Chapter 6—Select Countermeasures

6.1. INTRODUCTION

This chapter outlines the third step in the roadway safety management process: selecting countermeasures to reduce crash frequency or severity at specific sites. The entire roadway safety management process is shown in Figure 6-1. In the context of this chapter, a "countermeasure" is a roadway strategy intended to decrease crash frequency or severity, or both, at a site. Prior to selecting countermeasures, crash data and site supporting documentation are analyzed and a field review is conducted, as described in Chapter 5, to diagnose the characteristics of each site and identify crash patterns. In this chapter the sites are further evaluated to identify factors that may be contributing to observed crash patterns or concerns, and countermeasures are selected to address the respective contributing factors. The selected countermeasures are subsequently evaluated from an economic perspective as described in Chapter 7.

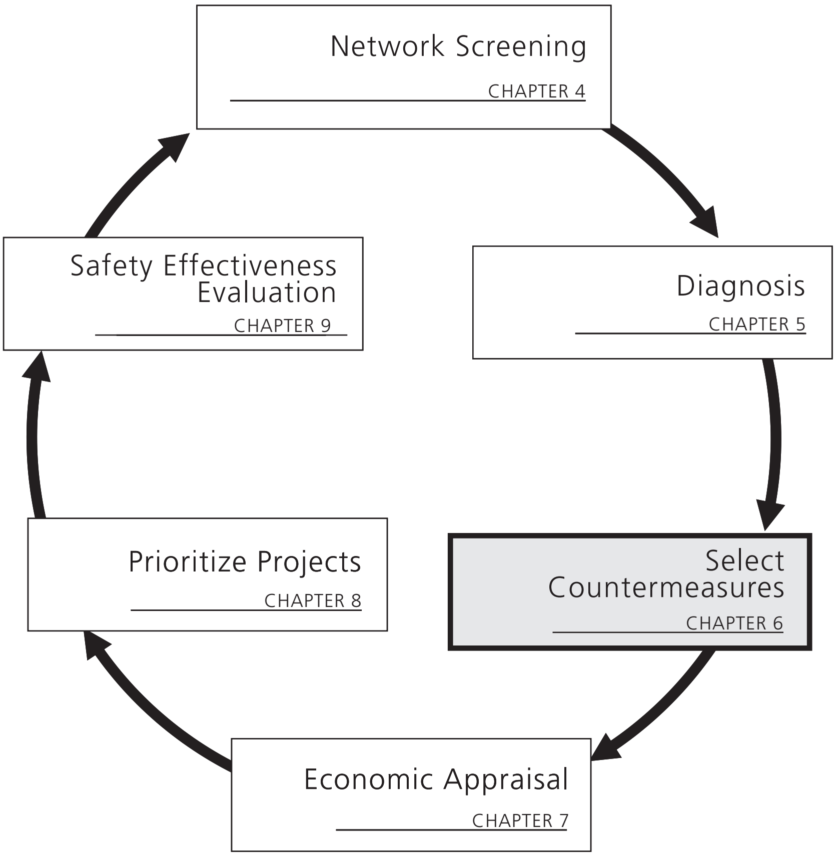

Figure 6–1. Roadway Safety Management Process Overview

Vehicle- or driver-based countermeasures are not covered explicitly in this edition of the HSM. Examples of vehicle-based countermeasures include occupant restraint systems and in-vehicle technologies. Examples of driver-based countermeasures include educational programs, targeted enforcement, and graduated driver licensing. The following documents provide information about driver- and vehicle-based countermeasures:

- The *National Cooperative Highway Research Program (NCHRP) Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan* (7); and
- The National Highway Traffic Safety Administration's (NHTSA) report *Countermeasures that Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices* (3).

6.2. IDENTIFYING CONTRIBUTING FACTORS

For each identified crash pattern there may be multiple contributing factors. The following sections provide information to assist with development of a comprehensive list of possible crash contributing factors. The intent is to assist in identification of a broad range of possible contributing factors in order to minimize the probability that a major contributing factor will be overlooked.

Once a broad range of contributing factors have been considered, engineering judgment is applied to identify those factors that are expected to be the greatest contributors to each particular crash type or concern. The information obtained as part of the diagnosis process (Chapter 5) will be the primary basis for such decisions.

6.2.1. Perspectives to Consider When Evaluating Contributing Factors

A useful framework for identifying crash contributing factors is the Haddon Matrix (2). In the Haddon Matrix, the crash contributing factors are divided into three categories: human, vehicle, and roadway. The possible crash conditions before, during, and after a crash are related to each category of crash contributing factors to identify possible reasons for the crash. An example of a Haddon Matrix prepared for a rear-end crash is shown in Table 6-1. Additional details on the Haddon Matrix are provided in Chapter 3.

Table 6-1. Example Haddon Matrix for Rear-End Crash

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

The engineering perspective considers items like crash data, supporting documentation, and field conditions in the context of identifying potential engineering solutions to reduce crash frequency or severity. Evaluation of contributing factors from an engineering perspective may include comparing field conditions to various national and local jurisdictional design guidelines related to signing, striping, geometric design, traffic control devices, roadway classifications, work zones, etc. In reviewing these guidelines, if a design anomaly is identified, it may provide a clue to the crash contributing factors. However, it is important to emphasize that consistency with design guidelines does not correlate directly to a safe roadway system; vehicles are driven by humans who are dynamic beings with varied capacity to perform the driving task.

When considering human factors in the context of contributing factors, the goal is to understand the human contributions to the cause of the crash in order to propose solutions that might break the chain of events that led to the crash. The consideration of human factors involves developing fundamental knowledge and principles about how people interact with a roadway system so that roadway system design matches human strengths and weaknesses. The study of human factors is a separate technical field. An overview discussion of human factors is provided in Chapter 2 of this Manual. Several fundamental principles essential to understanding the human factor aspects of the roadway safety management process include:

- *Attention and information processing*—Drivers can only process limited information and often rely on past experience to manage the amount of new information they must process while driving. Drivers can process information best when it is presented in accordance with expectations; sequentially to maintain a consistent level of demand, and in a way that helps drivers prioritize the most essential information.
- *Vision*—Approximately 90 percent of the information a driver uses is obtained visually (4). Given that driver visual abilities vary considerably, it is important that the information be presented in a way that users can see, comprehend, and respond to appropriately. Examples of actions that help account for driver vision capabilities include: designing and locating signs and markings appropriately, ensuring that traffic control devices are conspicuous and redundant (e.g., stops signs with red backing and words that signify the desired message), providing advanced warning of roadway hazards, and removing obstructions for adequate sight distance.
- *Perception-reaction time*—The time and distance needed by a driver to respond to a stimulus (e.g., hazard in road, traffic control device, or guide sign) depends on human elements, including information processing, driver alertness, driver expectations, and vision.
- *Speed choice*—Each driver uses perceptual and road message cues to determine a travel speed. Information taken in through peripheral vision may lead drivers to speed up or slow down depending on the distance from the vehicle to the roadside objects. Other roadway elements that impact speed choice include roadway geometry and terrain.

6.2.2. Contributing Factors for Consideration

Examples of contributing factors associated with a variety of crash types are provided in the following sections. The examples may serve as a checklist to verify that a key contributing factor is not forgotten or overlooked. Many of the specific types of highway crashes or contributing factors are discussed in detail in *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*, a series of concise documents that were developed to assist state and local agencies in reducing injuries and fatalities in targeted emphasis areas (1,5,6,8–15).

The possible crash contributing factors listed in the following sections are not and can never be a comprehensive list. Each site and crash history are unique and identification of crash contributing factors is can be completed by careful consideration of all the facts gathered during a diagnosis process similar to that described in Chapter 5.

Crashes on Roadway Segments

Listed below are common types of crashes and multiple potential contributing factors for crashes on roadway segments. It is important to note that some of the possible contributing factor(s) shown for various crash types may overlap, and that there are additional contributing factors that could be identified through the diagnosis process. For example, fixed object crashes may be the result of multiple contributing factors, such as excessive speeds on sharp horizontal curves with inadequate signing.

Possible contributing factors for the following types of crashes along roadway segments include:

Vehicle rollover

- Roadside design (e.g., non-traversable side slopes, pavement edge drop off)
- Inadequate shoulder width
- Excessive speed
- Pavement design

Fixed object

- Obstruction in or near roadway
- Inadequate lighting
- Inadequate pavement markings
- Inadequate signs, delineators, guardrail
- Slippery pavement
- Roadside design (e.g., inadequate clear distance)
- Inadequate roadway geometry
- Excessive speed

Nighttime

- Poor nighttime visibility or lighting
- Poor sign visibility
- Inadequate channelization or delineation
- Excessive speed
- Inadequate sight distance

Wet pavement

- Pavement design (e.g., drainage, permeability)
- Inadequate pavement markings
- Inadequate maintenance
- Excessive speed

Opposite-direction sideswipe or head-on

- Inadequate roadway geometry
- Inadequate shoulders
- Excessive speed
- Inadequate pavement markings
- Inadequate signing

Run-off-the-road

- Inadequate lane width
- Slippery pavement
- Inadequate median width
- Inadequate maintenance
- Inadequate roadway shoulders
- Poor delineation
- Poor visibility
- Excessive speed

Bridges

- Alignment
- Narrow roadway
- Visibility
- Vertical clearance
- Slippery pavement
- Rough surface
- Inadequate barrier system

Crashes at Signalized Intersections

Listed below are common types of crashes that occur at signalized intersections and possible contributing factor(s) for each type. The crash types considered include: right-angle, rear-end or sideswipe, left- or right-turn, nighttime, and wet pavement crashes. The possible contributing factors shown may overlap with various crash types. This is not intended to be a comprehensive list of all crash types and contributing factors.

Possible contributing factors for types of crashes at signalized intersections include the following:

Right-angle

- Poor visibility of signals
- Inadequate signal timing
- Excessive speed
- Slippery pavement
- Inadequate sight distance
- Drivers running red light

Rear-end or sideswipe

- Inappropriate approach speeds
- Poor visibility of signals

- Unexpected lane changes on approach
- Narrow lanes
- Unexpected stops on approach
- Slippery pavement
- Excessive speed

Left- or right-turn movement

- Misjudge speed of on-coming traffic
- Pedestrian or bicycle conflicts
- Inadequate signal timing
- Inadequate sight distance
- Conflict with right-turn-on-red vehicles

Nighttime

- Poor nighttime visibility or lighting
- Poor sign visibility
- Inadequate channelization or delineation
- Inadequate maintenance
- Excessive speed
- Inadequate sight distance

Wet pavement

- Slippery pavement
- Inadequate pavement markings
- Inadequate maintenance
- Excessive speed

Crashes at Unsignalized Intersections

Listed below are common types of crashes that occur at unsignalized intersections along with possible contributing factor(s) for each type. The types of crashes include: angle, rear-end, collision at driveways, head-on or sideswipe, left- or right-turn, nighttime, and wet pavement crashes. This is not intended to be a comprehensive list of all crash types and contributing factors.

Possible contributing factors for types of crashes at unsignalized intersections include the following:

Angle

- Restricted sight distance
- High traffic volume
- High approach speed

- Unexpected crossing traffic
- Drivers running "stop" sign
- Slippery pavement

Rear-end

- Pedestrian crossing
- Driver inattention
- Slippery pavement
- Large number of turning vehicles
- Unexpected lane change
- Narrow lanes
- Restricted sight distance
- Inadequate gaps in traffic
- Excessive speed

Collisions at driveways

- Left-turning vehicles
- Improperly located driveway
- Right-turning vehicles
- Large volume of through traffic
- Large volume of driveway traffic
- Restricted sight distance
- Excessive speed

Head-on or sideswipe

- Inadequate pavement markings
- Narrow lanes

Left- or right-turn

- Inadequate gaps in traffic
- Restricted sight distance

Nighttime

- Poor nighttime visibility or lighting
- Poor sign visibility
- Inadequate channelization or delineation
- Excessive speed
- Inadequate sight distance

Wet pavement

- Slippery pavement
- Inadequate pavement markings
- Inadequate maintenance
- Excessive speed

Crashes at Highway-Rail Grade Crossings

Listed below are common types of crashes that occur at highway-rail grade crossings and possible contributing factor(s) associated with each type. This is not intended to be a comprehensive list of all crash types and contributing factors.

Possible contributing factors for collisions at highway-rail grade crossings include the following:

- Restricted sight distance
- Poor visibility of traffic control devices
- Inadequate pavement markings
- Rough or wet crossing surface
- Sharp crossing angle
- Improper pre-emption timing
- Excessive speed
- Drivers performing impatient maneuvers

Crashes Involving Bicyclists and Pedestrians

Common types of crashes and possible contributing factor(s) in crashes involving pedestrians are listed below. These are not intended to be comprehensive lists of all crash types and contributing factors.

Possible contributing factor(s) to crashes involving pedestrians include the following:

- Limited sight distance
- Inadequate barrier between pedestrian and vehicle facilities
- Inadequate signals/signs
- Inadequate signal phasing
- Inadequate pavement markings
- Inadequate lighting
- Driver has inadequate warning of mid-block crossings
- Lack of crossing opportunity
- Excessive speed
- Pedestrians on roadway
- Long distance to nearest crosswalk
- Sidewalk too close to travel way
- School crossing area

Possible contributing factors for crashes involving bicyclists include the following:

- Limited sight distance
- Inadequate signs
- Inadequate pavement markings
- Inadequate lighting
- Excessive speed
- Bicycles on roadway
- Bicycle path too close to roadway
- Narrow lanes for bicyclists

6.3. SELECT POTENTIAL COUNTERMEASURES

There are three main steps to selecting a countermeasure(s) for a site:

1. Identify factors contributing to the cause of crashes at the subject site;

2. Identify countermeasures which may address the contributing factors; and

3. Conduct cost-benefit analysis, if possible, to select preferred treatment(s) (Chapter 7).

The material in Section 6.2 and Chapter 3 provide an overview of a framework for identifying potential contributing factors at a site. Countermeasures (also known as treatments) to address the contributing factors are developed by reviewing the field information, crash data, supporting documentation, and potential contributing factors to develop theories about the potential engineering, education, or enforcement treatments that may address the contributing factor under consideration.

Comparing contributing factors to potential countermeasures requires engineering judgment and local knowledge. Consideration is given to issues like why the contributing factor(s) might be occurring; what could address the factor(s); and what is physically, financially, and politically feasible in the jurisdiction. For example, if at a signalized intersection it is expected that limited sight-distance is the contributing factor to the rear-end crashes, then the possible reasons for the limited sight distance conditions are identified. Examples of possible causes of limited sight distance might include: constrained horizontal or vertical curvature, landscaping hanging low on the street, or illumination conditions.

A variety of countermeasures could be considered to resolve each of these potential reasons for limited sight distance. The roadway could be re-graded or re-aligned to eliminate the sight distance constraint or landscaping could be modified. These various actions are identified as the potential treatments.

Part D is a resource for treatments with quantitative crash modification factors (CMFs). The CMFs represent the estimated change in crash frequency with implementation of the treatment under consideration. A CMF value of less than 1.0 indicates that the predicted average crash frequency will be lower with implementation of the countermeasure. For example, changing the traffic control of an urban intersection from a two-way, stop-controlled intersection to a modern roundabout has a CMF of 0.61 for all collision types and crash severities. This indicates that the expected average crash frequency will decrease by 39 percent after converting the intersection control. Application of a CMF will provide an estimate of the change in crashes due to a treatment. There will be variance in results at any particular location. Some countermeasures may have different effects on different crash types or severities. For example, installing a traffic signal in a rural environment at a previously unsignalized two-way stop-controlled intersection has a CMF of 1.58 for rear-end crashes and a CMF of 0.40 for left-turn crashes. The CMFs suggest that an increase in rear-end crashes may occur while a reduction in left-turn crashes may occur.

If a CMF is not available, Part D also provides information about the trends in crash frequency related to implementation of such treatments. Although not quantitative and therefore not sufficient for a cost-benefit or cost-effectiveness analysis (Chapter 7), information about a trend in the change in crashes at a minimum provides guidance about the resulting crash frequency. Finally, crash modification factors for treatments can be derived locally using procedures outlined in Chapter 9.

In some cases a specific contributing factor or associated treatment, or both, may not be easily identifiable, even when there is a prominent crash pattern or concern at the site. In these cases, conditions upstream or downstream of the site can also be evaluated to determine if there is any influence at the site under consideration. Also, the site is evaluated for conditions which are not consistent with the typical driving environment in the community. Systematic improvements, such as guide signage, traffic signals with mast-arms instead of span-wire, or changes in signal phasing, may influence the overall driving environment. Human factors issues may also be influencing driving patterns. Finally, the site can be monitored in the event that conditions may change and potential solutions become evident.

6.4. SUMMARY OF COUNTERMEASURE SELECTION

Chapter 6 provides examples of crash types and possible contributing factors as well as a framework for selecting counter measures.

This chapter outlined the process for selecting countermeasures based on conclusions of a diagnosis of each site (Chapter 5). The site diagnosis is intended to identify any patterns or trends in the data and provide comprehensive knowledge of the sites, which can prove valuable in selecting countermeasures.

Several lists of contributing factors are provided in Section 6.2. Connecting the contributing factor to potential countermeasures requires engineering judgment and local knowledge. Consideration is given to why the contributing factor(s) might be occurring; what could address the factor(s); and what is physically, financially, and politically feasible in the jurisdiction. For each specific site, one countermeasure or a combination of countermeasures are identified that are expected to address the crash pattern or collision type. Part D information provides estimates of the change in expected average crash frequency for various countermeasures. If a CMF is not available, Part D also provides information in some cases about the trends in crash frequency or user behavior related to implementation of some treatments.

When a countermeasure or combination of countermeasures is selected for a specific location, an economic appraisal of all sites under consideration is performed to help prioritize network improvements. Chapters 7 and 8 provide guidance on conducting economic evaluations and prioritizing system improvements.

6.5 SAMPLE PROBLEMS

The Situation

Upon conducting network screening (Chapter 4) and diagnostic procedures (Chapter 5), a roadway agency has completed a detailed investigation at Intersection 2 and Segment 1. A solid understanding of site characteristics, history, and layout has been acquired so that possible contributing factors can be identified. A summary of the basic findings of the diagnosis is shown in Table 6-2.

Table 6-2. Assessment Summary

Data	Intersection 2	Segment 1
Major/Minor AADT	22,100/1,650	9,000
Traffic Control/Facility Type	Two-Way Stop	Undivided Roadway
Predominant Types of Crashes	Angle, Head-On	Rollover, Fixed Object
	Crashes by Severity	
Fatal	6%	6%
Injury	73%	32%
PDO	21%	62%

The Question

What factors are likely contributing to the target crash types identified for each site? What are appropriate countermeasures that have potential to reduce the target crash types?

The Facts

Intersections

- Three years of intersection crash data as shown in Table 5-2.
- All study intersections have four approaches and are located in urban environments.

Roadway Segments

- Three years of roadway segment crash data as shown in Table 5-2.
- The roadway cross-section and length as shown in Table 5-2.

Solution

The countermeasure selection for Intersection 2 is presented, followed by the countermeasure selection for Segment 1. The countermeasures selected will be economically evaluated using economic appraisal methods outlined in Chapter 7.

Intersection 2

Section 6.2.2 identifies possible crash contributing factors at unsignalized intersections by crash type. As shown, possible contributing factors for angle collisions include restricted sight distance, high traffic volume, high approach speed, unexpected crossing traffic, drivers ignoring traffic control on stop-controlled approaches, and wet pavement surface. Possible contributing factors for head-on collisions include inadequate pavement markings and narrow lanes.

A review of documented site characteristics indicates that over the past several years, the traffic volumes on both the minor and major roadways have increased. An analysis of existing traffic operations during the weekday afternoon/evening (p.m.) peak hour indicates an average delay of 115 seconds for vehicles on the minor street and 92 seconds for left-turning vehicles turning from the major street onto the minor street. In addition to the long delay experienced on the minor street, the operations analysis calculated queue lengths as long as 11 vehicles on the minor street.

A field assessment of Intersection 2 confirmed the operations analysis results. It also revealed that because of the traffic flow condition on the major street, very few gaps are available for vehicles traveling to or from the minor street. Sight distances on all four approaches were measured and met local and national guidelines. During the off-peak field assessment, the vehicle speed on the major street was observed to be substantially higher than the posted speed limit and inappropriate for the desired character of the roadway.

The primary contributing factors for the angle collisions were identified as increasing traffic volumes during the peak periods, providing few adequate gaps for vehicles traveling to and from the minor street. As a result, motorists have become increasingly willing to accept smaller gaps, resulting in conflicts and contributing to collisions. Vehicles travel at high speeds on the major street during off-peak periods when traffic volumes are lower; the higher speeds result in a larger speed differential between vehicles turning onto the major street from the minor street. The larger speed differential creates conflicts and contributes to collisions.

Chapter 14 of Part D includes information on the crash reduction effects of various countermeasures. Reviewing the many countermeasures provided in Chapter 14 and considering other known options for modifying intersections, the following countermeasures were identified as having potential for reducing the angle crashes at Intersection 2:

- Convert stop-controlled intersection to modern roundabout
- Convert two-way stop-controlled intersection to all-way stop control
- Provide exclusive left-turn lane on one or more approaches

The following countermeasures were identified as having potential for reducing the head-on crashes at Intersection 2:

- Increase intersection median width
- Convert stop-controlled intersection to modern roundabout
- Increase lane width for through travel lanes

The potential countermeasures were evaluated based on the supporting information known about the sites and the CMFs provided in Part D. Of the three potential countermeasures identified as the most likely to reduce target crashes, the only one that was determined to be able to serve the forecast traffic demand was the modern roundabout option. Additionally, the CMFs discussed in Part D provide support that the roundabout option can be expected to reduce the average crash frequency. Constructing exclusive left-turn lanes on the major approaches would likely reduce the number of conflicts between through traffic and turning traffic, but was not expected to mitigate the need for adequate gaps in major street traffic. Therefore, the roadway agency selected a roundabout as the most appropriate countermeasure to implement at Intersection 2. Further analysis, as outlined in Chapters 7, 8, and 9, is suggested to determine the priority of implementing this countermeasure at this site.

Segment 1

Segment 1 is an undivided two-lane rural highway; the segment end points are defined by intersections. The crash summary statistics in Chapter 5 indicate that approximately three-quarters of the crashes on the road segment in the last three years involved vehicles running off of the road, resulting in either a fixed object crash or rollover crash. The statistics and crash reports do not show a strong correlation between the run-off-the-road crashes and lighting conditions.

Section 6.2.2 summarizes possible contributing factors for rollover and run-off-the-road crashes. Possible contributing factors include low-friction pavement, inadequate roadway geometric design, inadequate maintenance, inadequate roadway shoulders, inadequate roadside design, poor delineation, and poor visibility.

A detailed review of documented site characteristics and a field assessment indicated that the roadway is built to the agency's standards and is included in its maintenance cycle. Past speed studies and observations made by the roadway agency's engineers indicate that vehicle speeds on the rural two-lane roadway often exceed the posted speed limit by 5 to 15 mph. Given the location of the segment, local agency staff expects that the majority of the trips that use this segment have a total trip length of less than 10 miles. Sight distance and delineation were also assessed to be within reason.

Potential countermeasures that the agency could implement were identified to include: increasing the lane or shoulder width, or both, removing or relocating any fixed objects within the clear zone; flattening the sideslope; adding delineation or replacing existing lane striping with retro-reflective material; and adding shoulder rumble strips.

The potential countermeasures were evaluated based on the supporting information known about the site and the CMFs provided in Part D. Given that the roadway segment is located between two intersections and that most users of the facility are making trips of a total length of less than 10 miles, it is not expected that drivers are becoming drowsy or not paying attention. Therefore, adding rumble strips or delineation to alert drivers of the roadway boundaries is not expected to be effective.

The agency believes that increasing the forgiveness of the shoulder and clear zone will be the most effective countermeasure for reducing fixed-object or roll-over crashes. Specifically they suggest flattening the sideslope in order to improve the ability of errant drivers to correct without causing a roll-over crash. The agency will also consider protecting or removing objects within a specified distance from the edge of roadway. The agency will consider the economic feasibility of these improvements on this segment and prioritize among other projects in their jurisdiction using methods in Chapters 7 and 8.

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