CHAPTER 6

SAFETY ANALYSIS METHODS

TABLE OF CONTENTS

LIST OF EXHIBITS

6.0 SAFETY ANALYSIS METHODS

In addition to operational needs, it is important for signalized intersections to operate safely. Intersections constitute of a small portion of the National Highway System. However, intersection related crashes constitute more than 20 percent of fatal crashes.[71] In some cases a signal is even installed for safety reasons (e.g., severe angle crashes at a stop-controlled intersection). As a result, the safety performance of signalized intersections is as important as the operational performance of these intersections. Signalized intersections must be systematically and continuously monitored throughout their life.

Historically, safety practitioners have identified intersections with the highest number of crashes in a specified time period and focused their efforts and resources at those intersections. This reactive approach can be effective in addressing a small number of high-crash locations.

During the past two decades, road agencies have started to recognize the challenges associated with a highly reactive approach to road safety.[71]

The paradigm shift from a reactive approach to road safety (i.e., only investigate locations with high crash frequency) to also incorporating a proactive approach (i.e., incorporate road safety in all stages of a roadway cycle) occurred in conjunction with the development of analytical tools by researchers and practitioners. These tools can be categorized into qualitative and quantitative tools.

Qualitative approaches are often used when enough historical data is not available or when an intersection is in the planning or design stage. A Road Safety Audit (RSA) is one of the qualitative approaches. The RSA is a formal safety performance examination of an existing or future road or intersection by an independent audit team.

Quantitative approaches have been mostly collected in the Highway Safety Manual (HSM), published by AASHTO in 2010.[11] The HSM presents a systematic approach for a road safety management process. The road safety management process shown in Exhibit 6-1 can be applied to one road entity (e.g., an intersection) or a network (e.g., all signalized intersections in a jurisdiction). This road safety management process starts with network screening in which the main goal is identification of road locations likely to benefit the most from safety improvements. The underlying assumption is that road design attributes often play a significant contributory role in crash occurrence. In network screening, the safety performance of each individual location is compared with the safety performance of similar locations in a jurisdiction to identify whether the safety performance of the subject location is acceptable.

The next step in the road safety management process is diagnosis. This step examines the contributing factors of crashes for locations identified in the network screening process to determine the cause and prepare for the identification of treatments in the next steps.

Countermeasure selection and economic appraisal constitute the next steps in the road safety management process. This involves the selection of treatments potentially able to address the safety issues identified in the diagnosis step. In the course of this selection process, more than one countermeasure with the potential to mitigate the problem is often identified. A subsequent economic appraisal will evaluate all options for all problem locations in order to ensure that the countermeasures are economically viable. In the prioritization of countermeasure projects, the objective is to maximize benefits in terms of crash reductions subject to budget restrictions. Safety effectiveness evaluation involves monitoring implemented improvements to assess their safety effectiveness. The information obtained in this step is extremely valuable for prospective studies so that practitioners can make informed decisions about the effectiveness of each countermeasure.

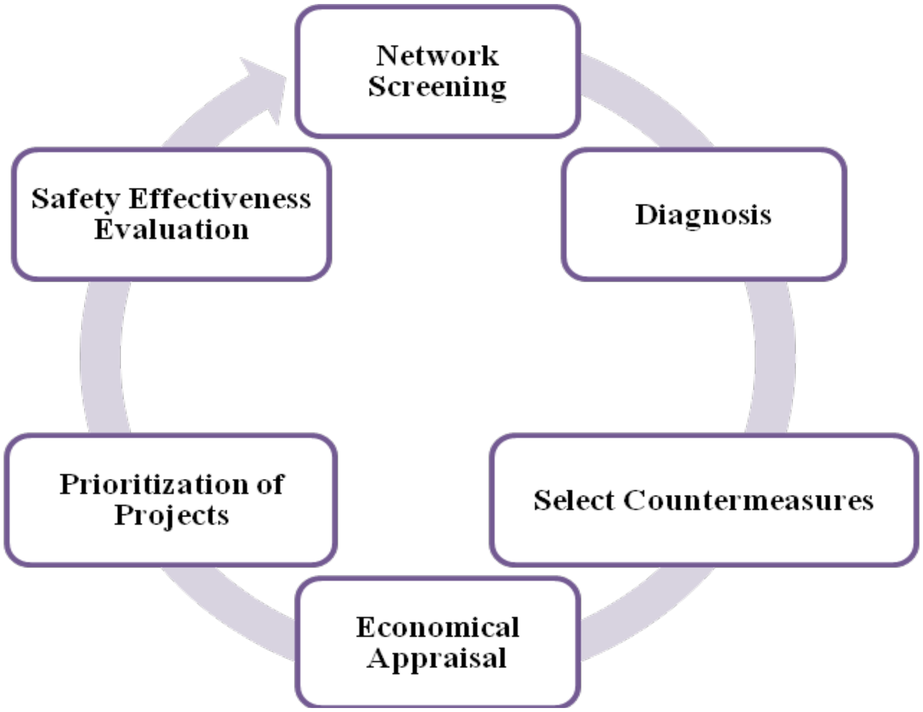

Exhibit 6-1. Road safety management process.[72]

The road safety management process is a continuous process demanding significant resources from road authorities, particularly jurisdictions which constitute large geographic areas (e.g., State agencies). The process requires an extensive amount of data, which should be collected annually. Consequently, road authorities automated the road safety management process as much as possible to increase the efficiency of their road safety programs. In response to this increasing need of road authorities, AASHTO released *SafetyAnalyst* in 2009. *SafetyAnalyst* is a software package that consists of four modules containing six analytical tools, and these analytical tools correspond to the six steps of the road safety management process outlined above.

6.1 QUALITATIVE APPROACH

Qualitative approaches to road safety are important tools that can help a traffic engineer to have a better understanding of the safety issues at signalized intersections. These techniques are especially helpful in circumstances in which the intersection is in the planning or design stage and sufficient operational data (to quantitatively identify the safety problems) or historical data (e.g., collision, volume, etc.) data about the subject intersection is not available. Different qualitative techniques are used by traffic engineers including:

- Positive guidance review.
- Driver behavior observation.
- Human factors review.
- Conflict analysis.
- Surrogate measures such as time to collision using traffic simulation models (e.g., Surrogate Safety Analysis Model (SSAM)).

The above techniques can be used independently or as part of a formal RSA process.

An RSA can be used in any phase of project development, from planning and preliminary engineering to design and construction, regardless of the size of the project. RSAs applied early in the planning and preliminary (functional) design of roads offer the greatest opportunity for benefit. As design progresses into detailed design and construction, changes that may improve safety performance typically become more difficult, costly, and time consuming to implement.

An RSA audit team consists of a multidisciplinary group of experts who review the intersection from different perspectives, such as safety, design, traffic operations, law enforcement, maintenance, etc. The level of success that can be achieved in using the RSA process is highly dependent on the knowledge, skills, experience, and attitudes of the auditors. The team should be able to review project data critically, get the most from the field visits, and engage in the kind of dialogue that leads to the identification of road safety issues. It is important to ensure that a local contact person is included in the audit team.

RSA process includes the following steps:

- **Step 1**: Identify intersection to be audited.
- **Step 2**: Select RSA team.
- **Step 3**: Conduct a pre-audit meeting to review project information.
- **Step 4**: Perform field observations under various conditions.
- **Step 5**: Conduct audit analysis and prepare report of findings.
- **Step 6**: Present audit findings to project owner/design team.
- **Step 7**: Project owner/design team prepares formal response.
- **Step 8**: Incorporate findings into the project when appropriate.

When conducting the field investigation component of an RSA of an existing signalized intersection, the following elements are reviewed:

<u>Conformance, Consistency, and Condition</u>

- Relating to intersection and approach geometrics and geometric characteristics, traffic control devices (traffic signals, signing, pavement markings etc.), illumination and delineation devices, safety devices (guide rail systems, end treatments, crash cushions etc.), and all other roadway features present within the roadway environment on the day of the field investigation, including physical evidence of road user collisions.

<u>Intersection and Approach Geometrics and Geometric Characteristics</u>

- Layout and “readability” (perception) by drivers.
- Horizontal and vertical alignment (visibility all for road users - sight distance review as required).
- Cross-section, lane configuration, and lane continuity.
- Driveway/side street accessibility.
- Access management and corner clearance.
- Active transportation/vulnerable road user facilities (walkability, bicycling, and mobility restricted).
- Alternate mode facilities (e.g. transit).

<u>Traffic Signals</u>

- Visibility and conspicuity of signal displays on approach to and at the intersection (including a sufficient number of indications, recommended one per lane over each lane).

- Placement of signal heads (horizontal and vertical; within the drivers cone of vision).
- Operations (vehicular volumes, level of service, queue lengths, volume/capacity etc.).

Signing

- Advance intersection signing (warning, lane use).
- Advance and turn-off roadway identification signing (lane use, route guidance).
- Signing at the intersection (regulatory and guide).

Pavement Markings

- Proper lane line and edge line markings based on intended lane uses.
- Transverse markings as appropriate (stop lines, horizontal signing, and supplemental legends/symbols).

Illumination and Delineation Devices

- Roadway illumination and luminaire poles.
- Reflective guidance devices (guide posts, post mounted delineators, etc.).

Roadside Features

- Guide rail systems, end treatments, and crash cushions (within the roadway clear zone).
- Potential unprotected roadway and/or roadside hazards.

Site Operations and Road User Interactions

- Road user operations and interactions from the perspective of all users (pedestrians, bicyclists, motorcycles, trucks, buses, automobiles etc.).
- Human factors (positive guidance principles).
- Traffic speed and classification.
- Traffic patterns and behavior from the perspective of all road users.

FHWA published RSA Guidelines in 2006 to help safety professionals conduct a valid and successful RSA. The Guidelines include an intersection-specific prompt list that could prove valuable in reviewing a signalized intersection.[72]

6.2 QUANTITATIVE APPROACH

The road safety management process systematically identifies deficient locations from safety perspectives and addresses safety problems at these locations. The following sections detail the road safety management process.

6.3 NETWORK SCREENING OR SELECTION OF AN INTERSECTION

In selecting an intersection for a detailed safety analysis, the key questions are:

- What is the safety performance of the location in comparison with other similar locations?
- Is the safety performance at the location acceptable or not acceptable?

Selection of an intersection may be the result of a systemic network screening of all signalized intersections in a jurisdiction or a complaint received by the traffic engineer in a jurisdiction. This section briefly describes most commonly used techniques for selecting one or more intersections that may have potential for safety improvements. This section also highlights the advantages and disadvantages of these techniques. It should be noted that the poor safety performance of an intersection (i.e., a sudden spike in frequency of crashes) during a few months or a year should not warrant selection of the intersection for detailed review, because it is likely that crash frequency will decrease in the next few months. This term is referred to as “regression to the mean.”

The crash history of a signalized intersection is the key indicator of its safety performance and is the focus of the remainder of this section. The network screening techniques for evaluating crash performance vary from basic to the complex. They may compare the safety performance of a single signalized intersection to another group of similar intersections or serve as a screening tool for sifting through a large group of sites and determining which site has the most promise for improvement.

Many jurisdictions carrying out a review of safety at a signalized intersection will usually have a crash database that provides information on the location, time, severity, and other circumstances surrounding each crash reported by police or the parties involved. Crash data in this form can provide the traffic engineer with a quick assessment of safety at a location. The crash data is critical to the overall road safety management process. As a result, it is important for the traffic engineer to fully understand the crash data processing practices in a jurisdiction. For example, it is important to know what types of crashes are non-reportable. It is also critical to know the methodology for assigning crashes to intersections. In some jurisdictions, intersection-related crashes are assigned to the legs of intersections, and in other jurisdictions these crashes are directly assigned to the intersections.

Once data are available, the most common method of network screening is to compare the crash history of each site to other similar locations. For signalized intersections, similar intersections should have the same number of approaches as the site being examined; sites with different traffic control devices and layouts can be expected to have differing levels of safety. Surrounding land use will also have a significant effect on crash frequency, with intersections in urban areas having a different crash profile than intersections in rural areas. Finally, comparisons with sites that are located in other jurisdictions may be tainted by differing crash reporting thresholds, enforcement, predominant land use, vehicle mix, road users, climatic conditions, or other unknown factors; results of such a comparison should be tempered with caution.

With these in mind, different methods of using crash data to conduct network screening and assess safety performance of a site are discussed in the following sections, highlighting their benefits and drawbacks. The different methods to be discussed are:

- Average annual crash frequency.
- Crash rate.
- Critical rate.
- Equivalent property damage only (EPDO) average crash frequency.
- Excess predicted average crash frequency using safety performance functions (SPFs).
- Excess expected average crash frequency with empirical Bayes adjustment.

Chapter 4 of the HSM provides details of the above methods. Also, the HSM provides additional techniques for network screening. However, the techniques provided in this Guide are the most commonly used techniques in practice.

6.3.1 Average Crash Frequency

Traditionally, traffic engineers used (and many still use) a frequency-based method of identifying and evaluating the safety of a site.[71],[73] Past average annual observed crash frequencies at a site over a certain time period may be used to compare and rank the site against crash frequencies at a reference group (i.e., a group of locations with similar characteristics). Many jurisdictions produce a top 10 list of the intersections producing the highest average crash frequency in their jurisdictions and concentrate all of their efforts at reducing crashes at these sites.

The average crash frequency method may also be used to screen candidate sites for improvements. The average crash frequency at the site may be compared to the average crash frequency for the reference population to calculate a potential for improvement.

The study period is often 3 to 5 years in safety analyses. Relatively short periods of time, such as one year of crash data, are not recommended as the basis for a safety intervention. Because crashes are relatively rare events, a high crash frequency in any given year at a particular intersection may be simply a random fluctuation around a much lower long-term average at the site. In the next year or series of years, the crash frequency may drop without any safety intervention at all. This phenomenon is referred to as regression to the mean. Regression to the mean may be minimized by using data collected over a longer period of time (3 to 5 years) when evaluating the site. Site selection based on multiple years of crash data will provide a truer picture of the crash profile of the intersection and avoid errors that can result from looking at crash history over a short period.

Apart from regression to the mean, there are several other disadvantages to using crash frequency as the sole means of evaluating safety at a site. First, a high crash frequency may not necessarily mean that a site is truly in need of safety improvement. It is known that sites with higher volumes will have a higher crash frequency than sites with lower volumes. Therefore, sites ranked simply by crash frequency will invariably end up with higher volume sites at the top of the list. Second, the method does not address the severity of crashes at the site. Failing to consider severity may result in the identification of sites with high numbers of minor crashes, while ignoring sites with fewer but more severe crashes. The approach results in a failure to identify sites at which the public has greater risk of injury or death.

6.3.2 Crash Rate

The crash rate method improves upon the average crash frequency in that it normalizes the frequency of crashes with the exposure, as measured by traffic. Crash rates are calculated by dividing the total crash frequency for a period of time by the estimated average annual daily traffic (AADT) of vehicles entering from all approaches in that time period. Crash rate provides an improved yardstick for comparison between sites. As with average crash frequency, a crash rate for an intersection undergoing a safety assessment may be compared to similar intersections (signalized, same number of legs, same range in AADT). The intersection may be ranked to produce a top 10 list, or a threshold value may be used above which a detailed safety analysis is warranted. Using a crash rate will account for the effect that volume has on crash frequency.

However, using a simple crash rate to screen locations has several disadvantages. First, using a crash rate to rank sites that have different volumes requires the assumption that crash frequency and volume have a linear relationship, but research suggests that this is not the case. Lower volume sites tend to experience a higher crash rate. Ignoring this fact means that low volume sites may appear less safe than their higher volume counterparts. Second, crash rates, as with crash frequency, do not consider crash severity. Sites with a high crash rate may have relatively few severe (fatal and injury) crashes. Last, as crash rates are calculated from crash frequency, which fluctuates around a long-term average and experiences regression to the mean, a site might be ranked high on a list due to a recent period with an unusually higher number of crashes. If crash rates are being used to screen out candidate sites for safety improvements, it is recommended that a study period between 3 to 5 years be selected.

6.3.3 Critical Rate

The critical crash rate method has been widely used among traffic engineers. In this method, the observed crash rate at a site is compared with a critical crash rate unique to each site. The critical crash rate for a site is a function of the average crash rate of a reference group associated with the site, the traffic volume of the site, and a desired level of confidence. In this method, sites where the crash rates exceed the critical rate require further detailed analysis in the diagnosis step, which is the next step of the road safety management process.

The critical crash rate method is more robust than using average crash frequency or crash rate alone, as it provides a means of statistically testing how different the crash rate is at a site when compared to a reference group. The desired level of confidence may vary depending on the preference of the user.

Disadvantages of using this method are that it still does not consider the severity of the crashes and assumes that traffic volume and crashes have a linear relationship. In addition, this approach does not consider regression to the mean.

6.3.4 Equivalent Property Damage Only (EPDO) Average Crash Frequency

In the above discussion, sites were considered for further analysis if the crash frequency and rate were particularly high. As indicated, a weakness with these methods is not considering the severity of the crashes involved. The crash severity method considers the distribution of crash severity for each site under consideration. A typical approach is through the use of the EPDO score. It attaches greater importance, or weight, to crashes resulting in a serious injury or a fatality, lesser importance to crashes resulting in a moderate or slight injury, and the least importance to property-damage-only crashes.

The HSM suggests using the ratio of the societal cost of crashes over the societal cost of PDO crashes as weighting factors to calculate an EPDO score for each site. Exhibit 6-2 shows the suggested societal crash costs and EPDO weight factors by the HSM.

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

Exhibit 6-2. Societal crash costs and EPDO weights.[71]

Depending on local considerations, the above weighting system may be modified to reflect actual values in terms of cost, such as property damage, lost earnings, lost household production, medical costs, and workplace costs. A comparison with similar intersections (signalized, same number of legs, same range of AADT) may be done by calculating the EPDO score for similar sites to the one being considered. The EPDO score will explicitly consider the severity breakdown of crashes, providing greater weight to fatal and injury crashes over PDO crashes. The traffic engineer should be aware, however, that because the severity of a crash is associated with higher speeds, signalized intersections on roads with a higher operating speed, such as in a rural location, will likely have a higher EPDO score than those in urban areas. This may result in a bias that emphasizes higher speed locations. In addition, as with rankings based on crash frequency and rate, regression to the mean will be an issue if the study period chosen is short.

6.3.5 Relative Severity Index

Monetary crash costs are assigned to each crash type and the total cost of all crashes is calculated for each site. An average crash cost per site is then compared to an overall average crash cost for the site's reference population. The overall average crash cost is an average of the total costs at all sites in the reference population. The resulting Relative Severity Index (RSI) performance measure shows whether a site experiences higher crash costs than the average for other sites with similar characteristics. Strengths of this method include the simplicity of the analysis and the consideration of collision type and crash severity. Weaknesses include lack of Regression-to-the-Mean bias or traffic volume considerations. This type of analysis can also overemphasize locations with a small number of severe crashes depending on weighting factors, and it can prioritize low-volume, low-collision sites.

6.3.6 Excess Predicted Average Crash Frequency Using Safety Performance Functions

In this technique for network screening, average crash frequency at a site is compared with a predicted average crash frequency, obtained from an SPF. If the observed average crash frequency exceeds the predicted average crash frequency at a site, the site is flagged for further analysis. The SPF equation presents the mathematical relationship between crash frequency and volume for a reference group (e.g., 4-leg signalized intersections in a jurisdiction). When crash frequency and volume are plotted, an equation can be developed that is represented by a curve that is the best fit possible through the various points. Generally, SPFs demonstrate that the expected number of crashes increases as traffic volume increases.

The advantages of this method are more accurately calculating the potential for safety improvement and acknowledging the complex, non-linear relationship between crash frequency and volume. Disadvantages are that this method is relatively complex and still does not acknowledge the random variation of crashes.

As part of the HSM, SPFs for intersections have been developed based on data obtained from a number of states in the U.S. Chapter 10, 11, and 12 of the HSM include these SPFs. The SPFs in the HSM were classified based on the surrounding area land-use (i.e., rural, suburban, and urban), geometric configuration of intersections (i.e., 3-leg and 4-leg), traffic control device of intersections (i.e., traffic signal and stop control), and functional classification of the main roadway.

It is advisable to develop SPFs for intersections in each jurisdiction based on the local intersection characteristic (e.g., number of approaches, traffic control device, and adjacent land-use). Road agencies require intersection characteristic data, traffic volume in the form of entering AADT volumes, and crash data. The traffic volume data and crash data need to be available for 3 to 5 years for each location. It should be noted that SPFs can be borrowed from similar jurisdictions (jurisdictions with the same network characteristics, traffic characteristics, weather conditions, driver population, and driving behavior).

6.3.7 Excess Expected Average Crash Frequency with Empirical Bayes Adjustment

Each of the above methods only considers past crash history, either by ranking and selecting a candidate site for further crash analysis or by determining whether a particular intersection under study has a crash problem. Using crash history alone is flawed because the frequency of crashes from year to year will randomly fluctuate about a long-term average (regression to the mean). Improved methods have evolved that identify high-risk sites that may benefit from remedial treatment(s), particularly the empirical Bayes (EB) method. Many jurisdictions are already employing the EB method.

The EB method calculates expected crash frequencies through a combination of observed and predicted crash frequencies. The predicted crash frequencies are derived through the development of an SPF.

The pivotal concept upon which contemporary methods for conducting proper road safety evaluations depend is the EB method. It is superior to traditional methods because it:

- Considers regression to the mean.
- Produces more stable and precise estimates of safety.
- Allows for estimates over time of expected crashes.

In case of a network screening for the entire jurisdiction, excess expected average crash frequency is calculated for all intersections in the study area. Expected crash frequency is the difference between the expected collision frequency and the predicted collision frequency, which is obtained from the SPF. The predicted collision frequency represents the overall safety performance of similar intersections. If a site has positive excess, it shows that the site has a potential for safety improvement and merits further detailed investigation. In a network screening exercise, sites are ranked based on their excess crash frequency. The same approach can be used to identify whether further analysis is warranted for a specific intersection.

6.3.8 Summary

The above section detailed various methods of assessing the safety of a location through consideration of its crash history and comparison with other similar sites. Care must be taken to ensure that the site is being compared with sites that should have a similar level of safety (i.e., sites with a traffic signal and the same number of legs). Methods such as crash frequency and crash rate may provide a simple and quick way of diagnosing a potential safety problem, but should be used with caution. The traffic engineer may consider using the critical rate method or the EPDO average crash frequency method as these provide a more balanced assessment of safety. Developing an SPF, either on its own or for use in applying to the EB method, is a much more sophisticated method of evaluating safety at a site. Given the availability of SPFs in many jurisdictions in the U.S. and Canada, as well as through the HSM, road agencies are encouraged to use the excess expected average crash frequency with EB adjustment methodology for network screening. Exhibit 6-3 presents a summary of the relative merits and drawbacks of each method.

Method	Advantages	Disadvantages
Average crash frequency	Simple to use Easy for the public to understand	Biased toward high-volume sites Does not consider exposure Severity not considered Regression to the mean not addressed
Crash rates	Simple to use Considers exposure	Biased toward low-volume sites Requires volume data Assumes crashes and volume have linear relationship Severity not considered Regression to the mean not addressed
Critical rate	Relatively simple Considers exposure Applies a recognized statistical method	Requires volume data Assumes crashes and volume have linear relationship Severity not considered Regression to the mean not addressed
Equivalent property damage only average crash frequency	Relatively simple Considers crash severity	Does not account for exposure May overemphasize sites with a low frequency of severe crashes depending on weighting factors used Regression to the mean not addressed
Excess predicted average crash frequency using safety performance	More accurate Considers exposure Acknowledges that crashes and volume have a nonlinear relationship	Requires volume data Regression to the mean not addressed Labor intensive Difficult for public to conceptualize
Excess expected average crash frequency with empirical Bayes adjustment	Most accurate Considers exposure Acknowledges that crashes and volume have a nonlinear relationship Addresses regression to the mean	Requires volume data Difficult for public to conceptualize

Exhibit 6-3. Common methods of assessing safety at a location.

6.3.9 Case Study

The purpose of this case study is to show the application of the network screening step of the road safety management process. This case study will be completed throughout this chapter as other steps of the road safety management process are described.

A County has conducted network screening using the excess expected average crash frequency with EB adjustment methodology for all signalized intersections within the county. Exhibit 6-4 shows the results of the network screening for the top 10 intersections that have been ranked based on Potential for Safety Improvement (PSI). The PSI is the difference between expected crashes (obtained from the EB method) and predicted crashes (obtained from SPFs).

This table is a typical output of a network screening exercise. The county then chooses to further analyze these intersections to address potential safety issues. As a case study, the first intersection presented in this exhibit STREET A @ ROAD B will be further analyzed and referred to throughout this chapter.

Rank	Description	Average AADT Major	Average AADT Minor	Intersection Type	Traffic Control	Study Period (Years)	Total Observed Crashes	Total Predicted Crashes	Total Expected Crashes	Potential for Safety Improvement (PSI)
1	STREET A @ ROAD B	27299	11341	4-legged	Signalized	5	90	52.337	87.610	35.273
2	STREET G @ ROAD H	30584	2935	4-legged	Signalized	5	42	19.599	38.568	18.969
3	STREET P @ ROAD Q	27154	3258	4-legged	Signalized	5	38	19.672	35.201	15.529
4	STREET R @ ROAD S	36966	5045	4-legged	Signalized	5	47	33.884	45.757	11.873
5	STREET A @ ROAD D	8132	4711	4-legged	Signalized	5	26	11.920	22.772	10.852
6	STREET E @ ROAD F	39732	8639	4-legged	Signalized	5	64	54.090	63.390	9.300
7	STREET G @ ROAD Q	52765	18028	4-legged	Signalized	5	122	115.747	121.814	6.067
8	STREET R @ ROAD H	27815	3773	4-legged	Signalized	5	28	22.414	27.237	4.823
9	STREET C @ ROAD D	38180	4506	4-legged	Signalized	5	37	31.683	36.465	4.782
10	STREET C @ ROAD F	32025	25576	4-legged	Signalized	5	113	109.720	112.897	3.177

Exhibit 6-4. Top 10 ranked signalized intersections in a county.

6.4 DIAGNOSIS

The previous section discussed different tools used to select a candidate intersection for a safety evaluation. At a certain point, the traffic engineer will conclude, based on past crash history, that there is a safety concern and a significant potential for safety improvement at the location in question. It should be noted that some traffic engineers may have completely bypassed the entire first step of this process (in determining a candidate intersection for safety improvements) because they have been asked to carry out a safety analysis of an intersection due to:

1. Safety complaints or concerns raised by others (other departments, local politicians, the public).
2. Planned reconstruction that would make it worthwhile to carry out a safety evaluation and improvements.
3. Identified operational deficiencies.

This section will discuss how the traffic engineer may correctly diagnose what types of safety problems/issue may be present at an intersection. Diagnosis of a particular safety concern can then lead to appropriate countermeasures.

The following four-step process can be used to diagnose safety problems at a site:

- Step 1 – Conduct Safety Data Review.
- Step 2 – Assess Supporting Documentation.
- Step 3 – Assess Field Conditions.
- Step 4 – Define Problem Statement(s).

The above process is consistent with the recommendations of Chapter 5 of the HSM.

6.4.1 Step 1 – Conduct Safety Data Review

In conducting a safety diagnosis at a signalized intersection, the traffic engineer seeks to understand any patterns in the crash data and identify contributing factors of crashes within the functional boundary of the intersection.

The safety data review can be conducted in three stages:

1. Assemble crash data.
2. Describe crash statistics.
3. Summarize crashes by location.

Assemble Crash Data

Crash data used for diagnosing safety at a signalized intersection should represent 3 to 5 years of crash data. It should include all crashes reported as occurring at or related to the intersection's influence zone. The relationship of crashes to intersections is often expressed in the Model Minimum Uniform Crash Criteria (MMUCC) Guideline [74] in "Relation to Junction."

Most agencies have electronic databases from which the following characteristics of crashes associated with the subject intersection can be extracted:

- Crash identifiers such as date, time of day, and time.
- Severity: which is often represented in the KABCO scale, defined as follows:
    - K-Fatal injury: an injury that results in death.
    - A-Incapacitating injury: any injury, other than a fatal injury, that prevents the injured person from walking, driving, or normally conducting the activities the person was capable of performing before the injury occurred.

  - B-Non-incapacitating evident injury: any injury, other than a fatal injury or an incapacitating injury, that is evident to observers at the scene of the crash in which the injury occurred.
  - C-Possible injury: any injury reported or claimed that is not a fatal injury, incapacitating injury, or non-incapacitating evident injury and includes claim of injuries not evident.
  - O-No Injury/Property Damage Only (PDO).
- Crash Type.
  - Rear-end.
  - Sideswipe.
  - Angle.
  - Turning.
  - Head-on.
  - Fixed object.
- Direction of travel before crash.
- Sequence of events.
- 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, dark-lighted, dark-not lighted.
  - Weather condition at the time of the crash – clear, cloudy, fog, rain, snow, ice.
  - Impairments of parties involved – alcohol, drugs, fatigue.

If available, the original police reports should be used to gather anecdotal comments written by police officers at the crash scene and firsthand accounts of the crashes from involved parties and eyewitnesses.

Describe Crash Statistics

Once crash data for the intersection has been extracted from the database, it is important to identify patterns and potential contributing factors from the historical crash data. Three techniques are often used by practitioners to identify crash patterns and contributing factors of crashes in a safety diagnosis exercise:

1. Develop visualization tools – graphs and charts can assist the traffic engineer in visualizing crash frequencies in terms of various crash attributes.
2. Conduct a crash cluster analysis – the crash cluster analysis process involves a manual screening of crash attributes. In this type of analysis, the object is to identify crash clusters for each crash attribute, such as crash impact type, road surface condition, lighting condition, etc.
3. Conduct over-representation analysis – over-representation analysis is used to determine whether the proportion of a characteristic found at a specific intersection is the same as that found in a group of similar sites. Identification of abnormal trends can lead toward possible solutions. To ensure that the determination of overrepresentation is valid, appropriate statistical techniques should be employed. The chi-square method is one of the methods for identifying over-representation at a site. The HSM refers to this analysis as “Specific Crash Types Exceeding Threshold Proportion,” and details of this technique can be found in Chapter 4 of the HSM.

The crash characteristics should be reviewed for over-representation through comparison with crash characteristic information representing the typical experience of a signalized intersection. Examples of questions that can be answered by the above three techniques to identify over-representations or patterns in the crash attributes are highlighted below.

An examination of crash pattern by season, day of week, or time of day may be helpful in finding patterns that relate to the general travel patterns of road users passing through the intersection. Seasonal patterns, indicating a higher-than-expected proportion of crashes occurring during a particular time of year, may coincide with an influx of unfamiliar drivers to an area—as may be the case in resort areas and/or areas with a significant number of tourist attractions. Day of week and time of day patterns should be examined. Morning/afternoon weekday over-representation may suggest crash patterns related to commuting traffic (coinciding with the morning and afternoon rush hours). A late night/early morning/weekend overrepresentation may suggest problems with drunk drivers.

Over-representation in crash severity will highlight a location that has an unusually high proportion of fatal and/or injury crashes. A higher proportion of fatal and/or injury crashes may suggest a problem with higher operating speeds.

Summarize Crashes by Location

The end product of the descriptive crash statistics will be a set of characteristics identified as being over-represented. The next step is to relate the patterns and over-represented characteristics of crashes to a particular approach. A crash diagram can be used to create such relationship. A crash diagram is a two-dimensional plan view representation of the crashes that have occurred at a site within a given time period. In a crash diagram, each crash type is represented by combinations of arrows and symbols. Exhibit 6-6 shows proposed symbols for classification of various crash types.

6.4.2 Step 2 – Assess Supporting Documentation

The main goal of this step is to gather and review documented information or personal opinion about the site. This information can be gathered from previous studies relevant to the subject intersection, complaints filed with the road agency by residents, or consultation with the authorities who have local knowledge about the study area. This is an important step in which the crash patterns can be studied in the context of the past changes in the study area. For example, an increase in pedestrian crashes in the past 3 years can be correlated with the opening of a new school in the vicinity of the subject intersection 3 years ago.

The HSM suggests that the following types of information may be useful as supporting documentation to the diagnosis of safety problems at a site:

- Current traffic volumes for all travel modes.
- As-built construction plans.
- Relevant design criteria and pertinent guidelines.
- Inventory of field conditions (e.g. traffic signs, traffic control devices, number of travel lanes, posted speed limits, etc.).
- Relevant photos.
- Maintenance logs.
- Recent traffic operations or transportation studies conducted in the vicinity of the site.
- Land use mapping and traffic access control characteristics.
- Historic patterns of adverse weather.
- Records of public comments or complaints on transportation issues.
- Roadway improvement plans in the site vicinity.
- Anecdotal information about travel through the site.

Appendix 5B of the HSM provides a list of questions and data to consider when reviewing past site documentations.

6.4.3 Step 3 – Assess Field Conditions

To supplement the analysis and diagnosis using crash data, a site visit or series of site visits should be undertaken. Before initiating site visit(s), the study team should be aware of:

- Whether certain crash characteristics were over-represented based on the analysis of crash over-representation.
- Which areas within the intersection's sphere of influence are showing unusual clusters of crashes.
- If available, what operational problems have been identified as part of the operational analysis.

The purpose of the site visit is to gather additional information that can aid in pinpointing potential underlying cause or causes of the abnormal crash patterns (Exhibit 6-6). The site visit should be undertaken to:

- Observe driver/road user behavior during the following conditions:
    - Peak and off-peak periods.
    - Evening/night (as necessary).
    - Wet weather (as necessary).
    - Weekend and special events (as necessary).
- Photograph relevant features. Consideration may be given to using video recording to capture each intersection approach from the driver's perspective.
- Review the site from the perspective of all users, including motorists, pedestrians, and bicyclists. This includes observing motorist, bicyclist, and pedestrian circulation and identifying origins and destinations in the vicinity.
- Check for physical evidence of crashes or near-crashes, such as vehicle damage to street furniture, signs and other objects near the roadway, skid marks on the intersection approaches, and tire marks on the shoulder or ground adjacent to the roadway.
- Conduct a conformance/consistency check: an assessment of signs and traffic control, markings, delineation, geometry and street furniture to ensure standard application and consistency and that all traffic control devices are in conformance with local, State, and Federal standards.

One of the key tasks the study team will wish to conduct during the site visit is a positive guidance review.[9] A positive guidance review uses an in-depth knowledge of human factors and the driving task to screen roadways for:

- Information deficiencies.
- Expectancy violations.
- Workload issues.

Each of the above may contribute to the occurrence of driver error and crashes.

Information deficiencies occur when information that the driver needs to carry out the driving task safely is missing. An example may be inadequate signing/pavement marking for a designated right-turn lane that traps drivers intending to proceed straight. Attempts to move over to the through lane can cause queuing and possible rear-end and sideswipe conflicts.

Expectancy violations occur when a driver encounters a traffic control or roadway design that conflicts with his or her expectations. The traffic engineer should structure expectancies about treatments at similar locations.[75] The key to effective expectancy structuring is uniformity and standardization.

Standard devices that are inconsistently applied can create expectancy problems for drivers. A prime example of this is the use of a left-hand exit amidst a series of right-hand exits. Positive guidance seeks to address this expectancy violation through clearly communicating to the driver that a left-hand exit is ahead.

Workload issues occur when the driver is bombarded with too much information, increasing the likelihood of error. This may occur at an intersection with an abundance of signing, pavement markings, traffic signals, and pedestrian and bicycle activity. All of the above may be further complicated if the operating speed on the approaches is high, giving the driver even less time to sort through and comprehend what to do to get safely through the intersection and on to the intended destination. The traffic engineer should seek to reduce the complexity of the information the driver receives at the intersection or to spread information by using advance signs.

Although positive guidance techniques are generally applied to the driving task, these concepts and tools can easily be considered from the perspective of all road users. Positive guidance is a holistic approach treating the roadway, the vehicle, and the driver as a single, integrated system. It recognizes drivers as the information gatherers and decision-makers within the system and focuses attention on assuring that they get the information they need, when they need it, in a form they can understand, in time to make rapid, error-free decisions and take appropriate actions. Creating and sustaining a supportive information environment on the roadway is the goal of positive guidance.

In conducting a positive guidance review, the analyst attempts to view the roadway through the eyes of an average driver, postulating what the driver's perceptions, interpretations, expectations, and actions might be. This is done to formulate theories and possible explanations regarding the cause or causes of previous or potential conflicts and/or crashes.

Positive guidance normally focuses on low-cost, information-oriented improvements that can be implemented quickly, either as solutions in and of themselves or as interim improvements until a more definitive solution can be achieved. It may also identify the need for additional investigation, in the form of conventional engineering analysis, to support theories regarding the contributory causes of crashes, and to justify mitigation measures.

Appendix 5C of the HSM provides a process required for preparation for a field assessment undertaking, and Appendix 5D of the HSM provides a field review checklist for signalized intersections.

It should be noted that an RSA, which was described in the qualitative approach for safety review of signalized intersections, always includes a field review for existing intersections (obviously a field review is not possible for intersections in planning and design stages). The process for conducting an RSA field review described in this section can be followed.

6.4.4 Define Problem Statement(s)

A set of one or more clear problem statements should be developed. The problem statement(s) are developed on the basis of the crash analysis (i.e., evidence of over-representation among a crash subgrouping) and should be supported through the site visit and any further analysis. The problem statement should correlate crash patterns observed with potential contributing factors.

The problem statement helps clearly define safety concerns at the location. Circumstances associated with these safety concerns may be mentioned along with possible causal factors. The problem statement may be multifaceted and encompass the physical and/or operational attributes of the intersection, road user behavior and/or actions, environment and/or temporal conditions, as well as transitory or peripheral events. In many instances, the study team will identify several problems or issues.

Example problem statements are given in Exhibit 6-5.

Problem Statement #1 Rear-end crashes and crashes occurring between 3 and 6 p.m. are over-represented. The crash diagram shows that almost all of these occur on the westbound approach. Based on the site visit, the initial problem statement is that these are occurring due to: • Lack of traffic signal visibility for westbound drivers. • Movement into and out of a commercial driveway on the near side of the intersection. • A polished pavement surface on this approach. • Glare from the afternoon sun.
Problem Statement #2 Fatal and injury crashes were over-represented, and four fatal or injury crashes involved pedestrians. The crash diagram indicates that all occurred on the southwest corner of the intersection and are related to the right-turn lane channelization. Based on the site visit and subsequent further analysis, the initial problem statement is that these are occurring due to: • The design of the right-turn channelization operating under YIELD control, which contributes to excessive driver speed. • Drivers failing to yield to pedestrians. • The presence of a bus shelter that partially blocks the view of the crosswalk.

Exhibit 6-5. Example problem statements.

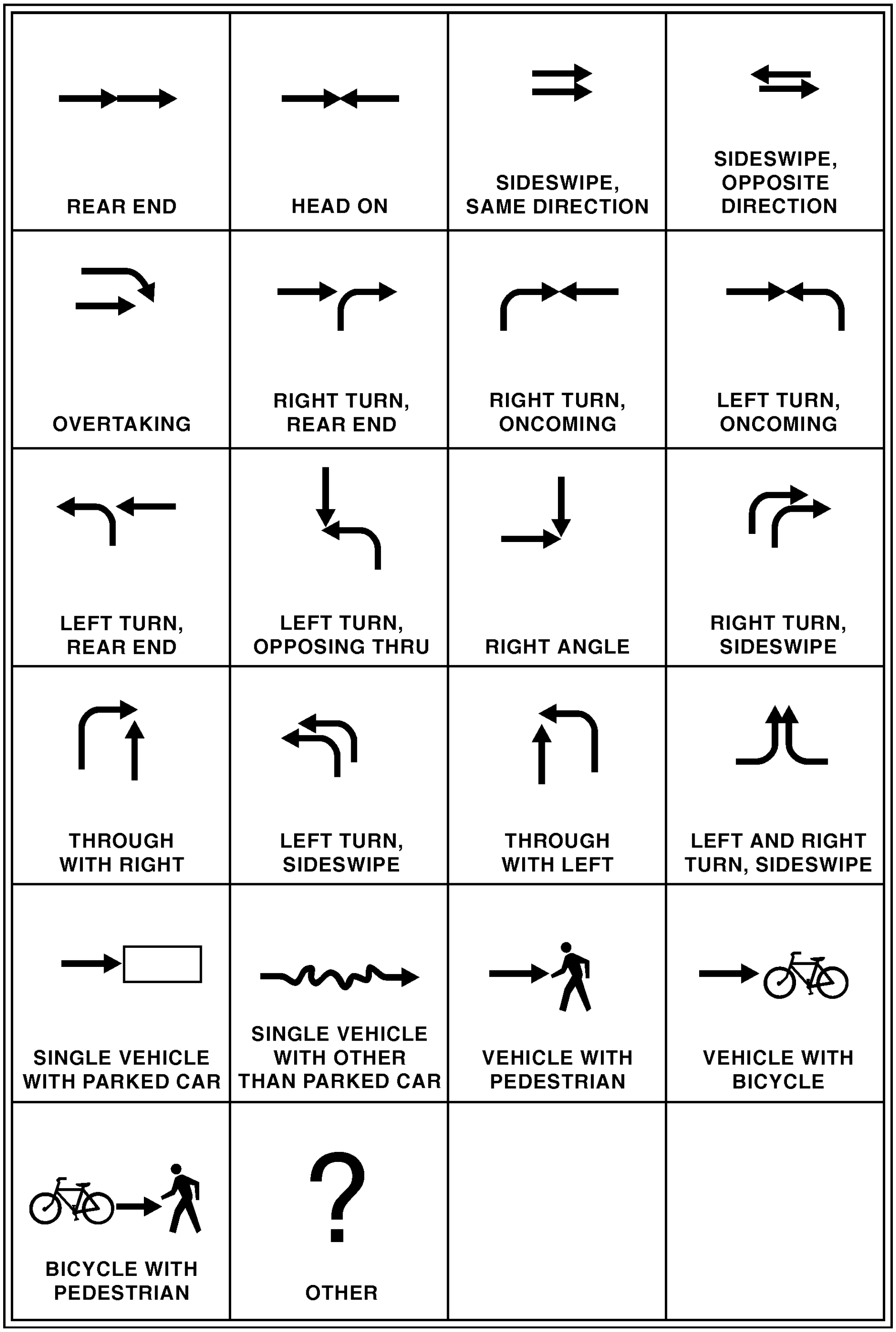

Exhibit 6-6. Possible taxonomy for crash type classification.

6.4.5 Case Study

The purpose of this case study is to show the application of the diagnosis step of the road safety management process.

The intersection of Street A and Road B (shown in Exhibit 6-7) was ranked first in the network screening exercise of all 4-leg signalized intersection in the county, as shown in the previous section. It was identified that the potential for safety improvement is 35.3 crashes per a 5 year period. The intersection characteristics include:

Geometric Characteristics

Street A (a major east-west arterial roadway), immediately east of Road B, is essentially flat and straight vertically and horizontally; to the west of Road B, Street A contains a horizontal curve and vertical curve. The vertical curve exists immediately west and in advance of the intersection, resulting in a vertical crest for eastbound approaching road users. Road B (a minor north-south arterial roadway) is essentially flat and straight on the approach to Street A.

Traffic Control

The intersection contains two mast arm-mounted primary signal displays for the through movements and a secondary signal display for the left-turning movements on all approaches. The signals are both horizontally and vertically located within the required mounting field of view, as per the FHWA MUTCD. The signal displays contain three-section, vertically arranged signal bulbs comprised of circular red, yellow, and green indications and are positioned over the appropriate lanes based on FHWA MUTCD 2009 guidance.[(1)]

Signing

Regulatory speed limit signs are present on all approaches to the intersection. Street name signs both for Street A and Road B are present on the primary signal pole for all approaches (far right quadrant of the intersection). Advance street name signing is present on both northbound and southbound approaches to the intersection Signal ahead warning signs are present on the northbound and southbound approaches to the intersection. The signs are all located appropriate distances upstream of the intersection.

Exhibit 6-7. Study intersection.
Source: Google, 2012

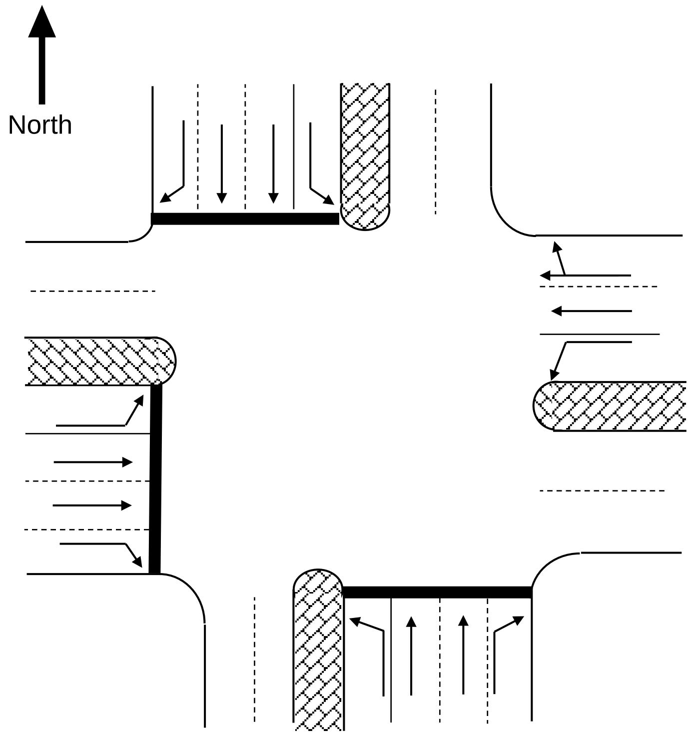

Exhibit 6-8. Lane configuration of the study intersection.

Step 1 – Safety Data Review

Assemble Crash Data

The County has provided crashes for the period of 2006 to 2010 to the traffic engineer. Exhibit 6-9 provides a summary of crashes in terms of severity, and Exhibit 6-10 shows the same crashes in terms of their impact type.

Crash Severity	Year					
	2006	2007	2008	2009	2010	Total
Fatal/Injury	3	10	8	1	3	25
PDO	10	15	18	14	8	65
Total	**13**	**25**	**26**	**15**	**11**	**90**

Exhibit 6-9. Crashes in the study intersection from 2006 to 2010, by severity.

Row Labels	2006	2007	2008	2009	2010	Grand Total
Angle	2	2	3	2	1	10
Rear End	6	14	14	8	5	47
Sideswipe	1	3	3	1	2	10
Turning	4	6	6	4	3	23
Grand Total	**13**	**25**	**26**	**15**	**11**	**90**

Exhibit 6-10. Crashes at the study intersection from 2006 to 2010, by impact type.

Descriptive crash statistics

Exhibit 6-11 shows crash frequencies in terms of crash types and road surface condition. Based on this exhibit, a significant number of rear-end and turning movement crashes have been identified at this intersection. There is also potential concern regarding the number of crashes during wet and slippery road surface conditions. However, to confirm whether such a problem exists, the proportions of road surface condition crashes at this intersection should be compared to similar intersections (over-representation analysis).

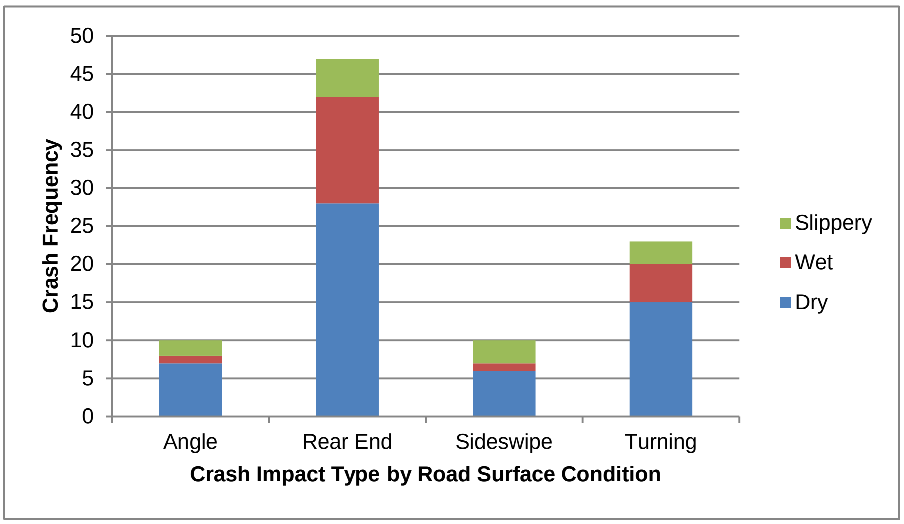

Exhibit 6-11. Crash frequencies in terms of crash impact types and road surface conditions.

Exhibit 6-12 shows crash frequencies in terms of crash impact types and light condition. This exhibit shows that most crashes occur during daylight. There might be some concerns related to turning movement crashes during dark hours of days. To be confident about these findings, an over-representation analysis should be conducted.

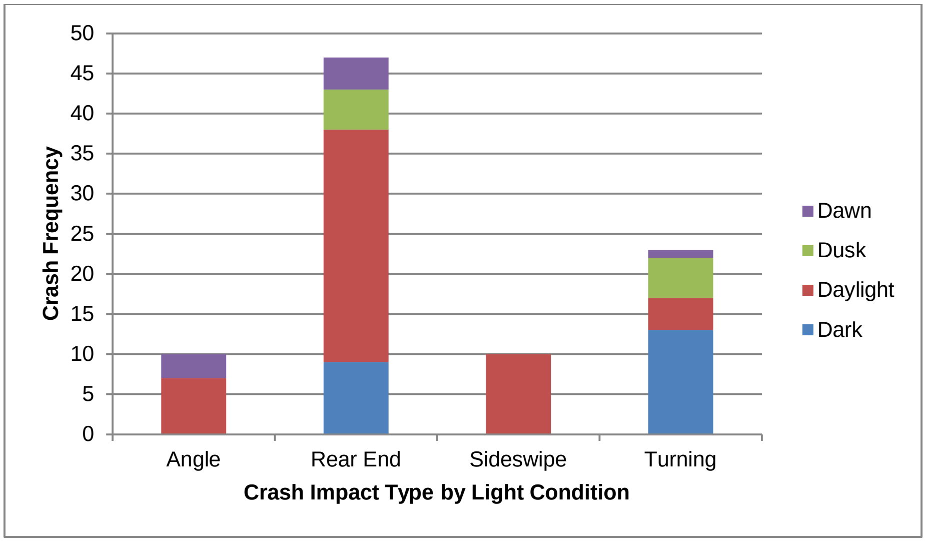

Exhibit 6-12. Crash frequencies in terms of crash impact types and light conditions.

The results of the proportional analysis (over-representation analysis) showed that the following crash attributes are over-represented at the study intersection:

- Angle crashes.
- Rear-end crashes.
- Turning movement crashes.
- Wet road surface condition.

Summarizing Crashes by Location

Exhibit 6-13 illustrates the crash diagram associated with the study area. In this diagram the crashes reviewed in the previous stage are related to each approach of the intersection. Different crash impact types are shown with different symbols. The number shown beside each crash cluster shows the number of crashes per each cluster. Red arrows in this diagram represent the at-fault vehicles. The crash diagram shows that most turning movements have occurred between eastbound left-turning vehicles and westbound through vehicles. Rear-end crash clusters dominantly exist on east and west approaches of the intersection. Angle crashes have occurred between southbound through vehicles and westbound through vehicles.

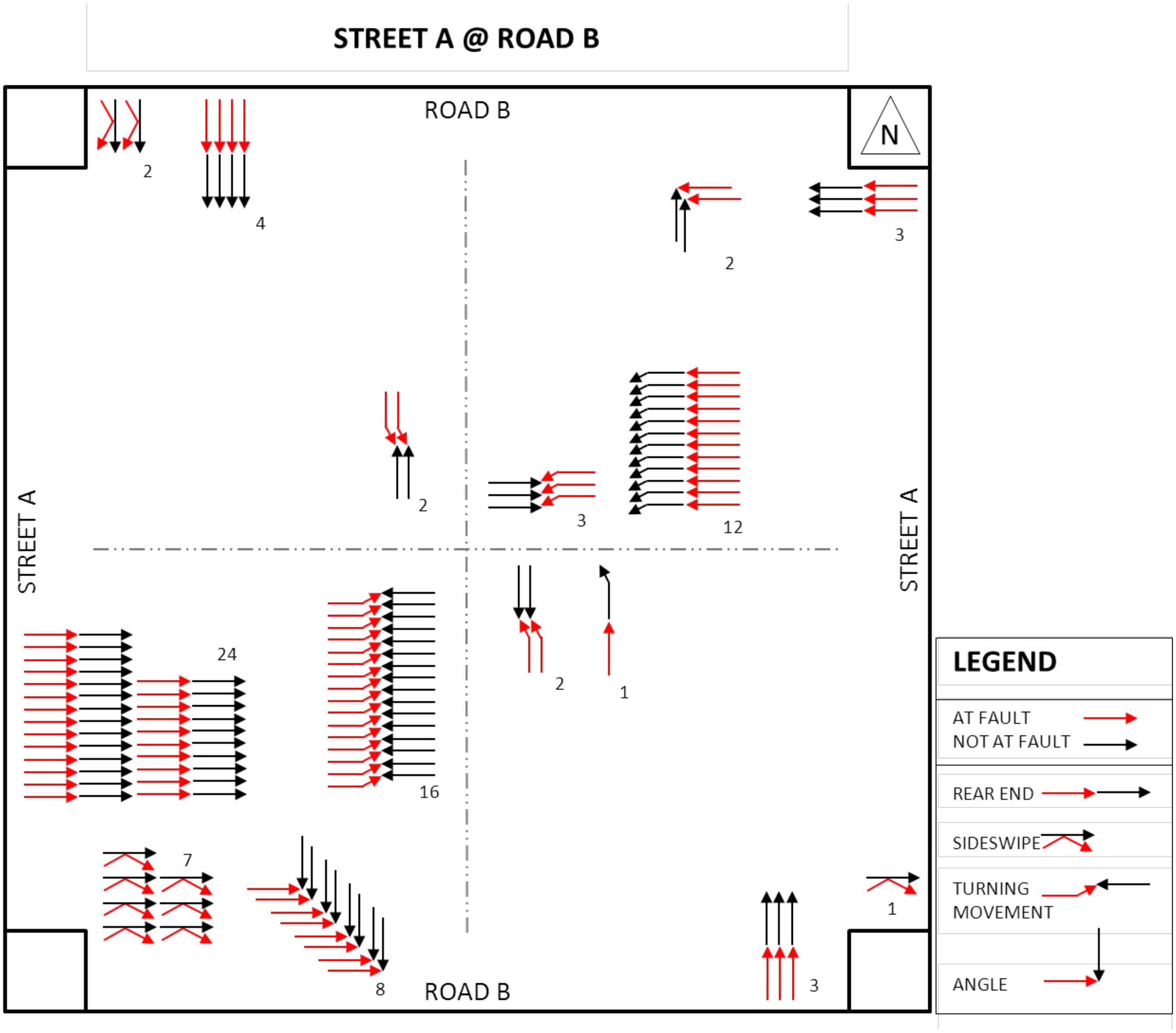

Exhibit 6-13. Crash diagram for the intersection of Street A and Road B.

Step 2 – Assess Supporting Documentation

- Speed limit on all approaches to the intersection is 35 mph.
- Entering AADT of the intersection is 53,866.
- The County has indicated that the following guidelines and manuals are relevant in this study:
  - The geometric design guideline pertinent to the study is the AASHTO Green Book – A Policy on Geometric Design of Highways and Streets.
  - All signing and other traffic control devices must conform to the latest edition of the MUTCD.
- Consultation with the County's traffic engineer revealed that the westbound left-turning vehicles have capacity challenges.

Step 3 – Assess Field Conditions

Exhibit 6-14 presents the findings of the field investigation. The field visit consisted of peak and off-peak visits as well as visits during day light and dark lighted.

Location	Findings
Street A, just west of and on approach to Road B	• Signal displays are inconspicuous on approach (signal bulbs are dull, and back plates are inconspicuous at night). • Vertical crest curve in advance of intersection – stopping sight distance measured and is inadequate. • Exclusive eastbound right-turn exit lane exists; however, no exclusive turn lane signs exist. Due to vertical crest curve, it is difficult to determine the lane configuration on intersection approach for drivers. • Polished and worn pavement surface on intersection approach. • The street name sign at the intersection is being obscured by auxiliary signal pole for opposing direction. • No advance street name signs exist on intersection approach. • No advance intersection ahead warning signs exist on intersection approach • Road user interactions (eastbound): red light running; high travel speeds (well in excess of posted speed limit); uncertain maneuvers made by road users, potentially due to non-present advance notice (signage); conflicts (near-misses) between eastbound road users, potentially leading to rear-end type as well as eastbound left-turning with westbound through-turning movement type crashes.
Street A @ Road B	• Road user interactions (westbound): conflicts (near-misses) between westbound left-turning and through-bound road users (potentially leading to rear-end type crashes).

Exhibit 6-14. Field investigation findings.

Step 4: Define Problem Statement

Exhibit 6-15 summarizes problem statements associated with the intersection of Street A and Road B. The crash patterns and over-represented crashes identified in Step 1 of the diagnosis process are correlated with potential contributing factors identified through assessment of supporting documents and assessment of field conditions.

Crash Attributes	Problem Statement
Angle: Eastbound through at fault, with southbound through movements. **Rear-end**: Westbound through at fault, with westbound left-turn movements. **Turning movement**: Eastbound left-turn at fault, with westbound through movements. **Rear-end**: Westbound through at fault, with westbound left-turn movements. **Wet Road Surface Conditions:** Westbound through vehicles contributing to rear-end crashes.	**Street A just west of, and on approach to, Road B** • Signal displays are inconspicuous on approach (signal bulbs are dull, and back plates are inconspicuous at night). • Vertical crest curve in advance of intersection – stopping sight distance measured and is inadequate. • Exclusive eastbound right-turn exit lane exists, however, no exclusive turn lane signs exist. Due to vertical crest curve, it is difficult to determine the lane configuration on intersection approach. • Polished and worn pavement surface on intersection approach. • The street name sign at the intersection is being obscured by auxiliary signal pole for opposing direction. • No advance street name signs exist on intersection approach. • No advance intersection ahead warning signs exist on intersection approach. • Road user interactions (eastbound): red light running; high travel speeds (well in excess of posted speed limit); uncertain maneuvers made by road users, potentially due to non-present advance notice (signing); conflicts (near-misses) between eastbound road users, potentially leading to rear-end type as well as eastbound left-turning with westbound through-turning movement type crashes, **Street A @ Road B** • Road user interactions (westbound): conflicts (near-misses) between westbound left-turning and through-bound road users (potentially leading to rear-end type crashes).

Exhibit 6-15. Problem statements.

6.5 SELECTING COUNTERMEASURES

After diagnosis, the next step in the road safety management process is countermeasure selection. The end product of the diagnosis process is one or more problem statements in which a crash pattern is related to a number of potential contributing factors. The objective of the countermeasure selection step is to develop countermeasures to address the contributing factors identified as part of the diagnosis step.

Countermeasures include all measures likely to decrease the frequency or severity of crashes identified as exhibiting an abnormal pattern (over-representation).

In Part III of this guide, the reader will find countermeasures (treatments) organized into five broad groups:

- System-wide treatments (Chapter 8).
- Intersection-wide treatments (Chapter 9).
- Approach treatments (Chapter 10).
- Individual movement treatments (Chapter 11).

For each treatment, there are references to possible crash groups that are likely to be positively affected through a treatment's implementation. At signalized intersections, the following crash patterns are most commonly identified:

- Rear-end crashes.
- Angle crashes.
- Left-turn or right-turn movement crashes.
- Nighttime crashes.
- Wet pavement crashes.
- Crashes involving pedestrians and bicyclists.

Exhibit 6-16 presents possible contributing factors and countermeasures for each of these types, along with the appropriate chapter.

The material presented in this section provides a range of options that could be selected, but is not fully comprehensive. It is not possible to develop a complete list of all potential crash treatments, because new tools and techniques for improving traffic safety are constantly being developed and adopted. It is important that the study team not limit itself to existing lists or tables of treatments. The team should consider a wide range of treatments (including those based on local practice) that may be beneficial, particularly when the crash pattern identified represents a unique situation.

Over the course of the above crash diagnostic analysis, site visits, and field analysis, the traffic engineer may have identified treatments that are of little cost and undoubtedly beneficial to improving safety at the intersection. Such treatments may relate to repairing sidewalks, removing sight obstructions, reapplying faded pavement markings, and relocating or adding new signs. These may be implemented without going through the process described below.

Crash Type	Possible Contributing Factors	Possible Treatment Group (Chapter)
Rear-end crashes	• Sudden and unexpected slowing or stopping when motorists make left turns in and out of driveways along corridor.	• Median treatments (Chapter 8)
	• Sudden and unexpected slowing or stopping when motorists make right turns in and out of driveways along corridor.	• Access management (Chapter 8)
	• Too much slowing and stopping along corridor due to turbulent traffic flow.	• Change signal control from pre-timed to actuated (Chapter 9)
	• Too much slowing and stopping along intersection approaches due to traffic-control issues. • Drivers caught in intersection during red phase due to inadequate traffic control or inadequate change and clearance interval. • Traffic signal not conspicuous or visible to approaching drivers, causing sudden and unexpected slowing or stopping movements.	• Change signal control from pre-timed to actuated (Chapter 9) • Red light camera enforcement (Chapter 10)
	• Sudden and unexpected slowing or stopping due to inadequate intersection capacity.	• Change signal control from pre-timed to actuated (Chapter 9) • Individual movement treatments (Chapter 11)
Angle crashes	• Drivers caught in intersection during red phase due to inadequate traffic control or inadequate change and clearance interval. • Traffic signal not conspicuous or visible to approaching drivers, causing drivers to get caught in intersection during red phase. • Drivers caught in intersection during red phase due to inadequate warning/inability to stop.	• Modify change and clearance intervals (Chapter 9) • Increase size of signal; Add supplemental signal heads; Provide backplates (Chapter 10)
Left-turn crashes	• Intersection cannot accommodate left-turn movements safely.	• Add single or multiple left-turn lane (Chapter 11) • Restrict turns (Chapter 11)
Nighttime related Crashes	• Poor nighttime visibility or light. • Poor sign visibility. • Inadequate channelization or delineation. • Inadequate maintenance. • Excessive speed. • Inadequate sight distance.	• Provide or upgrade illumination (Chapter 9) • Add channelizing islands (Chapter 10)
Wet pavement related crashes	• Slippery pavement • Inadequate pavement markings • Inadequate maintenance • Excessive speed	• High visibility crosswalks. (chapter 9) • Improve pavement surface. (chapter 10)
Crashes or conflicts involving bicyclists and pedestrians	• Either the intersection cannot safely accommodate the pedestrians and/or bicyclists, or motorists are failing to see or yield to their movements.	• Pedestrian, bicycle, and/or transit improvements (Chapter 9)

Exhibit 6-16. Crash types commonly identified, possible causes, and associated treatments.

The practitioner should generate a list of countermeasures (some of which may have been identified in this guide) that are based on local practice or are representative of a unique situation identified at the intersection through the diagnosis step. Before conducting the economic appraisal of each countermeasure, it is advisable to screen the countermeasures to narrow the options for the economic appraisal step.

The practitioner should generate a list of countermeasures (some of which may have been identified in this guide) that are based on local practice or are representative of a unique situation identified at the intersection through the diagnosis step. Before conducting the economic appraisal of each countermeasure, it is advisable to screen the countermeasures to narrow the options for the economic appraisal step.

One method of screening proposed countermeasure is to develop a matrix where each treatment is given a score within different categories based on the consensus among study team members. The individual score categories may be as follows:

- **Overall Feasibility:** How feasible would it be to implement the countermeasure? Would it involve a significant amount of work, time and/or coordination with police, maintenance staff, transportation planners, or the public? Straightforward treatments get positive scores. Difficult-to-implement countermeasures get negative scores.
- **Impact on Traffic Operations:** Is the countermeasure expected to improve the flow of traffic within the intersection influence area? Countermeasures that would improve traffic operations score positive. Countermeasures that would degrade traffic operations score negative.
- **Consistency with Local Practice:** Is the countermeasure consistent with local practice? Countermeasures that are familiar to the public and have known benefits score positive. Countermeasures that are unfamiliar and are largely untested score negative.

Scoring each countermeasure allows the study team to quickly determine which treatments are expected to have a positive or negative effect on the intersection. The long list of potential countermeasures then can be reduced to a short list of viable countermeasures. Based on a threshold score decided upon among the study team, the countermeasures may then be screened and those scoring poorly may be discarded.

6.5.1 Case Study

For the case study presented in the diagnosis step, Exhibit 6-17 shows a list of countermeasures proposed for the study intersection that can potentially address safety problems identified in the problem statements.

Countermeasure	Description
Heighten conspicuity of the signal displays for eastbound intersection-approaching road users.	This countermeasure involves installation of devices to heighten the conspicuity of the signal displays for road users approaching the intersection along Road B. The following treatments are recommended: • Install new signal bulbs and ensure they are conspicuous to intersection-approaching road users. • Install the recommended one signal per lane over each lane. • Install yellow retroreflective sheeting border on the eastbound traffic signal display back plates.[76]
Address stopping sight distance issues on eastbound approach to the intersection.	Low-Cost Solution: This countermeasure involves installation of warning signage to heighten awareness of the sight distance issue on the intersection approach. The following treatments are recommended: • Install either a "SIGNAL AHEAD" warning sign or a "BE PREPARED TO STOP" warning sign to heighten awareness of the presence of the

Countermeasure	Description
	intersection on approach. High-Cost Solution: This countermeasure involves re-design and reconstruction of the vertical curvature of the roadway to ensure the stopping sight distance on approach to the intersection is met.
Enhance presence of lane designation on eastbound approach to the intersection.	This countermeasure involves the installation of lane designation signs and markings for exclusive eastbound right-turn lane to ensure lane designation is evident to intersection-approaching road users.
Pavement friction test and potential follow-on construction work.	This countermeasure involves conducting a friction test of the existing pavement surface. An empirical test of the friction properties of the pavement could determine if additional friction should be added to the pavement surface. Increasing pavement friction may assist road users' ability to maneuver during events leading up to a potential collision, particularly eastbound rear-end collisions.
Installation/Relocation of street name signs	This countermeasure involves enhancing the conspicuity of the standard street regulatory name sign for Road B by increasing the size of the sign and relocating it to a position over the curb-through lane on the signal mast arm.
Further enhance the presence of Road B on approach along Street A.	This countermeasure involves installation of signage to better inform approaching road users of the downstream condition and the subject signalized intersection so that they can make appropriate decisions about lanes, etc., and can enter with caution due to the existing issue with vertical geometry. Advance street name sign for Road B on eastbound approach.(77) Conspicuity enhancement of the standard street regulatory name sign for Road B through increasing the size of the sign and relocating it to a position over the curb-through lane on the signal mast arm.
Install INTERSECTION AHEAD warning sign.	This countermeasure involves the installation of an INTERSECTION AHEAD warning sign to provide appropriate advance notice of the downstream condition to eastbound intersection-approaching road users.
Install a westbound left-turn lane.	This countermeasure involves the installation of a westbound left-turn lane at the intersection to remove westbound left-turning road users from the stream of through traffic.

Exhibit 6-17. Proposed long list of countermeasures.

6.6 ECONOMIC APPRAISAL

Economic appraisals identify whether the countermeasures identified in the previous step of the road safety management process have larger benefits than their costs. The economic appraisal quantifies countermeasures' benefits in terms of their safety impacts. The ability to evaluate the safety impacts of a countermeasure is paramount to implementing an intersection improvement plan. Information is needed on whether the treatment under consideration is effective in reducing crashes. Most treatments proposed in Part III of this guide have some published material that provides a quantitative estimate of effectiveness. For other treatments in Part III, no research was found that provided any quantifiable estimate of safety benefits. Before any further consideration as to be applicability of a treatment can occur, the study team will need to decide whether they have a quantifiable estimate of the expected results of a treatment available. If they do, they can proceed with the steps described below. If not, they should carefully consider whether the treatment should be implemented.

The economic appraisals include three steps:

- Step 1: Estimate benefits of countermeasures.
- Step 2: Estimate costs of countermeasures.
- Step 3: Evaluate cost effectiveness of countermeasures.

6.6.1 Step 1 – Estimate Benefits of Countermeasures

To estimate the benefits of safety improvement projects (countermeasures), crash modification factors (CMF) are utilized. CMF is a term that is widely used in road safety engineering. A CMF is the ratio of expected crash frequency at a location with a countermeasure divided by the expected crash frequency at the location without the countermeasure. If the expected crash frequency with a treatment is 9 and the expected crash frequency without the treatment is 12, then the CMF is 9/12 = 0.75.

Some jurisdictions have developed reference lists of CMFs to help them choose an appropriate treatment for an intersection improvement plan. In some cases, very little or no documentation exists showing how these CMFs were derived. Some State authorities are currently using CMFs developed from in-house projects; others use CMFs developed by other transportation authorities or based on published research. FHWA has developed the CMF Clearinghouse,[78] which houses a Web-based database of CMFs along with supporting documentation to help traffic engineers identify the most appropriate countermeasure for their safety needs. It is a live database in which new CMFs are added as they become available through research. The CMF clearinghouse has adopted a star rating to represent the quality of each CMF. A 5-star CMF represents a CMF that has been developed using a valid statistical methodology.

Part III of this guide reports study findings from a variety of sources. These findings reported a change in crash frequency or crash rate as part of a cross-sectional study, a before-after study, or by more sophisticated methods. Each study finding was reviewed in terms of:

- The reasonableness of the values presented.
- The year of the study.
- The general integrity of the study in terms of crash data used, methodology, and sample size.
- The country of origin.

In general, findings that appeared unreasonable, outdated, used overly simplistic methods, or were based on research carried out outside of North America (unless no other finding was available for the treatment in question) were discarded. The results are presented as the expected change in crash frequency, expressed as a percentage. A study finding of 50 percent means that there is expected to be a reduction of 50 percent in the number of crashes occurring after the application of the treatment the study finding describes. Each CMF or study finding in Part III of this guide is referenced. In applying a CMF or in finding ways to determine the expected outcome of implementing a treatment, the user is urged to review the source material from which the CMF or study finding was derived in order to determine its applicability to his or her specific project. Readers may wish to use their own CMFs or the results of another study finding known to them should they believe that it is more accurate or better reflects conditions occurring at the location in question.

The target benefit of any countermeasure is a reduction in the frequency or severity of crashes. Assumptions regarding the potential benefit(s) of a countermeasure must be realistic. The crash frequency (or crash frequency of a specific group of crashes) cannot be driven below zero. To quantify the safety benefit of implementing a countermeasure, the estimated crash reduction that will be connected with the implementation of the countermeasure must be determined. If a countermeasure is successful in eliminating or reducing the severity of crashes that would have been expected without the countermeasure, then the benefits can be attributed to the countermeasure.

When two countermeasures are considered and each has a quantifiable safety benefit, a common way to express the combined safety benefit is to multiply both values. For example, countermeasure A might have a CMF of 0.90, and countermeasure B might have a CMF of 0.80. Combined, the two countermeasures should have an expected benefit of 0.72 (CMF A (0.90) x CMF B (0.80)).

Usually, countermeasures will only be effective when applied to a particular target group of crashes. For example, the installation of protected left-turn phasing on one approach should substantially reduce left-turn crashes involving that particular approach, but cannot be expected to affect left-turn crashes on any other approach.

Countermeasures can also have undesirable effects worth considering in evaluating their overall benefit. For example, the installation of right-turn channelization may reduce crashes involving right-turning vehicles and possibly rear-end crashes on a particular approach, but may increase crashes involving pedestrians. If the countermeasure is to be applied, both positive and negative consequences need to be considered.

The potential crash reduction from a countermeasure is determined by multiplying the expected number of crashes by the percentage reduction that the countermeasure is expected to have. The expected number of crashes (total or by severity) may be assumed to be the same as in the period before the countermeasure, but a much more refined method would be to develop an estimate of the expected number of crashes based on SPF curves or the EB method.

Placing an economic value on crashes by severity is a common practice in quantifying the safety benefits of a countermeasure. There are several ways of arriving at societal cost (such figures are available from FHWA and various State transportation agencies).

Calculating the safety benefit of a countermeasure means multiplying the expected crash reduction by severity (property damage, injury, and fatal) by applicable society cost figures. A means of expressing the calculation of the safety benefit of the countermeasure is as follows:

$$\text{Safety Benefit (\$)} = \Delta n_{PDO} \times C_{PDO} + \Delta n_I \times C_I + \Delta n_F \times C_F \qquad (5)$$

Where:
Δn_{PDO} = Expected reduction in property-damage-only crashes
C_{PDO} = Societal costs of property-damage-only crashes
Δn_I = Expected reduction in injury crashes
C_I = Societal costs of injury crashes
Δn_F = Expected reduction in fatal crashes
C_F = Societal costs of fatal crashes.

Collision Type	Societal Crash Costs
Fatal (K)	$4,008,900
Disabling Injury (A)	$216,000
Evident Injury (B)	$79,000
Fatal/Injury (K/A/B)	$158,200
Possible Injury (C)	$44,900
PDO (0)	$7,400

Exhibit 6-18. Societal crash cost estimates by crash severity
Source: Table 7-1 of the Highway Safety Manual

As an example: a multilane signalized intersection has been diagnosed as having a safety problem associated with a particular approach. Adding a right-turn lane is being considered as a possible countermeasure. Calculation of the safety benefit involves determining the product of the yearly average number of crashes, the societal benefit, and the estimated reduction in crashes grouped by crash type (Exhibit 6-19). The total societal benefit is calculated to be $104,948.

Crash Type	5-Year Total Before Treatment	Yearly Average Before Treatment	Estimated Reduction Due to Treatment	Estimated Yearly Average After Treatment	Unit Societal Benefit	Estimated Yearly Benefit of Treatment
Fatal/ Injury	8	1.6	40%	0.64	$158,200	$101,248
PDO	25	5.00	10%	0.50	$7,4, 00	$3,700
Total						**$104,948**

Exhibit 6-19. Example calculation of safety benefit of adding a right-turn lane.

6.6.2 Step 2 – Estimate Costs of Countermeasures

The next step of economic appraisal is the estimation of implementation costs of projects (countermeasures). Similar to other roadway improvement projects, implementation costs of projects may include right-of-way acquisition, construction cost, utility relocation, environmental impacts, operation costs, maintenance costs, and the cost associated with planning and engineering.

The most important source for the implementation costs of projects is the local past experience of the road agency. The *SafetyAnalyst* software also has costs associated with a number of countermeasures built-in.

6.6.3 Step 3 – Evaluate Cost Effectiveness of Countermeasures

Once benefits and costs of road safety improvement projects are calculated, various methods for benefit-cost analysis practiced in engineering economy can be utilized to evaluate whether the projects are economically viable. In practice, net present worth and benefit-cost ratio are the most commonly used methods.

The benefits and costs estimated before are likely to occur in the future in different time spans. As a result, the present worth of benefits and costs are calculated using an average interest rate (discount rate). Then, the difference between the discounted costs and discounted benefits at the present year (net present worth) is calculated. A project with a net present worth greater than zero indicates a projects with benefits more than costs. These types of projects are economically viable.

In the benefit-cost ratio (BCR) method, first the present worth of benefits and costs are calculated. Then the ratio of present worth of benefits over present worth of costs is calculated. If the ratio is greater than 1.0, the project is economically justified.

The countermeasures which are found economically justified can be implemented to address the safety problems identified in the diagnosis step. However, the main challenge is that resources to implement all countermeasures are not available. As a result, the road agency needs to make a decision to identify which countermeasures should be implemented considering the scarce resources.

6.6.4 Case Study

Exhibit 6-20 summarizes the result of benefit-cost analysis. In this table, the countermeasures proposed in the countermeasure selection step are listed. CMFs associated with each countermeasure have been obtained from the CMF Clearinghouse. The original studies through which the CMFs were developed are cited as footnotes. No CMF was found for two of the countermeasures in Exhibit 6-20. Using the CMFs, crash reduction over a 5-year period was calculated. The crash reduction was converted to benefits using the societal cost of crashes shown in exhibit 6-20. Net present worth of benefits was calculated using a discount rate of 2%. Net present worth of total costs of projects was calculated. A life cycle of 20 years was assumed for countermeasures. The BCR for countermeasures shows that all proposed countermeasures are economically justified.

The two countermeasures for which no CMF was found are recommended because both are low cost countermeasures and potentially have positive operational impacts.

Countermeasure	CMF	5-Year Total Crash Reduction After Countermeasure	Benefits ($)	Total Cost ($)	BCR
Heighten conspicuity of the signal displays for eastbound intersection-approaching road-users	0.85 for all crashes (all severities)	13.5	627,267	6,000	104.5
Address stopping sight distance issues on eastbound approach to the intersection	0.65 for angle crashes (all severities)	3.5	162,625	2,000	81.3
Pavement friction test and potential follow-on construction work	0.76 for all crashes (all severities)	21.6	1,003,627	60,000	16.7
Further enhance the presence of Road B, on approach along Street A	0.984 for all crashes (all severities)	1.44	66,909	2,000	33.5
Install “Intersection Ahead” warning sign	0.65 for all crashes (all severities)	3.5	162,625	2,000	81.3
Install a westbound left-turn lane	0.9 for all crashes (all severities)	9	418,178	280,000	1.5

CMF values developed from a variety of sources, including the Highway Safety Manual and the CMF Clearinghouse

Exhibit 6-20. Summary of benefit-cost analysis.

6.7 PROJECT PRIORITIZATION

In the previous steps of the road safety management process, one or more countermeasures for one or more intersections might be selected. One countermeasure or a combination of countermeasures can be referred to as one project. Now the traffic engineer and the road agency face the important decision of which project should be implemented first and which projects should be implemented at all, considering the limited available resources to maximize benefits to the public (i.e., have most safety improvements).

The following two simple methods can help prioritize projects [71]:

- Ranking by economic effectiveness measures.
- Incremental benefit-cost analysis ranking.

The ranking by economic effectiveness methods is the simplest method for prioritization of projects. In this method, economically justified projects are ranking from high to low by any of the following measures:

- Net present worth.
- Projects costs.
- Monetary value of project benefits.

- Total number of crashes reduced.

Next, the agency may start the projects from the top of the list to the bottom. The main challenge associated with this method is that it ignores resource constraints and potential competing priorities.

In the incremental benefit-cost analysis ranking, the following steps are to be taken [71]:

1. Calculate the BCR for each project.
2. Arrange projects with a BCR greater than 1.0 in increasing order based on their estimated cost. The project with the smallest cost is listed first.
3. Calculate the BCR for the incremental investment by dividing the difference between benefits of the first two ranked projects by the difference between costs of the first two ranked projects.
4. If the BCR for the incremental investment is greater than 1.0, the project with the higher cost is compared to the next project in the list. If the BCR for the incremental investment is less than 1.0, the project with the lower cost is compared to the next project in the list.
5. Repeat this process. The project selected in the last pairing is considered the best economic investment.

To produce a ranking of projects, the entire evaluation is repeated without the projects previously determined to be the best economic investment until the ranking of every project is determined.

6.7.1 Case Study

Exhibit 6-21 shows the priority ranking of countermeasures, which were selected as part of the countermeasure selection step shown in Exhibit 6-20. In this case study, ranking was performed based on the monetary value of project benefits. It should be noted that the road agency has to consider their budget constraints to identify all or some of the projects that can be implemented. Also, if the criteria for ranking changes based on the road agency strategic directions, the priority ranking will change. For example, if the ranking is performed based on total cost of the project, another ranked list is obtained.

Rank	Countermeasure	CMF	5-Year Total Crash Reduction After Countermeasure	Benefits ($)	Total Cost ($)	BCR
1	Pavement friction test and potential follow-on construction work	0.76 for all crashes (all severities)	13.5	627,267	6,000	104.5
2	Heighten conspicuity of the signal displays for eastbound intersection-approaching road-users	0.85 for all crashes (all severities)	3.5	162,625	2,000	81.3
3	Install a westbound left-turn lane	0.9 for all crashes (all severities)	21.6	1,003,627	60,000	16.7
4	Address stopping sight distance issues on eastbound approach to the intersection	0.65 for all crashes (all severities)	1.44	66,909	2,000	33.5
5	Install “Intersection Ahead” warning sign	0.65 for all crashes (all severities)	3.5	162,625	2,000	81.3
6	Further enhance the presence of Road B, on approach along Street A	0.984 for all crashes (all severities)	9	418,178	280,000	1.5

Exhibit 6-21. Priority ranking of selected countermeasures.

6.8 SAFETY EFFECTIVENESS EVALUATION

Safety effectiveness evaluation is the process of developing quantitative estimates of how a countermeasure, project, or a group of projects has affected crash frequencies or severities. The effectiveness estimate for a project or treatment is a valuable piece of information for future safety decision making and policy development.

Safety effectiveness evaluation may include:

- Evaluating a single project at a specific site to document the safety effectiveness of that specific project.
- Evaluating a group of similar projects to document the safety effectiveness of those projects.
- Evaluating a group of similar projects for the specific purpose of quantifying a CMF for a countermeasure.
- Assessing the overall safety effectiveness of specific types of projects or countermeasures in comparison to their costs.

Practitioners should conduct a before-after study to evaluate the safety effectiveness of any project. A before-after study compares crash frequencies at a site are before and after implementation of a treatment. The main challenge associated with conducting a before-after study is that a number of factors change at the subject site from the before to after period, in addition to the treatment. These factors may include a change in traffic volume, a change in weather conditions, and other unknown factors. As a result, it is critical to separate the safety changes associated with the treatment from the other factors that have changed from the before period to the after period through a valid before-after study.

In a before-after study, the collision frequencies at the treated sites in the after period are compared with collision frequencies at the same sites had the treatment not been implemented in the after period. Obviously, the collision frequencies had the treatment not been applied are not known. As a result, there are a number of techniques in the literature to predict the collision frequencies in the after period had the treatment not been applied. The following section identifies the commonly used techniques in road safety:

6.8.1 Before-After Study with Comparison Group

In this type of before-after study, a comparison group is selected comprising sites that have similar geometric and operational characteristics as the treatment sites. The number of sites in the comparison group is more than the treatment group. The rationale behind this technique is that all contributing factors that affect safety (i.e., traffic volume, weather, etc.) from the before period to the after period impact both the treatment group and the comparison group in the same way, and the only difference between the treatment sites and comparison sites is the treatment itself. In this method, collision frequency of the treatment group had the treatment not been applied is predicted by multiplying crash frequency of the treatment sites in the after period by the ratio of crash frequency of the comparison sites in the after period to the crash ratio of the comparison sites in the before period.

This method has been widely used in road safety. The only challenge associated with this method is that it does not consider the regression-to-the-mean phenomenon.

6.8.2 Before-After Study with Empirical Bayes

In this technique, instead of using a comparison group, the SPF developed for the reference group associated with the treatment sites is used to predict crash frequency at the treatment sites in the after period had the treatment not been applied. This technique is the preferred technique because it considers the regression-to-the-mean phenomenon.

The HSM provides more details on study design and methods for evaluation of safety effectiveness of countermeasures, and Ezra Hauer provides details on various methods for conducting a valid before-after study in road safety in his seminal book.[79]