2015 Design Training Expo

# Engineering Statistics 101 for Safety

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*Celebrating 100 Years of Innovation, Mobility and Economic Development*

# Acknowledgements


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- Sivaramakrishnan (Siva) Srinivasan, Ph.D.
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# Presentation Overview

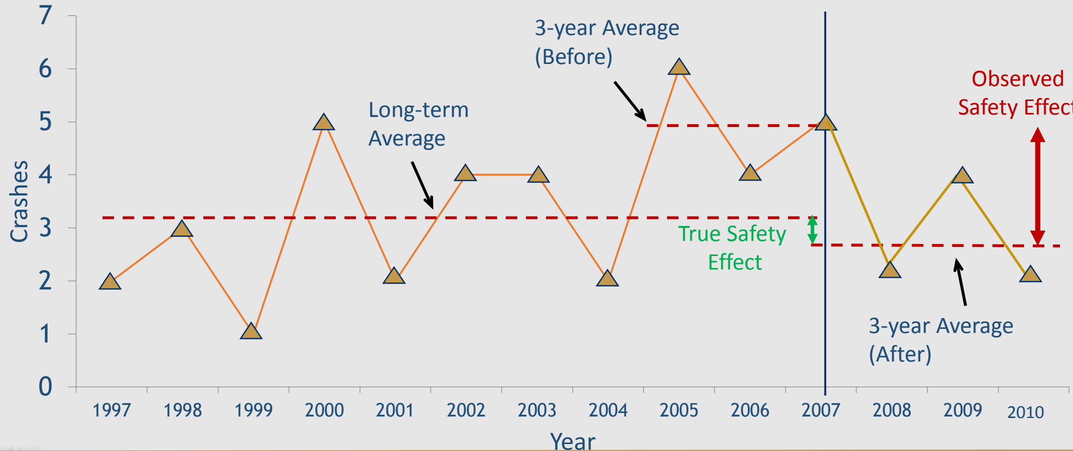
- Reactive and Proactive Approaches
- Issues with basic site selection methods
- Empirical Bayes Method



# Reactive vs. Proactive Approaches

- Reactive Approach
  - Based on analysis of crash data
  - Ex: Identification of high crash locations using crash counts
- Proactive Approach
  - Focuses on the evolving specific safety implications of highway design and operations decisions
  - Ex: Identification of high crash locations using empirical Bayes method

# Regression to the Mean (RTM) Effect

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# Influence of Low AADT on Crash Rates

BEFORE

| Year | No. of Crashes | AADT | Crash Rate |
|---|---|---|---|
| 1988 | 13 | 2,900 | 2.11 |
| 1989 | 11 | 2,900 | 1.79 |
| 1990 | 13 | 3,050 | 2.01 |
| 1991 | 23 | 3,400 | 3.19 |

Average Rate = 2.28

AFTER

| Year | No. of Crashes | AADT | Crash Rate |
|---|---|---|---|
| 1992 | 30 | 10,618 | 1.33 |
| 1993 | 30 | 13,200 | 1.07 |
| 1994 | 36 | 14,300 | 1.19 |
| 1995 | 40 | 13,900 | 1.36 |

Average Rate = 1.24

Gambling Introduced in 1992

*Example Provided by Jake Kononov, PhD, PE, CDOT*

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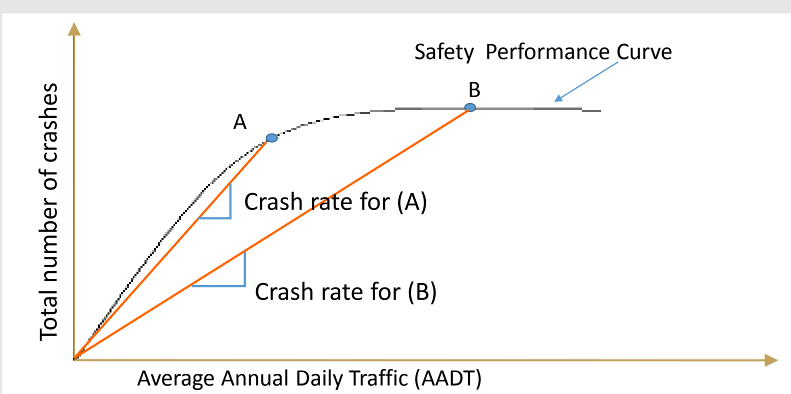
# Influence of Low AADT on Crash Rates - Conclusion

- Before gambling average rate = 2.28
- Highway alignment and typical cross-section were not changed
- After gambling average rate = 1.24
- Percent of alcohol-related crashes increased by 500%
- Possible Conclusion: Is drinking and driving as a result of gambling good for safety? **Probably not but crash rates say otherwise!**



# Non-linear Relation between Crashes and Exposure




Similar crash performance with increase in traffic gives better rate
Crashes still as bad or worse

# Safety Performance Functions (SPFs)

- An SPF describes the relation between number of crashes and measure of exposure
- Simple/Traffic SPFs

  Predicted Crashes = *f(traffic)*  $Crashes/year = 0.6278 \times SCL \times (AADT/1000)^{1.024}$

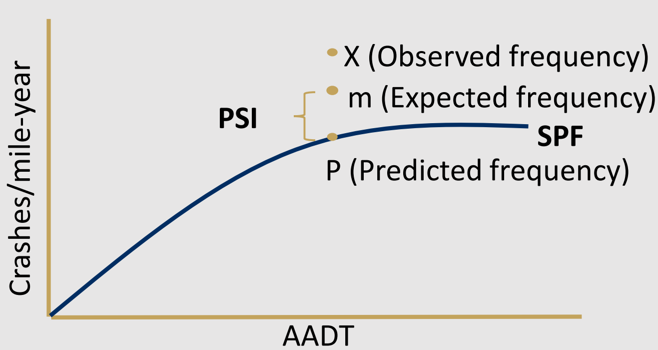
- All-inclusive/Full SPFs

  Predicted Crashes = *f(traffic + roadway geometric design features)*

  $Crashes/year = 0.001465 \times (CCR)^{0.0036} \times (AADT)^{0.7886} \times (TPERCNT)^{0.2866} \times (SEGLEN)^{0.3118} \times (SPDIFSQ)^{0.0479}$



# Empirical Bayes (EB) Approach




Expected crash frequency is the weighted average of the observed and predicted crash frequency

$$m = w(P) + (1 - w)(X)$$

$$0 \le W \le 1$$

$$w = \frac{1}{1 + k(\sum_{all\ yrs} P)}$$

*k is over dispersion parameter*

# Advantages of EB Approach

- Addresses RTM bias
- Uses non-linear relation between crashes and exposure
- Predicts the expected number of crashes in the future
- Ranks sites based on PSI
- Provides measures to determine the reliability of safety predictions



# EB Analysis as discussed in the HSM

$$\boxed{SPF} \times \boxed{CMF} \times \boxed{C} = \textit{Predicted Crashes}$$

- SPF is a regression equation used to estimate the predicted crash frequency at a site for a given "base condition"
- CMFs are used to adjust the "base condition" in the SPF to specific site characteristics
- Calibration Factor (C) is used to adjust average predicted crash frequencies to local site conditions

# Safety Performance Functions

- SPF is a regression equation used to estimate the predicted crash frequency at a site for a given "base condition"
- Segments
  $N = \exp[a + b \times \ln(AADT) + \ln(Length)]$
- Intersections
  $N = \exp[a + b \times \ln(AADT_{major}) + c \times \ln(AADT_{minor})]$



# CMFs and CRFs

- A crash modification factor (CMF) is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site.
- A crash reduction factor (CRF) is the percentage crash reduction that might be expected after implementing a given countermeasure at a specific site.

$$CMF = \frac{\text{Expected average crash frequency with condition 'b'}}{\text{Expected average crash frequency with condition 'a'}}$$

$$CMF = 1 - \frac{CRF}{100}$$

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# Calibration Factor

- To account for differences between jurisdictions not reflected in the base SPF and CMFs
  - Geographic area/terrain type
  - Seasonal factor
  - Drivers' attributes
  - Animal population
  - Crash reporting threshold
- To account for differences between time period for which the models were developed and to which they are applied

$$C = \frac{\sum_{allsites} \text{observed crashes}}{\sum_{allsites} \text{predicted crashes}}$$



# Example 1: Calculate $N_{Expected}$

- Two-lane rural road segment
- Segment length is 0.1 miles

| Year | AADT | Observed Crashes |
|---|---|---|
| 2008 | 8,000 | 1 |
| 2009 | 8,200 | 3 |
| 2010 | 8,500 | 2 |

# Steps to Calculate $N_{Expected}$ Crashes

1. Collect data (roadway characteristics, AADT, crash)
2. Apply SPF to calculate $N_{Predicted}$ under base conditions
3. Apply CMFs to adjust for base conditions
4. Calcualte $N_{Predicted}$ under site-specific conditions
5. Compute weighting factor
6. Determine $N_{Expected}$ crashes



# Step 1: Roadway Characteristics Data

- Lane width: 11 ft
- Shoulder width: 2 ft
- Shoulder type: gravel
- Grade: 1%
- Radius of horizontal curve: 1,200 ft
- Length of horizontal curve: 0.10 mile
- No spiral transition
- Superelevation rate: 0.04
- Driveway density: 5 driveways per mile
- No passing lane
- No centerline rumble strip
- No two-way left-turn lane
- No lighting
- No automated speed enforcement

# Step 1: Yearly AADT and Crash Data

| Year | AADT | Observed Crashes |
|---|---|---|
| 2008 | 8,000 | 1 |
| 2009 | 8,200 | 3 |
| 2010 | 8,500 | 2 |



# Step 2: Apply SPF

Apply the appropriate SPF for rural two-way two-lane segment

$$N_{spf} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)}$$
$$= 8000 \times 0.1 \times 365 \times 10^{-6} \times e^{(-0.312)}$$
$$= 0.214 \text{ crashes}$$

⇩

Predicted crash frequency under "base" conditions

# Step 3: Apply CMFs

| Data | Base Conditions | Site Conditions | CMF Calculation |
|---|---|---|---|
| Lane width | 12 ft | 11 ft | $CMF_{1r} = (CMF_{ra} - 1.0) \times p_{ra} + 1.0$ $= (1.05 - 1.0) \times 0.78 + 1.0 = \mathbf{1.04}$ |
| Shoulder width | 6 ft | 2 ft | $CMF_{2r} = (CMF_{wra} \times CMF_{tra} - 1.0) \times p_{ra} + 1.0$ $= (1.30 \times 1.01 - 1.0) \times 0.78 + 1.0 = \mathbf{1.24}$ |
| Shoulder type | paved | gravel | |
| Length of horizontal curve | 0 mi | 0.1 mi | $CMF_{3r} = \frac{(1.55 \times L_C) + (80.2/R) - (0.012 \times S)}{(1.55 \times L_C)}$ $= \frac{(1.55 \times 0.1) + (80.2/1200) - (0.012 \times 0)}{(1.55 \times 0.1)} = \mathbf{1.43}$ |
| Radius of curvature | 0 ft | 1,200 ft | |
| Spiral transition curve | not present | not present | |
| Superelevation variance | <0.01 | 0.02 | $CMF_{4r} = 1.06 + 3(SV - 0.02) = 1.06 + 3(0.02 - 0.02) = \mathbf{1.06}$ |
| Grade | 0% | 1% | $CMF_{5r} = \mathbf{1.00}$ (grade < 3%) |
| Driveway density | 5 driveways/mi | 0 | $CMF_{6r} = \mathbf{1.00}$ (≤ 5 driveways/mi) |

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# Step 3: Apply CMFs (cont'd)

| Data | Base Conditions | Site Conditions | CMF Calculation |
|---|---|---|---|
| Centerline rumble strip | not present | not present | $CMF_{7r} = \mathbf{1.00}$ |
| Passing lanes | not present | not present | $CMF_{8r} = \mathbf{1.00}$ |
| Two-way left-turn lane | not present | not present | $CMF_{9r} = \mathbf{1.00}$ |
| Roadside hazard rating | 3 | 5 | $CMF_{10r} = \frac{\exp(-0.6869+0.0668 \times RHR)}{\exp(-0.4865)} = \frac{\exp(-0.6869+0.0668 \times 5)}{\exp(-0.4865)} = \mathbf{1.14}$ |
| Segment lighting | not present | not present | $CMF_{11r} = \mathbf{1.00}$ |
| Auto speed enforcement | not present | not present | $CMF_{12r} = \mathbf{1.00}$ |

$$CMF_{combined} = CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{12r} = 1.04 \times 1.24 \times 1.43 \times 1.06 \times 1.14 = \mathbf{2.23}$$

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# Step 4: $N_{Predicted}$ Under Site-Specific Conditions

$$N_{predicted} = N_{spf} \times CMF_{combined} \times \text{Calibration Factor}$$

$$N_{predicted} = 0.214 \times 2.23 \times 1.10 = 0.525 \text{ crashes}$$

| Year | AADT | $N_{SPF}$ | $N_{Predicted}$ |
|---|---|---|---|
| 2010 | 8,000 | 0.214 | 0.53 |
| 2011 | 8,200 | 0.219 | 0.54 |
| 2012 | 8,500 | 0.227 | 0.56 |

$$N_{spf} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)}$$



# Step 5: Compute Weighting Factor

$$w = \frac{1}{1 + k \times \sum_{years} N_{predicted}}$$

$$k = \frac{0.236}{L} = \frac{0.236}{0.1} = 2.36$$

$$w = \frac{1}{1 + 2.36 \times (0.53+0.54+0.56)} = 0.206$$

# Step 6: Determine $N_{Expected}$

$$N_{expected} = w \times N_{predicted} + (1 - w) \times N_{observed}$$

$$N_{expected} = 0.206 \times \frac{(0.525+0.537+0.557)}{3} + (1 - 0.206) \times \frac{(1+3+2)}{3}$$

$$N_{expected} = 1.70 \text{ crashes per year}$$



# Example 2: Before/After Safety Effectiveness Evaluation

- Passing lane is installed at the site in December 2010

| Year | AADT | $N_{Observed}$ | $N_{Predicted}$ |
|---|---|---|---|
| 2008 | 8,000 | 1 | 0.53 |
| 2009 | 8,200 | 3 | 0.54 |
| 2010 | 8,500 | 2 | 0.56 |
| 2011 | 8,600 | 1 | 0.56 |
| 2012 | 8,750 | 1 | 0.57 |

Passing lane is installed

# Steps to Calculate $N_{Expected}$ Crashes

1. Collect data (roadway characteristics, AADT, crash)
2. Apply SPF to calculate $N_{Predicted}$ under base conditions
3. Apply CMFs to adjust for base conditions
4. Calcualte $N_{Predicted}$ under site-specific conditions
5. Compute weighting factor
6. Determine $N_{Expected}$ crashes



# Steps to Calculate Safety Effectiveness of a Treatment (Cont'd)

7. Apply adjustment factor to account for differences between "before" and "after" periods in duration and traffic volume
8. Calculate average $N_{Expected}$ in "After" period without treatment
9. Determine safety effectiveness

# Step 7: Apply Adjustment Factor

To account for differences between the "before" and "after" periods in duration and traffic volume

$$r = \frac{\sum_{\text{after years}} N_{\text{predicted}}}{\sum_{\text{before years}} N_{\text{predicted}}}$$

$$r = \frac{(0.56 + 0.57)}{(0.53 + 0.54 + 0.56)} = 0.693$$

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# Step 8: Calculate Average $N_{\text{Expected}}$ in "After" Period Without treatment

$$N_{\text{expected,A}} = r \times N_{\text{expected,B}}$$

$$= 0.693 \times 1.70$$

$$= 1.18 \text{ crashes per year}$$

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# Step 9: Determine Safety Effectiveness

$$\text{Safety Effectiveness} = 100 \times (1 - OR)$$

$$OR = \text{Odds Ratio} = \frac{N_{observed,A}}{N_{expected,A}}$$

$$OR = \frac{2}{2 \times 1.18} = 0.847$$

$$\text{Safety Effectiveness} = 100 \times (1 - 0.847)$$

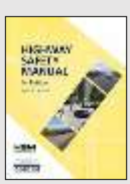
$$= 15.3\%$$

→ Percentage Reduction in Crashes



# Summary

- We discussed about:
  - Issues with basic site selection methods
  - Empirical Bayes Method (SPFs, CMFs, calibration factor, expected crashes)
- The EB method is used in the newer safety analysis tools




AASHTOWare Safety Analyst AASHTO

# Thank you!
# Questions?

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