Network Safety Screening – Basics and North American Perspectives

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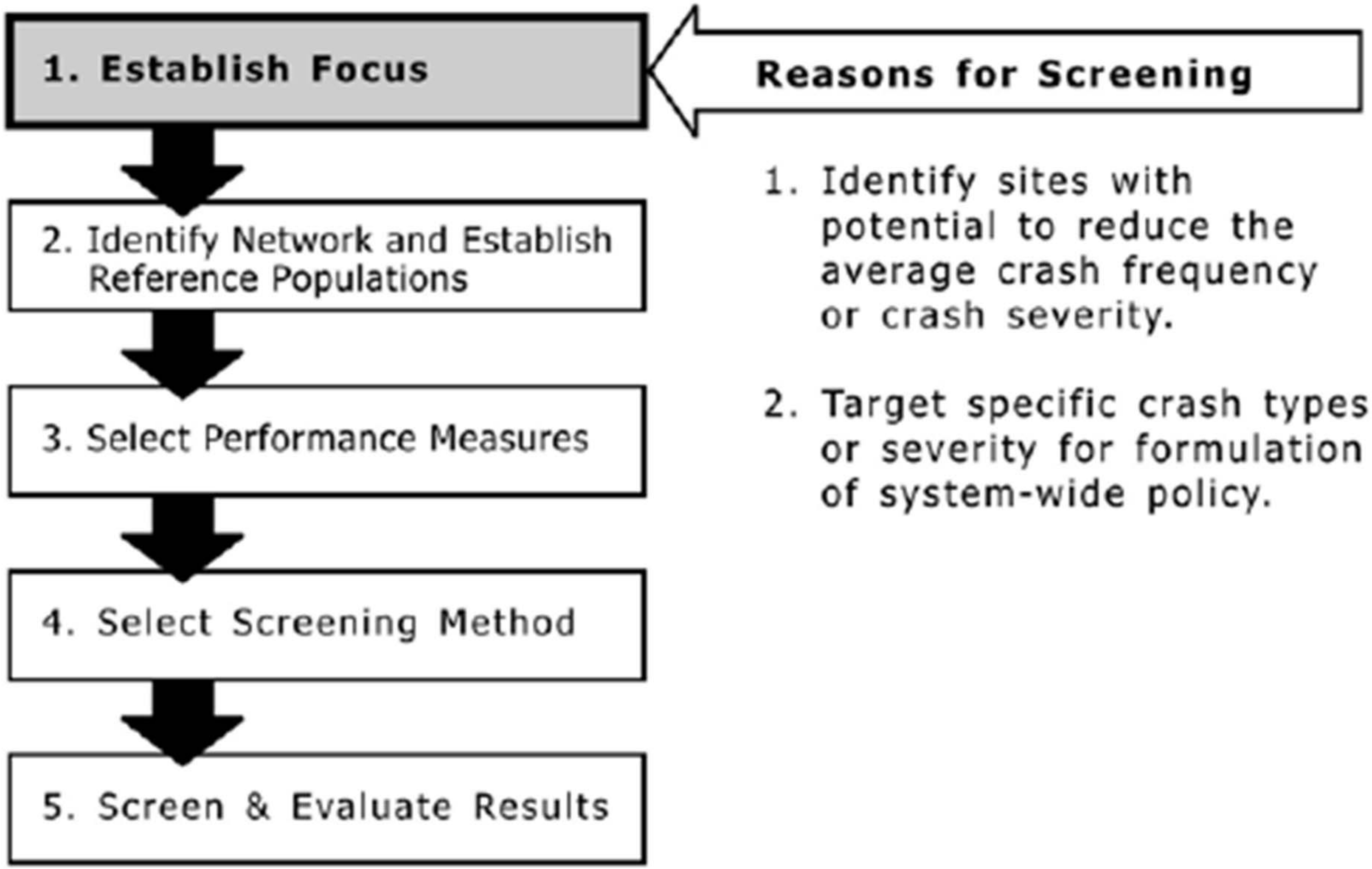
Overview

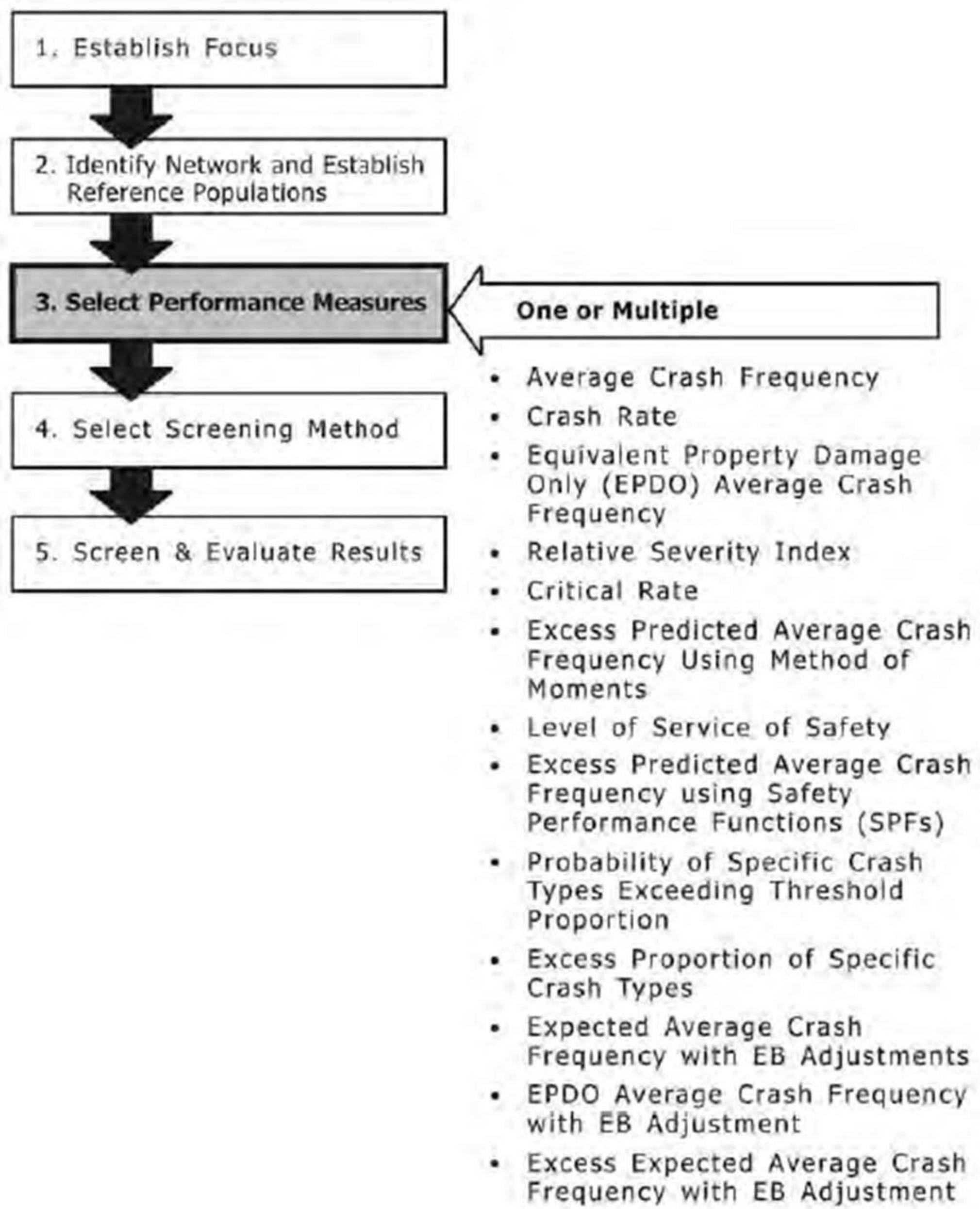
- Network screening defined
- Defining and measuring safety for Network Screening applications
  - How not to do it
  - How to do it right
- Network screening methods
  - North American practice and perspectives

Why network screening?

- Basic purpose is to use available data to review an entire road network and identify and prioritize sites that merit further investigation.
- The "further investigation" process is an expensive one, so only a limited set of sites can be investigated.
- The most efficient screening procedure will best identify "sites with promise" as those that would likely be the highest ranked in safety cost-effectiveness of potential improvements.
- Fundamental objective is to minimize "false positives" and "false negatives" and to maximize correct ones.

Network Screening Process




1. Establish Focus
2. Identify Network and Establish Reference Populations
3. Select Performance Measures
4. Select Screening Method
5. Screen & Evaluate Results
One or Multiple
Average Crash Frequency
Crash Rate
Equivalent Property Damage Only (EPDO) Average Crash Frequency
Relative Severity Index
Critical Rate
Excess Predicted Average Crash Frequency Using Method of Moments
Level of Service of Safety
Excess Predicted Average Crash Frequency using Safety Performance Functions (SPFs)
Probability of Specific Crash Types Exceeding Threshold Proportion
Excess Proportion of Specific Crash Types
Expected Average Crash Frequency with EB Adjustments
EPDO Average Crash Frequency with EB Adjustment
Excess Expected Average Crash Frequency with EB Adjustment

THE UPSHOT: METHODS REQUIRE THAT SAFETY BE DEFINED AND MEASURED

DEFINING AND MEASURING SAFETY FOR NETWORK SCREENING

Measuring Safety: Collision frequency or rates?

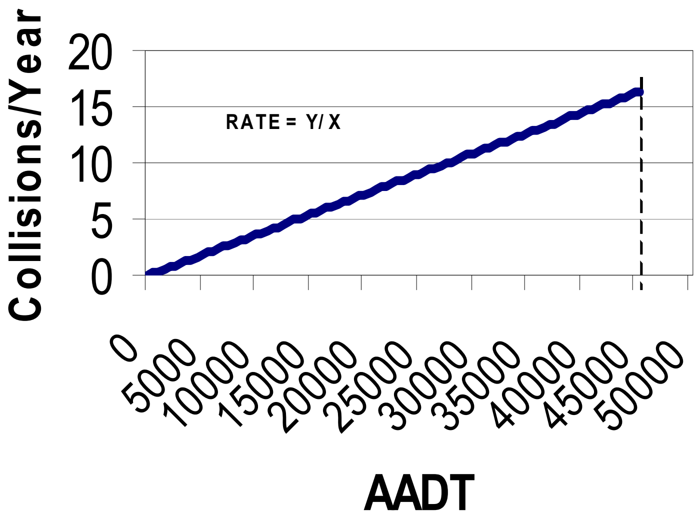
- Safety is measured using statistical estimates based on collision data
- Collision Rate = Frequency / (Exposure/Unit of Time)
- Relationship between Collision Frequency and AADT is usually non-linear, therefore:
  - Collision Rate varies with AADT
  - Using Collision Rate to measure safety can be misleading

Measuring Safety: Collision rate defined

$$\text{Collision Rate} = \frac{\text{Collision Frequency}}{\text{(Exposure/unit of time)}}$$

Example :

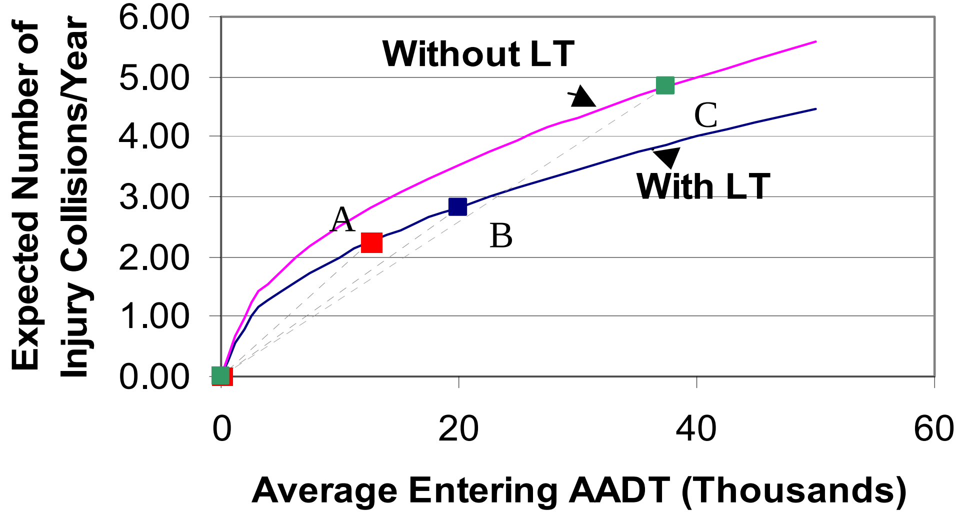
16.4 collisions /year
45,000 ENTERING AADT



$$\frac{16.4}{45{,}500 \times 365} \times 10^{6} = 0.99$$

collisions/million entering vehicles

Measuring Safety: The problem with rates



- **Is B safer than A?**
- **Is C safer than B?**

Measuring Safety: Conclusions on use of rates

- Sites with relatively low AADT can have a high collision rate and can be wrongly identified in screening
- VICE VERSA: A site with high AADT and potential for safety improvement can go untreated because of a relatively low collision rate
- Using collision rates can give incorrect conclusions about the relative safety of different types of sites
- Therefore, safety estimation and in particular, network screening, must not be done on the basis of collision rates

Is frequency a better measure than rates?

Problem is collision occurrence is a stochastic process

- Collisions are rare events
- Collisions are considered random events in a statistical sense
  - Spatial context
  - Temporal context
- Temporal and spatial variations are a function of identifiable factors plus a "noise" component.

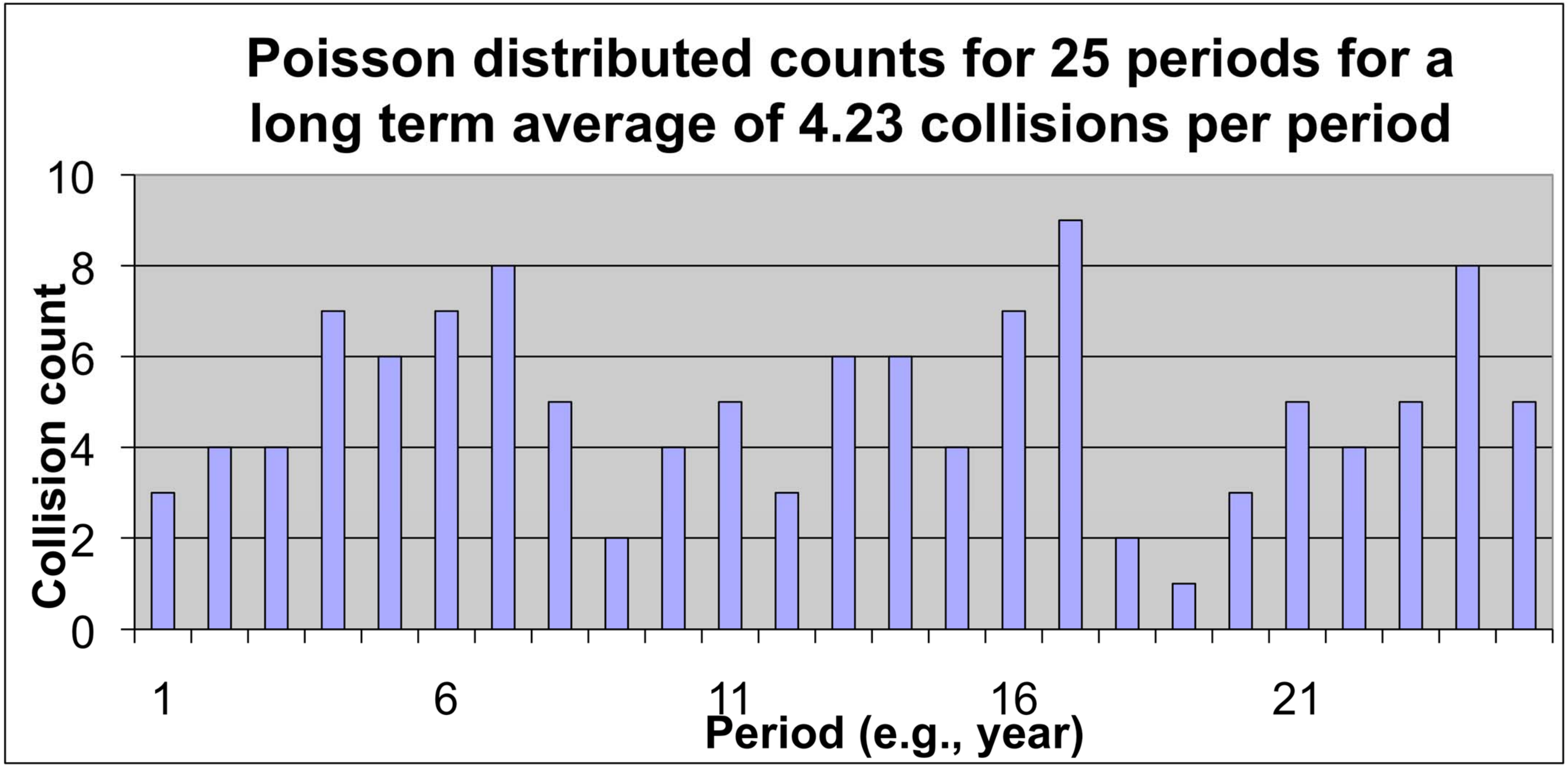
Implications of temporal fluctuation

The variation in counts about the long term average τ can be described by a Poisson distribution

$$P\{K|\tau\} = \tau^{K} e^{-\tau} / K!$$

Temporal characteristics

At a site the count of collisions in a time period fluctuates about some long term average τ, e.g.,



Implication of temporal fluctuation -- regression to the mean

- A high count will on average be followed by a reduced count even if site is unchanged
- Therefore, if a site is selected for treatment because of a high count it will experience an apparent improvement in safety even if the treatment is useless
- Therefore this regression to the mean effect must be accounted for in:
  - Selecting sites for treatment
  - Evaluating the safety effect of treatment

THE UPSHOT: Neither frequency or rates are valid as performance measures for network screening. Question is: What are valid measures?

NETWORK SCREENING METHODS IN NORTH AMERICA

NS methods used in North America

Performance Measure	Accounts for RTM Bias	Method Estimates a Performance Threshold
Average Crash Frequency	No	No
Crash Rate	No	No
Equivalent Property Damage Only (EPDO) Average Crash Frequency	No	No
Relative Severity Index	No	Yes
Critical Rate	Considers data variance but does not account for RTM bias	Yes
Excess Predicted Average Crash Frequency Using Method of Moments	Considers data variance but does not account for RTM bias	Yes
Level of Service of Safety	Considers data variance but does not account for RTM bias	Expected average crash frequency plus/minus 1.5 standard deviations
Excess Expected Average Crash Frequency Using SPFs	No	Predicted average crash frequency at the site
Probability of Specific Crash Types Exceeding Threshold Proportion	Considers data variance; not effected by RTM Bias	Yes
Excess Proportions of Specific Crash Types	Considers data variance; not effected by RTM Bias	Yes
Expected Average Crash Frequency with EB Adjustments	Yes	Expected average crash frequency at the site
Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment	Yes	Expected average crash frequency at the site
Excess Expected Average Crash Frequency with EB Adjustments	Yes	Expected average crash frequency per year at the site

ENGAGED DISCUSSION

SHOULD THE NOT SO GOOD METHODS STILL BE PRESENTED IN GUIDELINES?

State of the art methods (Mostly implemented in *SafetyAnalyst*)

- Potential for safety improvement (PSI)
  - Based on expected accident frequency
  - Based on expected excess accident frequency (amount by which the expected accident frequency exceeds that expected at similar, normal sites)
- Level of Service of Safety
- Over-representation of specific accident types
- Sudden or steady increase in mean accident frequency
- Screening for corridors with promise

Potential for safety improvement (PSI) methods

1. Based on expected crash frequency:

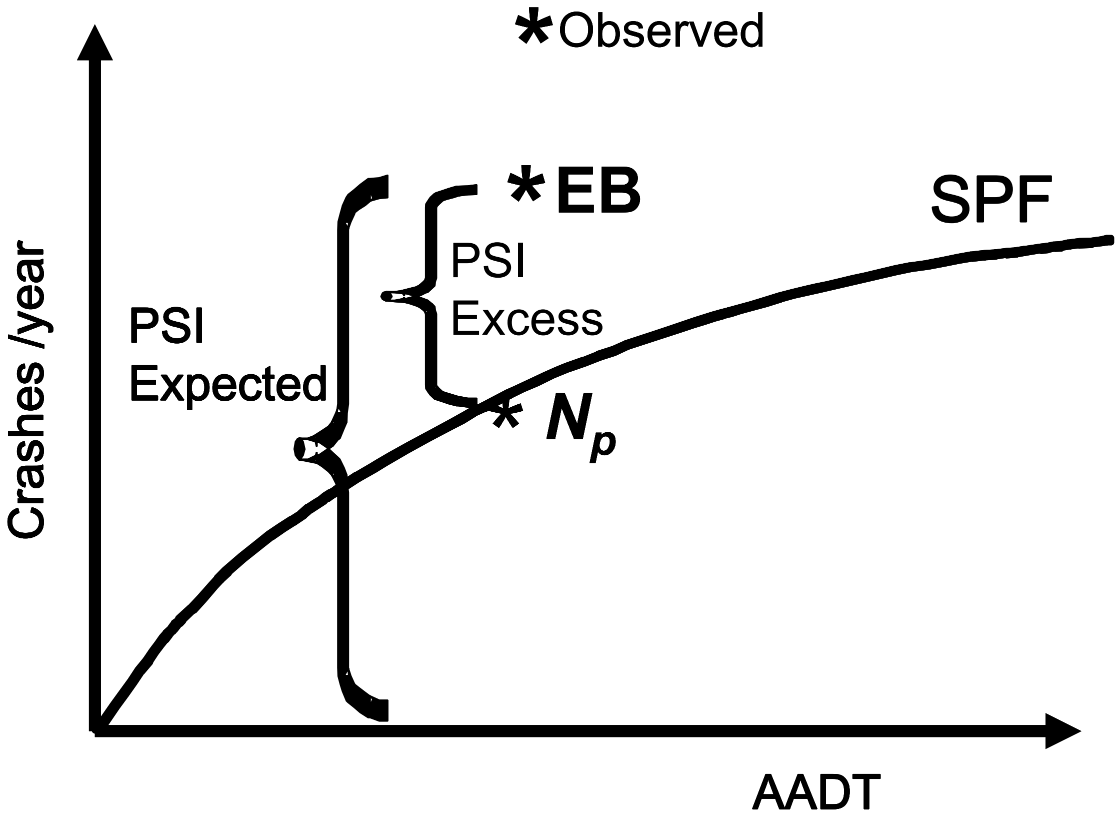
   … This is the EB estimate – a weighted average of the site's crash counts and the frequency expected at similar sites using a safety performance function (SPF)

2. Based on expected *excess* crash frequency:

   … This is essentially the EB estimate minus the frequency expected at "normal" sites – currently estimated from an AADT-only SPF

3. Based on expected crash cost or expected excess crash cost … convert results of 1. or 2. to costs

PSI Methods


*Observed
*EB
SPF
PSI
Excess
PSI
Expected
* N_p
Crashes /year
AADT

PSI Method Example: Screening freeway interchange areas

Consider the data for one freeway interchange area:
Mainline AADT = 40,000
Influence length = 2 km.
Fatal + Injury (FI) count in 7 years = 35
PDO count in 7 years = 90

Step 1

Use the appropriate SPFs to predict the expected number of FI and PDO collisions.

$$N_{pFI} = (7)EXP(-6.9649)(40000)^{0.7697}\, e^{0.0363(2)} = 24.8(3.5/year)$$

$$N_{pPDO} = (7)EXP(-8.9941)(40000)^{1.0419}\, e^{0.1931(2)} = 79.7(11.4/year)$$

PSI example, ctd.

Step 2

Apply EB weights to:

- the SPF prediction from Step 1, and
- the observed number of collisions

RESULT IS THE LONG TERM EXPECTED NUMBER OF COLLISIONS

$$EB_{(FI)} = 0.12(24.8) + (1 - 0.12)(35) = 33.8(4.8/year)$$

$$EB_{(PDO)} = 0.06(79.7) + (1 - 0.06)(90) = 89.4(12.8/year)$$

PSI Example, ctd.

Step 3

Calculate the screening measure(s) desired.

e.g. PSI excess method

Severity weighted expected excess annual collision frequency using relative weights of 8.325:1 for FI:PDO collision cost

$$(Weighted)PSI_{excess} = (EB_{PDO} - Np_{PDO})Weight_{PDO} + (EB_{FI} - Np_{FI})Weight_{FI}$$

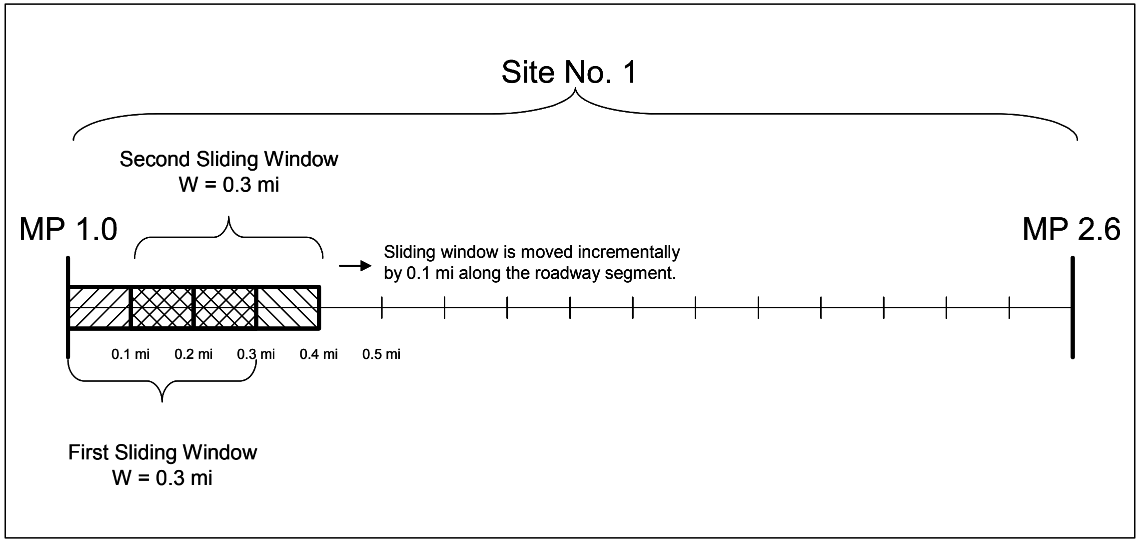
$$= (12.8 - 11.4)1.000 + (4.8 - 3.5)8.325 = 12.2 / year$$

Application of PSI Methods

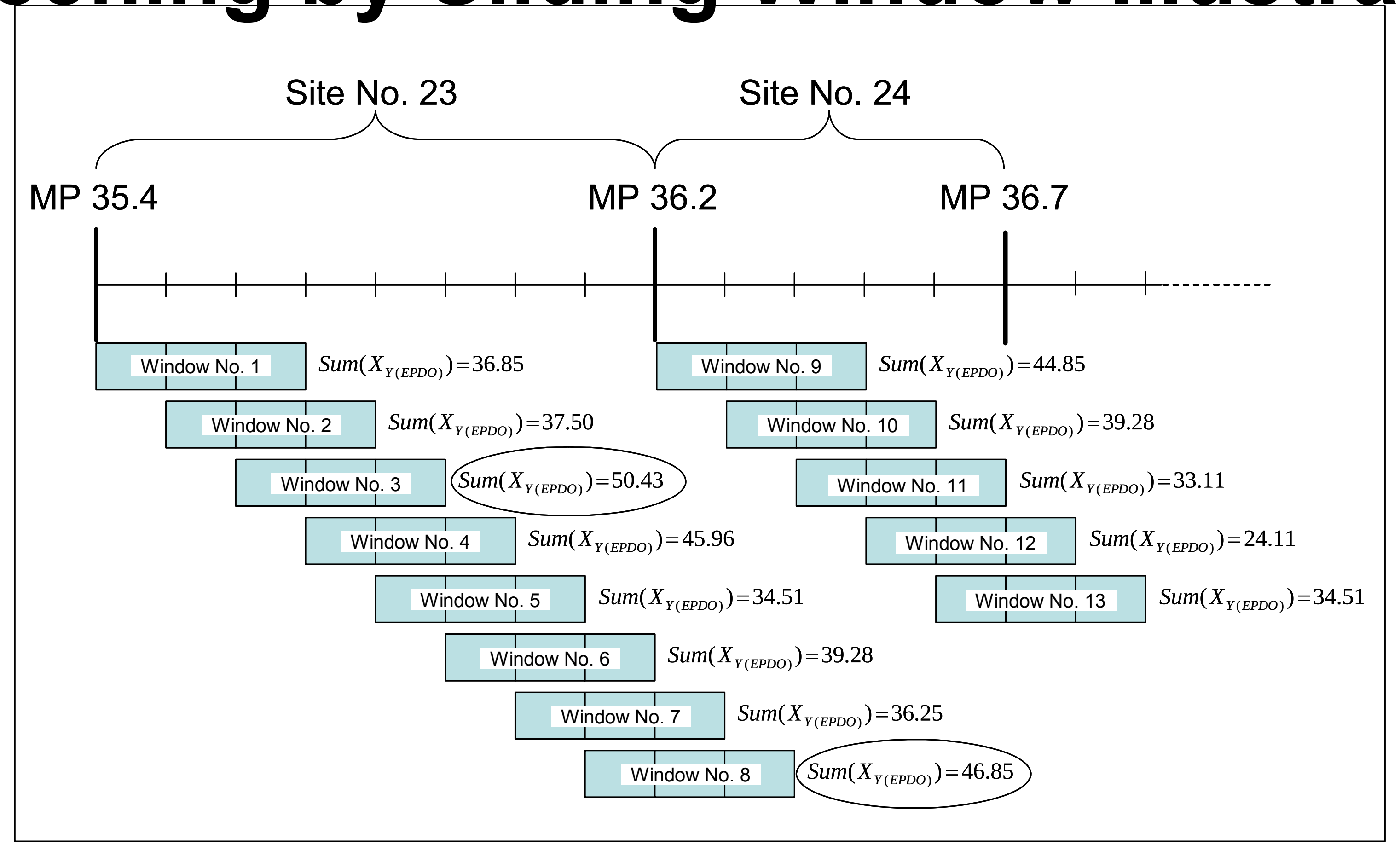
- Intersections
  - Separately screen groups categorized by:
    - Control type
    - Urban or rural
- Segments of equal length
  - Sliding window approach
- Segments of unequal length
  - Sliding Window or Peak searching algorithm

Screening by Sliding Window

- Window of specified length moves along roadway in increments
- Screening calculations are performed for each ‘window’ and segments are ranked by most critical window
- Window may overlap adjacent road segments that are not identical in terms of traffic volumes and geometry



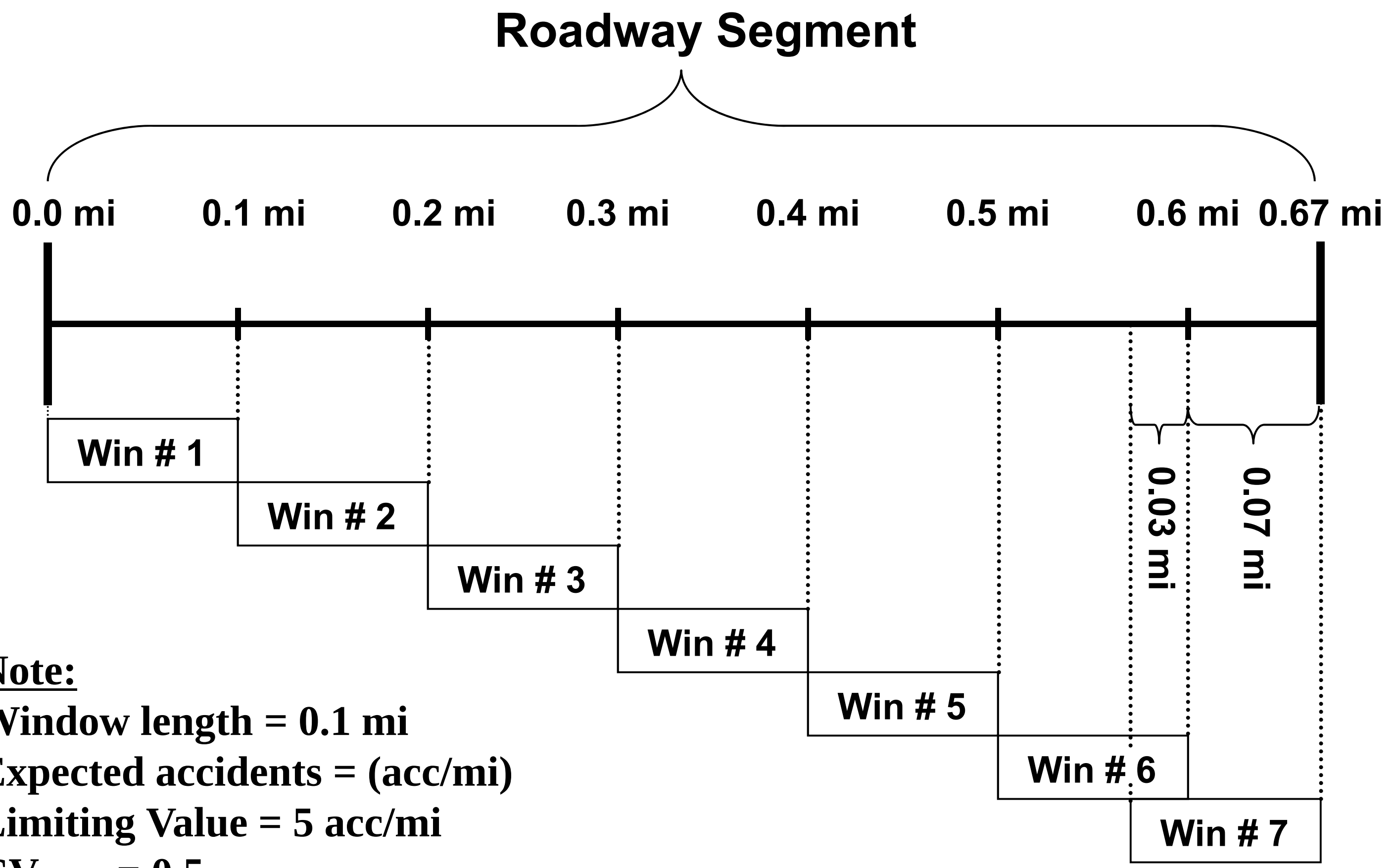
Screening by Sliding Window Illustration



Network Screening with Peak Searching on Roadway Segments

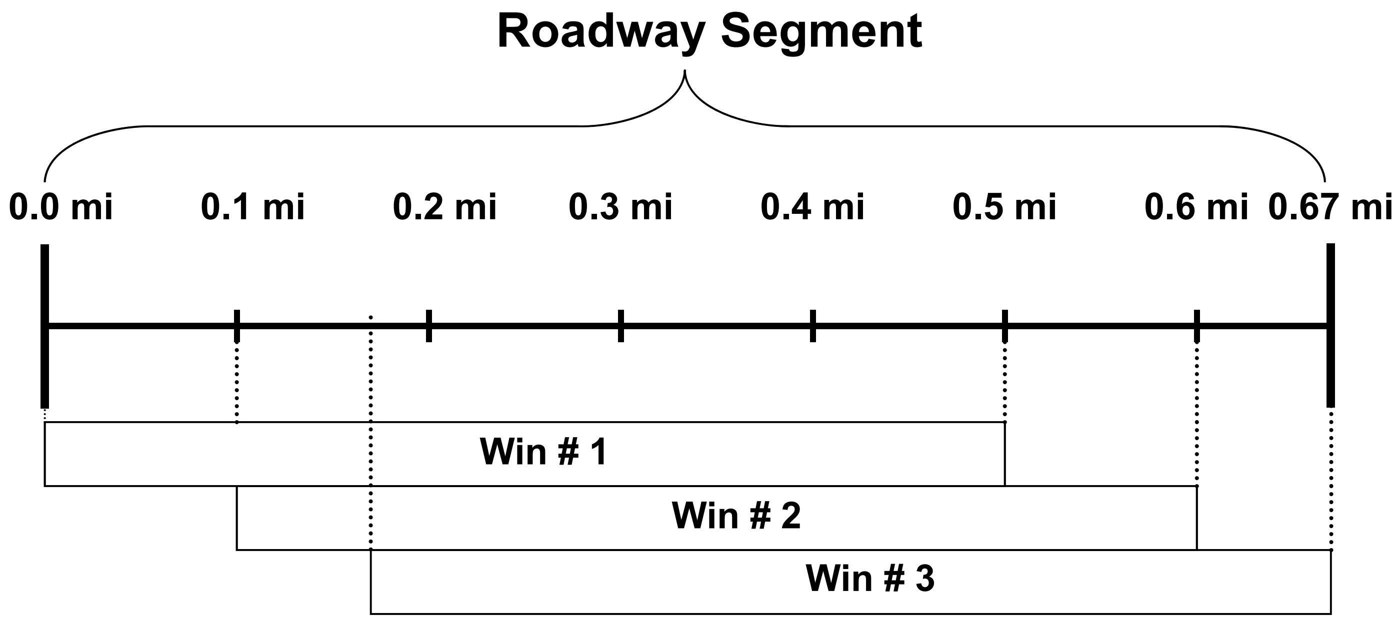
- For roadway segments, individual sites are divided into windows of size 0.1 mi
  - Crash frequencies are calculated for each window within a site
- Windows are flagged when:
  - Expected value greater than user-specified limit
  - Expected value is statistically reliable
- If no windows are flagged, incrementally increase window size by 0.1 mi and test again
- More than one window pertaining to a site can be flagged
- Rank order site based upon expected or excess crash frequencies

Peak Searching Concepts



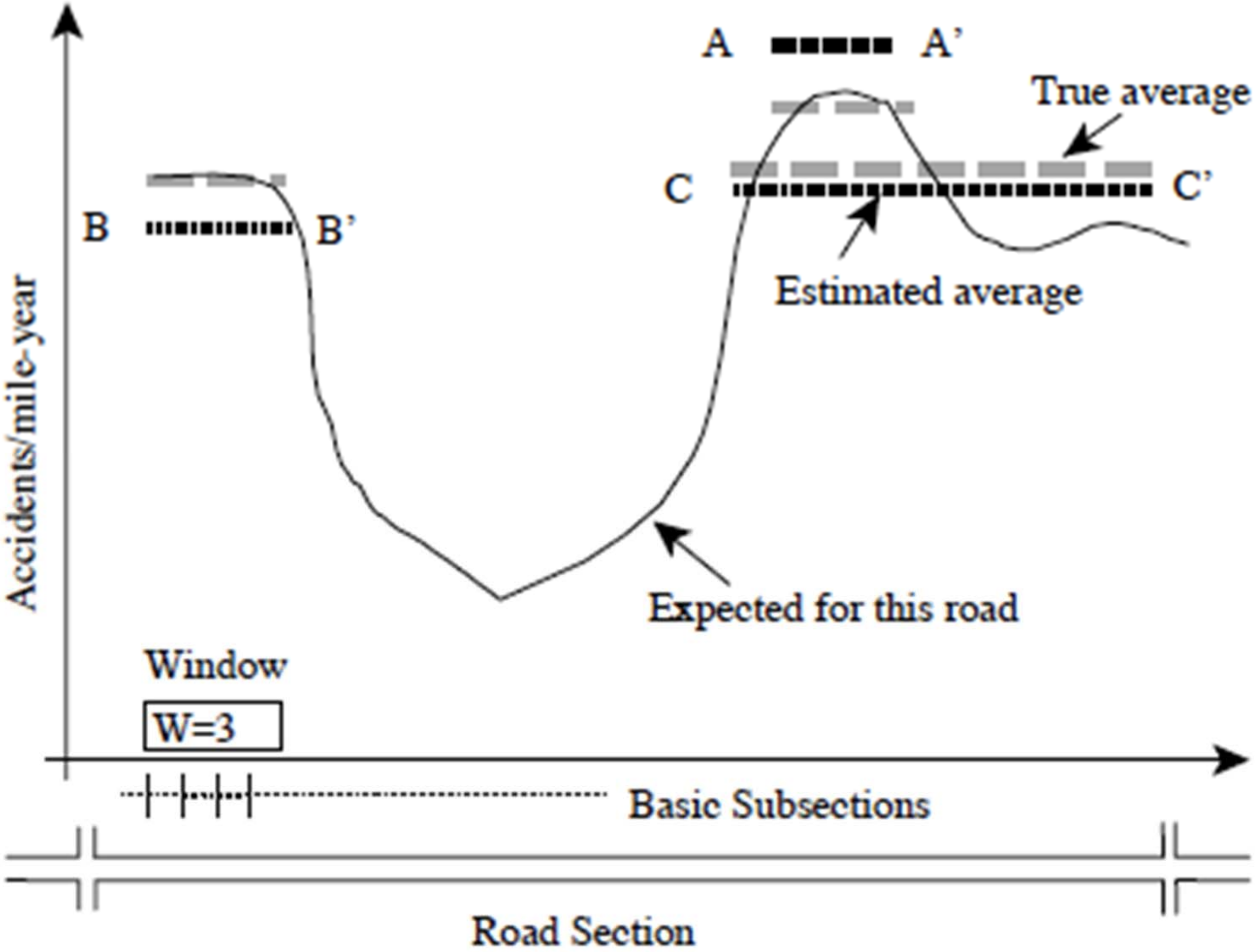
Note:
Window length = 0.1 mi
Expected accidents = (acc/mi)
Limiting Value = 5 acc/mi
CV_{Limit} = 0.5

Peak Searching Concepts



Note:
Window length = 0.5 mi
Expected accidents = (acc/mi)
Limiting Value = 5 acc/mi
CV_{Limit} = 0.5

Peak search algorithm – safety profile and window averages



ENGAGED DISCUSSION

How do we consolidate RANKED lists based on PSI for various site types?

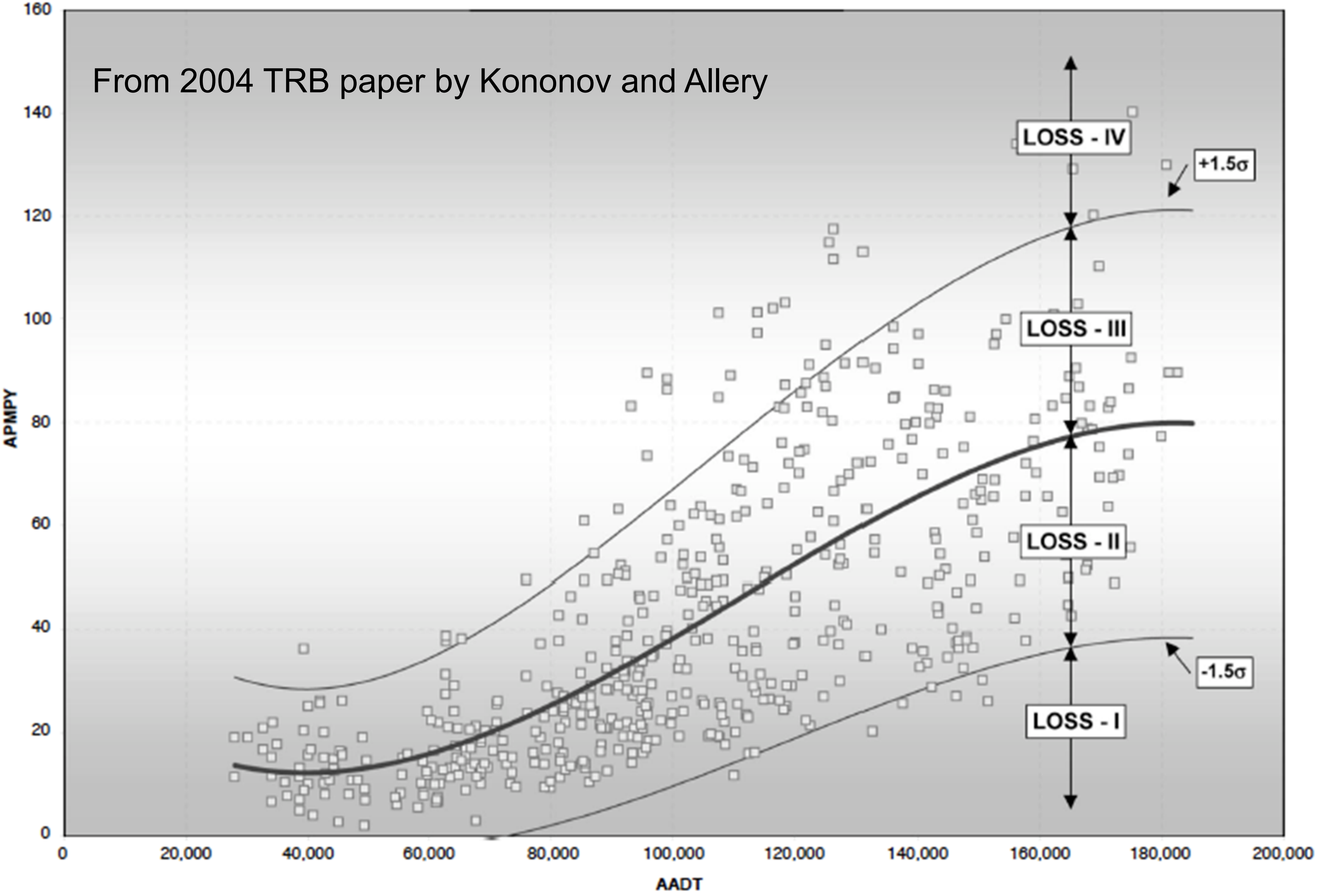
Level of service of safety (LOSS)

*Sites are ranked by comparing their observed*** *average crash frequency to the predicted average crash frequency from an SPF*

LOSS	Condition	Description
I	$0 < K < (N - 1.5 \times (\sigma))$	Indicates a low potential for crash reduction
II	$(N - 1.5 \times (\sigma)) \leq K < N$	Indicates low to moderate potential for crash reduction
III	$N \leq K < (N + 1.5 \times (\sigma))$	Indicates moderate to high potential for crash reduction
IV	$K_i \geq (N + 1.5 \times (\sigma))$	Indicates a high potential for crash reduction

$\sigma = (b \times N^2)^{0.5}$
where
b= overdispersion parameter of the SPF
N= SPF prediction

** More recently, it has been proposed to use the EB expected crash frequency. However, the LOSS boundaries require revision.


From 2004 TRB paper by Kononov and Allery
LOSS - IV
LOSS - III
LOSS - II
LOSS - I
+1.5σ
-1.5σ
APMPY
AADT
0
20
40
60
80
100
120
140
160
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
180,000
200,000

Screening Based on a High Proportion of Specific Crash Type

- Objective:
  - Identify sites having higher than expected proportions of specific target crash
  - Rank sites based on difference observed proportion and expected proportion of target crash
- Methodology
  - Calculate observed proportion (TOT only)
  - Calculate the probability that observed proportion is greater than limiting proportion (i.e., avg for site & crash type)
  - Site flagged when probability is greater than some user-specified significance level

Screening for high proportions of specific crash types -- Rationale

- Tool for diagnosis – is a specific crash type overrepresented?
- Can use to screen for specific crash types if AADTs unavailable

The issue

- Intersection A has 6 crashes of which 4 are rear-end
- Intersection B has 24 crashes, 15 of which are rear-end
- Which one has a rear-end crash "problem"?

Theoretical Background

If true proportion of target crashes at a site i is μ_i, then the probability of observing x_i target crashes at the site with n_i total crashes is given by the Binomial distribution as follows

$$f(x_i / n_i, \mu_i) = \binom{n}{x_i} \mu_i^{x_i} (1-\mu_i)^{n_i - x_i}, 0 \le x_i \le n_i$$

where

$$\binom{n}{x_i} = \frac{n!}{x_i!(n-x_i)!}$$

μ is constant for a site and varies randomly from site to site and follows Beta distribution

$$g(\mu/\alpha,\beta)=\frac{\mu^{\alpha-1}(1-\mu)^{\beta-1}}{B(\alpha,\beta)},\quad 0<\mu<1$$

Where *α* and *β* are parameters of Beta distribution

***B(α,β)* can be expressed as**

$$B(\alpha,\beta)=\frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)}$$

Expected value of μ is

$$E(\mu) = \frac{\alpha}{\alpha + \beta}$$

Variance of μ is

$$Var(\mu) = \frac{\alpha\beta}{(\alpha + \beta)^2 (\alpha + \beta + 1)}$$

α **and** ***β*** **can be estimated by method of moment or by maximum likelihood using Excel spreadsheet.**

Then the expected value and variance can be calculated.

α and β are combined with observed proportion of target crashes to get posterior Beta distribution as follows

$$g(\mu_i / \alpha', \beta') = \frac{\mu^{\alpha' - 1}(1 - \mu)^{\beta' - 1}}{B(\alpha', \beta')} \qquad 0 < \mu < 1$$

where

$$\alpha' = \alpha + x_i$$

$$\beta' = \beta + n_i - x_i$$

Pattern score is used to rank the sites.

It is defined as the probability that the μ_i is greater than some value, μ_m which can be expressed as

$$P(\mu_i > \mu_m) = 1 - B(\mu_m, \alpha', \beta')$$

where μ_m is such that

$$\int_{\mu_m}^{1} g(\mu) / \alpha, \beta) d\mu = \pi$$

π **is taken as 0.5, a neutral value which means μ_m is the median**

Ranking based on high proportion of rear-end crashes at 3-legged signalized ramp terminals In Ontario

Region	Hwy	LHRS	Offset	Ramp No.	Score	Rank
Central	401	47624	0	51	1	1
Southwest	401	47720	0	51	1	2
Central	401	47643	0	61	1	3
Central	401	47642	0	51	1	4
Central	400	46827	0	24	1	5
Central	401	47629	0	61	0.999	6
Central	401	47626	0	51	0.998	7
Central	403	48260	0	61	0.991	8
Central	401	47633	0	51	0.99	9
Central	401	47673	0	61	0.983	10

Sudden Increase in Mean Crash Frequency

- Screening for safety deterioration
  - Calculate differences in mean yearly crash frequencies
  - For the time period with the largest difference:
    - If the percentage increase is greater than a user-specified limiting value
    - Then perform test of significance
- Based on observed crashes
- Based on total crashes
- Flagged sites are not rank ordered

Steady Increase in Mean Crash Frequency

- Screening for safety deterioration
  - Fit regression model to data of crash frequency versus year
    - If value of slope is greater than a user-specified limiting slope
    - Then perform test of significance
- Based on observed crashes
- Based on total crashes
- Flagged sites are not rank ordered

Screening for Corridors with Promise (*SafetyAnalyst*)

- Analysis of extended corridors (e.g., 15 km or more)
  - Roadway segments, intersections, and ramps grouped together
- Rank order corridors based upon:
  - Crashes/km/yr
  - Crashes/million veh-km/yr
- Based on observed crashes
- State of the art, but is it good enough?

ENGAGED DISCUSSION (and/or homework)

- 1. Suppose we have $\dot{P}SI$ values and rankings for each intersection, road section, etc., in a corridor. How can we use that information to prioritize the entire corridor?

- 2. How do we choose between several valid screening measures/approaches
  - Can we use several and consolidate results?