Development of Work Zone Crash Modification Factors (CMFs)

Henry Brown, P.E.

Praveen Edara, Ph.D., P.E., P.T.O.E.

Carlos Sun, Ph.D., P.E., J.D

(University of Missouri)

April 15, 2021

Development and Application of Work Zone CMFs

Funded by the Work Zone and Guardrail Safety Training Grant Program

U.S. Department of Transportation

Federal Highway Administration

Disclaimer

This material is based upon work supported by the U.S. Department of Transportation under cooperative agreement Nos. DTFH6113RA00019 and 693JJ31750003. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the Author(s) and do not necessarily reflect the view of the U.S. Department of Transportation.

Webinar Overview

- Overview of work zone CMFs
- Process for development of work zone CMFs
- Methods, factors, and tips for developing work zone CMFs
- Evaluation and documentation of work zone CMFs
- CMF resources

Photo: FHWA

Definition of CMFs: A Refresher

When all other conditions and site characteristics remain constant, **CMFs** represent the relative change in crash frequency due to a change in one specific condition (AASHTO, 2010).

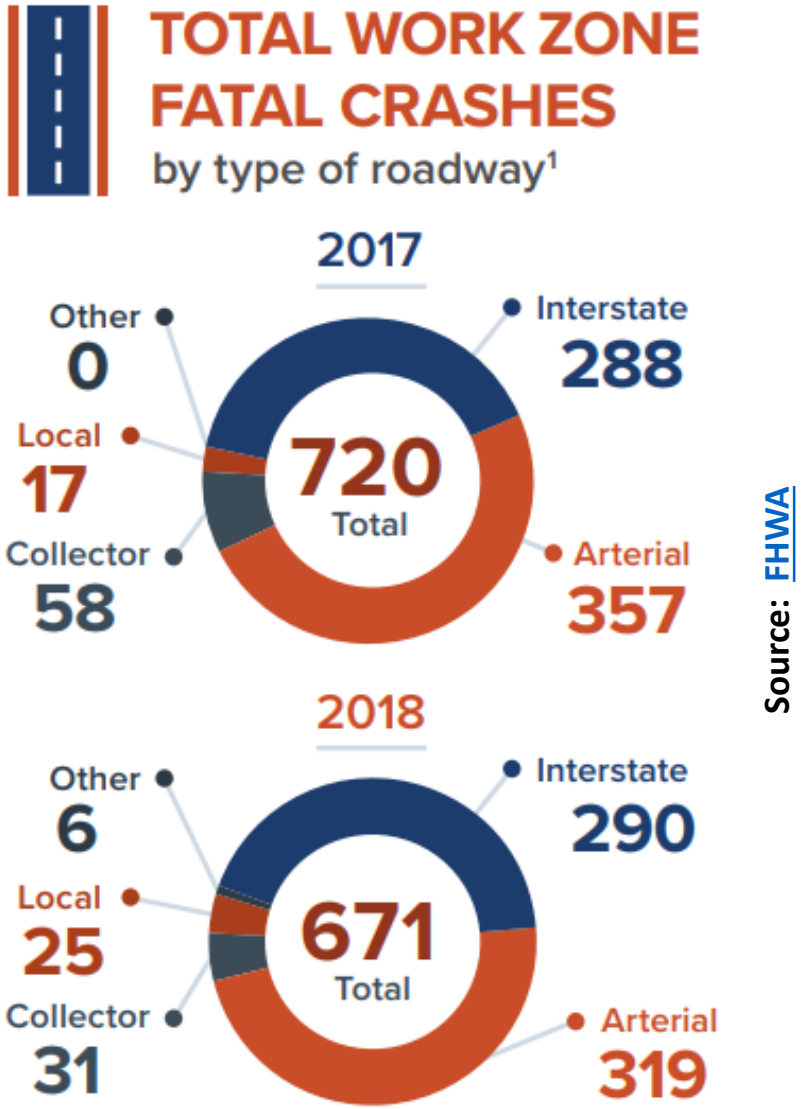
Provides the expected change in crash frequency due to:

- the implementation of a countermeasure or
- a change in a particular site

Expected number of crashes with countermeasure = CMF x Expected number of crashes before countermeasure is implemented

Motivation

- In 2018, there were 2.1 work zone fatalities per day (FHWA)
- In 2018, there was a work zone crash every 4.3 minutes (ARTBA)
- Need to quantify benefits of possible work zone safety countermeasures



Source: FHWA

Motivation cont.

- Need to quantify benefits of possible work zone safety countermeasures
- CMFs allow for safety evaluation of work zone countermeasures
  - Should I widen the work zone shoulder?
  - Should I install an end of queue warning system?
  - Should I offer the contractor an incentive to finish early?
- Ultimate goal – improve work zone safety!

Photo: FHWA

Poll Question

How would you categorize your existing knowledge of the process used to develop CMFs?

a. High
b. Moderate
c. Low
d. None

Sources of Work Zone CMFs

- Highway Safety Manual (AASHTO 2010)
  - Scientific approach to safety analysis
- CMF Clearinghouse (www.cmfclearinghouse.org)
  - Database of CMF values
- Other research studies

HSM Work Zone CMFs

Based on 36 California freeway work zones (high traffic volumes) (Khattak et al. cited in AASHTO 2010)

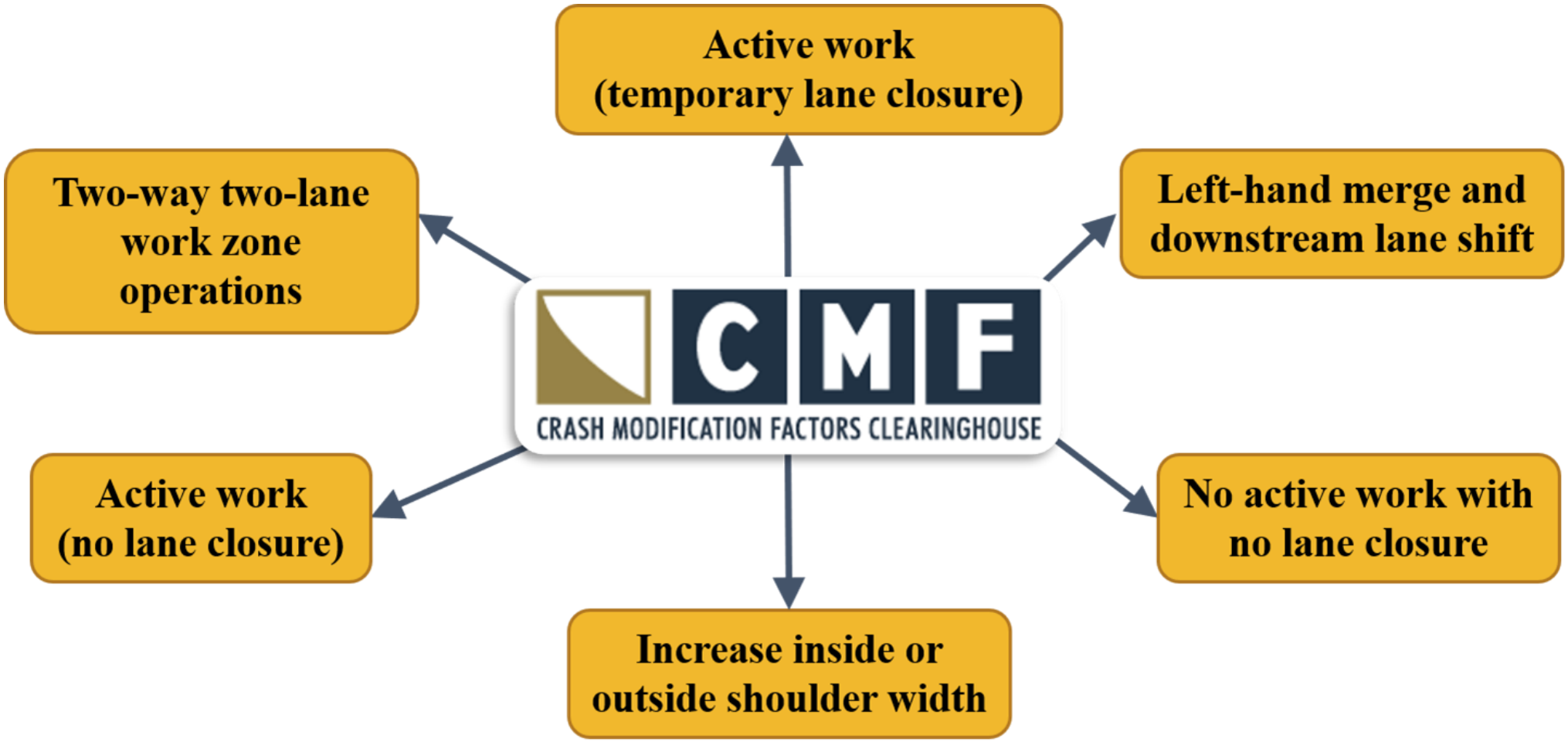
Work zone duration

$$\mathrm{CMF_{d,all}} = 1.0 + \frac{(\%\ \text{increase in duration} \times 1.11)}{100}$$

Work zone length

$$\mathrm{CMF_{l,all}} = 1.0 + \frac{(\%\ \text{increase in length} \times 0.67)}{100}$$

Work Zone CMFs in CMF Clearinghouse

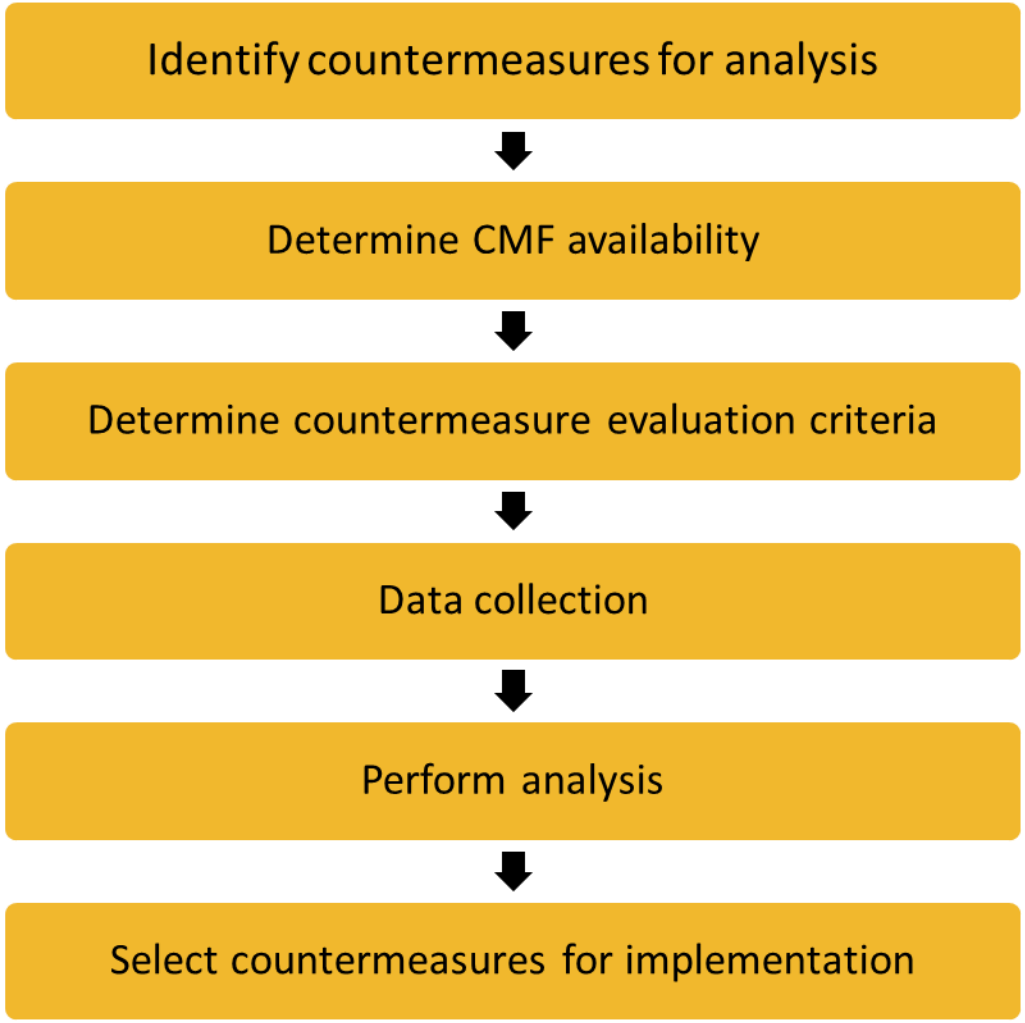


Source: FHWA 2020

Need for Additional WZ CMFs: DOT Interviews

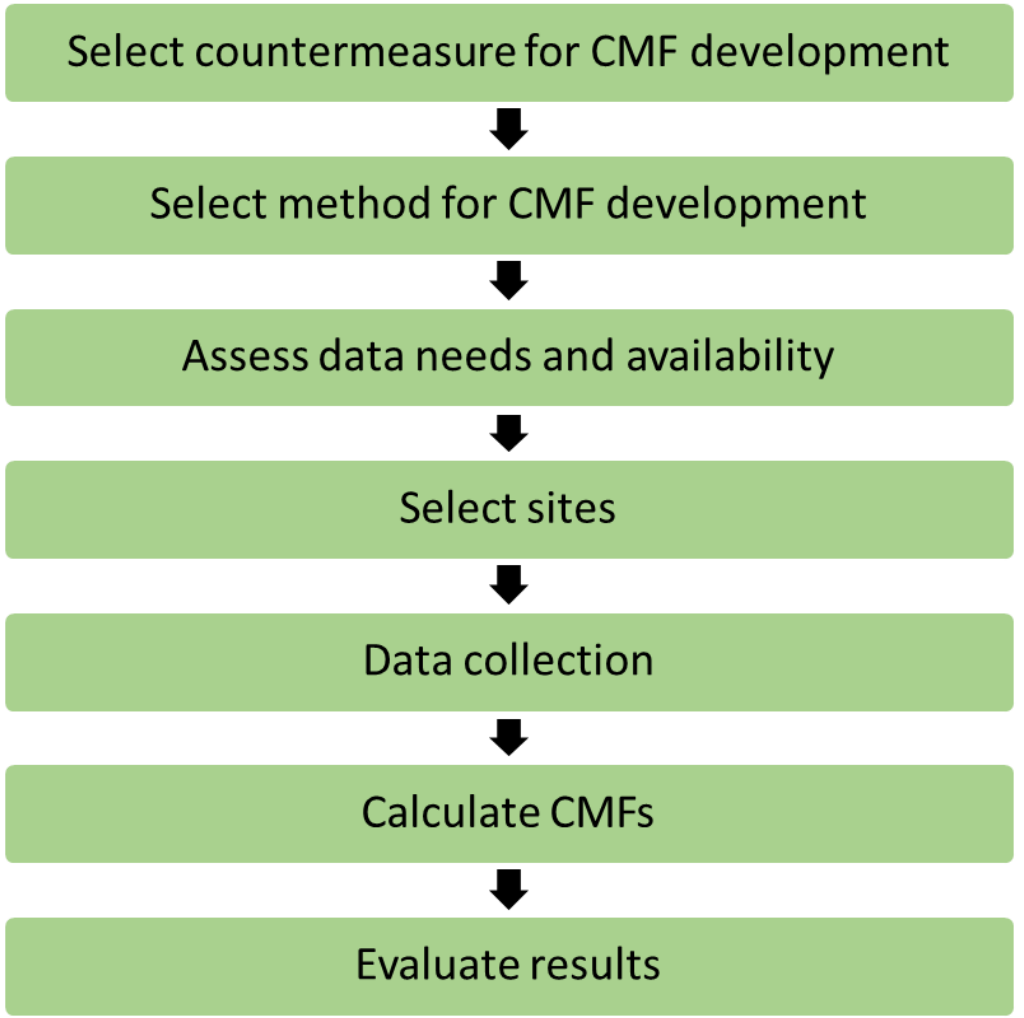
- Weaving sections
- Temporary raised rumble strips
- Divided highway crossover versus lane closures
- Lane width and shoulder width
- 3, 2, or 1 cone procedures for flagger operations
- Steel barrier versus concrete barrier
- Use of tubular marker versus drums for lane closure
- Road closure with detour versus staged construction (1 lane closed)
- Shy distance to barrier
- Early lane merge, late lane merge, zipper merge
- Temporary portable signal versus 24-hour flagging
- Presence of law enforcement
- Automated speed enforcement
- Work zone intrusion alarms
- Traffic sensor message board to say when construction vehicle entering or leaving site
- Wrong way driving prevention

Using Existing CMFs



Source: Edara et al. 2021

Process for Developing New Work Zone CMFs



Source: Edara et al. 2021

Developing Work Zone CMFs Step 1

Step 1: Select countermeasure for CMF development

- Increase lane or shoulder width
- Changeable speed warning signs
- Work zone intrusion alarms
- End of queue warning system
- Automated speed enforcement
- Wrong way driving prevention
- Other

Photo: Krupa 2010

Work zone intrusion alarm

Developing Work Zone CMFs Step 2

Step 2: Select method for CMF development

- Before-After with Comparison Group
- Empirical Bayes Before-After
- Cross-Sectional
- Other

Developing Work Zone CMFs Step 3

Step 3: Assess data needs and availability

- Types of data
  - Crash data
  - Work zone data
  - Traffic data
  - Geometric data
- Data fusion
- Accuracy versus level of effort

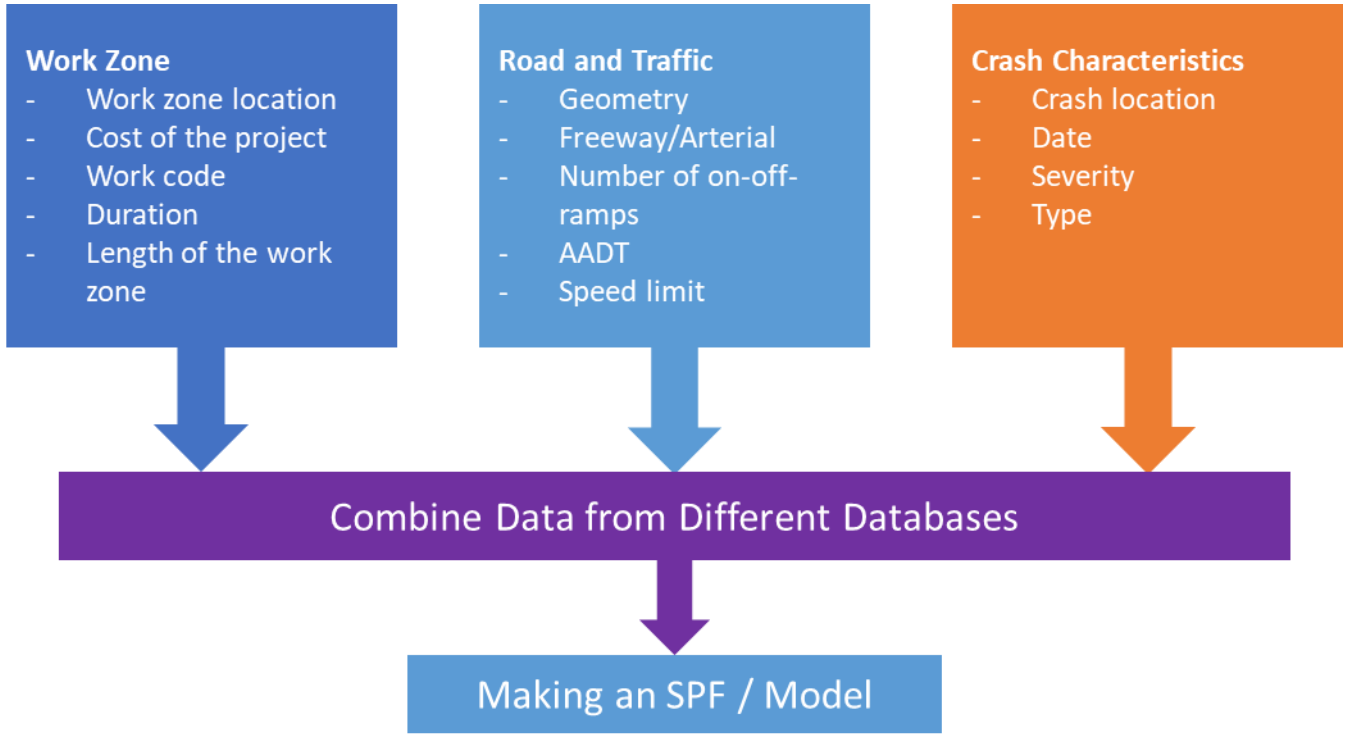


Image: Brown et al. 2016

Developing Work Zone CMFs Step 3, Cont.

Data challenges:

1. Accuracy of work zone presence and schedule
2. Inconsistency between crash database and crash report
3. Determining spatial influence of work zones
4. Lack of actual traffic volumes

Developing Work Zone CMFs Step 4

Step 4: Select sites

- Sample size
  - Statistical needs (e.g. standard error) versus level of effort
- Treatment and control sites (cross-sectional study)

Photo: FHWA

Developing Work Zone CMFs Step 5

Step 5: Data collection

- Work zone data
- Traffic data
- Geometric data
- Crash data
- Other data
- Link crashes to work zones

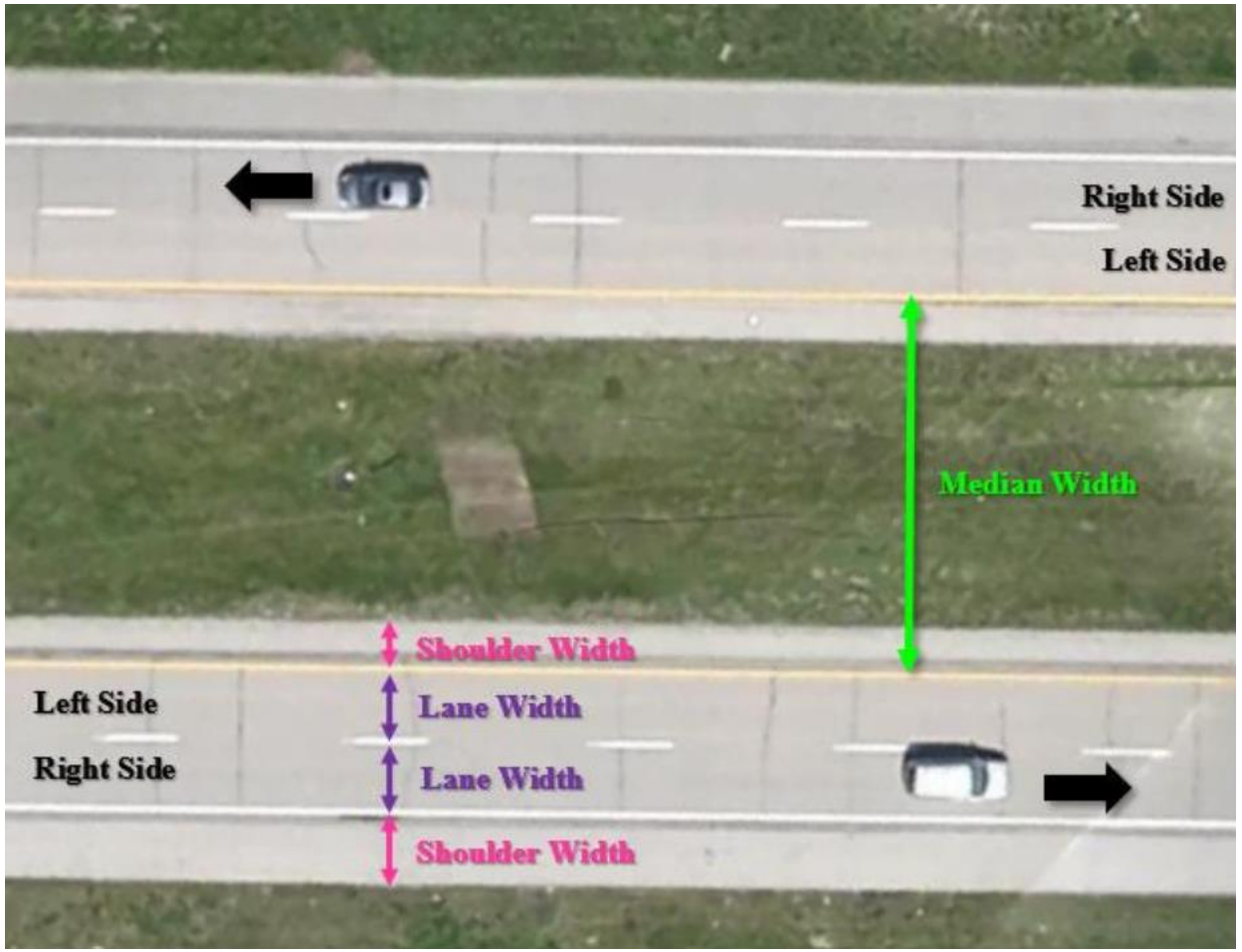


Image: Sun et al. 2018

Developing Work Zone CMFs Step 6

Step 6: Calculate CMFs

- Empirical Bayes before-after
  - Observed crash frequencies
  - Expected crash frequencies
  - Crash variance
- Cross-sectional
  - Ratio crashes (treatment/control)
- Multivariate regression models

Developing Work Zone CMFs Step 7

Step 7: Evaluate results

- Reasonableness
  - CMF > 1: increase in expected crash frequency
  - CMF < 1: decrease in expected crash frequency
- Applicability (e.g. variable ranges)
- Document results

Check-In Question

Which of the following is not considered to be a primary challenge related to data for the development of work zone CMFs?

a. Inconsistency between crash database and crash report
b. Determining spatial influence of work zones
c. Accuracy of work zone presence and schedule
d. Finding work zone countermeasures for which CMFs are needed

Answer: (d) Finding work zone countermeasures for which CMFs are needed

CMF Development Example: Steps 1-2

Study Objective: Develop freeway work zone CMFs using Missouri data (Rahmani et al. 2016)

- Step 1: Select countermeasure for CMF development
  - Work zone length
  - Work zone duration

- Step 2: Select method for CMF development
  - Cross-sectional study (using negative binomial regression)

CMF Development Example: Steps 3-4

- Step 3: Assess data needs and availability
  - Missouri Department of Transportation (MoDOT) databases
    - Work zone database
    - Crash database
    - Road segment database
- Step 4: Select sites
  - 1,571 freeway work zones in Missouri (2009-2014)
  - Minimum work zone length = 0.1 mile
  - Minimum work zone duration = 10 days

County	Desg	Travelway	Dir	Cont Log	Accident Class
CLAY	IS	29	S	122.06600	OUT OF CONTROL
CLAY	IS	29	S	122.06600	REAR END
CLAY	IS	29	S	122.06600	OUT OF CONTROL
CLAY	IS	29	S	122.08500	REAR END

Image: Sun et al. 2016

CMF Development Example: Steps 5-7

- Step 5: Data collection
  - Spatial and temporal matching of data
  - Assignment of crashes to work zone locations

- Step 6: Calculate CMFs
  - $$CMF_{Length} = 1.0 + \frac{(\%\ increase\ in\ Length \times 0.62)}{100}$$
  - $$CMF_{Duration} = 1.0 + \frac{(\%\ increase\ in\ Duration \times 1.01)}{100}$$

- Step 7: Evaluate results
  - Increase in length → Increase in crashes
  - Increase in duration → Increase in crashes

Before-After Methods for Developing Work Zone CMFs

- Simple Before-After
  - Crash frequency same in after period without treatment
- Comparison Group
  - Based on comparison ratio
- Empirical Bayes
  - Expected crashes in before period (w/o treatment) = f(weighted average of observed (treated sites) and predicted (reference sites))

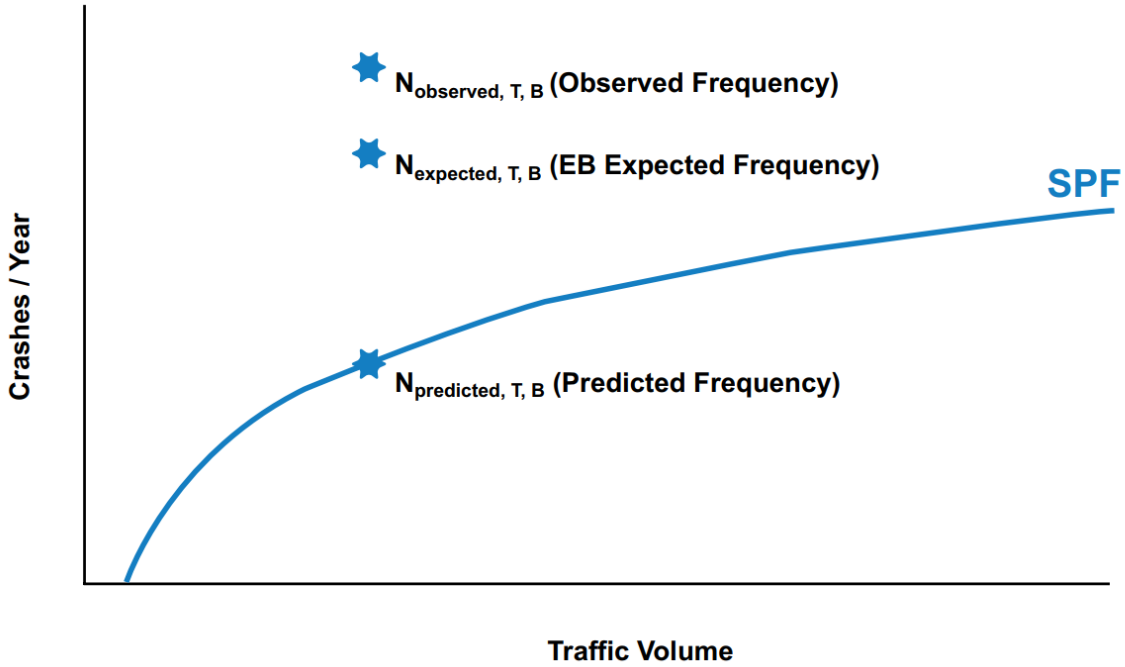


Image: Gross et al., 2010

Cross-Sectional Studies

- CMF = average crash frequency for sites with treatment / average crash frequency for sites without treatment
- Beneficial in absence of before-after data (e.g. work zones)
- Allow for CMF functions
- Considerations
  - Sample size
  - State-to-state differences
- Limitations
  - Possible inaccuracy due to function, bias, or correlation

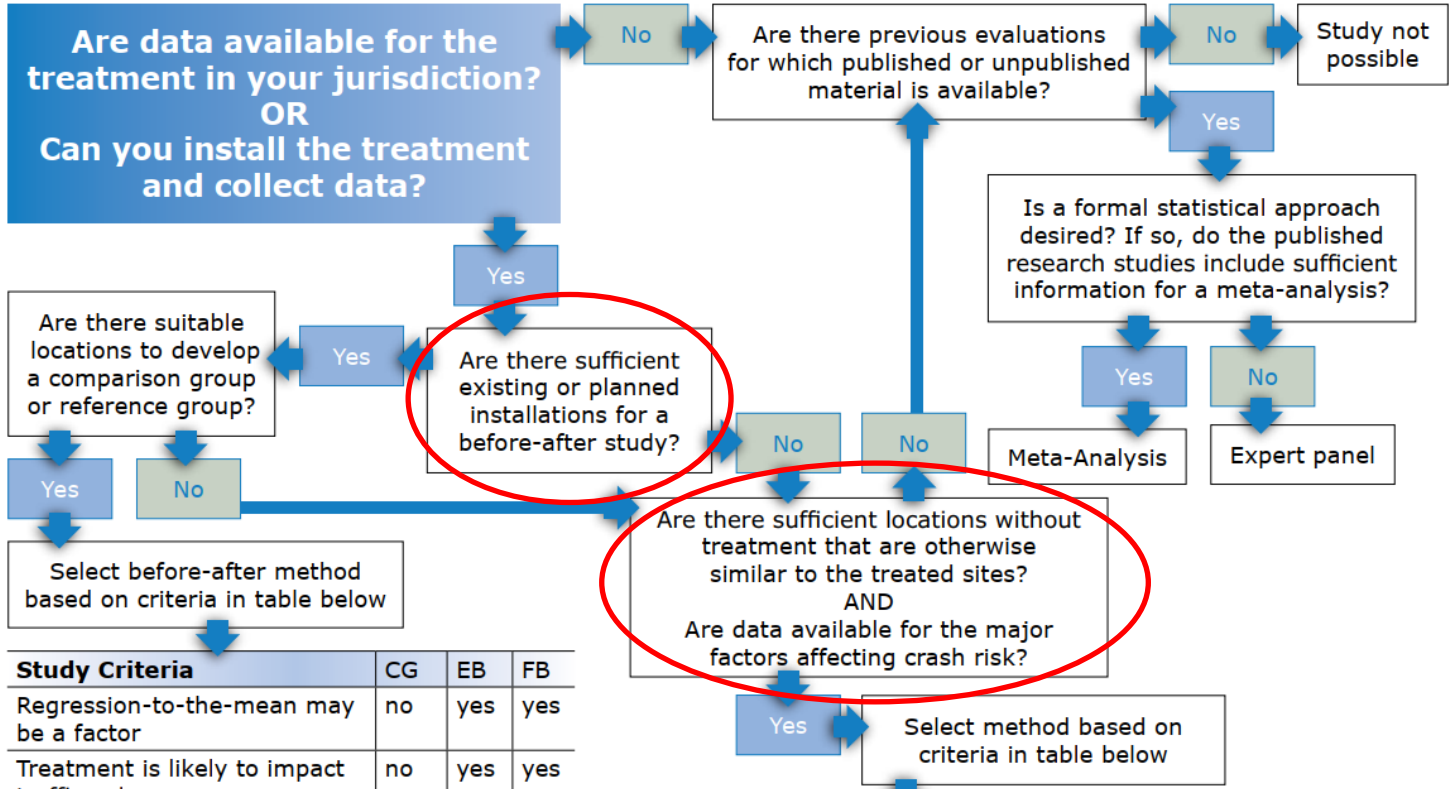
Photo: Texas DOT 2013

Photo: Texas LTAP 2019

Other Methods

- Full Bayes
- Case-Control
- Cohort
- Meta-Analysis
- Expert Panel
- Surrogate Measures

Process for Selecting the Right Method to Develop Work Zone CMFs



Study Criteria	CG	EB	FB
Regression-to-the-mean may be a factor	no	yes	yes
Treatment is likely to impact traffic volumes	no	yes	yes
Include spatial correlation (either among treated sites or among treated and comparison or reference sites)	no	no	yes
A complex model form is required	no	no	yes
Include prior knowledge of model or CMF estimates in the analysis	no	no	yes

Study Criteria	Cross-Sectional	Case-Control	Cohort
Crash type is rare	no	yes	no
Treatment is rare	no	no	yes
Accounts for locations with multiple crashes (rather than first occurrence)	yes	no	no
CMFunction desired	yes	no	no

Image: Gross et al., 2010

Legend:

CG = Comparison Group

EB = Empirical Bayes

FB = Full Bayes

Considerations for Work Zone CMF Studies

- Data challenges
  - Accuracy of work zone presence and schedule
  - Inconsistency between crash database and crash report
  - Determining spatial influence of work zones
  - Lack of actual traffic volumes
- Sample size
- Sufficient installations for before and after study?
- Surrogate measures
- Lack of existing work zone CMFs

Check-In Question

Which of the following methods would most likely be used to develop CMFs for short duration work zones?

a. Cross-Sectional
b. Before-After with Comparison Group
c. Empirical Bayes Before-After
d. Meta-Analysis

Answer: (a) Cross-Sectional

Factors to Consider When Developing Work Zone CMFs

1. Are previous evaluation studies for the countermeasure available?
2. Are sufficient data for the countermeasure available?
3. Are the data formatted in a way that allows for crashes to be linked to specific work zones?
4. Are there any steps needed to combine the different types of data?
5. Are there appropriate sites for a Cross-Sectional study?
6. Are there enough locations for a Before-After study?
7. How will Annual Average Daily Traffic (AADT) data be obtained?

Tips 1-3 for Developing a High-Quality Work Zone CMF

1. Sufficient sample size
   - Depends on study method
     - Before-After
     - Cross-Sectional
2. Study includes multiple years of data
   - Increases sample size
3. Low standard error
   - CMF variability
   - Square root of variance
   - Affected by sample size

Tips 4-6 for Developing a High-Quality Work Zone CMF

4. Potential sources of statistical bias have been taken into account
   - Traffic volume changes
   - Regression to the mean
   - Location differences
   - Differences in crash reporting
5. Diversity of sites
   - Geographic location
   - Other characteristics
6. High level of statistical rigor

Check-In Question

Which of the following is not a characteristic of a high-quality work zone CMF?

a. High standard error
b. Sufficient sample size
c. High level of statistical rigor
d. Data from diverse geographic locations

Answer: (a) High standard error

Importance of Documentation for Work Zone CMF Studies

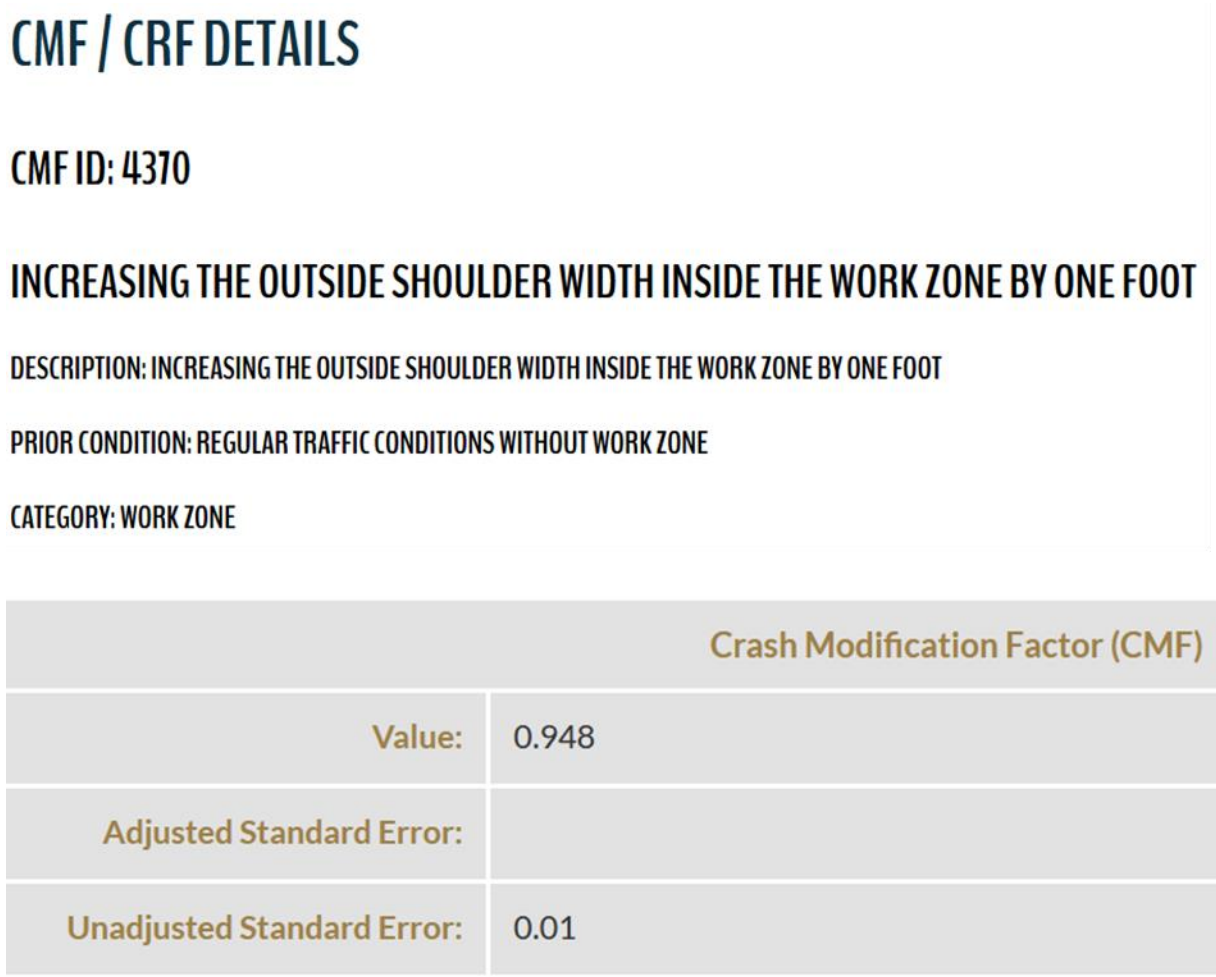
- Allow practitioner to assess applicability of CMF
  - Site characteristics (e.g. traffic volume range, area type)
  - Crash characteristics (e.g. crash type or severity)
- Evaluate quality and reliability of CMFs
  - Methodology
  - Sample size
  - Data sources
  - Standard error
  - Other considerations

Types of Documentation for Work Zone CMF Studies

- General documentation
  - CMF and countermeasure
  - Site characteristics
  - Crash characteristics
  - Study details
- Documentation of other considerations
  - Before-After studies
  - Cross-Sectional studies

General Documentation: CMF and Countermeasure

- Countermeasure name and description
- Crash modification factor (CMF) or crash modification function (CMFunction)
- Measures of precision
  - Standard error / standard deviation
- Prior conditions



CMF / CRF DETAILS

CMF ID: 4370

INCREASING THE OUTSIDE SHOULDER WIDTH INSIDE THE WORK ZONE BY ONE FOOT

DESCRIPTION: INCREASING THE OUTSIDE SHOULDER WIDTH INSIDE THE WORK ZONE BY ONE FOOT

PRIOR CONDITION: REGULAR TRAFFIC CONDITIONS WITHOUT WORK ZONE

CATEGORY: WORK ZONE

	Crash Modification Factor (CMF)
Value:	0.948
Adjusted Standard Error:	
Unadjusted Standard Error:	0.01

Image: FHWA

General Documentation: Site Characteristics

- Number of through lanes
- Speed limit
- Traffic volume range
- Roadway functional classification
- Road division type
- Municipality, state, and country
- Area type
- Intersection type
- Intersection geometry
- Traffic control (if applicable)

Roadway Types:	Principal Arterial Interstate
Number of Lanes:	
Road Division Type:	Divided by Median
Speed Limit:	
Area Type:	Urban
Traffic Volume:	
Average Traffic Volume:	
Municipality:	Indianapolis
State:	IN
Country:	USA

Image: FHWA

Site characteristics documented for the CMF of Increasing the Outside Shoulder Width Inside the Work Zone by One Foot.

General Documentation: Crash Characteristics

- Crash type
  Examples
  - All
  - Angle / Rear end
  - Wet weather
  - Run-off-road
- Crash severity
  - All
  - Fatal
  - Fatal and injury (KABC)
  - Fatal and injury (KAB)
  - Property damage only (PDO)
- Time of day
  - All
  - Day time only
  - Night time only

Image: FHWA

Crash characteristics documented for the CMF of Increasing the Outside Shoulder Width Inside the Work Zone by One Foot.

General Documentation: Study Details

- Years of data
- Method used for CMF development
  - Simple Before-After
  - Empirical Bayes Before-After
  - Cross-Sectional regression model
  - Cross-Sectional non-regression model
  - Case-control
  - Other
- Site selection criteria
- Sample size (crashes)
- Sample size (sites)

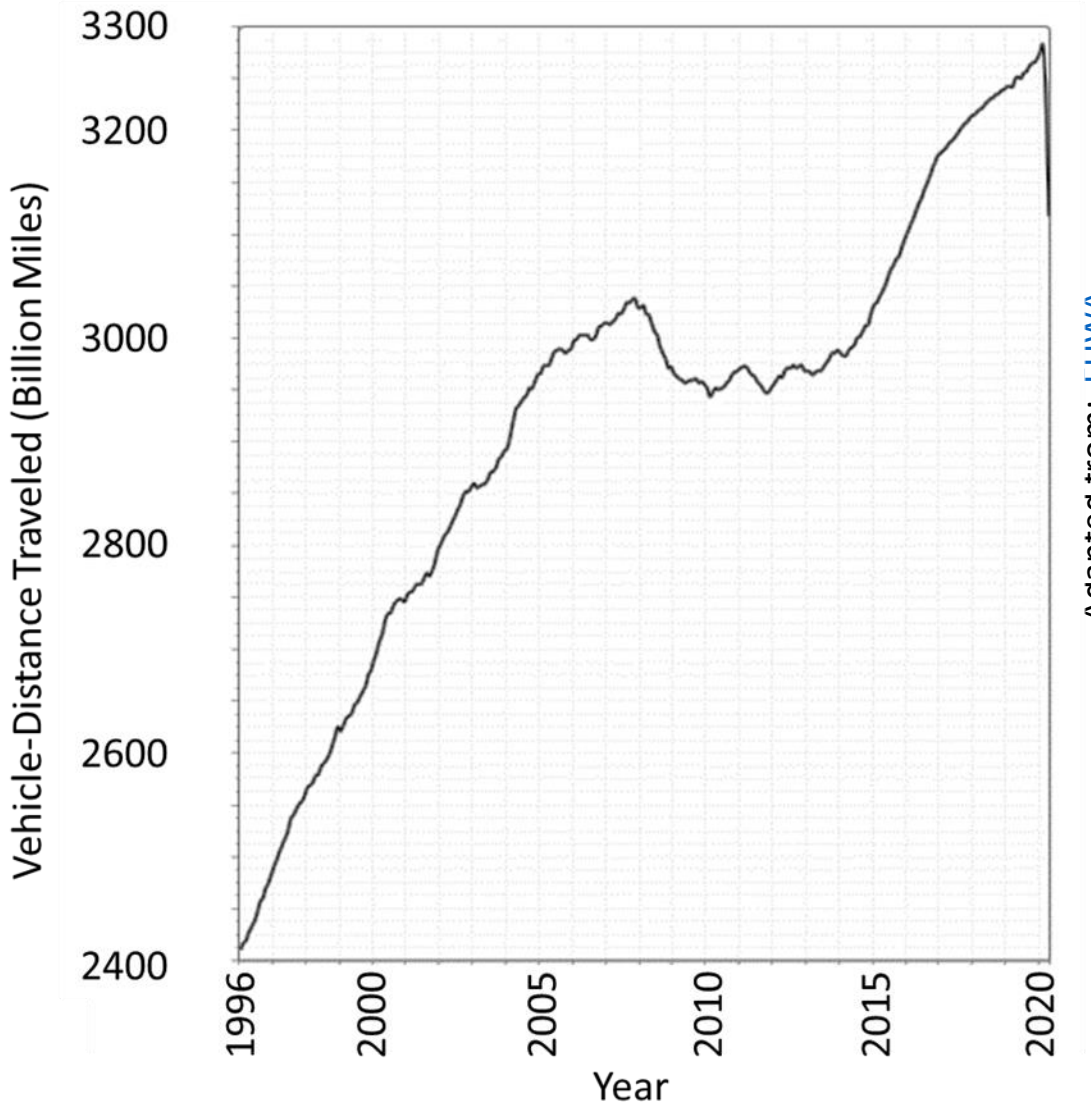
Date Range of Data Used:	2006 to 2008
Type of Methodology Used:	Regression cross-section
Sample Size (crashes):	1403 crashes

Image: FHWA

Study details documented for the CMF of Increasing the Outside Shoulder Width Inside the Work Zone by One Foot.

Documentation of Other Considerations: Before-After Studies

- Before-After Studies
  - Regression to the mean
  - Changes in traffic volumes
  - Historical trends
  - Other safety treatments
- Cross-Sectional Studies
  - Unobserved heterogeneity and omitted variable bias
  - Accounting for state-to-state differences (multiple states)
  - Selection of appropriate functional form
  - Correlation or collinearity



Adapted from: FHWA

Criteria for CMF Star Quality Rating

Relative Rating	Excellent	Fair	Poor
Study Design	Statistically rigorous study design with reference group or randomized experiment and control	Cross-Sectional study or other coefficient-based analysis	Simple Before-After study
Sample Size	Large sample, multiple years, diversity of sites	Moderate sample size, limited years, and limited diversity of sites	Limited homogeneous sample
Standard Error	Small compared to Crash Reduction Factor	Relatively large standard error (SE), but confidence interval does not include zero	Large SE and confidence interval includes zero
Potential Bias	Controls for all sources of known potential bias	Controls for some sources of potential bias	No consideration of potential bias
Data Source	Diversity in States representing different geographies	Limited to one State, but diversity in geography within State (e.g., CA)	Limited to one jurisdiction in one State

FHWA, 2020

Calculation of CMF Star Quality Rating

- Assign points
  - Excellent (2 points)
  - Fair (1 point)
  - Poor (0 points)
- Score = (2 * study design) + (2* sample size) + standard error + potential bias + data source

Score	Star Rating
14 (max possible)	5 Stars
11 – 13	4 Stars
7 – 10	3 Stars
3 – 6	2 Stars
1 – 2	1 Star
0	0 Stars

FHWA, 2020

CMF Star Quality Rating: Study Design

Excellent

- Empirical Bayes Before-After with reference group
- Full Bayes Before-After with reference group
- Before-After with comparison group without bias in site selection (areawide implementation or random selection)

Fair

- Cross-Sectional regression model
- Case-Control
- Cohort
- Other coefficient based analysis
- Before-After with comparison group with some site selection bias

Poor

- Simple Before-After
- Simple Cross-Sectional (non-regression)
- Before-After with comparison group with large effect from site selection bias

CMF Star Quality Rating: Sample Size

Study Type	Statistic	Excellent	Fair	Poor
Before-After	Before crashes plus expected after crashes for treatment group	> or = 200	100 to 200	< 100
Cross-Sectional	Total crashes	> or = 400	200 to 400	< 200

FHWA, 2020

CMF Star Quality Rating: Standard Error

Excellent

- CMF significantly different from 1.0 (0.05 significance level)

Fair

- CMF significantly different from 1.0 (0.1 significance level)

Poor

- CMF not significantly different from 1.0 (0.1 significance level)

CMF Star Quality Rating: Potential Bias

Excellent

- Controls for all potential bias

Fair

- Controls for important potential bias (e.g. traffic volume)

Poor

- Minimal consideration for potential bias

CMF Star Quality Rating: Data Source

Excellent

- Multiple states (or multiple countries for international)

Fair

- One state (or one country for international), multiple jurisdictions

Poor

- Single jurisdiction

Check-In Question

What is the minimum sample size (total crashes) required for a CMF developed from Cross-Sectional study to receive a score of excellent for sample size?

a. 200
b. 300
c. 150
d. 400

Answer: (d) 400

CMF Star Quality Ratings for Work Zone-Related Countermeasures (CMF Clearinghouse)

Countermeasure	CMF Star Quality Rating
Active work with no lane closure (compared to no work zone)	1 - 5
Active work with temporary lane closure (compared to no work zone)	3 - 4
No active work with no lane closure (compared to no work zone)	3 - 5
Implement left-hand merge and downstream lane shift (Iowa weave)	1 - 2
Increase work zone duration	Not rated (included in the HSM)
Modify work zone length	Not rated (included in the HSM)
Increasing the inside shoulder width inside the work zone by one foot	3
Increasing the outside shoulder width inside the work zone by one foot	3
TLTWO (two way traffic operations - crossover closures) in work zones	3

FHWA, 2020

Overview of Resources

- Recommended Protocols for Developing Crash Modification Factors (Carter et al., 2012)
- Better CMFs, Safer Roadways: Tips for Building High-Quality CMFs (FHWA, 2013)
- CMF Clearinghouse (FHWA, 2021)
- FHWA CMF Guide (Gross et al., 2010)
- Highway Safety Improvement Program (HSIP) Manual (Herbel et al., 2010)
- Methodology for the Development and Inclusion of Crash Modification Factors in the First Edition of the HSM (Transportation Research Circular E-C142) (TRB, 2010)
- Developing Quality Crash Modification Factors (NHI course)
- Development and Application of Work Zone Crash Modification Factors (2nd Edition) (Edara et al., 2021)
- Work Zone CMF Quick Reference Guide
- Self-paced training materials

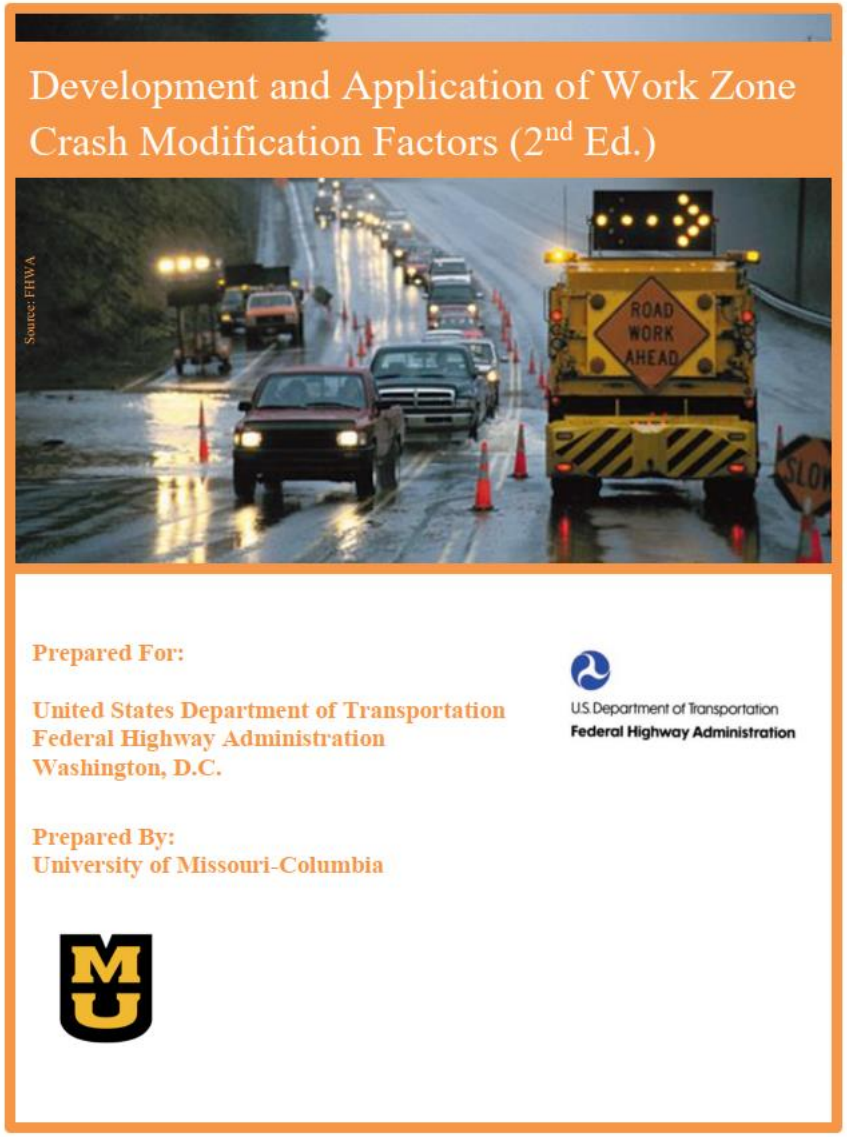


Image: Edara et al. 2021

Conclusions

- Need for additional high-quality WZ CMFs
- Characteristics of a high-quality CMF
- Various methods to develop WZ CMFs
- Work zone data challenges
- Multiple criteria for evaluation of CMFs
- Importance of documentation
- WZ CMF Guide (2nd Ed.) freely available online

Photo: FHWA

Acknowledgments

- WZ Safety Grant funded by FHWA
- Jawad Paracha (FHWA Program Manager)
- Nagham Matout (formerly Leidos) and Adil Cheema (Leidos)
- Personnel who participated in interviews
- MU Students
  - Farzaneh Azadi
  - Roozbeh Rahmani
- Missouri Center for Transportation Innovation (MCTI) (https://mcti.missouri.edu/)

References

- AASHTO. (2010). *Highway Safety Manual*. Washington, D.C.
- Bahar, G. (2010). *Methodology for the Development and Inclusion of Crash Modification Factors in the First Edition of the Highway Safety Manual*. (Transportation Research Circular E-C142). Transportation Research Board.
- Carter, D., Srinivasan, R., Gross, F., Council, F. (2012). *Recommended Protocols for Developing Crash Modification Factors*. National Cooperative Highway Research Program.
- Edara, P., Sun, C., Brown, H., Rahmani, R., Datta, T. (2016). *Development and Application of Work Zone Crash Modification Factors.* Federal Highway Administration.
- FHWA. *CMF Clearinghouse*.

References

- FHWA (2013). Better CMFs, Safer Roadways: Tips for Building High-Quality CMFs.
- Gross, F., Persaud, B., Lyon, C. (2010). *A Guide to Developing Quality Crash Modification Factors*. Federal Highway Administration.
- National Highway Institute (2020). *Developing Quality Crash Modification Factors* (Course Number FHWA-NHI-380119).
- Rahmani, R., Sun, C., Edara, P., Brown, H., and Zhu, Z. (2016). "Freeway Work Zone Crash Prediction Models Using Missouri Data." Presented at TRB 95th Annual Meeting, Washington D.C.

Disclaimer

This material is based upon work supported by the U.S. Department of Transportation under cooperative agreement Nos. DTFH6113RA00019 and 693JJ31750003. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the Author(s) and do not necessarily reflect the view of the U.S. Department of Transportation.

Questions?

Henry Brown, P.E.
E2509 Lafferre Hall
Columbia, MO 65211
573-882-0832
brownhen@missouri.edu

Thank you!