Lecture 7: Roadway Safety Management Process I

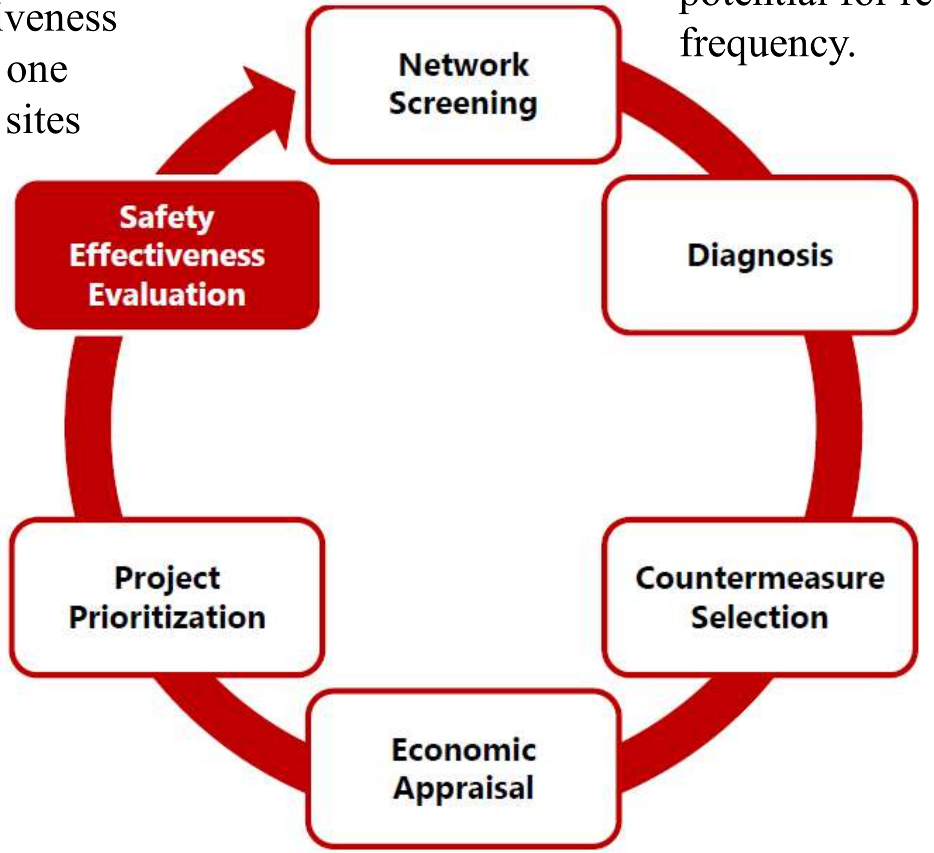
Outline

- Introduction
- Network Screening
- Diagnosis
- Countermeasure Selection
- References

Introduction

- There is no absolute safety. A universal objective is to reduce the number and severity of road crashes within the limits of available resources, science, technology and legislatively mandated priorities.
- A roadway safety management process is a quantitative and systematic process
  - studying roadway safety on existing transportation systems
  - identifying potential safety improvements.
- The activities within the roadway safety management process can be conducted independently, and can be integrated into a cyclical process for monitoring a transportation network.

Introduction



Review a transportation network to identify and rank sites based on the potential for reducing average crash frequency.

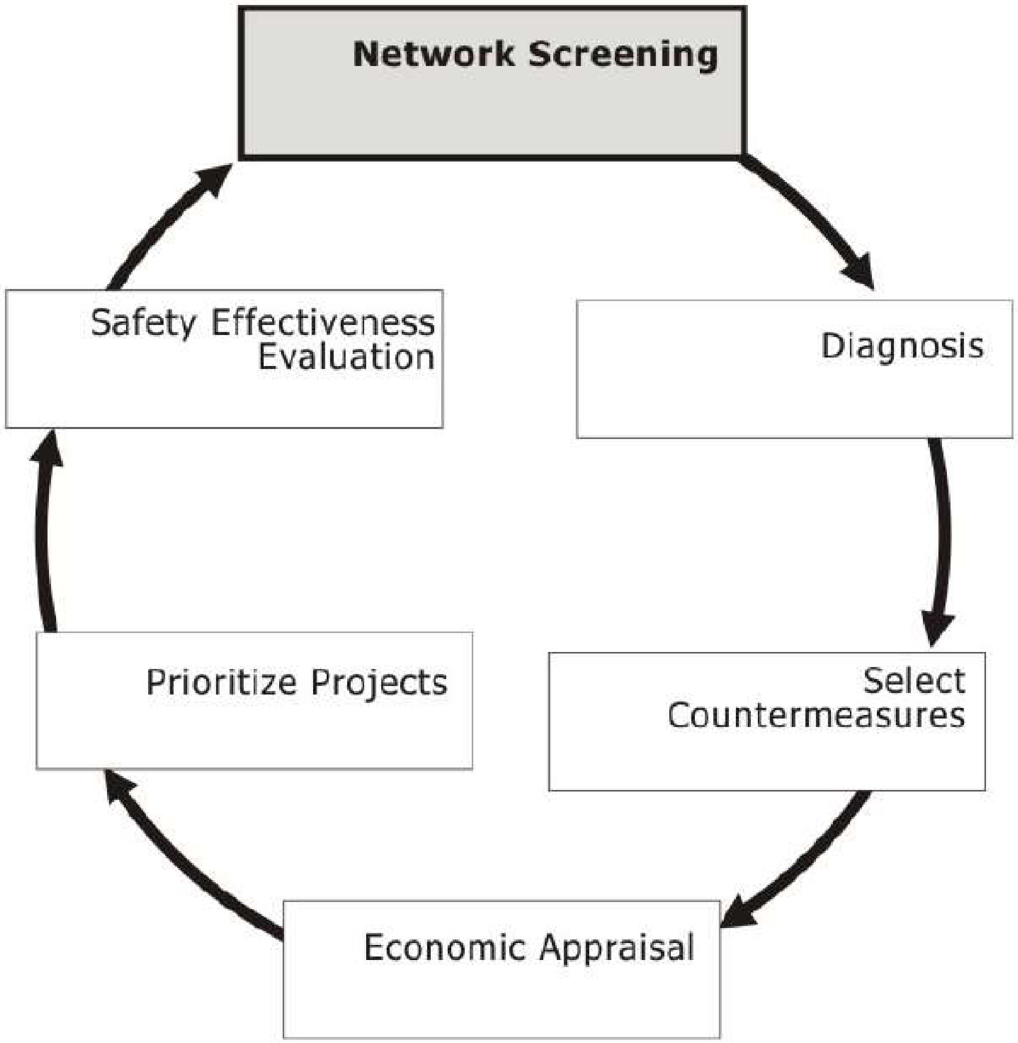
Evaluate crash data, historic site data, and field conditions to identify crash patterns

Identify factors that contribute to crashes at a site and select possible measures

Evaluate the benefits and costs of the possible measures and identify individual projects that are cost effective

Evaluate improvements at specific sites to identify a set of improvement projects to meet objectives

Evaluate effectiveness of a measure at one site or multiple sites

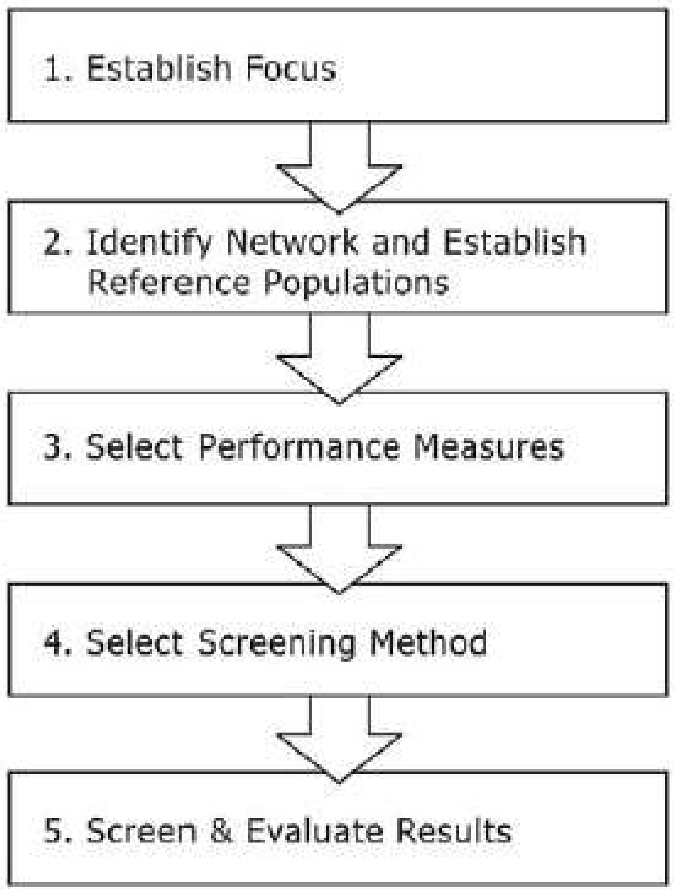

Network Screening
Diagnosis
Select Countermeasures
Economic Appraisal
Prioritize Projects
Safety Effectiveness Evaluation

Network Screening

- A process for reviewing a transportation network to identify and rank sites *from most likely to least likely* to realize a reduction in crash frequency with implementation of a countermeasure.
- Those sites identified as most likely to realize a reduction in crash frequency are studied in more detail to identify crash patterns, contributing factors, and appropriate countermeasures.

Network Screening

- There are five major steps in network screening:



Network Screening

- Step 1 Establish the focus of the analysis
  - Identify the purpose or intended outcome of the network screening analysis.
  - This decision will influence data needs, the selection of performance measures and the screening methods which can be applied.
  - Can be focused on:
    - Identifying and ranking sites where improvements have potential to reduce the number of crashes, e.g., a "black spot" analysis.
    - Evaluating a network to identify sites with a particular crash type or severity for formulation of system-wide policy.

Network Screening

- Step 1 Establish the focus of the analysis
  - An example:
    - A grant of funds has been received for installing rumble strips on rural two-lane highways. How should the network be screened to identify the best sites for installing the rumble strips?

  - Answer:
    - The main purpose: identify those sites that can possibly be improved by installing rumble strips.
      - First, identify crash types that respond to rumble strips, e.g., run-off the road crashes.
      - Then, select a method that provides a ranking of sites with high proportion of run-off the road crashes.

Network Screening

- Step 2 Identify network and establish reference populations
  - Identify road network elements to be screened
    - Roadway segments,
    - Intersections,
    - Facilities,
    - …
  - Organize these elements into reference populations
    - A grouping of sites with similar characteristics (e.g., four-legged signalized intersections, two-lane rural highways).

Network Screening

- Step 2 Identify network and establish reference populations

Intersection reference populations defined by functional classification and traffic control

Reference Population	Segment ID	Street Type 1	Street Type 2	Traffic Control	Fatal	Injury	PDO	Total	Exposure Range (TEV/Average Annual Day)
Arterial-Arterial Signalized Intersections	3	Arterial	Arterial	Signal	0	41	59	100	55,000 to 70,000
	4	Arterial	Arterial	Signal	0	50	90	140	55,000 to 70,000
	10	Arterial	Arterial	Signal	0	28	39	67	55,000 to 70,000
Arterial-Collector Signalized Intersections	33	Arterial	Collector	Signal	0	21	52	73	30,000 to 55,000
	12	Arterial	Collector	Signal	0	40	51	91	30,000 to 55,000
	23	Arterial	Collector	Signal	0	52	73	125	30,000 to 55,000
Collector-Local All-Way Stop Intersections	22	Collector	Local	All-way Stop	1	39	100	140	10,000 to 15,000
	26	Collector	Local	All-way Stop	0	20	47	67	10,000 to 15,000

What is the reference population for applying red-light running cameras?

Network Screening

- Step 3 Select performance measures
  - Used for evaluating the potential to reduce the number of crashes or crash severity at a site.
  - Key criteria
    - Data availability:

      including crash data, traffic volume data, safety performance functions, etc.
    - Regression-to-the-mean bias:

      whether a measure account for it or not
    - Performance threshold - a reference point for comparison of performance measure scores:

      whether a measure estimates it or not

Network Screening

- Step 3 Select performance measures

Performance Measure	Data and Inputs		
	Crash Data	Traffic Volume	Safety Performance Function
Average Crash Frequency	X		
Equivalent Property Damage Only (EPDO) Average Crash Frequency	X		
Relative Severity Index	X		
Probability of Specific Crash Types Exceeding Threshold Proportion	X		
Excess Proportion of Specific Crash Types	X		
Crash Rate	X	X	
Critical Rate	X	X	
Excess Predicted Average Crash Frequency Using Method of Moments[2]	X	X	
Level of Service of Safety	X	X	X
Excess Predicted Average Crash Frequency using Safety Performance Functions (SPFs)	X	X	X
Expected Average Crash Frequency with EB Adjustment	X	X	X
Equivalent Property Damage Only (EPDO) Average Crash Frequency with EB Adjustment	X	X	X
Excess Expected Average Crash Frequency with EB Adjustment	X	X	X

Performance Measure	Accounts for RTM Bias	Method Estimates a Performance Threshold
Average Crash Frequency	No	No
Equivalent Property Damage Only (EPDO) Average Crash Frequency	No	No
Relative Severity Index	No	Yes
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
Crash Rate	No	No
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
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

Network Screening

- An example: 20 intersections are screened to identify sites with potential for crash reduction.

Intersections	Traffic Control	Number of Approaches	Major AADT	Minor AADT	Crash Data				Crash Severity		
					Total Year 1	Total Year 2	Total Year 3	Total	Fatal	Injury	PDO
1	Signal	4	30,100	4,800	9	8	5	22	0	6	16
2	TWSC	4	12,000	1,200	9	11	15	35	2	23	10
3	TWSC	4	18,000	800	9	8	6	23	0	13	10
4	Signal	4	11,200	10,900	8	2	3	13	0	5	8
5	Signal	4	30,700	18,400	3	7	5	15	0	4	11
6	Signal	4	31,500	3,600	6	1	2	9	0	2	7
7	TWSC	4	21,000	1,000	11	9	14	34	1	17	16
8	Signal	4	23,800	22,300	2	4	3	9	0	2	7
9	Signal	4	47,000	8,500	15	12	10	37	0	22	15
10	TWSC	4	15,000	1,500	7	6	4	17	0	7	10
11	Signal	4	42,000	1,950	12	15	11	38	1	19	18
12	Signal	4	46,000	18,500	10	14	8	32	0	15	17
13	Signal	4	11,400	11,400	4	1	1	6	0	2	4
14	Signal	4	24,800	21,200	5	3	2	10	0	5	5
15	TWSC	4	26,000	500	6	3	8	17	1	4	12
16	Signal	4	12,400	7,300	7	11	3	21	0	11	10
17	TWSC	4	14,400	3,200	4	4	5	13	1	5	7
18	Signal	4	17,600	4,500	2	10	7	19	0	8	11
19	TWSC	4	15,400	2,500	5	2	4	11	1	5	5
20	Signal	4	54,500	5,600	4	2	2	8	0	3	5

Network Screening

- Average crash frequency

Column A			Column B			Column C	
Intersection	Total Crashes		Intersection	Fatal and Injury		Intersection	PDO Crashes
11	38		2	25		11	18
9	37		9	22		12	17
2	35		11	20		1	16
7	34		7	18		7	16
12	32		12	15		9	15
3	23		3	13		15	12
1	22		16	11		5	11
16	21		18	8		18	11
18	19		10	7		2	10
10	17		1	6		3	10
15	17		17	6		10	10
5	15		19	6		16	10
4	13		4	5		4	8
17	13		14	5		6	7
19	11		15	5		8	7
14	10		5	4		17	7
6	9		20	3		14	5
8	9		6	2		19	5
20	8		8	2		20	5
13	6		13	2		13	4

✓Simple;
✓Does not account for RTM bias;
✓Does not estimate a threshold;
✓Does not account for traffic volume.

Network Screening

- Equivalent property damage only (EPDO) average crash frequency
  - Assigns weighting factors to crashes by severity to develop a single combined frequency and severity score per location

Severity	Cost	Weight
Fatal (K)	$4,008,900	542
Injury (A/B/C)	$82,600	11
PDO (O)	$7,400	1

$$f_{y(weight)} = \frac{CC_y}{CC_{PDO}}$$

Where,

$f_{y(weight)}$= Weighting factor based on crash severity, y

CC_y= Crash cost for crash severity, y

CC_{PDO}= Crash cost for PDO crash severity

$$Total\ EPDO\ Score = f_{K(weight)}\left(N_{observed,i(F)}\right) + f_{inj(weight)}\left(N_{observed,i(I)}\right) + f_{PDO(weight)}\left(N_{observed,i(PDO)}\right)$$

Where

$f_{K(weight)}$ = Fatal Crash Weight , $f_{inj(weight)}$ = Injury Crash Weight , $f_{PDO(weight)}$ = PDO Crash Weight

$N_{observed,i(F)}$ = Number of Fatal Crashes per intersection, i

$N_{observed,i(I)}$ = Number of Injury Crashes per intersection, i

$N_{observed,i(PDO)}$= Number of PDO Crashes per intersection, i

Network Screening

- Equivalent property damage only (EPDO) average crash frequency

Intersection	EPDO Score
2	1347
11	769
7	745
17	604
19	602
15	598
9	257
12	182
3	153
16	131
18	99
10	87
1	82
4	63
14	60
5	55
20	38
6	29
8	29
13	26

✓Simple;
✓Considers crash severity;
✓Does not account for RTM bias;
✓Does not estimate a threshold;
✓Does not account for traffic volume.

Network Screening

- Crash rate

$$MEV = \left(TEV / 1{,}000{,}000 \right) \times (n) \times (365)$$

Where,

MEV= Million entering vehicles

TEV = Total entering vehicles per day

n = Number of years of crash data

$$R_i = N_{observed,i(TOTAL)} / MEV_i$$

Where,

R_i = Observed crash rate at intersection i

$N_{observed,i(TOTAL)}$ = Total observed crashes at intersection i

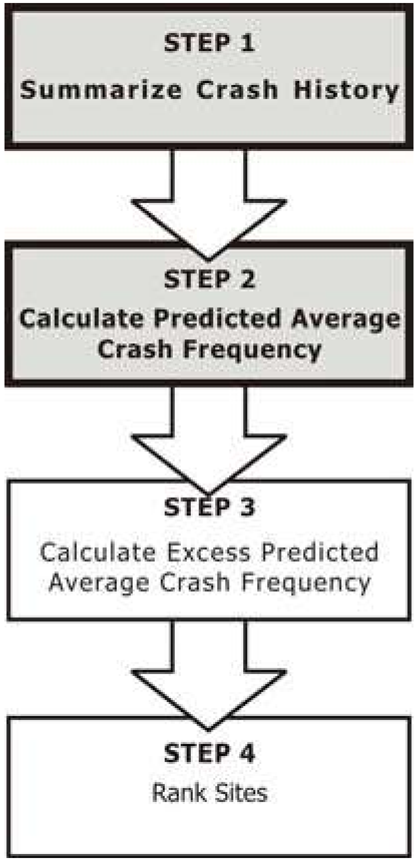
MEV_i = Million entering vehicles at intersection i

Intersection	Crash Rate
2	2.4
7	1.4
3	1.1
16	1.0
10	0.9
11	0.8
18	0.8
17	0.7
9	0.6
15	0.6
1	0.6
19	0.6
4	0.5
12	0.5
5	0.3
13	0.2
6	0.2
14	0.2
8	0.2
20	0.1

✓Simple;
✓Considers traffic volume;
✓Does not account for RTM bias;
✓Does not estimate a threshold.

Network Screening

- Excess predicted average crash frequency using SPFs

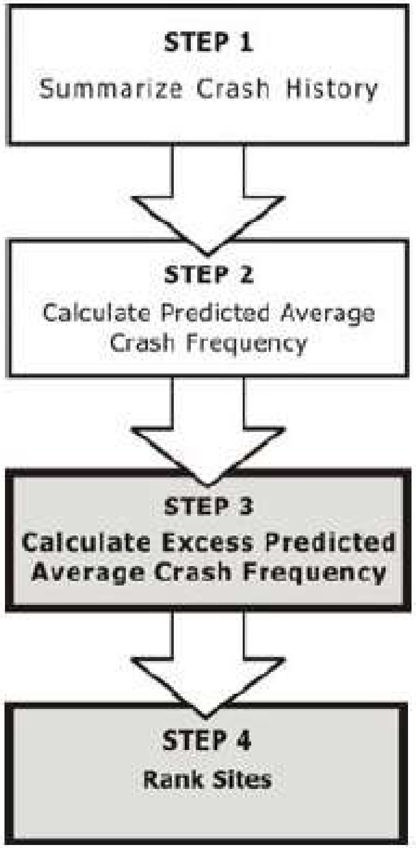


TWSC preference population

Intersection	Year	AADT Major Street	AADT Minor Street	Observed Number of Crashes	Average Observed Crash Frequency	Predicted Average Crash Frequency from SPF (Total)	Average Predicted Crash Frequency
	1	12,000	1,200	9		1.7	
2	2	12,200	1,200	11	11.7	1.7	1.7
	3	12,900	1,300	15		1.8	
	1	18,000	800	9		2.1	
3	2	18,900	800	8	7.7	2.2	2.2
	3	19,100	800	6		2.2	
	1	21,000	1,000	11		2.5	
7	2	21,400	1,000	9	11.3	2.5	2.6
	3	22,500	1,100	14		2.7	
	1	15,000	1,500	7		2.1	
10	2	15,800	1,600	6	5.7	2.2	2.2
	3	15,900	1,600	4		2.2	
	1	26,000	500	6		2.5	
15	2	26,500	300	3	5.7	2.2	2.3
	3	27,800	200	8		2.1	
	1	14,400	3,200	4		2.5	
17	2	15,100	3,400	4	4.3	2.6	2.6
	3	15,300	3,400	5		2.6	
	1	15,400	2,500	5		2.4	
19	2	15,700	2,500	2	3.7	2.5	2.5
	3	16,500	2,600	4		2.6	

Network Screening

- Excess predicted average crash frequency using SPFs



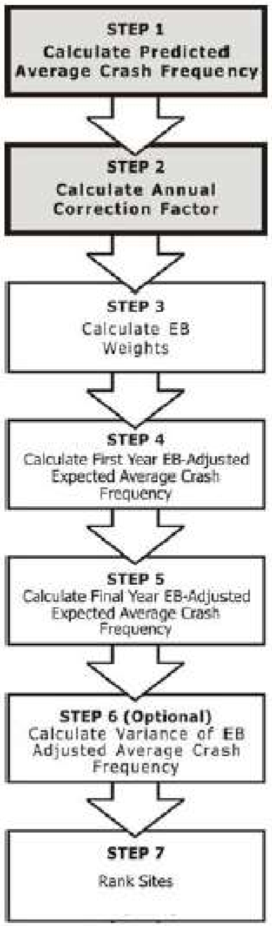
$$Excess(N) = \overline{N_{observed,i}} - \overline{N_{predicted,i}}$$

Intersection	Observed Average Crash Frequency	Predicted Average Crash Frequency from an SPF	Excess Predicted Average Crash Frequency
2	11.7	1.7	10.0
7	11.3	2.6	8.7
3	7.7	2.2	5.5
10	5.7	2.2	3.5
15	5.7	2.3	3.4
17	4.3	2.6	1.7
19	3.7	2.5	1.2

✓Accounts for traffic volume;
✓Estimates a threshold for comparison;
✓Effects of RTM bias may still be present.

Network Screening

- Expected average crash frequency with Empirical Bayes (EB) Adjustment



$$C_{n(TOT)} = \frac{N_{predicted,n(TOTAL)}}{N_{predicted,1(TOTAL)}}$$

Where,

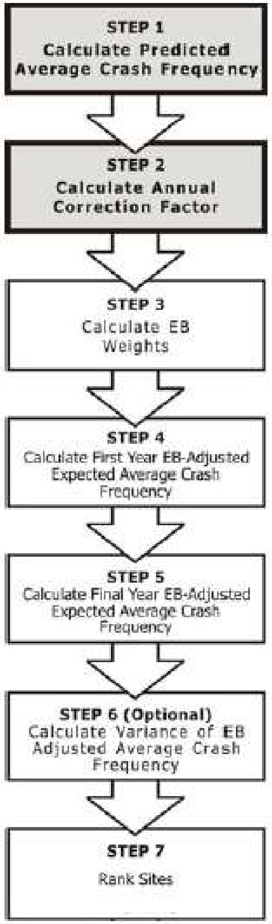
$C_{n(TOTAL)}$ = Annual correction factor for total crashes

$N_{predictedn(TOTAL)}$ = Predicted number of total crashes for year n

This factor is intended to capture the effect that annual variations in traffic, weather, and vehicle mix have on crash occurrences.

Network Screening

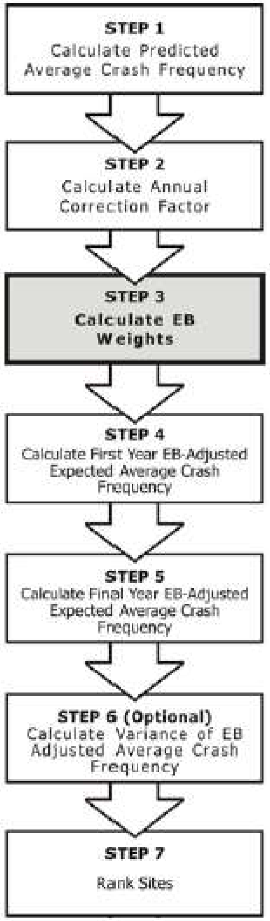
- Expected average crash frequency with Empirical Bayes (EB) Adjustment



Intersection	Year	Predicted Average Crash Frequency from SPF (TOTAL)	Correction Factor (TOTAL)
2	1	1.7	1.0
	2	1.7	1.0
	3	1.8	1.1
3	1	2.1	1.0
	2	2.2	1.0
	3	2.2	1.0
7	1	2.5	1.0
	2	2.5	1.0
	3	2.7	1.1
10	1	2.1	1.0
	2	2.2	1.0
	3	2.2	1.0
15	1	2.5	1.0
	2	2.2	0.9
	3	2.1	0.8
17	1	2.5	1.0
	2	2.6	1.0
	3	2.6	1.0
19	1	2.4	1.0
	2	2.5	1.0
	3	2.6	1.1

Network Screening

- Expected average crash frequency with Empirical Bayes (EB) Adjustment



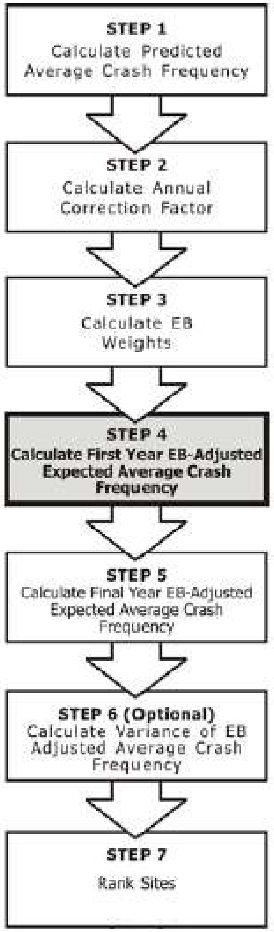
$$w_{TOTAL} = \frac{1}{1 + k_{TOT} \times \sum_{n=1}^{N} N_{predicted,\, n(TOTAL)}}$$

$$w_{TOTAL} = \frac{1}{(1+(0.49 \times 7.7))} = 0.2$$

Intersection	W_{TOTAL}
2	0.3
3	0.2
7	0.2
10	0.2
15	0.2
17	0.2
19	0.2

Network Screening

- Expected average crash frequency with Empirical Bayes (EB) Adjustment



$$N_{expected,1(TOTAL)} = W_{TOTAL} \times N_{predicted,1(TOTAL)} + (1 - W_{TOTAL}) \times \left(\frac{\sum_{n=1}^{N} N_{observed,y(TOTAL)}}{\sum_{n=1}^{N} C_{n(TOTAL)}} \right)$$

Where,

$N_{expected,1}$ = EB-adjusted estimated average crash frequency for year 1

$N_{predicted,1(TOTAL)}$ = Estimated average crash frequency for year 1 for the intersection

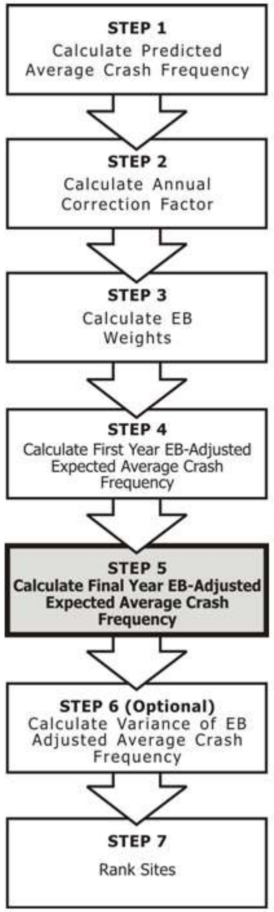
$N_{observed,n}$ = Observed crash frequency at the intersection

C_n = Annual correction factor for the intersection

$$N_{expected,1(TOTAL)} = 0.2 \times (2.5) + (1 - 0.2) \times \frac{34}{3.1} = 9.3$$

Network Screening

- Expected average crash frequency with Empirical Bayes (EB) Adjustment



$$N_{expected,n(TOTAL)} = N_{expected,1(TOTAL)} \times C_{n(TOTAL)}$$

Where,

$N_{expected,n}$ = EB-adjusted expected average crash frequency for final year

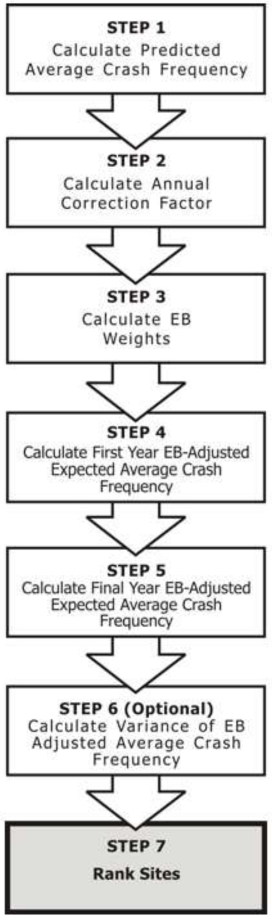
$N_{expected,1}$ = EB-adjusted expected average crash frequency for year 1

C_n = Annual correction factor for year, n

$$N_{expected,3(TOTAL)} = 9.3 \times (1.1) = 10.2$$

Network Screening

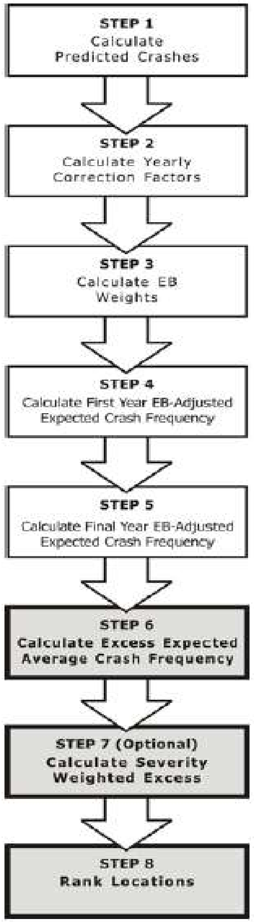
- Expected average crash frequency with Empirical Bayes (EB) Adjustment



Intersection	EB-Adjusted Average Crash Frequency
7	10.2
2	9.6
3	6.1
10	4.5
15	4.3
17	3.9
19	3.7

Network Screening

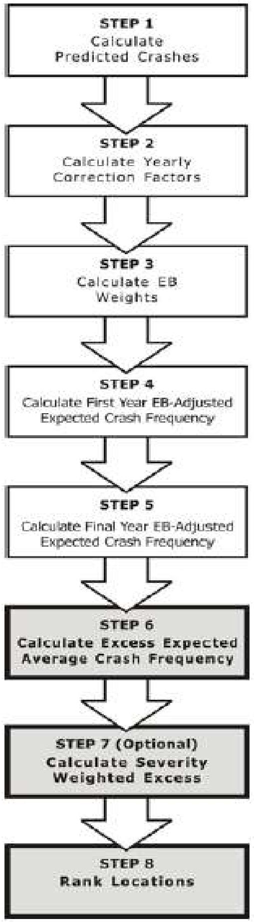
- Excess expected average crash frequency with EB Adjustment



Intersection	Year	Observed Average Crash Frequency (FI)	Observed Average Crash Frequency (PDO)	SPF Predicted Average Crash Frequency (FI)	SPF Predicted Average Crash Frequency (PDO)	EB-Adjusted Expected Average Crash Frequency (FI)	EB-Adjusted Expected Average Crash Frequency (PDO)
2	1	8	1	0.6	1.1	4.9	3.8
	2	8	3	0.6	1.1	4.9	3.8
	3	9	6	0.7	1.1	5.8	3.8
3	1	8	1	0.8	1.3	3.0	3.1
	2	3	5	0.8	1.4	3.0	3.1
	3	2	4	0.9	1.4	3.3	2.8
7	1	5	6	1.0	1.6	4.3	5.0
	2	5	4	1.0	1.6	4.3	5.0
	3	8	6	1.1	1.7	4.8	5.4
10	1	4	3	0.8	1.3	1.7	2.8
	2	2	4	0.9	1.4	1.9	2.8
	3	1	3	0.9	1.4	1.9	2.6
15	1	1	5	1.0	1.6	1.6	3.8
	2	1	2	0.9	1.4	1.4	3.4
	3	3	5	0.8	1.3	1.3	3.0
17	1	2	2	1.0	1.5	1.7	2.2
	2	2	2	1.0	1.6	1.7	2.4
	3	2	3	1.0	1.6	1.7	2.2
19	1	3	2	1.0	1.5	1.7	1.7
	2	1	1	1.0	1.5	1.7	1.8
	3	2	2	1.0	1.6	1.7	2.0

Network Screening

- Excess expected average crash frequency with EB Adjustment



$$Excess_y = (N_{expected,n(PDO)} - N_{predicted,n(PDO)}) + (N_{expected,n(F.I)} - N_{predicted,n(F.I)})$$

Defined as the difference between the predicted estimates and EB-adjusted estimates for each intersection.

$$Excess_3 = 5.4 - 1.7 + 4.8 - 1.1 = 7.4 \text{ [crashes/year]}$$

Intersection	Excess
2	7.8
7	7.4
3	3.8
10	2.2
15	2.2
17	1.3
19	1.1

Network Screening

- Step 4 Select screening method
  - Used for applying the selected performance measures to all sites under consideration.
  - Three types of screening methods
    - Simple ranking method (for e.g., intersections)
    - Sliding window method (for e.g., segments)
    - Peak searching method (for e.g., segments)

Network Screening

- Sliding window method
  - *A window of a specified length* is conceptually moved along the road segment from beginning to end *in increments of a specified size*.
  - The performance measure chosen to screen the segment is applied to *each position of the window*, and the results of the analysis are recorded for each window.
  - The window that shows *the most potential for reduction in crash frequency* out of the whole segment is identified and is used to represent the potential for reduction in crash frequency of the whole segment.

Network Screening

- An example
  - Segment A is 0.60 miles long. If the sliding window method is used to study this segment with a window of 0.30 miles and 0.10 mile increments, how many times will the performance measure be applied on Segment A?

Sub-segment	Window Position	Excess Predicted Average Crash Frequency
A1	0.00 to 0.30 miles	1.20
A2	0.10 to 0.40 miles	0.80
A3	0.20 to 0.50 miles	1.10
A4	0.30 to 0.60 miles	1.90

Sub-segment A4 has the highest potential for reducing the average crash frequency, which is 1.90 crashes. This sub-segment would therefore be used to define the total segment crash frequency.

Network Screening

- Peak searching method
  - A roadway segment is subdivided into windows of *similar length*, and the windows do not overlap.
  - The performance measure is calculated for each window, and the results are subjected to *precision testing*.
  - If *at least one sub-segment* satisfies the desired precision level, the segment is ranked based on the maximum performance measure that meet the precision level.
  - If not, the length of each window is *incrementally moved forward* until a maximum performance measure with the desired precision is found or the window length equals the site length.

Network Screening

- Peak searching method
  - The precision of the performance measure is assessed by calculating *the coefficient of variation (CV)* of the performance measure:

$$\text{Coefficient of Variation (CV)} = \frac{\sqrt{Var(\text{Performance Measure})}}{\text{PerformanceMeasure}}$$

  - A small CV indicates a high level of precision in the estimate.
  - If the calculated CV is less than or equal to the specified limiting CV value, the performance measure meets the desired precision level.

Network Screening

- An example
  - Segment B is 0.47 miles long. The CV limiting value is assumed to be 0.25. If the peak searching method is used to study this segment with an initial window of 0.10 miles, how is the segment potentially ranked?

Sub-segment	Window Position	Excess Expected Average Crash Frequency	Coefficient of Variation (CV)
B1	0.00 to 0.10 miles	5.2	0.53
B2	0.10 to 0.20 miles	7.8	0.36
B3	0.20 to 0.30 miles	1.1	2.53
B4	0.30 to 0.40 miles	6.5	0.43
B5	0.37 to 0.47 miles	7.8	0.36
	Average	5.7	-

$$VAR_B = \frac{(5.2-5.7)^2 + (7.8-5.7)^2 + (1.1-5.7)^2 + (6.5-5.7)^2 + (7.8-5.7)^2}{(5-1)} = 7.7 \qquad CV_{B1} = \frac{\sqrt{7.7}}{5.2} = 0.53$$

Network Screening

- An example

Iteration 2

Sub-segment	Window Position	Excess Expected Average Crash Frequency	Coefficient of Variation (CV)
B1	0.00 to 0.20 miles	6.50	0.25
B2	0.10 miles to 0.30 miles	4.45	0.36
B3	0.20 miles to 0.40 miles	3.80	0.42
B4	0.27 miles to 0.47 miles	7.15	0.22
	Average	5.5	

The CVs for B1 and B4 are less than or equal to the CV limiting value of 0.25. Segment B would be ranked and compared to other segments according to the 7.15 Excess Expected Crash Frequency calculated for B4.

If during Iteration 2, none of the calculated CVs were less than the CV limiting value, a third iteration would have been necessary with 0.3 mile window lengths, and so on, until the final window length considered would be equal to the segment length of 0.47 miles.

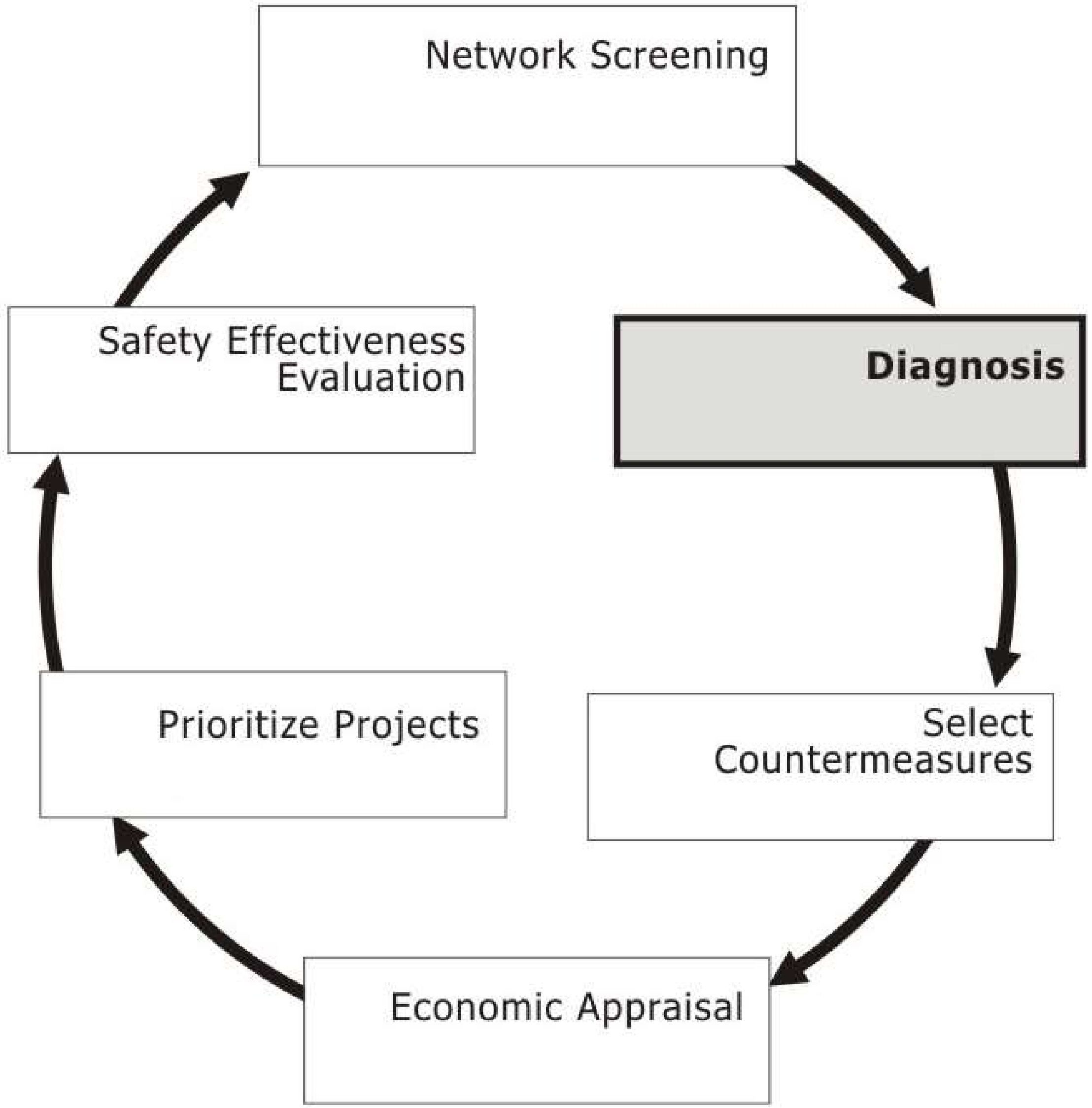
Network Screening

- Step 5 Screen and evaluate results
  - The results of the screening analysis is a list of sites ordered according to the selected performance measure and the screening method.
  - Those sites higher on the list are considered most likely to benefit from countermeasures intended to reduce crash frequency.
  - Multiple performance measures can be applied to the same data set, and sites that repeatedly appear at the higher end of the list could become the focus of more detailed site investigations.

Network Screening

- Step 5 Screen and evaluate results

TWSC intersection	Ranking					
	Average crash frequency	Equivalent property damage only average crash frequency	Crash rate	Excess predicted average crash frequency using SPFs	Expected average crash frequency with EB Adjustment	Excess expected average crash frequency with EB Adjustment
2	1	1	1	1	2	1
3	3	6	3	3	3	3
7	2	2	2	2	1	2
10	4	7	4	4	4	4
15	4	5	5	5	5	5
17	6	3	7	6	6	6
19	7	4	6	7	7	7


Network Screening
Diagnosis
Select Countermeasures
Economic Appraisal
Prioritize Projects
Safety Effectiveness Evaluation

Diagnosis

- Involves three steps:
  - Step 1 Review safety data
  - Step 2 Assess supporting documentation
  - Step 3 Assess field conditions

- Intended outcomes
  - Identify crash patterns
  - Understand site conditions
  - Gain insight into countermeasure selection

Diagnosis

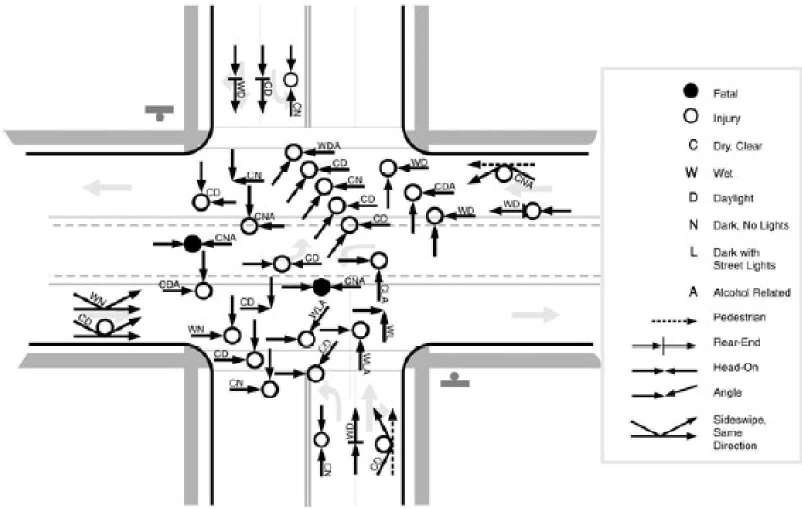
- Step 1 Review safety data
  - A site diagnosis begins with a review of safety data that may identify patterns in crash type, crash severity, or roadway environmental conditions.
  - Descriptive crash statistics
    - Crash Identifiers: date, day of week, time of day
    - Crash Type: rear-end, sideswipe, angle, turning, head-on, run-off the road, fixed object, animal, out of control, work zone
    - Crash Severity: e.g., the KABCO scale
    - Sequence of Events: direction of travel; location of parties involved (e.g., specific approach at a specific intersection or specific roadway milepost)

Diagnosis

- Step 1 Review safety data
  - Descriptive crash statistics (cont.)
    - Contributing Circumstances:
      - Parties Involved: vehicle only, pedestrian and vehicle, bicycle and vehicle;
      - Road Condition at the Time of the Crash: dry, wet, snow, ice;
      - Lighting Condition at the Time of the Crash: dawn, daylight, dusk, darkness with/without lights, lights;
      - Weather Conditions at the Time of the Crash: clear, cloudy, fog, rain, snow, ice;
      - Impairments of Parties Involved: alcohol, drugs, fatigue.
  - These data are compiled from police reports, and can be presented in *tabular* and *graphical* form to make patterns visible.

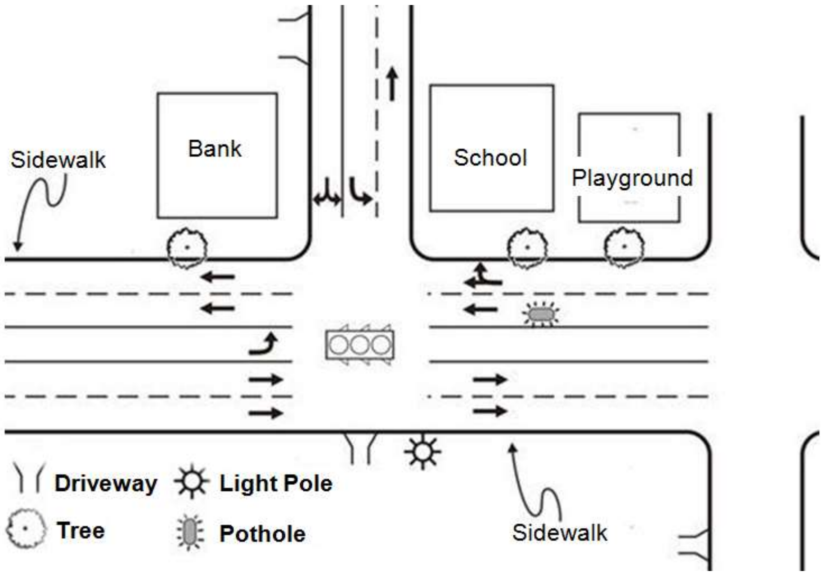
Diagnosis

- Step 1 Review safety data
  - Crash location - can be summarized using 3 tools:
    - Collision diagrams:
      - A two-dimensional plan view representation of the crashes that have occurred at a site within a given time period.
      - Using arrows to indicate the type of crash and the direction of travel.
      - Additional information (e.g., severity, date, time of day, pavement condition, lighting condition) is also provided.



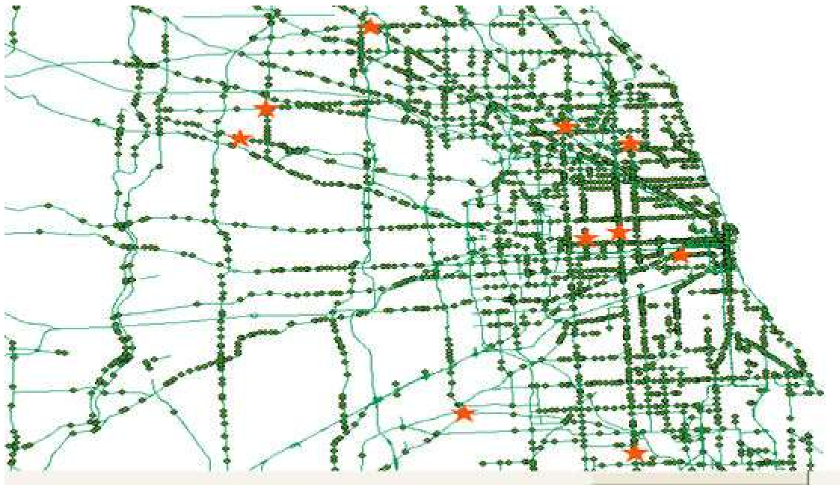
Diagnosis

- Step 1 Review safety data
  - Crash location - can be summarized using 3 tools:
    - Condition diagrams
      - A plan view drawing of site characteristics, such as lane configurations and traffic control; presence of roadway medians; landscaping; shoulder; type of land uses (e.g., school, retail, commercial, residential), pavement conditions, etc.



Diagnosis

- Step 1 Review safety data
  - Crash location - can be summarized using 3 tools:
    - Crash mapping
      - Evaluating crash locations and trends with Geographic Information Systems (GIS), which allow data to be displayed and analyzed based on spatial characteristics.
      - The accuracy of crash location data is the key to achieving the full benefits of GIS crash analysis.



Diagnosis

- Step 2 Assess supporting documentation
  - To obtain and review documented information of local transportation professionals that provides additional perspective to the crash data review.
    - Relevant design criteria
    - Inventory of field conditions
    - Land use mapping
    - Historic weather patterns
    - Public comment records
    - Roadway improvement plans
    - …

Diagnosis

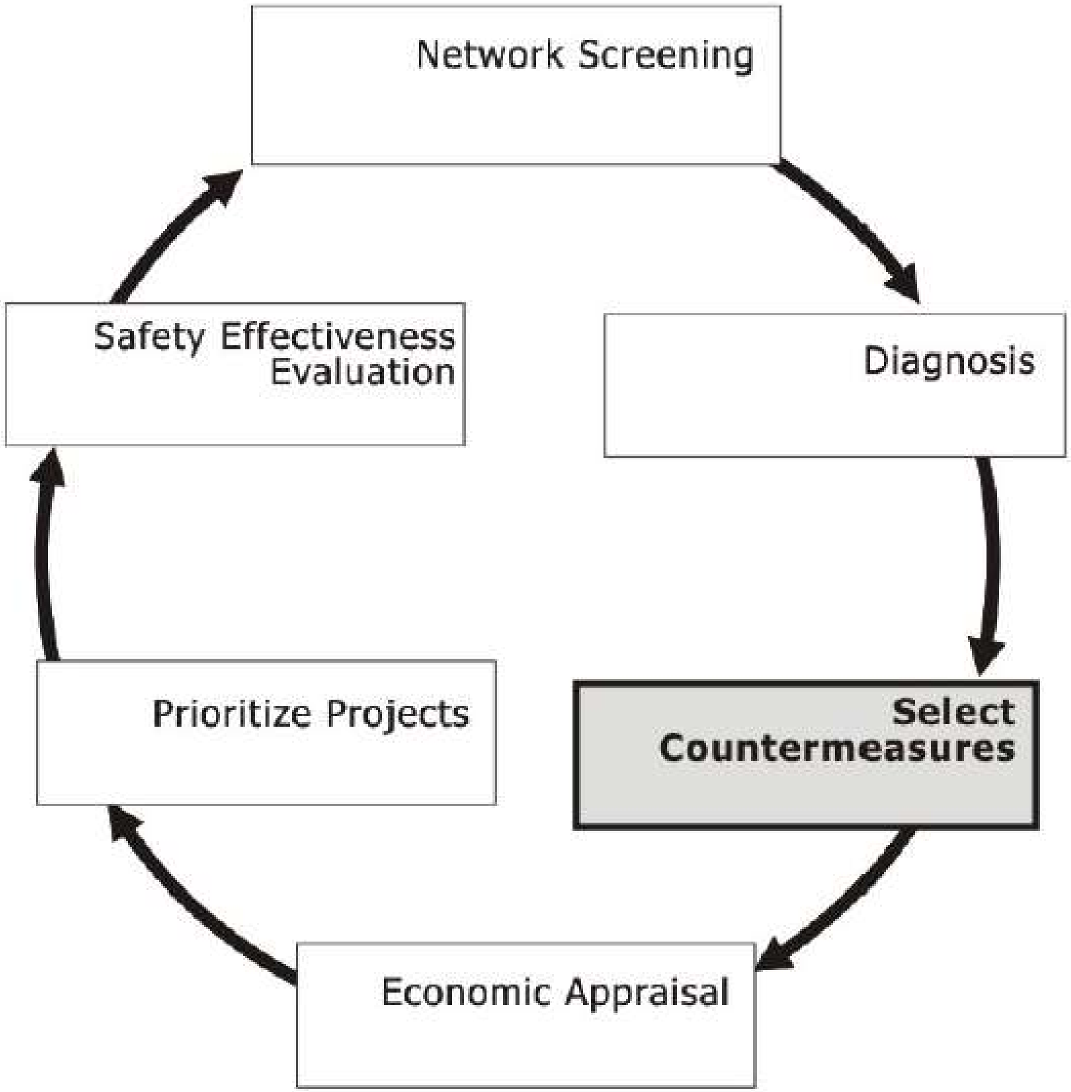
- Step 2 Assess supporting documentation
  - For example, a review of crash data reveals that the frequency of *left-turning crashes* at a signalized intersection *increased significantly three years ago* and have remained at that level.
  - Associated project area documentation may show *a corridor roadway widening project had been completed at that time*, which may have led to the increased observed crash frequency due to increased travel speeds and/or the increase in the number of lanes opposing a permitted left turn.

Diagnosis

- Step 3 Assess field conditions
  - To validate safety concerns identified by a review of crash data and/or supporting documentation.
  - During a field investigation, first-hand site information is gathered and compared to help understand motorized and non-motorized travel to and through the site.
    - roadway and roadside characteristics,
    - live traffic conditions,
    - traveler behavior,
    - land uses,
    - roadway consistency,
    - weather conditions, and
    - any unusual characteristics not identified previously.

Diagnosis

- Once the field assessment, crash data review, and supporting documentation assessment are completed, the information can be compiled to identify *any specific crash patterns* that could be addressed by a countermeasure.
- Key elements
  - Data - sufficient quantity and quality
  - Field observations
  - Diagnostic tools
  - Knowledge on safety fundamentals, human factors, etc.
  - Good judgment


Network Screening
Diagnosis
Select Countermeasures
Economic Appraisal
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Countermeasure Selection

- In this stage, the sites are evaluated to *identify factors* that may be contributing to observed crash patterns or concerns and *countermeasures are selected* to address the respective contributing factors.
- A countermeasure is a roadway strategy intended to decrease crash frequency or severity, or both at a site.

Countermeasure Selection

- Identify contributing factors
  - For each identified crash pattern there may be *multiple* contributing factors.

Example Haddon Matrix for rear-end crashes

Period	Human Factors	Vehicle Factors	Roadway Factors
Before the Crash (Causes of the hazardous situation)	distraction, fatigue, inattention, bad judgment, age, cell phone use, impaired cognitive skills, deficient driving habits	bald tires, worn brakes	wet pavement, polished aggregate, steep downgrade, poor signal coordination, limited stopping sight distance, lack of warning signs
During the Crash (Causes of crash severity)	vulnerability to injury, age, failure to wear a seat belt	bumper heights and energy absorption, headrest design, airbag operations	pavement friction and grade
After the Crash (Factors of crash outcome)	age, gender	ease of removal of injured passengers	the time and quality of the emergency response, subsequent medical treatment

Countermeasure Selection

- Identify contributing factors
  - Once a broad range of contributing factors have been considered, engineering judgment is applied to identify those factors that are expected to be *the greatest contributors* to each particular crash type or concern.
- Select potential countermeasures
  - Relate contributing factors to treatable actions
  - Identify and list potential countermeasures

Countermeasure Selection

- An example

Factors	• At a signalized intersection, it is identified that *limited sight-distance* is the contributing factor to the rear-end crashes.
Possible reasons	• Constrained horizontal or vertical curvature, landscaping hanging low on the street, illumination conditions, etc.
Potential measures	• Re-grade or re-align the roadway, modify landscaping, improve illumination, etc.

References

- Highway Safety Manual, Chps. 4-6

Lecture 8: Roadway Safety Management Process II

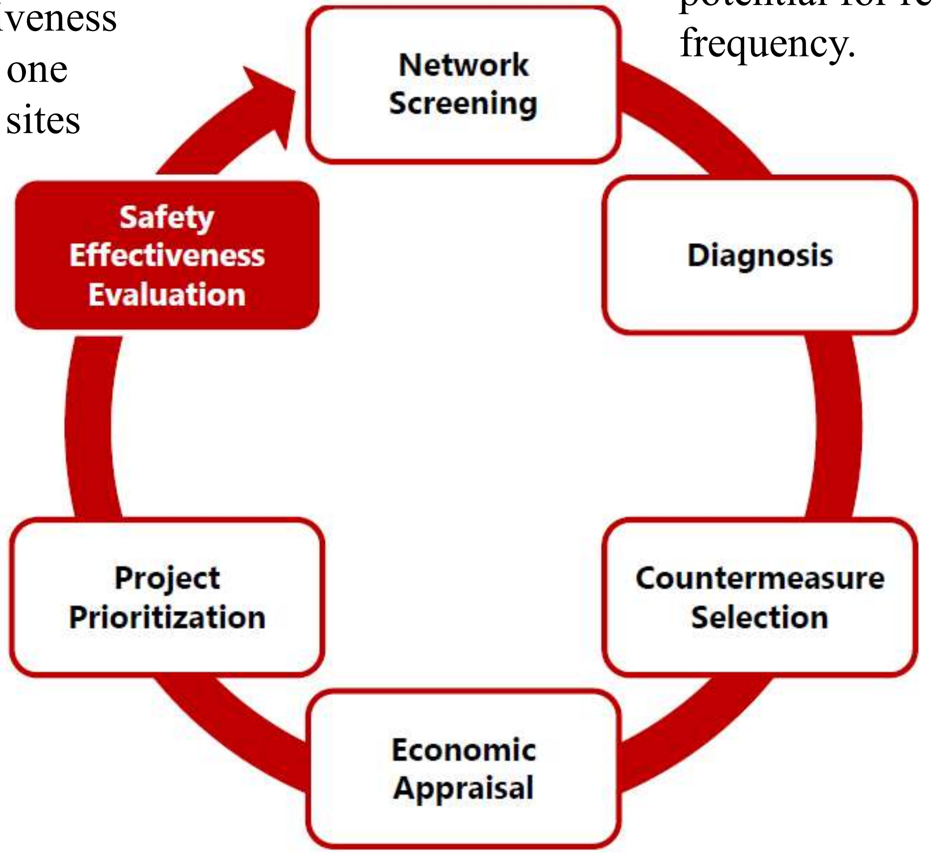
Outline

- Introduction
- Economic Appraisal
- Project Prioritization
- Summary
- References

Introduction

Review a transportation network to identify and rank sites based on the potential for reducing average crash frequency.

Evaluate effectiveness of a measure at one site or multiple sites

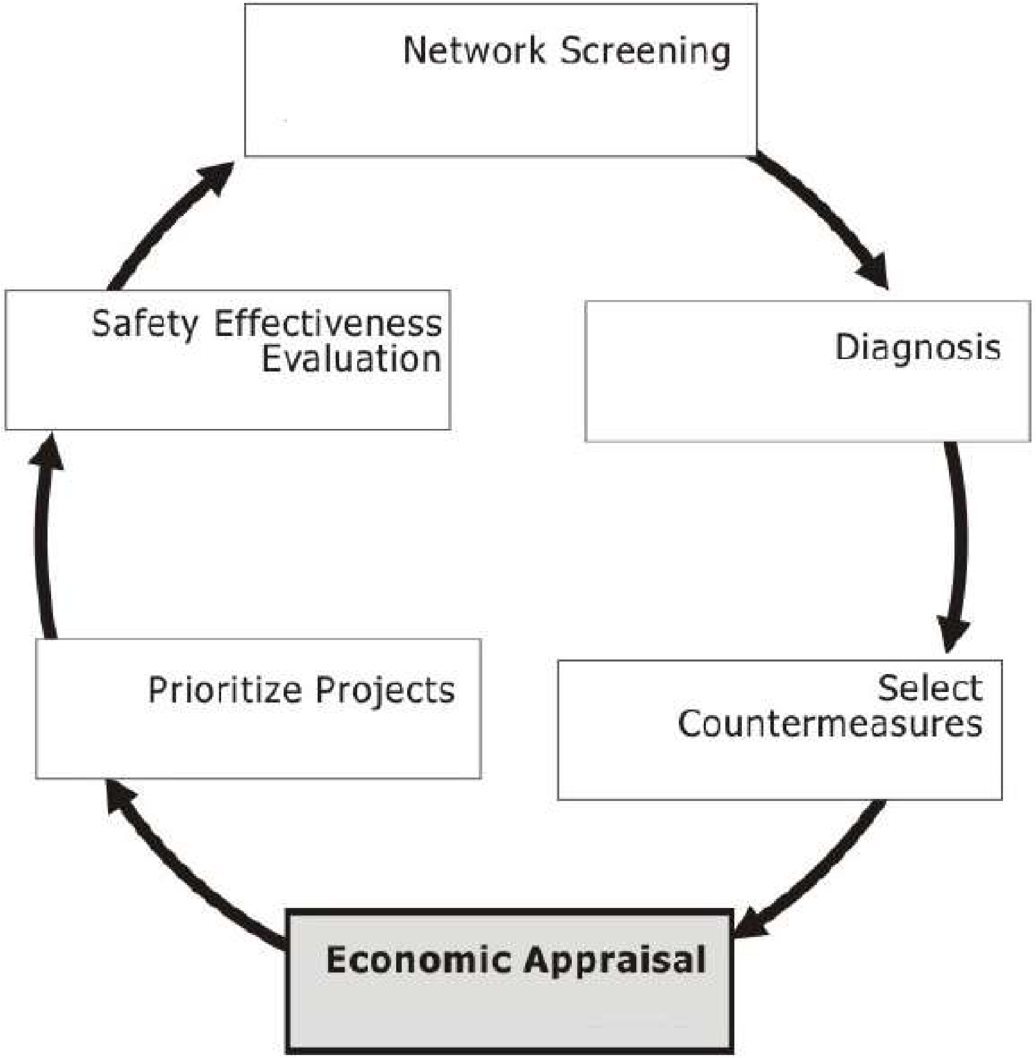


Evaluate crash data, historic site data, and field conditions to identify crash patterns

Identify factors that contribute to crashes at a site and select possible measures

Evaluate improvements at specific sites to identify a set of improvement projects to meet objectives

Evaluate the benefits and costs of the possible measures and identify individual projects that are cost effective


Network Screening
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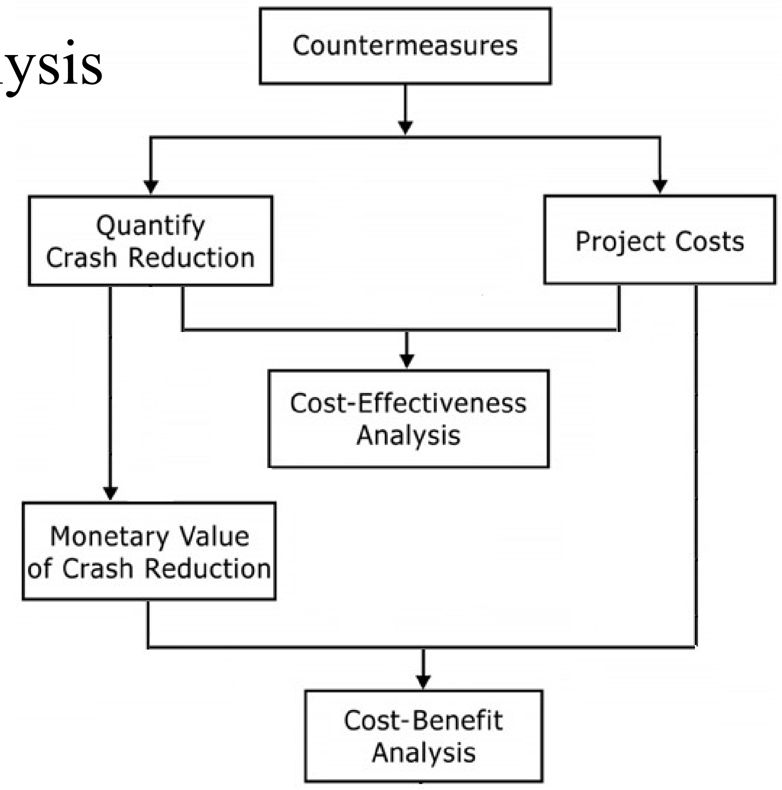
Economic Appraisal

- Performed to compare the benefits of potential crash countermeasure to its project costs.
  - Cost-benefit analysis
  - Cost-effectiveness analysis



Economic Appraisal

- The data needed for the economic appraisal process

Activity	Data Need
Calculate Monetary Benefit	
Estimate change in crashes by severity	Crash history by severity
	Current and future Average Annual Daily Traffic (AADT) volumes
	Implementation year for expected countermeasure
	SPF for current and future site conditions (if necessary)
	AMFs for all countermeasures under consideration
Convert change in crash frequency to annual monetary value	Monetary value of crashes by severity
	Change in crash frequency estimates
Convert annual monetary value to a present value	Service life of the countermeasure
	Discount rate (minimum rate of return)
Calculate Costs	
Calculate construction and other implementation costs	Subject to standards for the jurisdiction
Convert costs to present value	Service life of the countermeasure(s)
	Project phasing schedule

Economic Appraisal

- Possible outcomes of the economic appraisal process:
  - Project costs
  - Number of total crashes reduced
  - Number of fatal and injury crashes reduced
  - Monetary value of project benefits
  - Net Present Value (NPV)
  - Cost-Benefit Ratio (CBR)
  - Cost-Effectiveness Index

Economic Appraisal

- A Case Study

Data	Intersection
Major/Minor AADT	22,100 / 1,650
Predominate Collision Types	Angle Head-On
Crashes by Severity	
Fatal	6%
Injury	65%
PDO	29%
Contributory Factors	Increase in traffic volumes
	Inadequate capacity during peak hour
	High travel speeds during off-peak

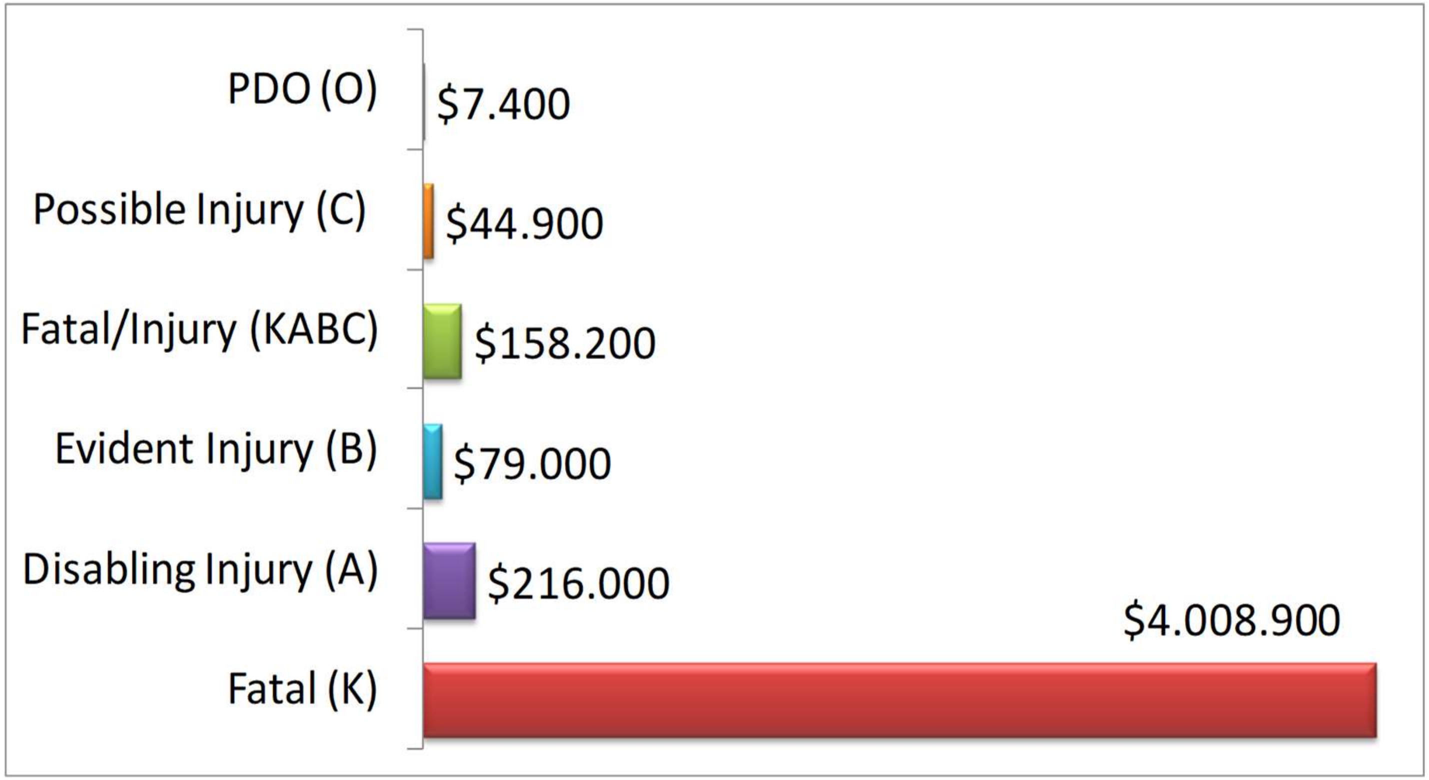
Economic Appraisal

- A Case Study

Countermeasure: Install a single-lane roundabout in place of the two-way stop controlled intersection	
Service life	10years, from 2005
Annual traffic growth	2.0%
Discount rate	4.0%
Project cost	$2,000,000
CMF	
Total crashes	0.56
Fatal and injury crashes	0.18

Economic Appraisal

- A Case Study



Crash cost estimates by crash severity, 2005

Economic Appraisal

- Step 1 Calculate the expected average crash frequency at the intersection *without* the roundabout

Year in service life (y)	Major AADT	Minor AADT	$N_{expected(TOT)}$	$N_{expected(FI)}$
1	23,553	1,758	10.4	5.2
2	23,906	1,785	10.5	5.3
3	24,265	1,812	10.5	5.3
4	24,629	1,839	10.6	5.4
5	24,998	1,866	10.7	5.4
6	25,373	1,894	10.7	5.4
7	25,754	1,923	10.8	5.5
8	26,140	1,952	10.9	5.5
9	26,532	1,981	11.0	5.5
10	26,930	2,011	11.0	5.6
Total			107.1	54.1

Economic Appraisal

- Step 2 Calculate the expected average crash frequency at the intersection *with* the roundabout

$$N_{expected\ roundabout\ (TOTAL)} = N_{expected(TOTAL)} \times AMF_{(TOTAL)}$$

$$N_{expected\ roundabout\ (FI)} = N_{expected(FI)} \times AMF_{(FI)}$$

Year in service life (y)	$N_{expected(TOTAL)}$	$AMF_{(TOTAL)}$	$N_{expected\ roundabout(TOTAL)}$
1	10.4	0.56	5.8
2	10.5	0.56	5.9
3	10.5	0.56	5.9
4	10.6	0.56	5.9
5	10.7	0.56	6.0
6	10.8	0.56	6.0
7	10.8	0.56	6.0
8	10.9	0.56	6.1
9	11.0	0.56	6.2
10	11.0	0.56	6.2
Total			60.0

Year in Service Life (y)	$N_{expected(FI)}$	$AMF_{(FI)}$	$N_{expected\ roundabout(FI)}$
1	5.2	0.18	0.9
2	5.3	0.18	1.0
3	5.3	0.18	1.0
4	5.4	0.18	1.0
5	5.4	0.18	1.0
6	5.4	0.18	1.0
7	5.5	0.18	1.0
8	5.5	0.18	1.0
9	5.5	0.18	1.0
10	5.6	0.18	1.0
Total			9.9

Economic Appraisal

- Step 3 Calculate the change in expected average crash frequency for total, FI, and PDO crashes

$$\Delta N_{expected\ (FI)} = N_{expected(FI)} - N_{expected\ roundabout(FI)}$$

$$\Delta N_{expected(TOTAL)} = N_{expected(TOTAL)} - N_{expected\ roundabout(TOTAL)}$$

$$\Delta N_{expected(PDO)} = N_{expected(TOTAL)} - N_{expected(FI)}$$

Year in service life, *y*	$\Delta N_{expected(TOTAL)}$	$\Delta N_{expected(FI)}$	$\Delta N_{expected(PDO)}$
1	4.6	4.3	0.3
2	4.6	4.3	0.3
3	4.6	4.3	0.3
4	4.7	4.4	0.3
5	4.7	4.4	0.3
6	4.7	4.4	0.3
7	4.8	4.5	0.3
8	4.8	4.5	0.3
9	4.8	4.5	0.3
10	4.8	4.6	0.2
Total	47.1	44.2	2.9

Economic Appraisal

- Step 4 Convert the change in crashes to a monetary value for each year of the service life

$$AM_{(PDO)} = \Delta N_{expected(PDO)} \times CC_{(FI)}$$

$$AM_{(FI)} = \Delta N_{expected(FI)} \times CC_{(FI)}$$

$$AM_{(TOTAL)} = AM_{(PDO)} + AM_{(FI)}$$

Year in service life (y)	$\Delta N_{(FI)}$	FI Crash Cost	$AM_{(FI)}$	$\Delta N_{(PDO)}$	PDO Crash Cost	$AM_{(PDO)}$	$AM_{(TOTAL)}$
1	4.3	$158.200	$680.260	0.3	$7.400	$2.220	$682.480
2	4.3	$158,200	$680,260	0.3	$7,400	$2,220	$682,480
3	4.3	$158,200	$680,260	0.3	$7,400	$2,220	$682,480
4	4.4	$158,200	$696,080	0.3	$7,400	$2,220	$698,300
5	4.4	$158,200	$696,080	0.3	$7,400	$2,220	$698,300
6	4.4	$158,200	$696,080	0.3	$7,400	$2,220	$698,300
7	4.5	$158,200	$711,900	0.3	$7,400	$2,220	$714,120
8	4.5	$158,200	$711,900	0.3	$7,400	$2,220	$714,120
9	4.5	$158,200	$711,900	0.3	$7,400	$2,220	$714,120
10	4.6	$158,200	$727,720	0.2	$7,400	$1,480	$729,200

Economic Appraisal

- Step 5 Convert annual monetary values to a present value

$$PV_{benefits} = TotalAnnualMonetaryBenefits \times (P/A,\ i,\ y)$$

Where,

$(P/A, i, y)$ = Conversion factor for a series of uniform annual amounts to present value

$$(P/A, i, y) = \frac{(1.0+i)^{(y)} - 1.0}{i \times (1.0+i)^{(y)}}$$

i = Minimum attractive rate of return or discount rate (i.e., if the discount rate is 4%, the i = 0.04)

y = Year in the service life of the countermeasure(s)

Economic Appraisal

- Step 5 Convert annual monetary values to a present value

Year in service life (y)	(P/A, i, y)	$AM_{(TOT)}$	Present Value
1	1.0	$682,480	$682,480
2	1.9	$682,480	$1,296,710
3	2.8	$682,480	$1,910,940
4	3.6	$698,300	$2,513,880
5	4.5	$698,300	$3,142,350
6	5.2	$698,300	$3,631,160
7	6.0	$714,120	$4,284,720
8	6.7	$714,120	$4,784,600
9	7.4	$714,120	$5,284,490
10	8.1	$729,200	$5,906,520
Total			$33,437,850

Economic Appraisal

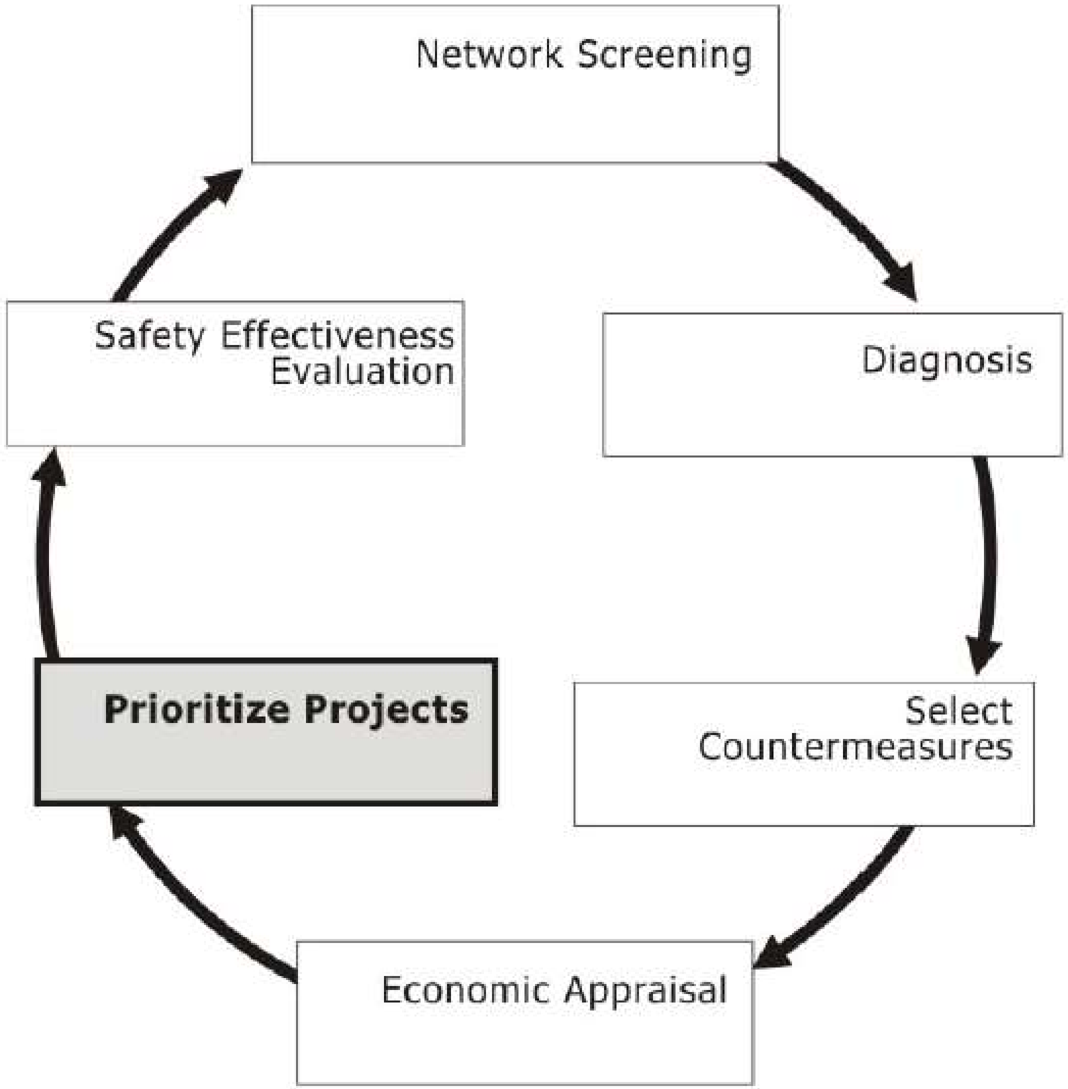
- Cost-Benefit Analysis
  - Net Present Value (NPV)
    - NPV = Present value of benefits – Present value of project costs
    - If the NPV > 0, then the project is economically justified
  - Cost-Benefit Ratio (CBR)
    - CBR = Present value of benefits / Present value of project costs
    - If the CBR > 1, then the project is economically justified

Economic Appraisal

- Cost-Effectiveness Analysis
  - Cost-Effectiveness Index (CEI)
    - CEI = (Present value of project costs) / (Estimated average annual crash reduction)
    - Expressed as annual cost per crash reduced
    - Method does not consider crash severities

Economic Appraisal

- Additional considerations
  - Other monetary considerations
    - Road user costs (delay, operating costs)
    - Maintenance and operations
    - Costs to achieve environmental standards
    - Costs to achieve ecological protection
    - …
  - Non-monetary considerations: not every benefit or cost can be translated to monetary terms
    - Public perceptions
    - Air pollution
    - Energy consumption
    - …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Project Prioritization

- Refers to a review of possible projects or project alternatives for construction and developing an ordered list of recommended projects based on the results of *ranking* and *optimization* processes.
- Three prioritization methods:
  - Ranking by economic effectiveness measures
  - Incremental cost-benefit analysis ranking
  - Optimization methods
    - Select a set of projects or project alternatives by maximizing benefits according to budget and other constraints.
    - e.g., linear programming, integer programming, dynamic programming.

Project Prioritization

- Ranking by economic effectiveness measures

Intersection	Countermeasure	Estimated Average Reduction in Crash Frequency	Present Value of Crash Reduction	Cost Estimate
2	Single-Lane Roundabout	47	$33,437,850	$695,000
7	Add Right Turn Lane	6	$1,200,000	$200,000
11	Add Protected Left Turn	7	$1,400,000	$230,000
12	Install Red Light Cameras	9	$1,800,000	$100,000
Segment	**Countermeasure**	**Estimated Average Reduction in Crash Frequency**	**Present Value of Safety Benefits**	**Cost Estimate**
1	Shoulder Rumble Strips	18	$3,517,400	$250,000
2	Shoulder Rumble Strips	16	$2,936,700	$225,000
5	Convert to Divided	458	$7,829,600	$3,500,000
6	Convert to Divided	110	$6,500,000	$2,750,000
7	Convert to Divided	120	$7,000,000	$3,100,000

Project Prioritization

- Ranking by economic effectiveness measures
  - Cost-Effectiveness ranking

Project	Cost-Effectiveness
Segment 5	$7,600
Intersection 12	$11,100
Segment 1	$14,000
Segment 2	$14,100
Intersection 2	$14,800
Segment 6	$25,000
Segment 7	$25,800
Intersection 11	$32,900
Intersection 7	$33,300

Project Prioritization

- Ranking by economic effectiveness measures
  - Net Present Value ranking

Project	Present Value of Benefits ($)	Cost of Improvement Project ($)	Net Present Value
Intersection 2	$33,437,850	$695,000	$32,742,850
Segment 5	$7,829,600	$3,500,000	$4,329,600
Segment 7	$7,000,000	$3,100,000	$3,900,000
Segment 6	$6,500,000	$2,750,000	$3,750,000
Segment 1	$3,517,400	$250,000	$3,267,400
Segment 2	$2,936,700	$225,000	$2,711,700
Intersection 12	$1,800,000	$100,000	$1,700,000
Intersection 11	$1,400,000	$230,000	$1,170,000
Intersection 7	$1,200,000	$200,000	$1,000,000

Project Prioritization

- Incremental cost-benefit analysis ranking
  - Step 1 Calculate the cost-benefit ratio (CBR)

Location	Present Value of Crash Reduction	Cost Estimate
Intersection 2	$33,437,850	$695,000
Intersection 7	$1,200,000	$200,000
Intersection 11	$1,400,000	$230,000
Intersection 12	$1,800,000	$100,000
Segment 1	$3,517,400	$250,000
Segment 2	$2,936,700	$225,000
Segment 5	$7,829,600	$3,500,000
Segment 6	$6,500,000	$2,750,000
Segment 7	$7,000,000	$3,100,000

Project Prioritization

- Incremental cost-benefit analysis ranking
  - Step 2 Organize projects by project cost

Project	Cost of Improvement
Intersection 12	$100,000
Intersection 7	$200,000
Segment 2	$225,000
Intersection 11	$230,000
Segment 1	$250,000
Intersection 2	$695,000
Segment 6	$2,750,000
Segment 7	$3,100,000
Segment 5	$3,500,000

Project Prioritization

- Incremental cost-benefit analysis ranking
  - Step 3 Calculate incremental CBR

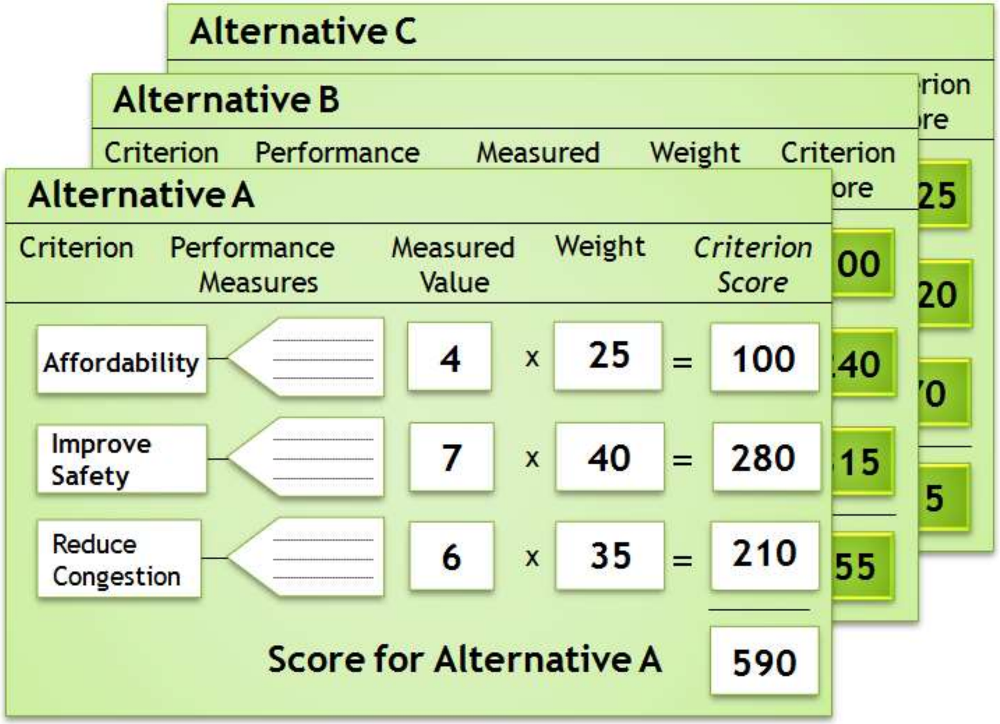
$$Incremental\ CBR = (PV_{benefits\ 2} - PV_{benefits\ 1}) / (PV_{costs\ 2} - PV_{costs\ 1})$$

If the incremental BCR > 1, the higher-cost project is preferred
If the incremental BCR < 1, the lower-cost project is preferred

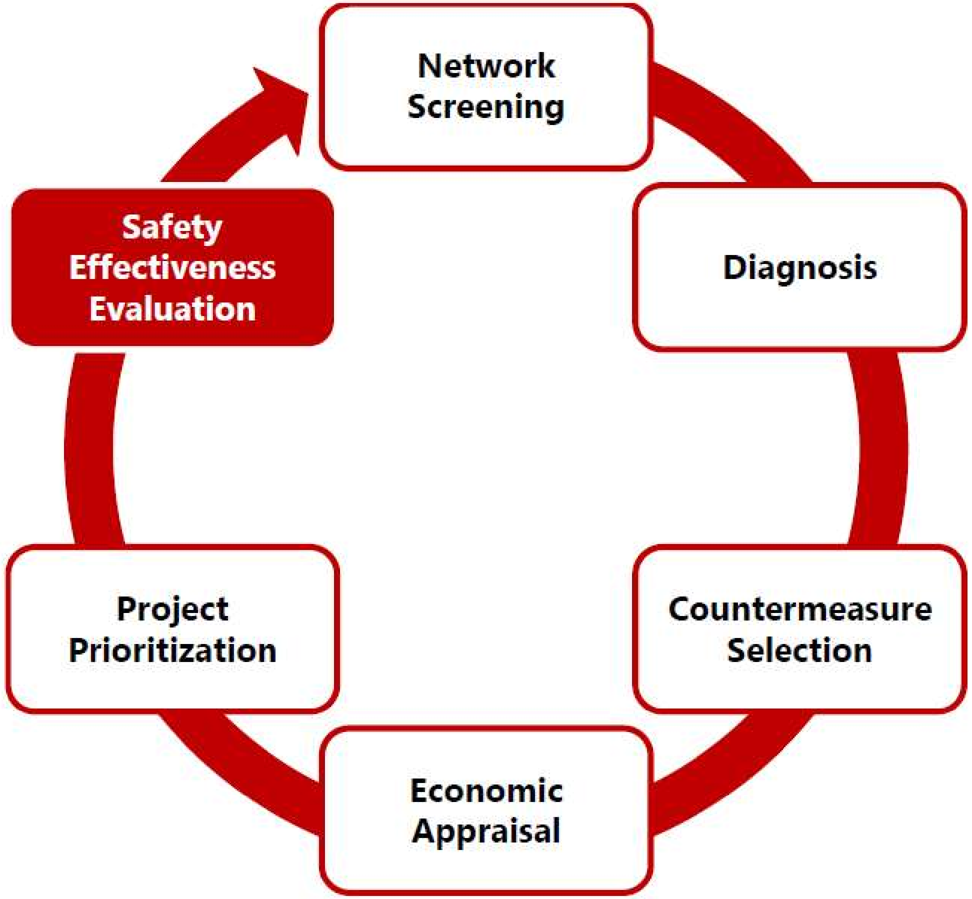
Comparison	Project	$PV_{benefits}$	PV_{costs}	Incremental BCR	Preferred Project
1	Intersection 12	$1,800,000	$100,000	-6	Intersection 12
	Intersection 7	$1,200,000	$200,000		
2	Intersection 12	$1,800,000	$100,000	9	Segment 2
	Segment 2	$2,936,700	$225,000		
3	Segment 2	$2,936,700	$225,000	-307	Segment 2
	Intersection 11	$1,400,000	$230,000		
4	Segment 2	$2,936,700	$225,000	23	Segment 1
	Segment 1	$3,517,400	$250,000		
5	Segment 1	$3,517,400	$250,000	67	Intersection 2
	Intersection 2	$33,437,850	$695,000		
6	Intersection 2	$33,437,850	$695,000	-13	Intersection 2
	Segment 6	$6,500,000	$2,750,000		
7	Intersection 2	$33,437,850	$695,000	-11	Intersection 2
	Segment 7	$7,000,000	$3,100,000		
8	Intersection 2	$33,437,850	$695,000	-9	Intersection 2
	Segment 5	$7,829,600	$3,500,000		

Project Prioritization

- Multi-objective resource allocation
  - In many decisions concerning highway improvement projects, reducing crashes is just one of many factors that influence project selection and prioritization.



Summary


Network Screening
Diagnosis
Countermeasure Selection
Economic Appraisal
Project Prioritization
Safety Effectiveness Evaluation

Summary

- The benefits of implementing a roadway safety management process include:
  - Systematic and repeatable process for identifying opportunities to reduce crashes and identifying potential countermeasures resulting in a prioritized list of cost-effective safety countermeasures.
  - A quantitative and systematic process that addresses a broad range of roadway safety conditions and tradeoffs.
  - The opportunity to leverage funding and coordinate improvements with other planned infrastructure improvement programs.

Summary

- The benefits of implementing a roadway safety management process include:
  - Comprehensive methods that consider traffic volume, collision data, traffic operations, roadway geometry, and user expectations.
  - The opportunity to use a proactive process to increase the effectiveness of countermeasures intended to reduce crash frequency.

References

- Highway Safety Manual, Chps. 7-8