Developing CMFs

Study Types and Potential Biases

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VHB
Three Objectives

1. Explain difference between before-after and cross-sectional studies
2. Identify potential biases related to before-after study designs
3. Identify potential biases related to cross-sectional study designs
Overview of Before-After and Cross-Sectional Studies

Before-After vs. Cross-Sectional
Before-After Studies

• Comparison of safety performance of site(s) before and after the application of a treatment
Before-After Studies

- **Observed Crashes Before Treatment**
- **Observed Crashes After Treatment**

\[
CMF = \frac{A \text{ with}}{B \text{ without}}
\]
Strengths of Before-After Studies

- Primary benefit is time series of events
  - Definite change before and after treatment
Limitations of Before-After Studies

• Changes other than treatment of interest
  • Traffic volume
  • Temporal trends (weather, crash reporting, etc.)

• Identifying sufficient treatment sites
  • Prevalence of strategy
  • Records of location and installation date
Cross-Sectional Studies

• Comparison of the safety performance of sites with and without a treatment during the same time period.

Site 1: No centerline or chevron treatment

Site 2: Centerline and chevron treatment
Cross-Sectional Studies

\[ CMF = \frac{A \text{ with}}{B \text{ without}} \]

- Crashes at Sites Without Treatment
  - \( A \text{ without} \)
  - Before Period Without Treatment
- Crashes at Sites With Treatment
  - \( A \text{ with} \)
  - After Period With Treatment

Performance Measure vs. Time
Strengths of Cross-Sectional Studies

• Before-after studies not always possible
• No actual treatment required
Limitations of Cross-Sectional Studies

• Comparison between two distinct groups

• Need to account for differences between groups
  • Geometric and traffic characteristics
  • Reason for treatment
  • Driver demographics
  • Weather patterns
Potential Biases

Before-After vs. Cross-Sectional
Potential Biases: Before-After Studies

• Changes over time
  • Traffic, crash reporting, weather, drivers, vehicles

• Statistical issues
  • Regression-to-the-mean
  • Suitability of comparison or reference group

• Regional differences

\[ CMF = \frac{A \text{ with}}{A \text{ without}} \]
Changes Over Time Impact Crash Frequency

- Traffic, crash reporting, weather, drivers, vehicles
Regression-to-the-Mean

• Random variation in crashes over time
Suitability of Comparison or Reference Group

• Similar characteristics to treatment group
• Same before and after periods
• Safety performance NOT affected by treatment
Suitability of Comparison or Reference Group

- Potential spillover effects
Suitability of Comparison or Reference Group

• Potential crash migration
Regional Differences Impact Safety Performance

• Safety culture, climate, topography
Potential Biases: Cross-Sectional Studies

• Differences among sites
• Statistical issues
  • Inappropriate functional form
  • Omitted variable bias
  • Correlated and confounding variables

\[ CMF = \frac{A \text{ with}}{A \text{ without}} \]
Differences Among Sites

• Regression-based models
  • Account for geometric, operational, and regional differences

\[ \text{Crash Frequency} = \text{majAADT}^{\beta_1} \times \text{minAADT}^{\beta_2} \times \text{ISD}^{\beta_3} \times \exp(\text{Constant} + C_1X_1 + \cdots + C_nX_n) \]

\( \text{majAADT} \) = major road annual average daily traffic
\( \text{minAADT} \) = minor road annual average daily traffic
\( \text{ISD} \) = available ISD
\( X_i \) = vector of geometric, operational, and regional characteristics
\( \text{Constant}, \beta_i, C_i \) = Parameters estimated in the modeling process
Statistical Issues

- Inappropriate Functional Form
  - Over-fitting prediction models
  - Low sample mean and small sample size
  - Aggregated, averaged, or incomplete data
  - Misspecification of error structure

 Recommended Protocols for Developing Crash Modification Factors

Requested by:
American Association of State Highway and Transportation Officials (AASHTO)
Standing Committee on Highway Traffic Safety

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Statistical Issues

• Omitted variable bias
• Correlation and confounding
• Example: Estimate CMF for Chevrons
  • Sample curves with and without chevrons
  • Analysis fails to account for roadside hazards
  • Curves with chevrons have more severe roadside hazards
  • Conclude chevrons increase crash severity
Review

• What are potential biases related to Before-After Studies?
  • Changes over time (traffic, crash reporting, etc.)
  • Statistical issues (RTM, suitability of comparison or reference group)
  • Regional differences
Review

- What are potential biases related to **Cross-Sectional Studies**?
  - Differences among sites
  - Geometric, operational, and regional
  - Statistical issues
    - Inappropriate functional form, omitted variable bias, confounding, correlation
Resource

A Guide to Developing Quality Crash Modification Factors

Are data available for the treatment in your jurisdiction? OR Can you install the treatment and collect data?

Are there suitable locations to develop a comparison group or reference group?

Select before-after method based on criteria in table below

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

Are there sufficient existing or planned installations for a before-after study?

Are there sufficient locations without treatment that are otherwise similar to the treated sites? AND Are data available for the major factors affecting crash risk?

Select method based on criteria in table below

<table>
<thead>
<tr>
<th>Study Criteria</th>
<th>Cross-Sectional</th>
<th>Case-Control</th>
<th>Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash type is rare</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Treatment is rare</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Accounts for locations with multiple crashes (rather than first occurrence)</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>CMFFunction desired</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

FIGURE 5. Flow Chart for Study Design Selection.
Questions

• Can you:
  • Explain the difference between before-after and cross-sectional studies?
  • Identify potential biases related to before-after study designs?
  • Identify potential biases related to cross-sectional study designs?

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Importance of Good CMF Documentation

Daniel Carter
UNC Highway Safety Research Center
TRB Webinar, August 11, 2016
Intro Scenario

- An engineer plans to convert stop-controlled intersection to signalized intersection
- Her goal is to reduce fatal and serious injury crashes
- She needs a CMF for the benefit-cost analysis

Identified: CMF (fatal and serious injury crashes) = 0.6

Information reported:
- Based on 80 sites
- Data from CA, MN, WA
- Before/after study

Not reported:
- Number of lanes?
- Urban or rural?
- Traffic volume?
- “Serious” injury = A?
Why is good CMF documentation important?

1. To know the **conditions** where the CMF can be applied most appropriately
2. To judge the **quality** of the CMF
What conditions should be reported?

- **Countermeasure**
  - What was installed or converted?
  - How was it implemented?
  - What was the prior condition?

- Installed median barrier
- Installed three-strand high-tension cable median barrier
- Installed flashing beacons
- Installed overhead and sign post mounted flashing beacons (flashing yellow for the major road and red for the minor road)
What conditions should be reported?

- Roadway Class
- Divided vs. Undivided
- State/Municipality
- Urban vs. Rural
- Number of Lanes
- Speed Limit
- Traffic Volume Range
- Traffic Control, Intersection Type, Intersection Geometry
- Other Relevant Details

Install a traffic signal

<table>
<thead>
<tr>
<th>Intersection Type:</th>
<th>Roadway/roadway (not interchange related)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection Geometry:</td>
<td>3-leg, 4-leg</td>
</tr>
<tr>
<td>Traffic Control:</td>
<td>Stop-controlled</td>
</tr>
<tr>
<td>Major Road Traffic Volume:</td>
<td>Minimum of 3261 to Maximum of 29926 Annual Average Daily Traffic (AADT)</td>
</tr>
<tr>
<td>Minor Road Traffic Volume:</td>
<td>Minimum of 101 to Maximum of 10300 Annual Average Daily Traffic (AADT)</td>
</tr>
</tbody>
</table>
What conditions should be reported?

• Crash characteristics
  – Crash type
  – Crash severity
  – Time of day

“Bicycle and moped riders, all injuries, non intersection”

“CMF applies only to red-light-related crashes”

“Applies to driveway-related crashes. A rectangular buffer area is used to identify driveway-related crashes. CMF applies to high-turnover driveways (i.e., fast food, gas station, drive-thru bank).”
What information is needed to judge quality of the CMF?

- CMF Clearinghouse: Study design, sample size, standard error, data source, potential biases
- HSM 1\textsuperscript{st} Edition Part D: Study design, standard error, potential biases
- HSM 2\textsuperscript{nd} Edition: \textit{TBD} (NCHRP 17-72)
What information is needed to judge quality of the CMF?

- Sample size
  - Years of data
  - Number of sites or miles
  - Number of crashes
- Study methodology (e.g., before-after, cross-sectional)
- Standard error
- Selection criteria for treatment and reference sites
- Bias avoidance/addressing (Frank’s topic)

- If something is unknown, rating is lowered
Resources

CMF Clearinghouse
www.cmfclearinghouse.org

Flyer on Developing High Quality CMFs
Guide to Developing Quality CMFs
Recommended Protocols for Developing CMFs
Contact

Daniel Carter
UNC Highway Safety Research Center
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TRB WEBINAR:
GUIDANCE ON DEVELOPING CRASH MODIFICATION FACTORS
AUGUST 11, 2016

STATE DEPARTMENT OF TRANSPORTATION
CONSIDERATIONS
& CASE STUDY

Randy Laninga, Illinois Department of Transportation
Kerrie Schattler, Bradley University
Illinois SHSP

- Zero Fatality Goal
- All public roads
- Severe Crashes
- Substantive Safety
- 4E Partnership
- Continual Evaluation

Driving Zero Fatalities to a Reality

Partnering for Illinois
Strategic Highway Safety Plan

- Sets the **vision, goal and performance metrics**
- Uses **data** to identify **safety priorities**
- Provides **data analysis resources** for stakeholder safety planning
- Provides **collaboration and coordination** opportunities
- Provides **strategies** for implementation consideration
- **Unifying document for safety statewide**
Use of CMFs

• Setting Priorities
• Accurate Benefit to Cost ratio
• Best use of Funds
• Analysis of alternative designs
• Not only the safety projects but all highway projects
Considerations using CMFs

• Don’t use a CMF blindly
  ✓ Geographical Location
  ✓ Spot or systemic

• Does the situation match

• Applying multiple CMF’s
Our CMF Research

- CMFs are produced whenever we do a safety study
- Follow up on safety projects that use CMFs to see if they are reasonable
- Change our policy to reflect what we have found
Example Project

• Flashing Yellow Arrows in Peoria
• Dr. Kerrie Schattler from Bradley University performed the evaluation study
• State provide data
  ✓ Where and when installed
  ✓ Crash data
  ✓ Updates
  ✓ Guidance
Case Study
FYA Study Sites

• FYAs installed at 112 intersections
  ✓ At 26 intersections, other safety improvements were also installed
    o Excluded from study

• Sample Size for Evaluation
  ✓ 86 test intersections
  ✓ 164 approaches

• Located across 10 cities in Peoria area
  ✓ On state routes
FYA Study Sites

• 164 FYA approaches
  ✓ All had dedicated left-turn lanes
  ✓ At 90 approaches FYA supplemental sign was installed

• Intersection Characteristics
  ✓ Average Daily Traffic (ADT) 8,500 to 40,700 veh/day
  ✓ 3- and 4- legged urban configurations with various geometries
  ✓ Freeway ramps
  ✓ One way streets, divided highways
FYA Study Sites

• All 164 FYA approaches
  ✓ In *before* and *after* conditions, signals operated with protected/permissive left-turn (PPLT) control
  o Yellow & all-red intervals following *both* the protected and permissive phases
  ✓ Permissive left-turn interval of PPLT phasing
    o Before Condition ⇒ 5-section signal heads with Circular Green (CG)
    o After Condition ⇒ 4-section signal heads with FYA

5-section signal head with CG

4-section signal head with FYA
Traffic Crash Evaluation

• 3,307 crash reports analyzed
  ✓ Over a 6-year period
    ○ 3 years of before data
    ○ 3 years of after data
  ✓ Focused on left-turn crashes, categorized into 9 crash types

• Targeted Crash Types
  ✓ Left-turn (LT) -related
  ✓ Left-turn Opposing-Through (LTOT)
Empirical Bayes Method

- Increases precision of estimation and corrects for the regression-to-mean bias
- Calculates expected crash frequency
  - Observed crash frequency
  - Predicted crash frequency
    - Safety Performance Functions (SPF)

Source: Highway Safety Improvement Program, FHWA 2010
Safety Performance Functions

• SPF's developed for project
  ✓ 100 comparison sites in central Illinois
  ✓ Located in 8 cities in central IL, outside the Peoria area
  ✓ 266 approaches operating with PPLT with CG

• Data Collected
  o Crash Data by type and severity (2009 to 2011)
  o Average Daily Traffic
    o Intersection ADT
    o Minor street ADT
    o Major street ADT
    o Approach ADT
  o Laneage
  o Speed limit
Safety Performance Functions

- Models developed
  - Assuming Poisson/negative binomial distribution
  - Variables with statistically significant relationship with crashes

\[
P_{\text{intersection}} = e^\alpha \times e^{(\text{Approach ADT})\beta_1}
\]

\[
P_{\text{total}} = e^\alpha \times e^{(\text{Total Intersection ADT})\beta_1} \times e^{\left(\frac{\text{Prop. Approach ADT}}{\text{Total ADT}}\right)\beta_2} \times e^{(\text{OppThruLanes})\beta_3}
\]

\[
P_{\text{injury}} = e^\alpha \times e^{(\text{Total Intersection ADT})\beta_1} \times e^{(\text{OppThruLanes})\beta_2}
\]

\[
P_{\text{LT-related}} = e^\alpha \times e^{(\text{Approach ADT})\beta_1} \times e^{(\text{OppThruLanes})\beta_2}
\]

\[
P_{\text{LTOT}} = e^\alpha \times e^{(\text{Total Intersection ADT})\beta_1} \times e^{(\text{OppThruLanes})\beta_2}
\]
Safety Performance Function

- Standard error of the coefficients
  - Measure quality of an SPF
  - Represents ability of SPF to predict crashes accurately

- Small standard error with respect to the magnitude of coefficients indicates SPF predicts crashes accurately
  - Standard error $\Rightarrow 0.000005$ to $0.4$
  - Ratio of standard error/coefficient value $\Rightarrow 0.08$ to $0.41$
Crash Modification Factors

• Determined for targeted crash types on an approach basis
  ✓ Per the empirical Bayes method, using
    o Observed crash frequency
    o Predicted crash frequency using SPF's
    o Expected crash frequency
    o Weighting factors as a function of overdispersion factor, k
    o Unbiased estimate of effectiveness ($\theta$), CMF
      • Variance of $\theta$, Standard error of $\theta$
    o Unbiased safety effectiveness (percent reduction, crash reduction factor)
      • Variance, Standard Error
    o Statistical Significance
    o Confidence Interval of CMF
Crash Modification Factor Results

- **LT-related crashes at FYA approach**
  - Percent Reduction = 38.3%
  - CMF = 0.617
    - 95% confidence interval = 0.617 ± 1.96 × 0.063 = **0.494 to 0.740**

- **LT-related crashes at FYA approach with supplemental sign**
  - Percent Reduction = 41.1%
  - CMF = 0.589
    - 95% confidence interval = **0.425 to 0.753**

- **LTOT crashes at FYA approach**
  - Percent reduction = 28.6%
  - CMF = 0.714
    - 95% confidence interval = **0.545 to 0.883**

- **LTOT crashes at FYA approach with supplemental sign**
  - Percent reduction = 29.8%
  - CMF = 0.711
    - 95% confidence interval = **0.474 to 0.948**
Recommendations

• FYAs continue to be installed on state routes in Illinois because they were found to have significant safety impacts and reduce left-turn crashes at locations where installed

• Supplemental signs should be used when implementing the FYA in Illinois
  ✓ Especially while the FYA remains a new traffic control device
  ✓ In Peoria, especially on city roads, supplemental signs are commonly displayed at other left-turn signals, in addition to the FYA

• Additional research is needed to justify the long-term and continual use of the FYA supplemental sign, once more drivers become familiar with its meaning