MV	PDO	Injury
MAD	Training	1.232	0.960	0.562	1.110	0.309	0.868	0.723	1.032	0.489
	Validation	1.484	1.159	0.675	1.330	0.369	1.014	0.855	1.225	0.556
MSPE	Training	5.485	3.448	1.142	4.412	0.492	2.476	2.471	3.743	0.976
	Validation	9.280	5.780	1.881	7.373	0.773	3.726	4.104	6.068	1.326
MAPD	Training	0.523	0.616	0.747	0.538	1.150	0.625	0.746	0.589	0.810
	Validation	0.530	0.648	0.698	0.547	1.080	0.592	0.788	0.573	0.844
R^2 McFadden	Training	0.266	0.263	0.281	0.272	0.278	0.268	0.257	0.262	0.274
	Validation	0.265	0.261	0.275	0.267	0.209	0.256	0.246	0.252	0.270

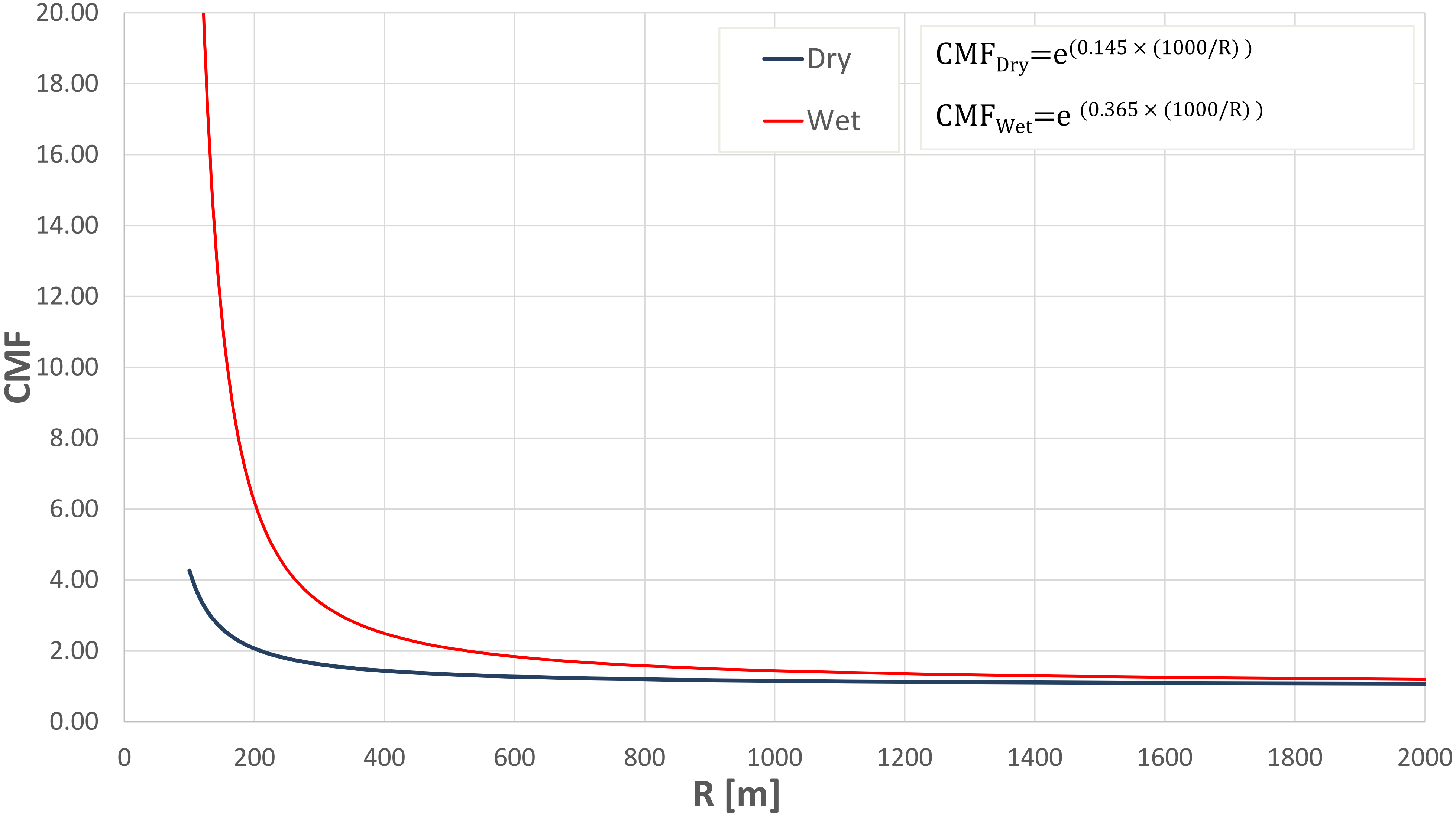
Goodness-of-fit measures, curves

Measure	Sample	Total	Day	Night	Dry	Wet	Sv	MV	PDO	Injury
MAD	Training	0.945	0.730	0.431	0.791	0.338	0.755	0.436	0.818	0.321
	Validation	0.936	0.738	0.423	0.772	0.358	0.765	0.426	0.804	0.337
MSPE	Training	2.498	1.459	0.446	1.465	0.547	1.436	0.602	1.743	0.302
	Validation	1.872	1.156	0.403	1.144	0.495	0.498	1.170	1.284	0.325
MAPD	Training	0.870	1.014	1.326	0.911	1.660	1.014	1.280	0.947	1.447
	Validation	0.876	1.031	1.342	0.932	1.596	1.024	1.326	0.960	1.458
R^2 McFadden	Training	0.100	0.108	0.116	0.123	0.148	0.077	0.140	0.101	0.094
	Validation	0.064	0.056	0.071	0.090	0.101	0.068	0.116	0.061	0.059

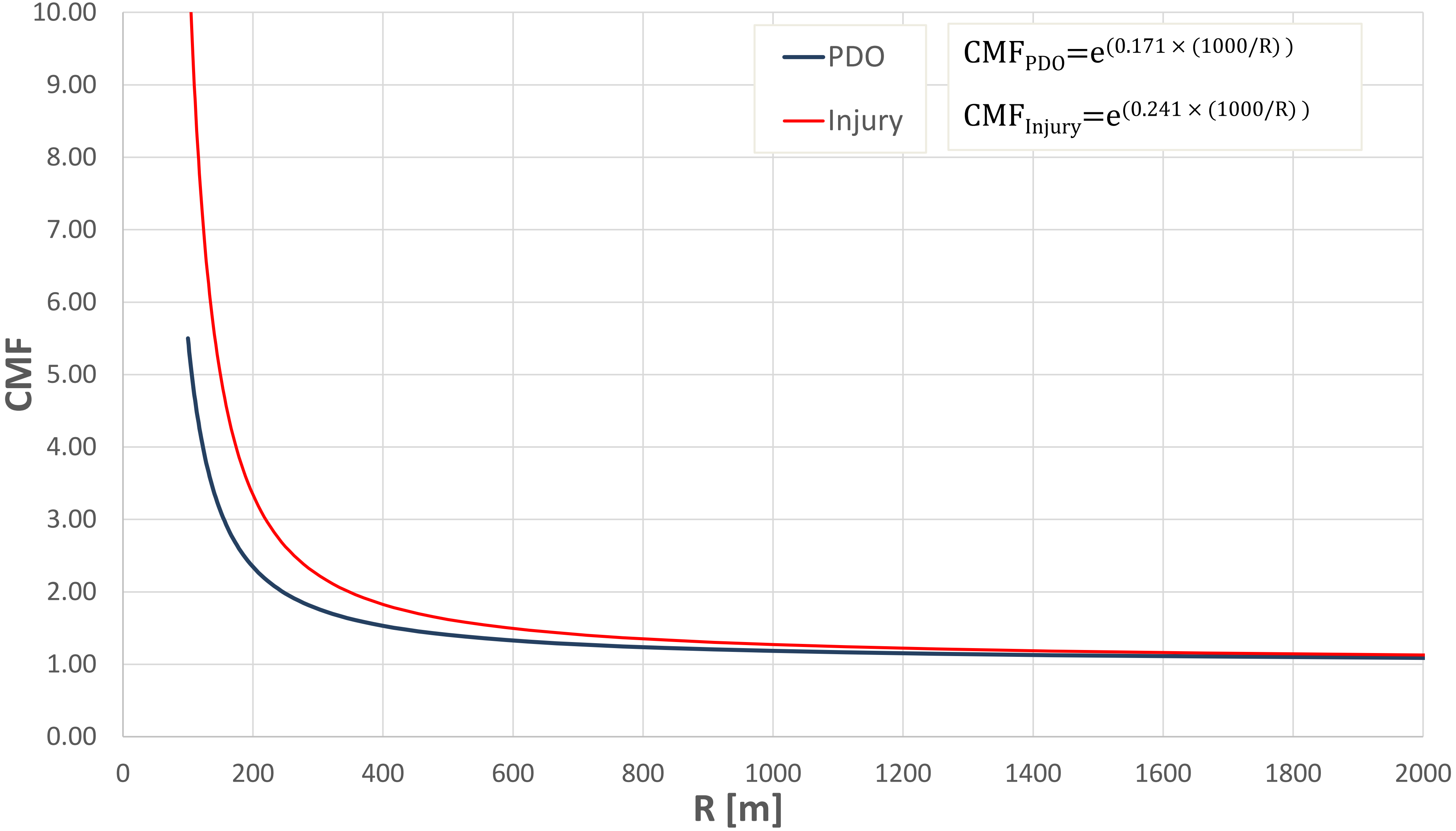
CMF curvature, total crashes



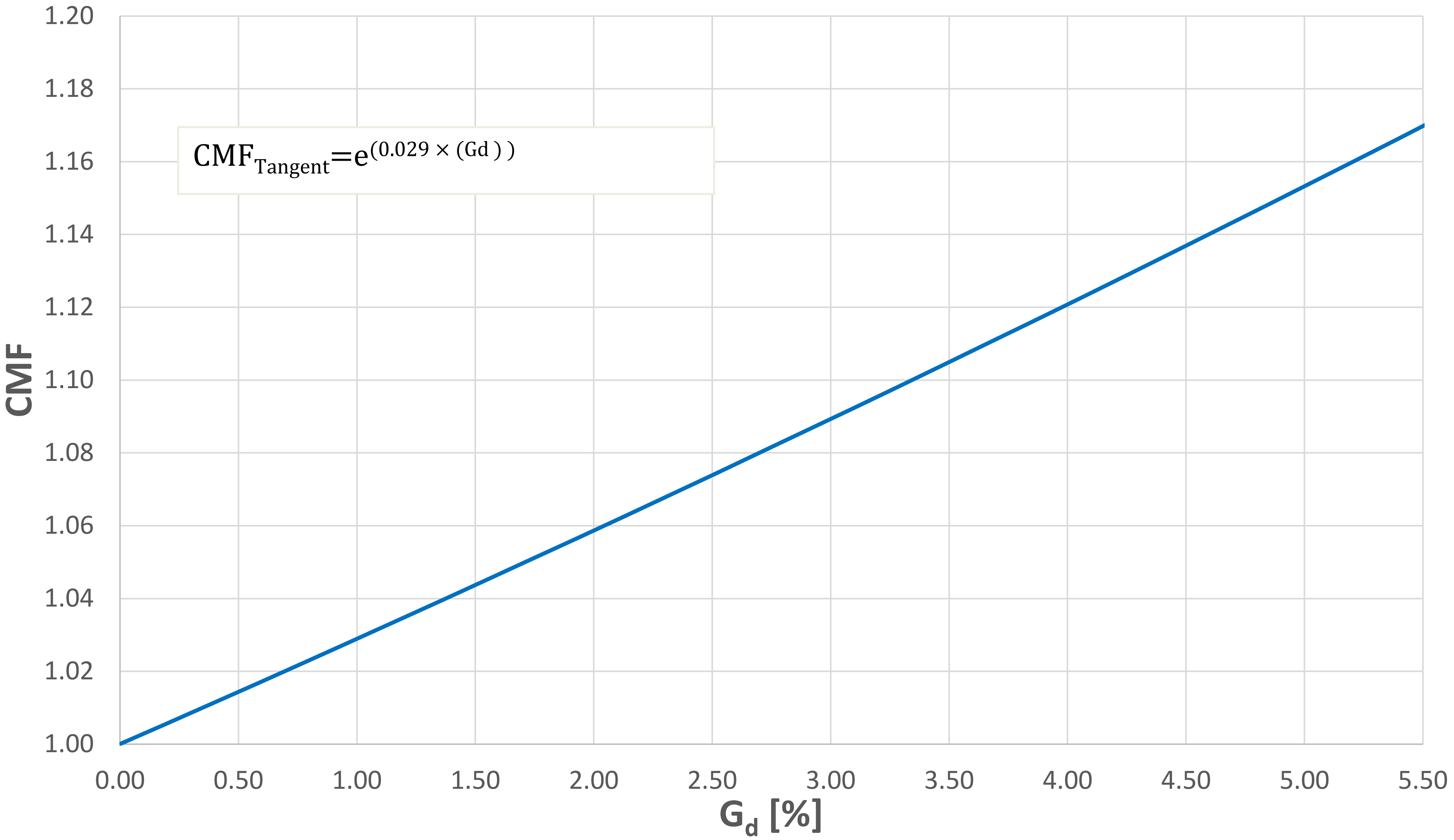
CMF curvature, dry vs wet pavement



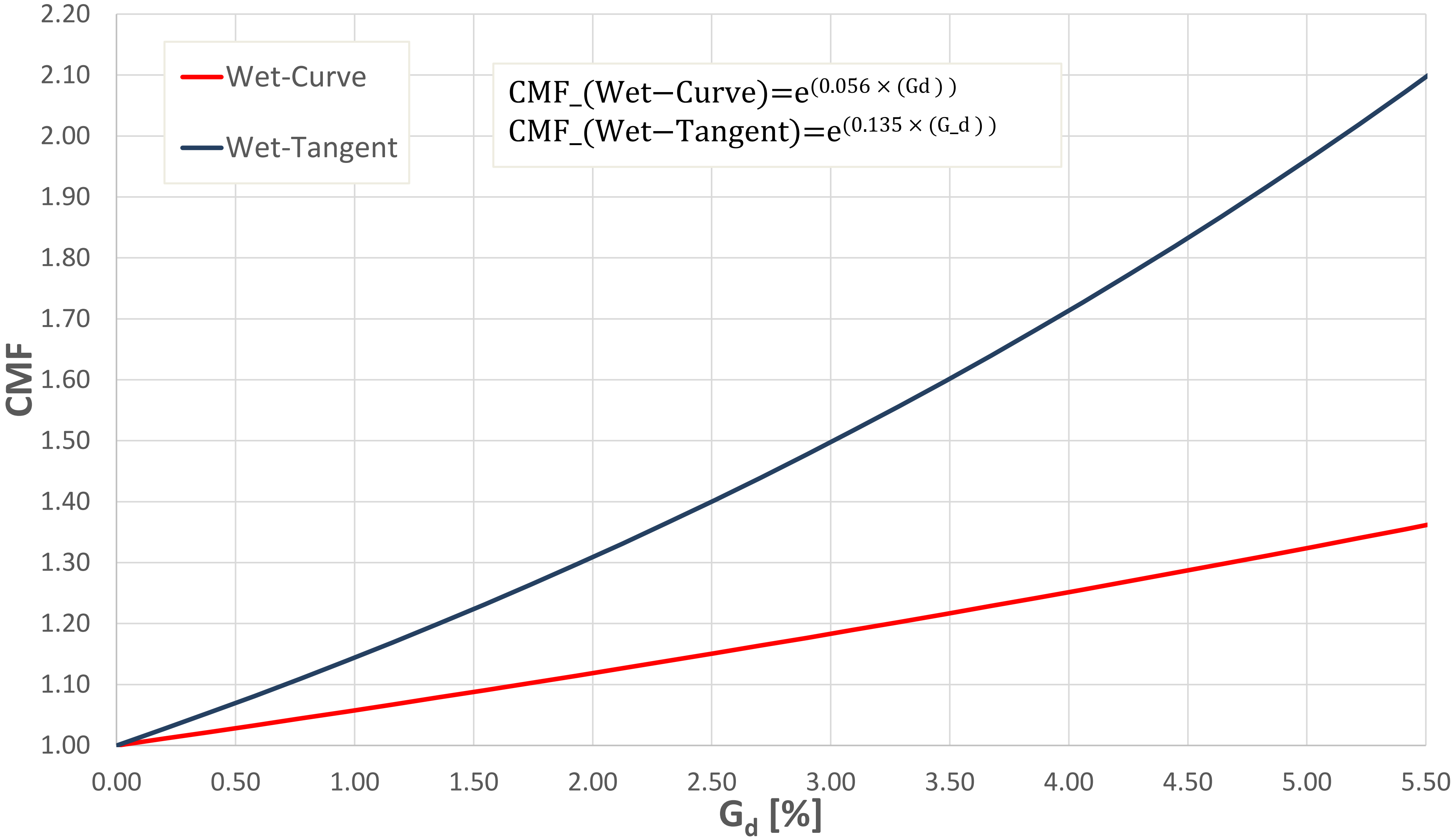
CMF curvature, PDO vs injury and fatal crashes



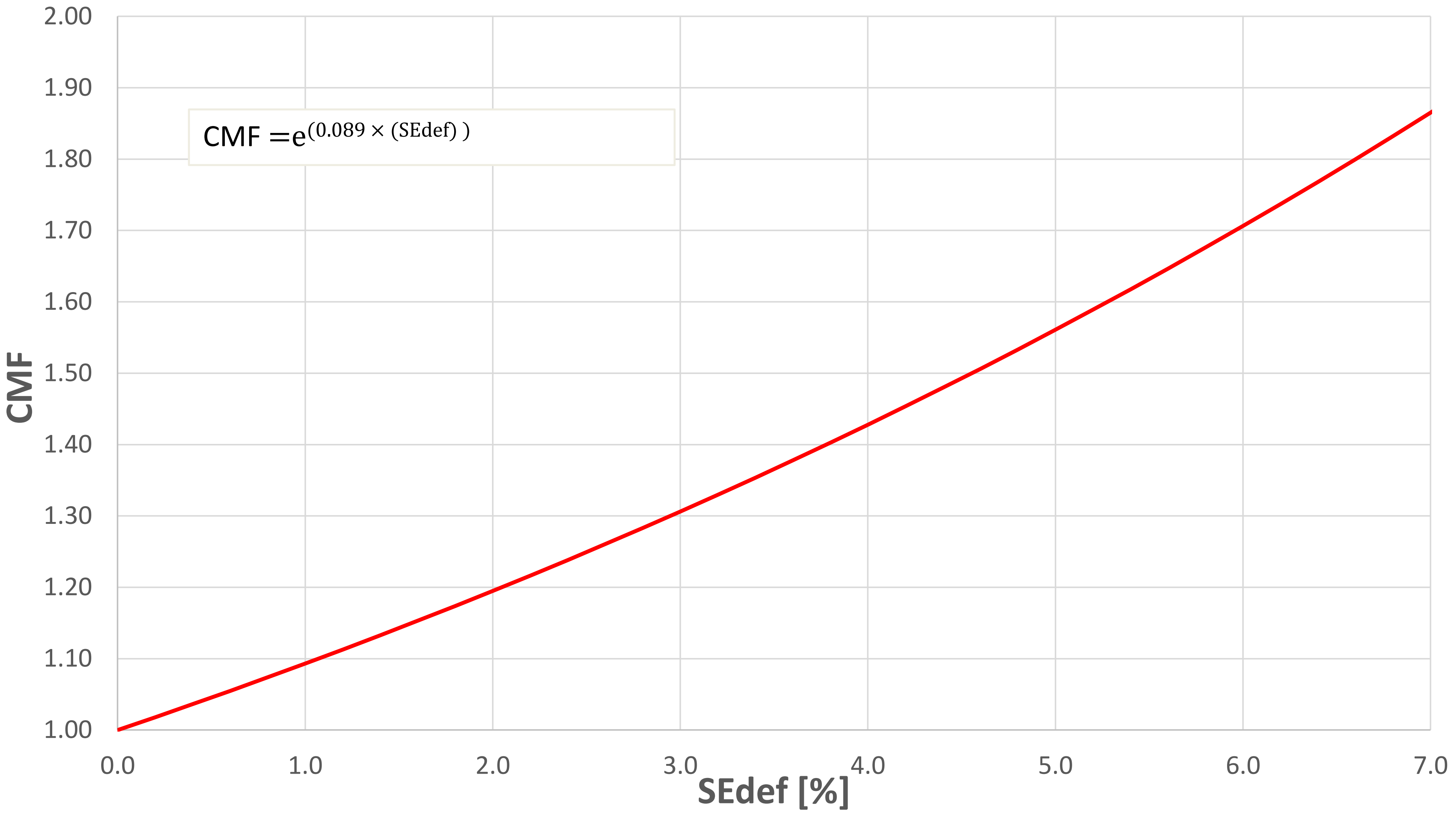
CMF downgrade, total crashes



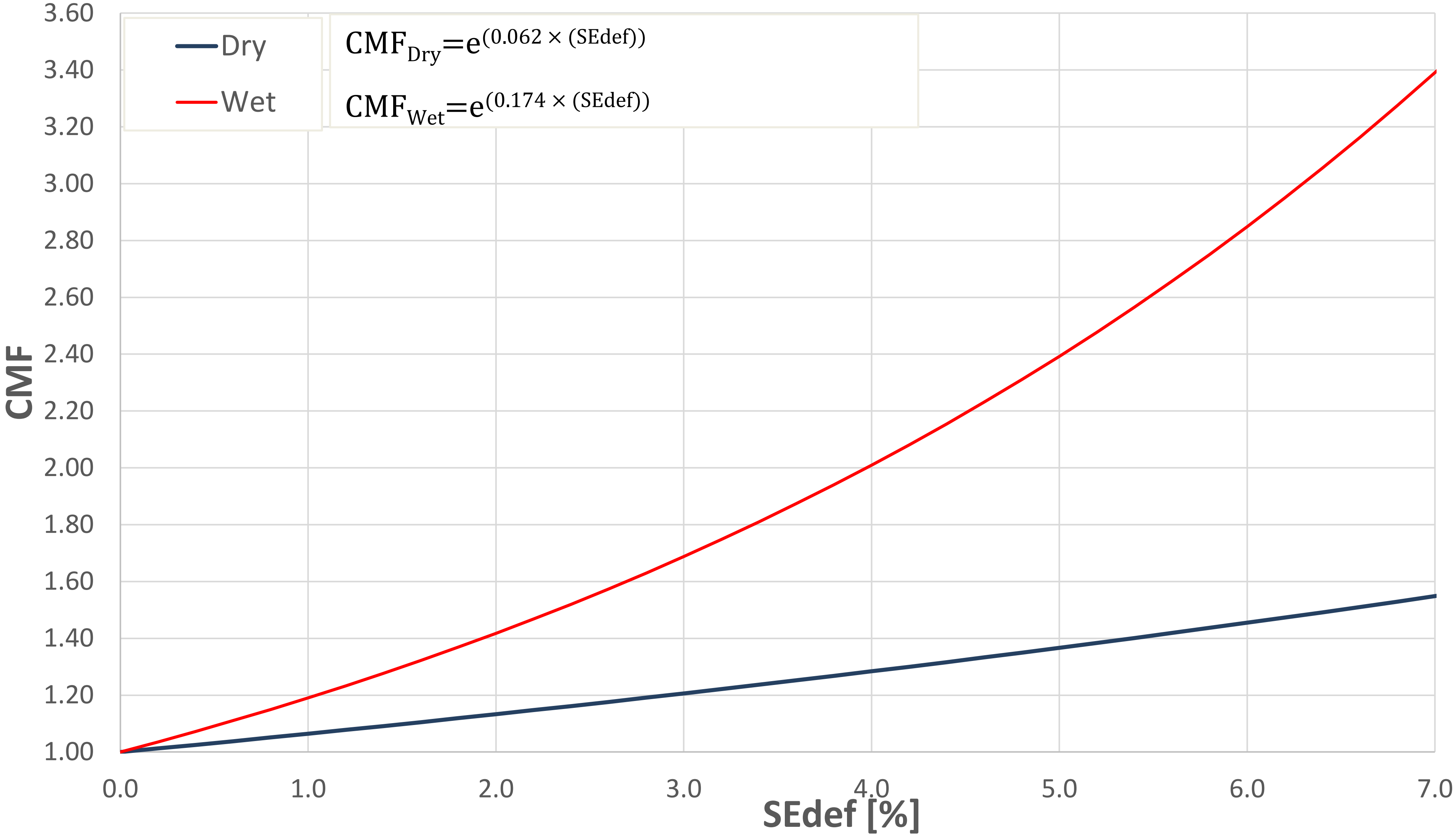
CMF downgrade, wet pavement



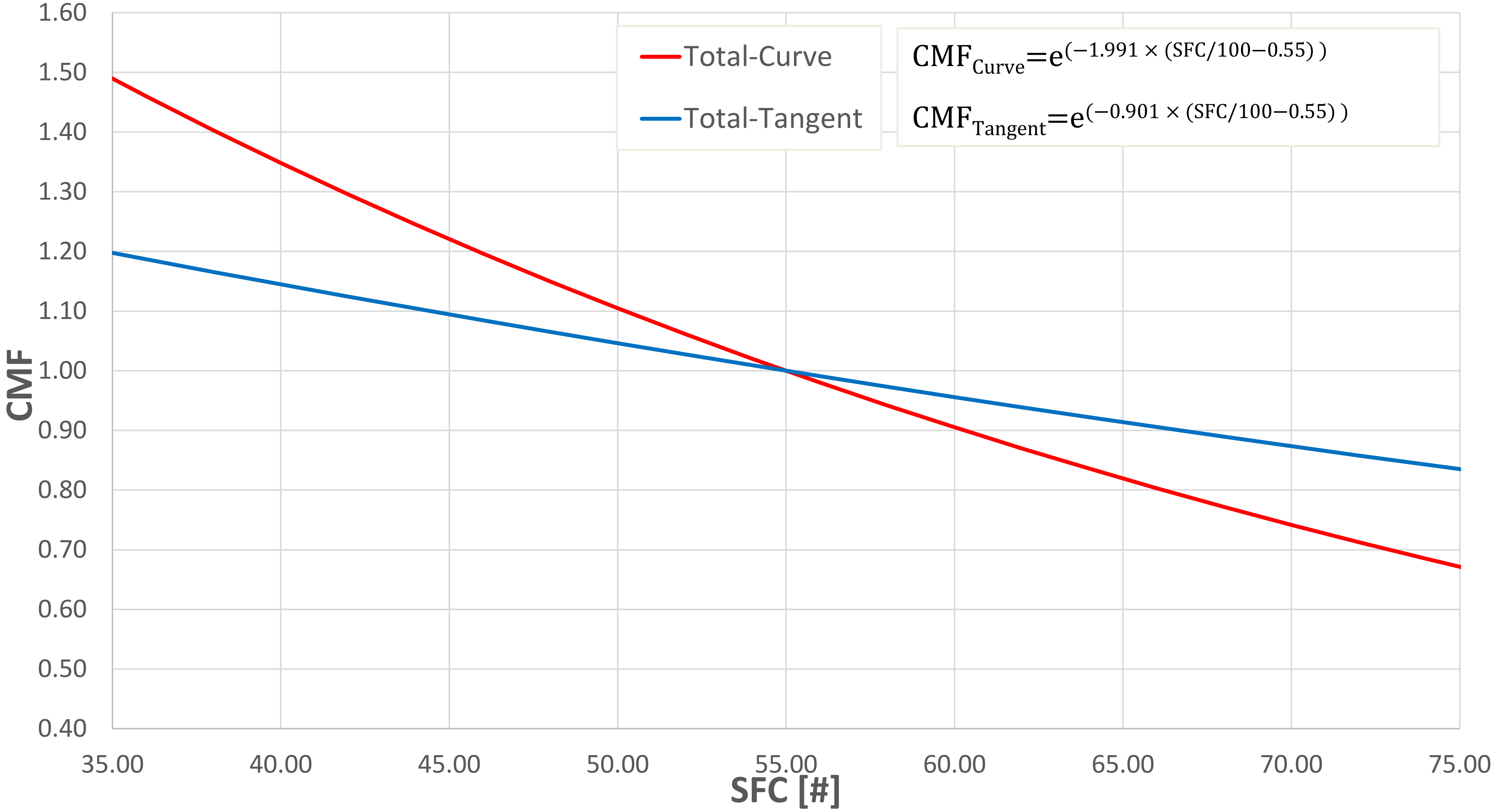
CMF superelevation deficiency, total crashes



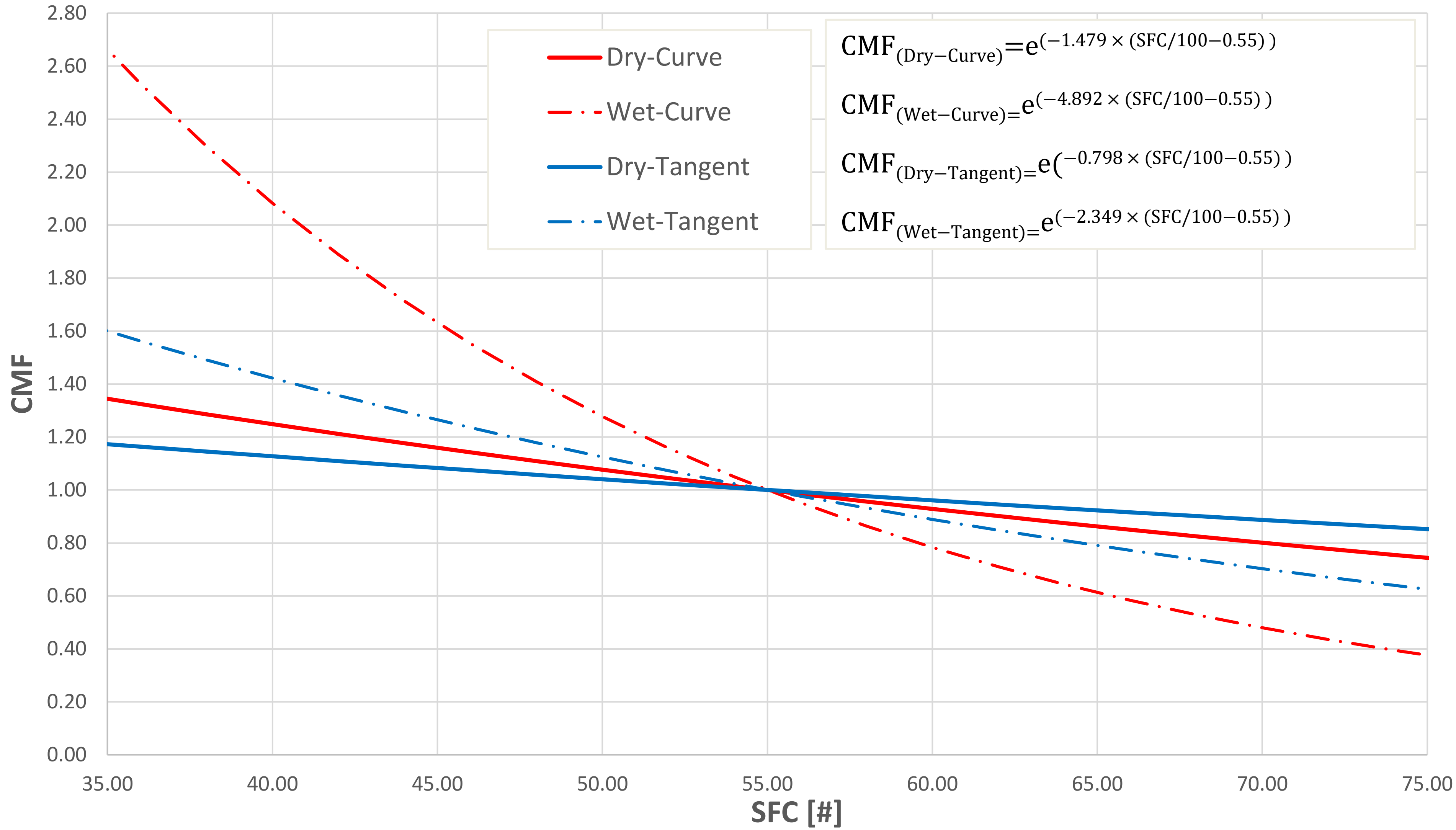
CMF SE, dry vs wet pavement



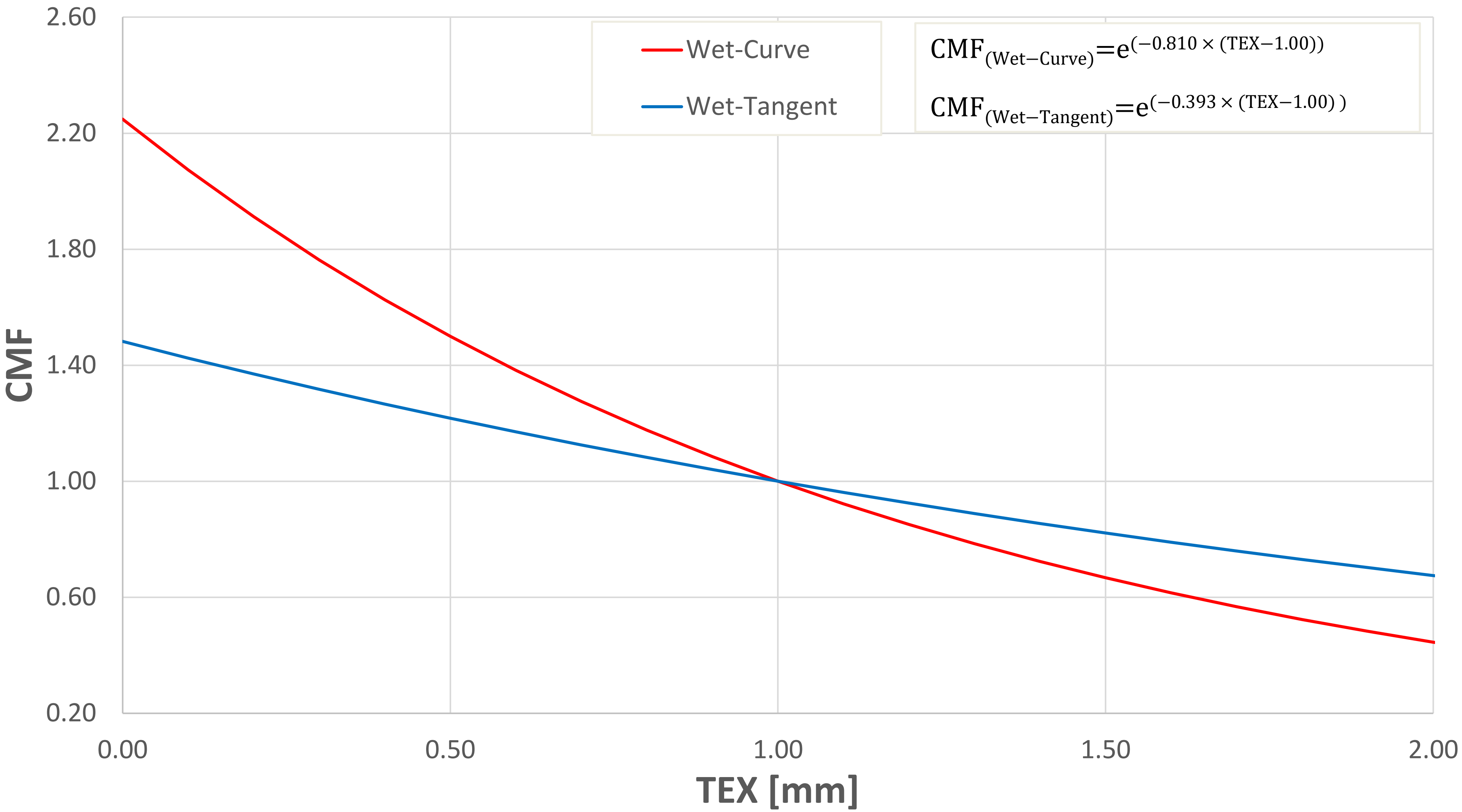
CMF SFC, total crashes



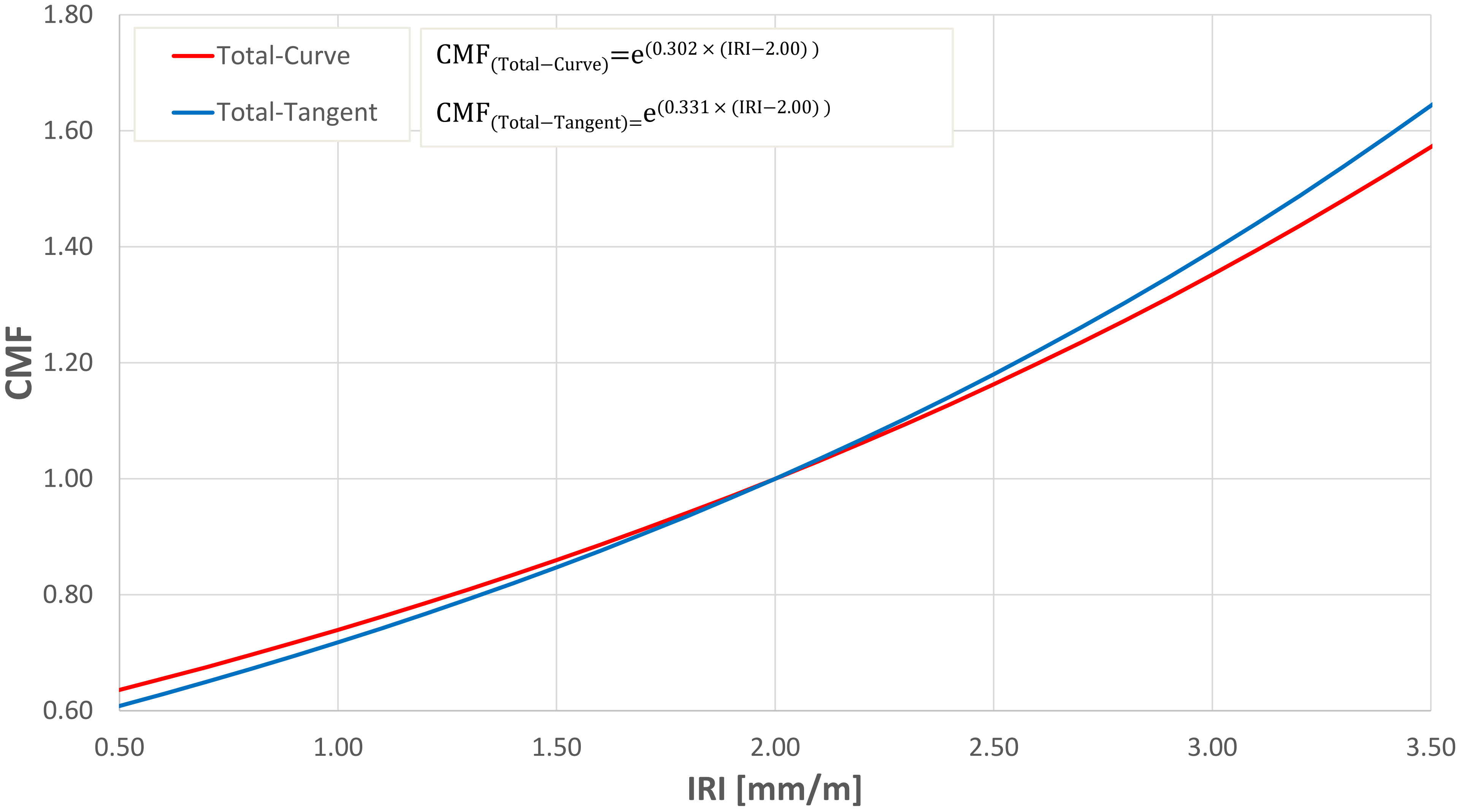
CMF SFC, dry vs wet pavement



CMF TEX, dry vs wet pavement



CMF IRI



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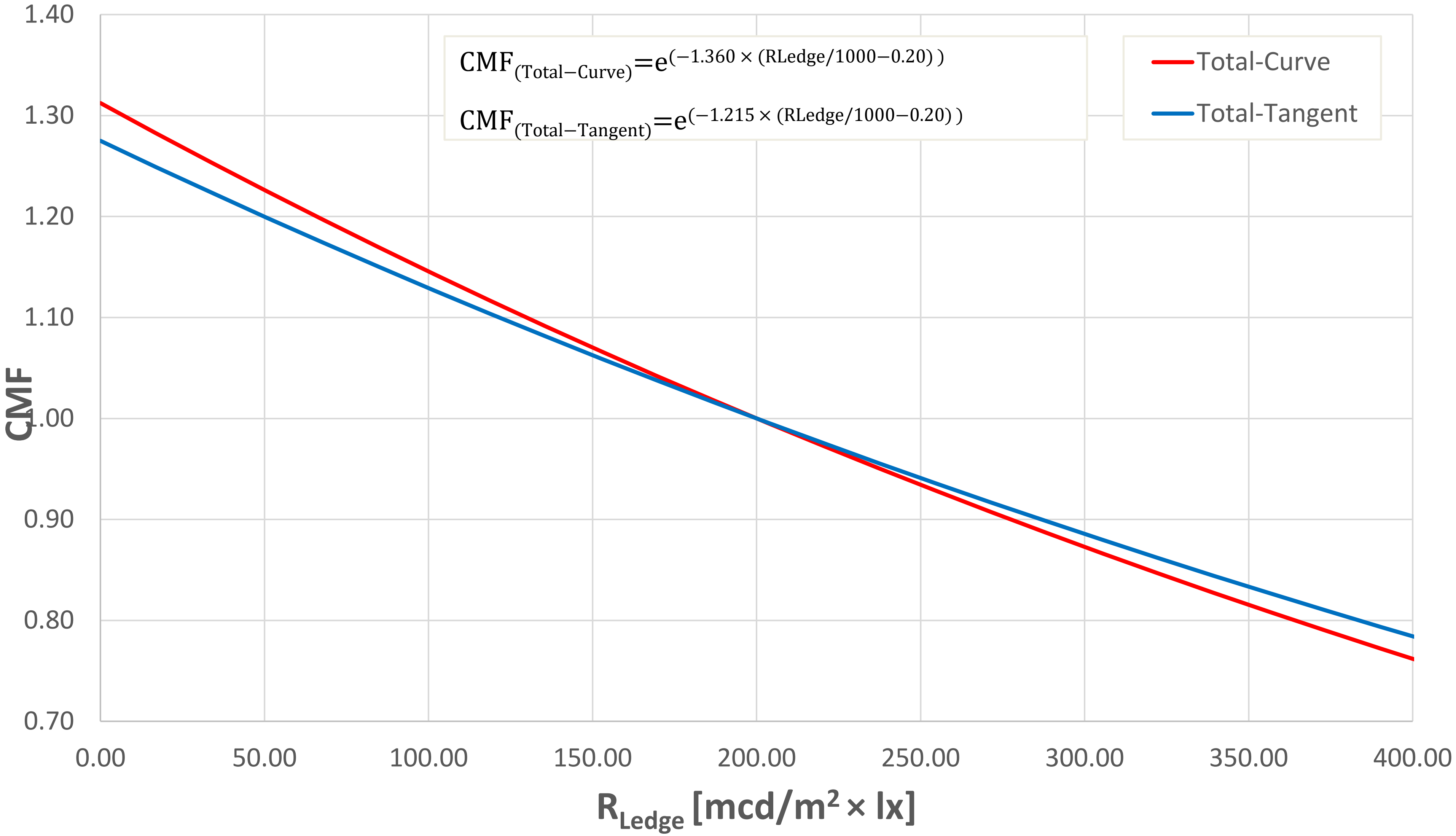
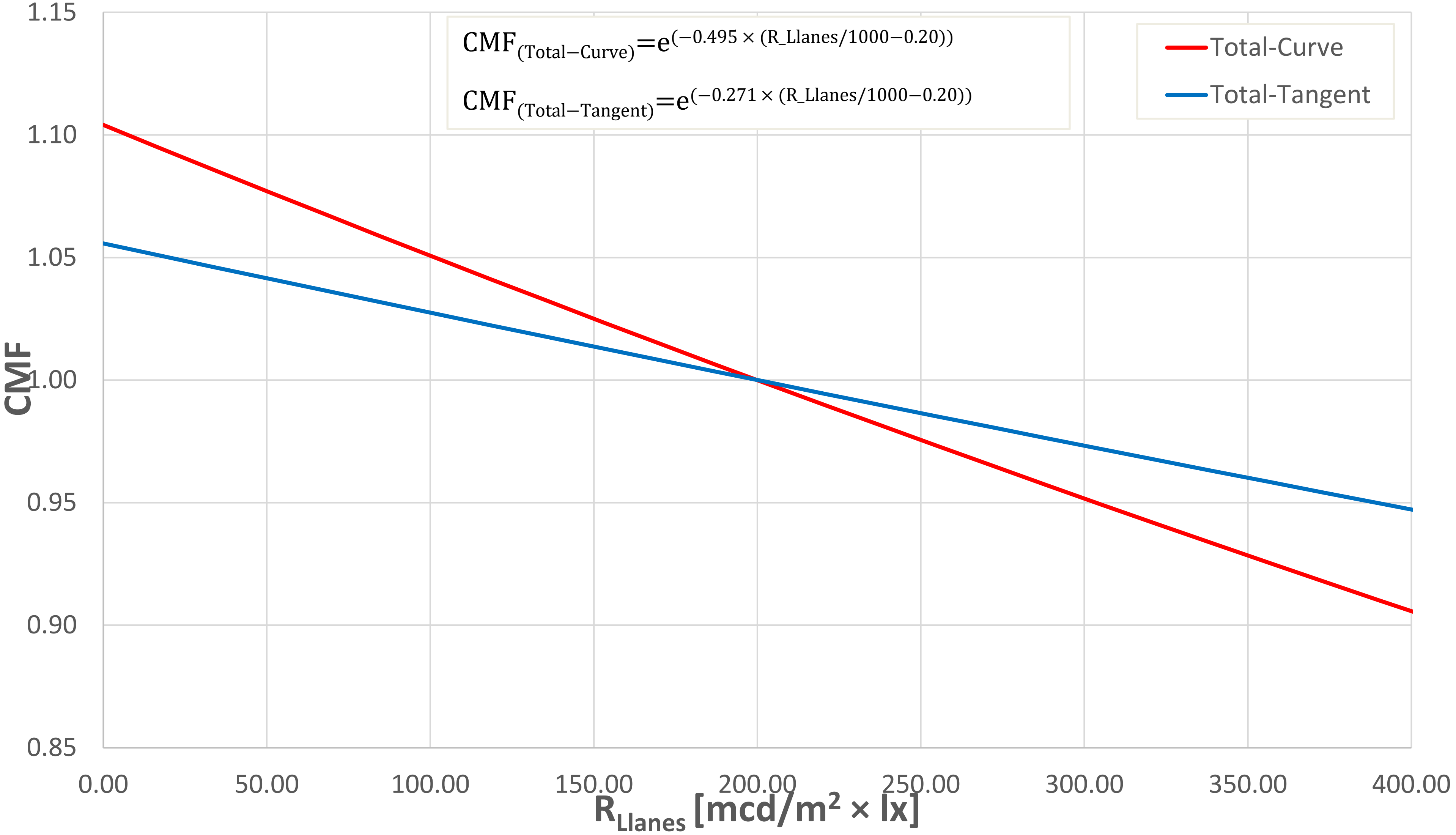
CMF R_{Ledge}, total crashes



CMF R_{Llines}, total crashes



Markings, discussion

- Performance of longitudinal markings has a relevant safety effect
- The **Manual on Uniform Traffic Control Devices now includes minimum maintained levels of retroreflectivity** for longitudinal markings
- The CMFs developed in this research allow **quantifying the safety benefits of improving marking retroreflectivity**

Thank you for your kind attention!

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