Chapter 8 – SAFETY AND TRAFFIC DESIGN

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CHAPTER 8

SAFETY AND TRAFFIC DESIGN

8.1 GENERAL

The purpose of this chapter is to provide guidance for evaluating and developing highway safety alternatives to be incorporated into roadway and structural designs. This includes providing for the safe accommodation of traffic through construction work zones. The safety guidelines of any highway facility are primarily a reflection of the attitude of the administration responsible for the facility and the priority placed on the use of available funds. While the overall objective is maximum highway safety, environmental and economical restraints may prohibit achieving this goal. The designer must, therefore, ensure that the design provides the maximum safety enhancements for each dollar spent.

Agreements have been negotiated with most of the Federal agencies with significant public road mileage, and they have active programs to meet the applicable guidelines. These interagency agreements are described in Chapter 2. The FLH Divisions provide technical guidance to many of these agencies in the design and construction of their roads. In addition, they work to ensure that objectives of the *Highway Safety Guidelines* are accomplished.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

8.1.1 SAFETY PHILOSOPHY

In support of the national goals set forth within the US Department of Transportation and the Federal Highway Administration, FLH is equally committed to reducing the number of deaths and serious injuries and improving the overall safety of transportation on Federal and Indian lands. Building on FLH's strong history in leading context sensitive engineering solutions, FLH will continue to evaluate individual projects and their appropriate functional classification to balance the FHWA transportation and safety mission with the land management and resource protection mission of the Federal Lands Managing Agencies (FLMAs). Appropriate safety applications are to be incorporated while respecting the resource impacts, historic and cultural values of the associated facility. This is to be achieved through a collaborative and cooperative effort between the FLH and the FLMAs. This includes:

- Collection and reporting of accurate and timely crash data,
- Implementation of Safety Management Systems and principles,
- Early consideration of safety in all highway programs and projects,
- The identification and investigation of impacted hazardous locations and features and establishing countermeasures and priorities to address the identified or potential hazards,
- Incorporating appropriate safety improvements in all FLH projects, and

- Systematic upgrading of roadside features and elements will be designed to meet current nationally accepted standards for crashworthiness.

It is FLH's conviction that the respective statutory missions of FLH and partner agencies relating to enhancing safety are compatible. The FLH Vision is ''Creating the best transportation system in balance with the values of Federal and Tribal lands.'' This requires a unique effort to build a harmonic blend of the transportation access and environmental and resource protection elements of the respective agency missions. FLH is confident that its efforts in providing partnership, dedicated to addressing public safety concerns and historic and cultural issues, compliment the unique setting of the projects. The overall goal is to work cooperatively to integrate safety as a basic business principle in all activities jointly undertaken by the FLH and FLMAs.

Also refer to Section 9.1.5 for additional information on the FLH highway design philosophy and Context Sensitive Solutions.

8.1.2 SAFETY DESIGN POLICY

New construction and reconstruction involves the application of appropriate policies, standards, and criteria in the design and construction of the facility as described in Section 4.4. The application of those guidelines virtually ensures a reasonable level of geometrics and safety. Even with their use, however, operational or roadside safety problems may still exist that will not be identified unless a safety analysis is performed.

The design policy applicable for RRR projects is the same as for new construction and reconstruction, unless a separate FHWA approved State or local RRR design policy is applicable to the project. However, because of the limited scope of RRR projects, reconstruction to meet full standards may not be possible and is generally not intended. When this occurs, the designer must identify the substandard features and analyze their potential effect on highway safety. The analysis and proposed mitigation are to be documented as discussed in Section 9.1.3.

8.1.3 ROADWAY SAFETY

A crash is seldom the result of a single cause. Typically, several influences affect the situation at any given time. These influences can be separated into three elements:

- The human,
- The vehicle, and
- The environment.

The environmental element includes the roadway and its surroundings. The designer can only control roadway elements and must make a judicious selection of the roadway geometrics, drainage, surface type and other related items to lessen the potential for crashes and/or reduce the severity should they occur. The ideal design applies appropriate guidelines over a section of roadway.

The designer should avoid discontinuities in the highway environment. Some examples include:

- Abrupt changes in design speeds;
- Short transitions in roadway cross section;
- Short radius curves in a series of longer radius curves or at the end of a long tangent;
- Changes from full to partial access control;
- Roadway width constrictions (e.g., narrow bridges, other structures);
- Intersections and pullouts with inadequate sight distances;
- Hidden sag vertical curves and inadequate sight distance at crest vertical curves; and/or
- Other inconsistencies in the roadway design.

Standardizing highway design features and traffic control devices reduces driver confusion and makes the task of driving easier. Through the use of these standard features, the driver learns what conditions to expect on a certain type of highway. The goal, if possible, is to design a highway so that a driver needs to make only one decision at a time. Multiple decisions confuse and distract a driver.

8.1.4 ROADSIDE SAFETY

When a vehicle leaves the roadway, any object in or near its path may become a contributing factor to the severity of the crash. The basic concept of a forgiving roadside is that of providing a clear recovery area where an errant vehicle can be redirected back to the roadway, stop safely or slow enough to mitigate the effects of the crash.

Consult the AASHTO *A Policy on Geometric Design of Highways and Streets* (*Green Book*) and the AASHTO *Roadside Design Guide* for guidance on appropriate clear recovery areas.

The designer must evaluate these requirements in conjunction with environmental, contextual and economic constraints to determine the acceptable clear zone for the traffic, speed and terrain of the project.

Potentially hazardous features located within the identified clear zone should be treated with one of the following options, which are listed in order of preference:

1. Remove the hazard.
2. Redesign the hazard so it can be traversed safely.
3. Relocate the hazard to a point where it is less likely to be struck, preferably outside the clear zone.
4. When a potential hazard remains in the clear zone, reduce the impact severity by using an appropriate breakaway device.
5. If the feature is potentially more hazardous than a barrier system that could shield it, consider installing a barrier system, a crash cushion or both.

6. If it is not feasible or practical to shield the hazard, delineate it.

8.2 GUIDANCE AND REFERENCES

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. While this list is not all-inclusive, the publications listed will provide a designer with additional information to supplement this manual:

1.	RDG	*Roadside Design Guide*, AASHTO, Current Edition.
2.	MUTCD	*Manual on Uniform Traffic Control Devices for Streets and Highways*, FHWA, Current Edition, with approved revisions.
3.	SHS	*Standard Highway Signs*, FHWA, Current Edition.
4.	Traffic Engineering Handbook	*Traffic Engineering Handbook*, Institute of Transportation Engineers, Current Edition.
5.	Traffic Control Devices Handbook	*Traffic Control Devices Handbook*, Institute of Transportation Engineers, Current Edition.
6.	HCM	*Highway Capacity Manual*, Transportation Research Board, Current Edition.
7.	AASHTO SR-3	*Highway Safety Design and Operations Guide*, AASHTO, 1997.
8.	FHWA SA-93-001	*Roadway Delineation Practices Handbook*, Report No. FHWA SA-93-001, 1994.
9.	NPS UniGuide Standards	*UniGuide Standards Manual*, US Department of the Interior, National Park Service, June 2002.
10.	Forest Service Sign Manual	*Signs and Poster Guidelines for the Forest Service*, USDA Forest Service, EM-7100-15.
11.	Special Report 214	*Designing Safer Roads*, Special Report 214, Transportation Research Board, 1987.
12.	Safety Effectiveness of Highway Design Features	Safety Effectiveness of Highway Design Features, Vol. I: *Access Control* (FHWA-RD-91-044), Vol. II: *Alignment* (FHWA-RD-91-045), Vol. III: *Cross-Sections* (FHWA-RD-91-046) Vol. IV: *Interchanges* (FHWA-RD-91-047) Vol. V: *Intersections* (FHWA-RD-91-048) Vol. VI: *Pedestrians and Bicyclists* (FHWA-RD-91-049) Federal Highway Administration, Washington, D.C., 1992.
13.	NCHRP 350	*Recommended Procedures for the Safety Performance Evaluation of Highway Features*, NCHRP Report No. 350, National Cooperative Highway Research Program, 1993.

14. Roadside Hardware — Roadside Hardware web site, FHWA Office of Safety

15. FHWA SA-90-017 — *A Users' Guide to Positive Guidance*, Report No. FHWA SA-90-017, September 1990.

16. FHWA-SA-07-010 — *Railroad-Highway Grade Crossing Handbook*, Report No. FHWA-SA-07-010, FWHA, Revised 2nd edition, March 2008.

17. NCHRP Report 148 — *Roadside Safety Improvement Programs on Freeways — A Cost Effectiveness Approach*, Glennon, J.C., NCHRP 148, 1974.

18. AASHTO GL-6 — *Roadway Lighting Design Guide,* AASHTO, 2005.

19. FLH Barrier Guide — *Barrier Guide for Low Volume and Low Speed Roads*, FLH, 2005

20. AASHTO Green Book — *A Policy on Geometric Design of Highways and Streets*, AASHTO, current ed.

21. FP-XX — *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects*, FHWA, current ed.

8.3 INVESTIGATION PROCESS

The investigation process begins with the initial consideration and priority given to candidate projects for safety improvements. FLH Program projects involve the preservation or improvement of the facility and the enhancement of roadway safety.

The majority of FLH projects involve existing roadways. On existing highways, historical information relating to the highway's operation or safety should be analyzed. State DOT's generally have operational and safety records for the Federal system. Respective agencies frequently have data for routes on their systems. Unfortunately, on off-system county roads, the available data may be scarce. This is often due to the low-volume rural nature of the facility. As a result, many crashes on these facilities go unreported. Information retrieval systems may also be less developed for these roads. Good sources of information are law enforcement officials, local maintenance personnel, property owners, local businesses, mail carriers, school bus companies, etc. A drive through of the project, with a keen eye towards operational or safety problems, or potential problems, will often detect areas requiring special attention during design.

8.3.1 CRASH DATA

Many State highway agencies maintain computerized crash files. They can provide statistics regarding statewide rates for fatal, injury and property damage crashes as well as rates on specific routes. By comparing statistical trends in a given area of the State, the designer may detect clues to the basic causes or problems that should be addressed during design. For example, if a proposed FLH Program project were located in a portion of a State that has a higher than normal run-off-the-road crash rate, further analysis of the types of crashes (e.g., skidding) may be warranted.

The designer should review available crash reports to determine if any engineering features may have contributed to the problem. Law enforcement agencies can usually provide available crash reports. In the case of the National Park Service (NPS), each park maintains its own crash reports and in a central Service-wide Traffic Crash Reporting System (STARS). Forest highway crash data can be obtained through Forest Rangers and sometimes even through State crash data systems. Contact the Highway Safety Engineer for more information on crash data sources.

8.3.2 TRAFFIC SAFETY STUDIES

Traffic safety studies, when available, provide excellent references for evaluating safety and operational characteristics. The NPS has had traffic safety studies performed in many of their larger parks. The States or other agencies may also have such information available on their systems. While the content and form of traffic safety studies vary widely, they usually include an introduction that describes the goals and purpose of the study and defines the study area and project specifics.

8.4 SAFETY ANALYSIS

The extent of appropriate safety enhancements on all projects can be determined by performing a safety analysis. A safety analysis consists of analyzing potentially hazardous features and locations; both the project's crash history and the list of potentially hazardous locations and features should be used during the project development process. At a minimum, review this information on each project where a design exception is requested. The project files should contain documentation of the safety analysis performed and any improvements or mitigations taken to enhance safety.

8.4.1 CRASH ANALYSIS

The amount of data available for analysis will vary from project-to-project as well as the level of detail and accuracy of the data. Therefore, the designer must determine on a case-by-case basis whether the data furnished for safety analysis purposes is satisfactory.

In some cases, the circumstances may indicate the need to evaluate crash reconstruction. This involves drawing inferences concerning the interactions of speed, position on the road, driver reaction, comprehension and obedience to traffic control devices and evasive tactics. Crash reconstruction uses basic engineering knowledge of vehicle motion analysis, force analysis and mechanical energy.

8.4.1.1 Crash History

The crash history for the project should be developed and analyzed to determine possible causes and to select appropriate safety enhancements. Where practical, crashes should be summarized by location, type, severity, contributing circumstances, environmental conditions and time period. This will help identify high accident locations (HAL) and may indicate some spot safety deficiencies.

Depending on how crash information is filed, it may be necessary to record the information first and then group all crashes occurring at specific locations. This serves to identify HALs. Analysis of the types of crashes can suggest appropriate corrective action. The use of computer spread sheet programs will enhance the ability to evaluate this data.

Limited crash data are common on rural two-lane highways with low to moderate traffic volumes. Data generated from a small sampling can be misleading because they can be significantly influenced by small variances. The limited amount of this type of data often makes traditional methods of analysis difficult.

Crash or fatality rates are calculated by a formula consisting of the number of crashes or fatalities, the time over which the crashes or fatalities occurred, the traffic volume, and the length of the segment. Crash rates are traditionally shown in crashes per million vehicle miles [kilometers] traveled (VMT [VkmT]), while fatality rates are shown in fatals per hundred million vehicle miles [kilometers] traveled.

The equation for calculating a crash rate is shown below.

$$\text{Crash Rate} = \frac{\text{Crashes in Period}}{\text{Exposure in Same Period}} = \frac{\text{Crash Frequency}}{\text{Exposure per Unit of Time}}$$

Exposure is usually based on traffic volume; which explains why the crash rate for a road may have many values depending on the analyzed segment (and its associated traffic volume). Rates from different roads or segments should be compared under similar traffic volume conditions for a more accurate comparison.

In addition to crash data analysis, a Road Safety Audit may be a more appropriate tool to use because it relies on an examination of an existing facility as well as reviewing crash data collected in the past. The procedure for performing this audit is described in Section 8.4.6, Roadway Safety Audits.

Special consideration should be given to analyzing crash data on RRR projects. To more fully understand the safety issues, analysis of RRR projects may often require the following special efforts:

- A study of individual crash reports including those just beyond the project termini,
- A review to relate crash data with field conditions, and
- Interviews with maintenance and/or police personnel. These interviews may reveal areas where operational problems or minor crashes occur, but are not documented.

Crash analysis study procedures involve determining the significance of the crash history and developing summaries of the crash characteristics. The project's crash rates and summaries are used to detect abnormal crash trends or patterns and to distinguish between correctable and non-correctable crashes. Analyses of these summaries are used to identify possible safety deficiencies of the existing facility.

When summarizing crash data for analysis purposes, adhere to the following criteria:

1. **Time Period.** Select a time period for the collection of the crash data (e.g., five years). The time period chosen should contain reasonably current information on traffic volumes, pavement condition and other site-related data. Past changes in the character of the facility (e.g., physical changes, roadside development) are accounted for when evaluating the crash activity.
2. **Direction of Traffic.** Examine crash data with respect to the direction the vehicles were traveling.
3. **Location.** Examine crash data with respect to location. Crashes occurring within an intersection area should be separated from those occurring outside the area of influence of the intersection. In addition, similar crash types occurring in differing situations should be recorded separately. For example, left-turn crashes into a driveway should not be

included with left-turn crashes at an intersection. Collision diagrams may be useful in the analysis.

4. **Project Termini.** Examine the number of crashes and the crash rates within the project termini. A comparison of this data with statewide norms for similar facilities should provide a reasonable indication of the relative safety of the existing roadway.

5. **Compare Crash Statistics.** Summarize the crash data and compare it to typical statistics on similar facilities. A specific crash type categorizes patterns. The identification of crash-type patterns may be used to suggest possible causes. Consider the severity patterns to determine if particular roadway or roadside features have contributed to the overall severity of the crashes that have occurred.

6. **Contributing Circumstances.** Summarize the contributing circumstances portion of the crash report. This identifies possible crash causes noted by the investigating police officer. Contributing circumstances are categorized by:

   - Human (driver) factors,
   - Vehicle related factors, and
   - Environmental factors.

   The contributing circumstances information is used to verify, add or delete possible causes developed by the crash summary by type procedure.

7. **Correctable Versus Non-Correctable Crashes**. The contributing circumstance data can be used to separate correctable and non-correctable crashes. In separating the crashes by these classifications, careful consideration should be made to ensure that the crashes are indeed non-correctable. Exhibit 8.4–A lists the contributing circumstances found on most crash reports and indicates if they are generally correctable or non-correctable through highway improvements.

8. **Environmental Conditions**. Summarize crashes by environmental conditions. This procedure identifies possible causes of safety deficiencies related to the existing condition of the roadway environment at the time of the crash. Typical classifications used in the analysis include lighting condition (i.e., daylight, dusk, dawn, dark) and roadway surface condition (i.e., dry, wet, snowy, icy, unknown). These summaries are compared to average or expected values for similar locations or areas to determine whether the occurrence of a specific environmental characteristic is greater or less than the expected value at the location.

8.4.1.2 Probable Causes and Safety Enhancement

Probable crash causes need to be defined once the crash patterns are identified. On-site or photolog reviews of field conditions of crash sites are used to reduce the list of possible causes identified on the crash history to the most probable causes. The probable causes identified can then be used as a basis for selecting appropriate safety enhancements to alleviate the safety deficiency. Exhibit 8.4–B is a listing of probable crash causes and possible safety enhancements. This list is not all-inclusive; however, it does provide a general list of possible crash causes as a function of crash patterns and appropriate safety enhancements.

Exhibit 8.4–A CONTRIBUTING CIRCUMSTANCES

Driver-Related	
Unsafe speed	Sick
Failed to yield right-of way	Fell asleep
Following too close	Lost consciousness
Improper passing	Driver inattention
Disregard traffic controls	Distraction
Turning improperly	Physical disability
Alcohol involvement	Drug involvement
Vehicle-Related	
Brakes defective	Tow hitch defective
Headlights defective	Overload or improper loaded
Other lighting defects	Oversize load on vehicle
Steering failure	Tire failure/inadequate
Environment-Related	
Animal on roadway	Holes/deep ruts/bump
Glare	Road under construction/maintenance
View obstructed/limited	Improperly marked vehicle(s)
Debris in roadway	Fixed objects
Improper/nonworking traffic controls	Slippery surface
Shoulders defective	Water ponding
Roadside hazards	

8.4.2 EXISTING SITE CONDITIONS ANALYSIS

Hazardous locations or features on existing roadways may or may not be HALs. Many locations with narrow bridges, slippery pavement, rigid roadside obstacles or other potentially hazardous conditions have crash potential but may not yet have a crash history. Therefore, it is important to identify potentially hazardous locations or features in the development of projects. When crash history is not available, a project listing of potentially hazardous features and locations may be used to determine the need for safety enhancements.

Exhibit 8.4–B GENERAL CRASH PATTERNS

Crash Pattern	Probable Cause	Safety Enhancement
Run-off roadway	Slippery pavement	Improve skid resistance Provide adequate drainage Groove existing pavement
	Roadway design inadequate for traffic conditions	Widen lane/shoulders Relocate islands Provide proper superelevation Install/improve traffic barriers Improve alignment/grade Flatten slopes/ditches Provide escape ramp
	Poor delineation	Improve/install pavement markings Install roadside delineators Install advance warning signs
	Poor visibility	Improve roadway lighting Increase sign size
	Inadequate shoulder	Upgrade roadway shoulder
	Poor or confusing channelization	Improve channelization
Bridges	Alignment	Realign bridge/roadway Install advance warning signs Improve delineation/markings
	Narrow roadway	Widen structure Improve delineation/markings Install signing/signals
	Visibility	Remove obstruction Install advance warning signs Improve delineation and markings
	Vertical clearance	Rebuild structure/adjust roadway grade Install advance warning signs Improve delineation and markings Provide height restriction/warning
	Slippery surface (wet/icy)	Resurface deck Improve skid resistance Provide adequate drainage Provide special signing
	Rough surface	Resurface deck Rehabilitate joints Regrade approaches

Exhibit 8.4–B GENERAL CRASH PATTERNS
(Continued)

Crash Pattern	Probable Cause	Safety Enhancement
Bridges (cont.)	Inadequate barrier system	Upgrade bridge rail Upgrade approach rail/terminals Upgrade bridge - approach rail connections Remove hazardous curb Improve delineation and markings
Overturn	Roadside features	Flatten slopes and ditches Relocate drainage facilities Extend culverts Provide traversable culvert end treatments Install/improve traffic barriers
	Inadequate shoulder	Widen shoulder Upgrade shoulder surface Remove curbing/obstructions
	Pavement feature	Eliminate edge drop-off Improve superelevation/crown
Parked vehicles	Inadequate road design	Widen shoulders
Fixed object	Obstructions in or too close to roadway	Remove/relocate obstacles Make drainage headwalls flush with side slope Install breakaway features to light poles, signposts, etc. Protect objects with guardrail Delineation/reflectorized safety hardware
	Inadequate lighting	Improve roadway lighting
	Inadequate pavement markings, signs, delineators, and guardrail	Install reflectorized pavement lines/raised markers Install reflectorized paint and/or reflectors on the obstruction Add special signing Upgrade barrier system
	Inadequate road design	Improve alignment/grade Provide proper superelevation Install warning signs/delineators Provide wider lanes
	Slippery surface	Improve skid resistance Provide adequate drainage Groove existing pavement

Exhibit 8.4–B GENERAL CRASH PATTERNS
(Continued)

Crash Pattern	**Probable Cause**	**Safety Enhancement**
Sideswipe or head-on	Inadequate road design	Provide wider lanes Improve alignment/grade Provide passing lanes Provide roadside delineators Sign and mark unsafe passing areas
	Inadequate shoulders	Improve shoulders
	Excessive vehicle speed	Install median devices
	Inadequate pavement markings	Install/improve centerline, lane lines and edge lines Install reflectorized markers
	Inadequate channelization	Install acceleration and deceleration lanes Improve/install channelization Provide turning bays
	Inadequate signing	Provide advance direction and warning signs Add illuminated signs
Access-related	Left-turning vehicles	Install median devices Install-two-way left-turn lanes
	Improperly located driveway	Move driveway to side street Install curbing to define driveway locations Consolidate adjacent driveways
	Right-turning vehicles	Provide right-turn lanes Increase width of driveways Widen through lanes Increase curb radii
	Large volume of through traffic	Move driveway to side street Construct a local service road
	Large volume of driveway traffic	Signalize driveway Provide acceleration and deceleration lanes Channelize driveway
	Restricted sight distance	Remove obstructions
	Inadequate lighting	Improve street lighting

Exhibit 8.4–B GENERAL CRASH PATTERNS
(Continued)

Crash Pattern	Probable Cause	Safety Enhancement
Intersection (signalized/ unsignalized) left turn, head-on, right angle, rear end	Large volume of left/right turns	Widen road Channelize intersection Install STOP signs Provide signal Increase curb radii
	Restricted sight distance	Remove sight obstruction Provide adequate channelization Provide left/right-turn lanes Install warning signs Install STOP signs Install signal Install advance markings to supplement signs Install STOP bars
	Slippery surface	Improve skid resistance Provide adequate drainage Groove pavement
	Large numbers of turning vehicles	Provide left- or right-turn lanes Increase curb radii Install signal
	Inadequate lighting	Improve roadway lighting
	Lack of adequate gaps	Provide signal Provide STOP signs
	Crossing pedestrians	Install/improve signing or marking of pedestrians crosswalks Install signal
	Large total intersection volume	Install signal Add traffic lane
	Excessive speed on approaches	Install rumble strips in travel lane
	Inadequate traffic control devices	Upgrade traffic control devices
	Poor visibility of signals	Install/improve advance warning signs Install overhead signals Install 12 in [300 mm] LED signal lenses Install visors/back plates Relocate signals Remove sight obstructions Add illuminated/retroreflectorized signs

Exhibit 8.4–B GENERAL CRASH PATTERNS
(Continued)

Crash Pattern	Probable Cause	Safety Enhancement
Intersection (cont.)	Unwarranted signals	Remove signals
	Inadequate signal timing	Upgrade signal system timing/phasing
Nighttime	Poor visibility or lighting	Install/improve street lighting Install/improve delineation/markings Install/improve warning signs
	Poor sign quality	Upgrade signing Provide illuminated/retroreflectorized signs
	Inadequate channelization or delineation	Install pavement markings Improve channelization/delineation
Wet pavement	Slippery pavement	Improve skid resistance Groove existing pavement
	Inadequate drainage	Provide adequate drainage
	Inadequate pavement markings	Install raised/reflectorized pavement markings
Pedestrian/bicycle	Limited sight distance	Remove sight obstructions Install/improve pedestrian crossing signs and markings
	Inadequate protection	Add pedestrian refuge islands
	Inadequate signals/signs	Install/upgrade signals/signs
	Mid-block crossings	Install warning signs/markings
	Inadequate pavement markings	Supplement markings with signing Upgrade pavement markings
	Lack of crossing opportunity	Install traffic/pedestrian signals Install pedestrian crosswalk and signs
	Inadequate lighting	Improve lighting
	Excessive vehicle speed	Install proper warning signs
	Pedestrians/bicycles on roadway	Install sidewalks Install bike lanes/path Eliminate roadside obstructions Install curb ramps
	Long distance to nearest crosswalk	Install pedestrian crosswalk If warranted, install pedestrian actuated signals

Exhibit 8.4–B GENERAL CRASH PATTERNS
(Continued)

Crash Pattern	Probable Cause	Safety Enhancement
Railroad crossings	Restricted sight distance	Remove sight obstructions Reduce grade Install active warning devices Install advance warning signs
	Poor visibility	Improve roadway lighting Increase size of signs Install advance markings to supplement signs
	Inadequate pavement markings	Install STOP bars Install/improve pavement markings
	Rough crossing surface	Improve crossing surface
	Sharp crossing angle	Rebuild crossing with proper angle or offset

8.4.2.1 Potential Roadside Hazards Review

Conduct a site investigation of the roadway project. Document all potential roadside hazards that are outwardly visible, and include those documented in previous reports that still exist in the field. Exhibit 8.4–C presents an example of a roadside hazard review.

Document not only those elements that appear to be a potential hazard, but identify all of the site elements that point to past problems or items that required maintenance. Some examples include:

- Locations of skid and tire marks, indicating where abrupt turns or stops were required;
- Damaged guardrail sections;
- Recently replaced signs, poles and barriers (indicating that something may have struck the previous feature);
- Dips or bumps in the pavement;
- Scars in the pavement (showing locations either rocks/debris have fallen, or where hitches/bumpers have scraped due to poor vertical alignment, grade or cross slope); and/or
- Visible signs of impacts to the bottoms of bridges or overhead structures (showing a lack of vertical clearance for the vehicles using the roadway).

Exhibit 8.4–C SAMPLE ROADSIDE HAZARD REVIEW

Page 1 of 1

State: **Montana** Prepared by: **Paul Schneider**
County: **Flathead** Date: **May 19, 1996**

National Forest/Park: **Glacier National Park**

Highway Route: **US Route 2** Limits: **193+116 to 202+128** Length: **9.0 km**

General Location: **Beginning 1 km south of Camas and extending north to top of graveyard hill at Essex.**

Item	Hazard Location		Description of Hazard	Action	Cost	Remarks
	Station	Offset (m)				
1	193+438	6.0 Rt	100×100 wood sign post	Yes	$ 90	Relocate to backslope
2	194+082	4.9 Rt	100×100 wood sign post	Yes	$ 90	Relocate to backslope
3	194+243	5.5 Lt	Concrete culvert headwall	Yes	$ 500	Replace existing culvert
4	194+323	4.9 Rt	Concrete culvert headwall	Yes	$ 600	Replace existing culvert
5	194+564	3.7 Lt	Mailbox in no-passing zone	Widen	$1000	Provide mailbox turnout
6	194+886	4.3 Rt	Two 100×150 wood sign posts (not drilled)	Yes	$ 50	Drill posts
7	195+530	4.9 Lt	Abrupt culvert ends	Yes	$ 250	Lengthen culvert – provide metal end sections
8	196+013	4.6 Lt	Mailbox - good sight Distance	No	-	Tight right-of-way
9	196+013	5.5 Lt	Abrupt approach road Culvert	Yes	$ 600	Extend approach culvert and flatten slope to 1:10
10	196+174 to 196+656	6.7 Rt	Steep fill slope	None	-	Not cost effective Guardrail
11	197+300	6.0 Lt	Concrete culvert headwall	Yes	$ 500	Replace and extend
12	198+105	5.5 Rt	Abrupt approach road Culvert	Yes	$ 600	Extend culvert and flatten slope to 1:10
13	200+680	4.3 Rt	Concrete culvert headwall	Yes	$ 500	Replace existing culvert
14	201+645	3.7 Lt	Mailboxes (4)	Widen	$2500	Provide mailbox turnout

8.4.2.2 Two-Way Travel on Narrow, Single Lane Facilities

While not desirable, two-way travel on a narrow roadway cannot always be avoided, especially if widening the roadway would significantly interfere with the context of the adjacent landscape. When reviewing these facilities, document in particular where sight distance needs are critical issues. Rather than widening the entire roadway, perhaps only widening through the curves is necessary, especially if there is a low history of crashes on the facility.

8.4.2.3 Access Evaluation

Access management seeks to improve traffic distribution, reduce vehicle conflicts and reduce crashes by providing better access control. Better access control can be achieved by combining, reducing and improving safety elements of access points. The result is a roadway that functions safely and efficiently for its useful life, and creates a more attractive corridor. A good access management plan can offer a great combination among operation, geometric design and safety.

8.4.2.4 Turning Movements, Intersection Sight Distance

Evaluation of existing site turning movements, whether into a driveway, within a site facility (i.e. an entry station, parking lot, bus pullout, etc.), or at an intersection, includes a review of the geometry to make the turn and the ability to see oncoming traffic to safely make the turning movement. Evidence that either of these conditions is not adequately available is the existence of tire marks over a curb, heavy wear either on or beyond the shoulder, or skid marks leading to the intersection.

Evaluation of the sight distance at intersections includes the geometry of the intersection, the traffic control at the intersection, and driver behavior. Sight distance is affected by sight obstructions. Examples of sight obstructions at intersections include:

- Buildings
- Parked or Turning Vehicles
- Landscaping and Trees
- Intersection Signing Panels and Light Poles
- Fences
- Retaining Walls
- Graded Slopes too close to the Mainline
- Vertical Grades of Approaching Roadways

Intersection sight distance (ISD) is the minimum sight distance required for drivers to safely negotiate intersections, including intersections with or without stop controls or traffic signals. Refer to Section 9.3.7.5 for more information.

Decision sight distance (DSD) is the length of road a driver needs to receive and interpret information, select an appropriate speed and path and begin and complete an action in a safe maneuver. This distance is greater than the distance needed to simply bring a vehicle to a stop, and provides for a reasonable continuity of traffic flow. Use DSD for the approach to intersections if it is greater than the ISD. Refer to Section 9.3.7.3 for more information.

The speed at which vehicles approach and move through an intersection, along with the design vehicle used, are the primary factors which influence the minimum dimensions of intersection design. Features such as minimum sight distance, curve radii, and lengths of turning and storage lanes, directly relate to the design speed and design vehicle. Refer to Section 9.3.14 for geometry guidelines at an intersection.

8.4.2.5 Adequate Facility Capacity

Capacity is a term that indicates the ability of a specific facility to fulfill a specific function. For roadways, it generally means the amount of traffic that can pass by a specific point on a roadway or through an intersection. For evaluating these situations, the *Highway Capacity Manual* (*HCM*) is the document of choice. There are also many facilities that can restrict traffic from moving, resulting in vehicles queuing on the mainline. Queuing of traffic on the mainline that results from restricted access off of the main roadway, queuing at a toll/fee facility, and/or vehicles stopping and accumulating at an overwhelmed intersection typically requires analysis developed for that particular activity, and may require individual traffic studies that are unique for a given application.

If the mainline traffic is routinely restricted, evaluate the site to see if sufficient warnings are in place to alert the driver of the potential restriction. This is particularly important if the facility or the queued traffic is in any way hidden from the oncoming mainline traffic (i.e., located around a bend or curve). If the mainline traffic is not supposed to be delayed, such as traffic leaving the mainline to enter a facility through a driveway or intersection, evaluate whether a separate turning lane is necessary. Such a facility should provide enough storage to allow the queued vehicles to get off of the mainline and not obstruct the through traffic.

When evaluating facility capacity, also review the site for adequate storage and operation of pedestrian facilities as well. This is particularly important around trailheads and visitor facilities where parking may be on one side of a roadway or access, and the attraction on the other. Similar to queued traffic, pedestrians will only be delayed for a limited period of time before they decide to reduce their necessary decision sight distance.

8.4.2.6 Appropriate, Visible Signing and Marking

Provide appropriate, visible signing and marking in accordance with the MUTCD in plans, specifications and estimates (PS&E). **Design all PS&Es using the current edition of the *MUTCD*.**

Evaluation of existing signing and markings is not only a review of the appropriate placement of these elements, but a review of their functionality and condition with respect to their current location. For evaluating proper application signing and markings, refer to the *MUTCD*, which discusses signs, including Regulatory, Warning, Guide, Specific Service, Tourist Oriented Direction Signs, Recreational and Cultural Interest, and Emergency signs. The *MUTCD* also discusses pavement markings on all types of facilities. It is used as a standard so that all drivers can understand the consistent use, meaning and purpose of every traffic control device. The FHWA *Standard Highway Sign Guide* (*SHS*), the *NPS UniGuide Standards*, and other documents (e.g., USFS, State, etc.) should also be used for additional guidance when evaluating individual signs. Upgrading pavement markings and signing to MUTCD requirements can reduce crashes and help guide motorists. This is especially important when motorists are unfamiliar with the roadway.

The retroreflective sheeting on sign panels gradually deteriorates over time making signs less visible at night. The *MUTCD* requires that traffic signs be illuminated or retroreflective to enhance nighttime visibility. Sign sheeting does not have a life expectancy that matches typical project design life. Therefore, replace all permanent regulatory (black on white / white on red), warning (black on yellow), and destination and directional guide (white on green / white on brown) signs with new panels conforming to the *MUTCD*. Although all signs are required to be retroreflective and maintained, the following signs may be excluded from the above retroreflectivity replacement policy and should be evaluated on a project by project basis to determine the need for replacement:

- Parking, Standing, Stopping signs,
- Walking/Hitchhiking signs,
- Adopt-A-Highway signs,
- Blue/brown background information signs, including educational plaques and recreational and cultural interest area symbol signs, and
- Bikeway signs for exclusive use by pedestrians/bicyclists.

Projects can be exempted from this sign replacement policy if there are already plans for another agency to replace the signs in the very near future.

In addition to review of the appropriate application of these elements, also review the following:

- Visibility/location of signs/markings. It is important that the motorist can see the sign or pavement marking, so that it can be clearly seen and reacted to (such as a warning sign placed an adequate distance from the safety condition, such as a Stop Ahead sign in advance of a Stop sign). Advance warning sign distances as well as other appropriate information are discussed in the *MUTCD*.
- Size of text/font on signs appropriate for posted speed. Similar to visibility, the text/font must be appropriate for the driver to read while moving at the design speed. The *MUTCD, SHS* and the *NPS UniGuide Standards* should be used for evaluating text/fonts.
- Light screening. Visitor facilities, especially those with heavy pedestrian use, will incorporate site lighting. Occasionally, the projection of the lighting can interfere with the driver’s ability to see. Lighting at athletic facilities in particular can blind a driver if they look directly at these fixtures. If the site has extensive use of specialty or flood lights, evaluate their location and projection at night to see if these facilities impair a driver’s ability to see the road, signing, markings, and pedestrians. Occasionally, screening is warranted to block the lighting from obstructing the driver’s view.

8.4.2.7 Evaluation of Lighting and Traffic Signal Warrants

A careful analysis of traffic operations, pedestrian and bicyclist needs, and other factors at a large number of signalized and unsignalized locations, coupled with engineering judgment, has provided a series of signal warrants, described in Chapter 4C of the *MUTCD*, that define the minimum conditions under which installing traffic control signals might be justified.

Highway lighting is discussed in Section 8.7.3, and in AASHTO's *Roadway Lighting Design Guide*, which includes a similar discussion on lighting warrants.

8.4.3 EXISTING GEOMETRIC CONTROLLING FEATURES ANALYSIS

Refer to Section 4.4 for determination of current design standards and controls that are applicable to the project.

Many existing highways do not meet current design standards and have safety deficiencies when compared to the current design standards of the AASHTO *Green Book*. The amount of upgrading necessary to bring an existing facility to current design standards has been a continuing concern. This concern was recognized in the 1982 *Surface Transportation Assistance Act*, Section 101(a), which emphasized safety by stating that RRR projects "shall be constructed in accordance with standards that preserve and extend the service life of the highways and enhance highway safety." Although the primary objective of RRR projects is to restore the structural integrity of the existing roadway, both the safety and capacity of the facility should be reviewed and enhanced, when required.

To properly review an existing roadway for conformance to current and acceptable design criteria, the following factors should be evaluated. If the feature is within the current design guidelines, no changes are necessary. If the feature does not meet the current standards, it should either be improved or documented to warrant a design exception. Economics, anticipated growth, crash history, program schedules, time, manpower, etc., may have some bearing prior to final determination.

8.4.3.1 Horizontal and Vertical Stopping Sight Distance

As-built plans are normally the best source of data available for evaluation of existing horizontal curves and vertical profile alignments. In some instances, hard copy maps or other survey information may be available in the absence of as-built plans. Once the existing alignment has been determined, the AASHTO *Green Book* can be utilized to determine the theoretical adequacy of the existing horizontal alignment and the vertical profile. Refer to Section 9.3.7.2 for more information on Stopping Sight Distance (SSD).

Stopping sight distance on horizontal curves is an important feature that should be closely observed during the initial field review. During the drive through the project, features that would appear to restrict horizontal and vertical sight distance (e.g., narrow cut ditches, trees, outcroppings) should be observed. Measurements can be taken during the field visit to determine if restrictions do exist or additional data can be requested as needed.

8.4.3.2 Cross Section

Lane width and shoulder width on an existing roadway can be determined by researching the as-built plans or by actual field measurement. During the field reviews, lane and shoulder widths should be observed and verified as necessary to determine how the existing widths compare with AASHTO guidelines. Refer to Section 9.3.8 for more information.

8.4.3.3 Existing Superelevation

While the horizontal curvature shown on as-built plans is generally very reliable, the superelevation data cannot be relied upon because revisions to superelevation during construction may not have been well documented. Also, subsequent overlay projects and maintenance work may have changed the original superelevation.

Since as-built superelevation data may not be reliable, other means of reviewing superelevation are needed. It is not the intent to field survey each curve to determine actual values; however, the following actions should be performed during the initial field review:

- Observe the comfort level of the existing curves as they are driven through at the posted speeds.
- Arrange to review any particular problem areas in more detail (e.g. discuss with the maintenance foreman responsible for the area).

8.4.3.4 Roadway Cross Slope

AASHTO has established guidelines for ranges of cross slopes for various roadway classifications. See Section 9.3.8.4.1 for the FLH standard practice regarding cross slope. The primary consideration on cross slope is to provide adequate pavement drainage. This item should be addressed by visual observation during the site visit. Also, agency maintenance representatives should be asked to provide any historical information in regard to problems with cross slope, ponding on the pavement or irregular shape of the cross section.

In some instances, the existing pavement cross section may have become distorted due to several overlays and/or maintenance treatment. If this is the case, the new pavement design should consider alternatives (e.g., additional removal, milling, total reconstruction) for the pavement section. This should be coordinated closely with the materials team and should be included as part of their pavement evaluation process.

8.4.3.5 Intersection Stopping Sight Distance/Decision Sight Distance

The at-grade intersections of the through facility with intersecting roads should be reviewed for adequacy of sight distance during the initial field review for the project. If there appears to be a potential problem with sight distance, the sight distance may need to be determined on site.

Consideration should be given to modifications of obstructions occurring within the sight triangle. The location of the intersection on the vertical alignment is also an important factor. See Section 9.3.7 for more information on sight distance requirements.

8.4.3.6 Vertical Grades

The existing profile on a route can be determined by a review of the as-built plans. The review of the vertical alignment and stopping sight distance will provide some indication of grades that may need further evaluation. In general, AASHTO has established guidelines for suggested maximum grades for various roadway classifications.

8.4.3.7 Vertical Clearance

Underpass clearances at bridge structures should be verified through a review of the bridge inspection or maintenance reports. Existing clearances can then be compared with the AASHTO recommended clearances. Whenever a change in the existing profile grade on an existing route is being contemplated, the vertical clearances at existing structures should be reviewed to determine how the proposed changes in profile (e.g., overlay, mill) affect the clearance. AASHTO provides recommended vertical clearances for various roadway classifications.

8.4.3.8 Structural and Functional Sufficiency

Bridge width is defined as the minimum clear roadway width on the bridge as listed under the column heading “Curb to Curb” of the Bridge Record. For all existing bridges contained within the project limits, the bridge width should be compared with the AASHTO guidelines. AASHTO provides bridge width criteria for the various functional roadway classifications.

Structural sufficiency is determined in part by the maintaining agency, but is generally desirable to achieve an HS20 [MS-18] load rating, regardless of the functional classification of the roadway. AASHTO provides structural capacity criteria for the various roadway functional classifications. Refer to Chapter 10 for guidance on rating structural capacity.

Functional sufficiency is the adequacy of the bridge to carry the traffic volume and speed from an operational and capacity standpoint. Refer to the *Green Book* for guidance on the overall clear roadway width and design speed recommended for the particular functional classification and design traffic volume.

And finally, the bridge barrier type and sufficiency should be evaluated. For information regarding bridge barrier and off-bridge transition features (e.g., barrier curbs, walkways and roadside barriers) refer to the *RDG*.

8.4.4 EVALUATION OF PEDESTRIAN/MULTI-MODAL FACILITIES

When evaluating the existing conditions, make a separate evaluation of the site from the perspective of pedestrians, bicyclists, handicapped persons and those using alternative forms of transportation (e.g., horseback, snowmobiles, ATVs). Clear delineation of the path these users are intended to follow, supplemented with adequate signing and information placards, is another important safety evaluation element of the roadway. Also refer to Section 9.3.16 and Section 9.3.17.

8.4.4.1 Accessibility Requirements

Refer to the *ADA Accessibility Guidelines for Buildings and Facilities* (*ADAAG*) for design guidelines.

8.4.4.2 Path Width/Accessibility

Where pedestrians are present, verify that the path for the pedestrian is clearly delineated. In addition, observe the paths that pedestrians choose to take and review the safety of the alternative routes. If any of these conditions are determined to be unsafe, positive pedestrian barriers such as railings may be necessary to ensure safe pedestrian crossings and keep them from crossing the roadway at hazardous locations.

The size of pedestrian facilities is volume dependent. The National Park Service uses many useful resources for estimating visitor traffic. These should be reviewed when sizing the sidewalk and pathway facilities.

8.4.4.3 Parking/Trails access from Roadways/Bridges

Pedestrians will generally use the shortest path of least resistance to reach their destination. If their destination is visible, and a "short-cut" can be seen that will significantly reduce their walking distance, given no other means of restriction, they may attempt to use the short-cut. Ingress/egress from trails, comfort stations, parking facilities and buildings must be coordinated with crosswalks and sidewalks.

If a sidewalk is not provided, the visitor may become resourceful and use other transportation facilities to view or access their desired destination. For example, if a bridge crosses a beautiful canyon and provides a unique photo opportunity, but does not have a sidewalk, most people will simply walk on the roadway. While some environmental and historic restrictions could prevent the structure from having a sidewalk, the designer must address how keep the pedestrian and vehicular traffic separated. This will likely require discussions with the resource agencies, but could reduce future safety implications if these concerns are addressed early in the design.

8.4.5 SAFETY EVALUATION COMPUTER PROGRAMS

Several computer programs are available to aide in the evaluation of the safety of an existing roadway. While these programs work as a great tool, they should not be used as a replacement of site evaluation and professional assessment.

8.4.5.1 Interactive Highway Safety Design Model (IHSDM)

The IHSDM is a suite of software analysis tools for explicit, quantitative evaluation of safety and operational effects of geometric design decisions during the highway design process. It culminates a multiyear research and development effort conducted by the Federal Highway Administration.

The IHSDM is intended for use throughout the highway design process from preliminary planning and engineering through detailed design to final review for two-lane rural roads. It may be used both for projects to improve existing roadways and for projects to construct new roadways. The 2006 release of IHSDM has six evaluation modules:

- Policy review,
- Crash prediction,
- Design consistency,
- Driver/Vehicle
- Intersection review, and
- Traffic analysis.

Additional capabilities including evaluations of multilane rural highways are planned for future releases.

8.4.5.2 Roadside Safety Analysis Program (RSAP)

Highways are designed to provide motorists with reasonable levels of protection against serious run-off-the-road crashes. When hazards cannot be removed or relocated within the clear zone, a determination needs to be made if a safety device is warranted to protect motorists from the roadside obstacle. RSAP uses the concept of incremental benefit/cost analysis to weigh the risk of death or injury to the motoring public against the initial cost of installing and maintaining the safety improvement. Appendix A of the *Roadside Design Guide* provides a cost-effective selection procedure for comparing alternative solutions to problem locations and instructions for operating the Roadside Safety Analysis Program (RSAP) computer software. The annual cost of each alternative is computed over a given period of time, taking into consideration initial costs, maintenance costs and crash costs. Crash costs incurred by the motorist, including vehicle damage and personal injury, are considered together with crash costs incurred by the highway department or agency. The alternative with the least total cost is normally selected, except when environmental or aesthetic considerations dictate otherwise.

The ability to easily vary input data allows the designer to explore various areas of sensitivity of the analysis at a given location. The effects of current traffic and future traffic can be explored to evaluate cost effectiveness over the design life of a project. Although most of the data collected through research pertains to high-speed situations, the designer can analyze how sensitive the cost effectiveness is with respect to the severity index. However, a correlation can be made provided the designer recognizes that lower design/running speeds would lessen severity. Use of this tool has been successful in persuading agencies to recognize the cost effectiveness of selected safety feature applications.

This program accesses research information by Kennedy-Hutcheson for high-volume roads and Glennon for low-volume roads with roadway widths less than 28 ft [8.5 m]. The program shows both annual cost comparison and present worth. Generally, the annual cost is used to facilitate comparison of different alternatives with varying design life.

Refer to NCHRP Report 492, the RSAP Engineer's Manual, for more information.

8.4.5.3 Resurfacing Safety Resource Allocation Program (RSRAP)

Highway agencies face a dilemma in determining the appropriate balance of resurfacing and safety improvement in their programs to maintain the structural integrity and ride quality of highway pavement. RSRAP uses an optimization process based on integer programming to determine the most cost-effective set of safety enhancements that achieve the optimal benefits for a specified set of candidate resurfacing projects. In this way, RSRAP can maximize the system wide safety benefits for a given set of resurfacing projects as a whole, rather than maximizing the benefits at any particular site. RSRAP incorporates the best available estimates of the safety effectiveness of specific geometric design and safety improvements.

8.4.6 ROAD SAFETY AUDITS

A Road Safety Audit (RSA) is a formal safety performance examination of an existing or future road or intersection by an independent audit team. They can be performed during any stage of project development from planning through construction and throughout the operation of the completed facility. RSAs can also be used on any size project, from minor maintenance assessments to major new program expansions. Typical improvements suggested include:

- Removal of sight distance obstructions,
- Addition/design changes to turn lanes,
- Improvement to acceleration/deceleration lane design,
- Illumination,
- Median barrier placement,
- Consideration of pedestrian's ability to cross a street,
- Improvements to superelevation,
- Drainage improvements,
- Roadway shoulder and lane width modifications,
- Access management/consideration of driveways,
- Realignment of intersection approaches, and
- Improvements to signing and pavement marking.

The recommended procedure for conducting an RSA is as follows:

1. **Audit Team**. Following identification of a project or roadway that is to be evaluated, select an interdisciplinary audit team to conduct the review. The team should consist of three to five people from various design and operations disciplines including highway design, traffic safety, traffic engineering, planning, geometric design, construction, maintenance, human factors and enforcement.

2. **Pre-Audit Meeting**. Conduct a pre-audit meeting with the interdisciplinary team and the Project Owner/Design Team to review available project drawings and site information, including traffic and crash data.
3. **Field Review**. Consider field reviews under various conditions like during peak travel times or at night. The team should have the willingness to investigate new ideas outside the traditional scope of work.
4. **Audit Analysis**. Analyze collisions, geometrics, operations, traffic conflicts, and human factors and identify deficiencies. Select countermeasures and prepare a report listing the team's findings and recommendations.
5. **Report Audit Findings**. Present report and audit findings to the Project Owner/Design Team.
6. **Prepare Formal Response**. The Project Owner/Design Team prepares a formal response, incorporating the findings into the project when appropriate.

RSAs are different from traditional safety reviews because these multi-discipline team reviews tend to be more proactive, considering all of the various types of road users that may be using the facility and all of the factors that contribute to a crash. These reviews include day and night field reviews by independent teams. The synergy created by these teams has resulted in more safety implementation recommendations being recommended than in the past when only one safety individual was responsible for the review.

8.4.7 SAFETY EVALUATION REPORT

After the accumulation of available data, this information and all observations must be consolidated and documented in a Safety Evaluation Report. The results of the crash analysis and the list of potential roadside hazards provide the input for this evaluation. From these two sources, the designer should develop a composite list that locates and describes the identified safety problems.

Alternatives for correcting the safety problems should be developed and evaluated for effectiveness, cost and environmental impact. Alternatives may range from site-specific improvements to total reconstruction. The evaluations, alternatives and the action selected should be documented in the project files.

8.5 SAFETY DESIGN

8.5.1 DESIGN EXCEPTIONS

Although often viewed as dictating a set of national standards, the AASHTO *Green Book* is actually a series of guidelines on geometric design within which the designer has a range of flexibility. As stated in the forward to this document:

> *"The intent of this policy is to provide guidance to the designer by referencing a recommended range of values for critical dimensions. Sufficient flexibility is permitted to encourage independent designs tailored to particular situations."*

While it provides guidance on the geometric dimensions of the roadway (e.g., travel lanes, medians, shoulders, horizontal clearance, etc.), there are many aspects of design that are not directly addressed in the *Green Book*. Despite the range of flexibility that exists with respect to virtually all the major road design features, there are situations in which the application of even the minimum criteria would result in unacceptably high costs or major impact on the adjacent environment. For these instances, the design exception process allows for the use of criteria lower than those specified as minimum acceptable values in the *Green Book*.

For a full discussion on the elements that must be addressed in a design exception, refer to Section 9.1.3.

8.5.2 DEFINING THE CLEAR ZONE

A clear zone (L_c) is defined as the roadside border area (starting at the edge of the traveled way) that is available for safe use by errant vehicles. The width of the clear zone is influenced by the type and volume of traffic, speed, horizontal alignment and side slopes. Slopes steeper than 1V:4H are non-recoverable and most vehicles will be unable to stop or return to the road easily. See Exhibit 4.3-B as an example. Slopes steeper than 1V:3H are considered critical since a vehicle is more likely to overturn. The need for traffic barriers as discussed in Section 8.5.3 should be evaluated when slopes within the clear zone are in these ranges.

Determine clear zone widths for all roadway sections by using Table 3.1 or Figure 3.1 of the AASHTO *Roadside Design Guide* or by using the *FLH Barrier Guide*. Where feasible and environmentally acceptable, the clear zone width should be a minimum of 10 ft [3 m]. On rural collectors and local roads and streets with a design speed of less than 40 mph [60 km/h] or an ADT less than 750, the clear zone width may be determined and documented on a project-by-project basis.

Note that many publications (*RDG* and the *Green Book*) consider a foreslope to include the entire sideslope(s) from the outside edge of the roadway shoulder down to the bottom of the ditch or fill/embankment section.

8.5.3 TRAFFIC BARRIERS

For all projects, FLH standard practice is to establish an appropriate clear zone and design the roadside accordingly. When clear zone requirements cannot be met, the designer should give special attention to the roadside hazards. Obstacles located within the clear zone should be removed, redesigned, relocated or made breakaway. If this is not feasible, then guardrail or some other type of roadside barrier should be considered, provided that the roadside barrier offers the least hazard potential. If it is determined that a traffic barrier is not needed, consider delineating the hazard.

While the following sections provide policy and direction for installing traffic barriers, the designer should also review the *FLH Barrier Guide* for a more comprehensive review of available barriers, their applications and their installation requirements.

8.5.3.1 Identifying Needs

Roadside obstacles may be classified as non-traversable hazards or fixed objects.

The following are examples of non-traversable hazards that may warrant roadside barriers:

- Steep embankments (slopes steeper than 1V:3H),
- Rock cuts,
- Large boulders,
- Ditches,
- Culvert openings,
- Permanent bodies of water over 2 ft [0.6 m] in depth,
- Large trees over 4 in [100 mm] diameter, and/or
- Shoulder edge drop-offs steeper than 1V:1H and depth greater than 2 ft [0.6 m].

A ditch section is safe or hazardous depending upon the type of sideslopes and widths. The *Roadside Design Guide* contains examples of a variety of ditch configurations. Frequently, limited right-of-way, environmental factors and terrain will preclude the designer from being able to develop these preferred ditch sections. Preferred ditch sections should receive greater consideration on high-speed, high-volume facilities. Medians on divided roadways also deserve special attention.

The following are examples of fixed objects that may warrant roadside barriers:

- Bridge piers, abutments, parapets or railings;
- Retaining walls;
- Fixed sign bridges and non-breakaway sign supports;
- Trees over 4 in [100 mm] in diameter;
- Headwalls of box culverts or pipe culverts;
- Culvert end sections with diameters larger than 36 in [900 mm]; and/or

- Utility appurtenances.

The unprotected end of a bridge rail or parapet is considered a hazard. In most designs, an approach roadside barrier with a smooth transition to the bridge barrier is warranted. Exceptions to this policy may include structures designed for use on low-volume, low-speed highways. Refer to Section 8.5.3.4 and the *Roadside Design Guide* for more discussions on bridge rails and transition barriers.

Crashes involving roadside hazards represent a problem inherent to any existing highway facility. Even on new or reconstructed projects, the complete elimination of all roadside hazards may not be feasible or practical.

When determining the need for traffic barriers, consider cost, feasibility, and environmental impacts when evaluating the following four alternatives:

1. **Remove or Reduce Hazard.** Remove a hazard in it's entirety or by relocating it. Reduce the degree of the hazard through a redesign of the object or use of breakaway devices.
2. **Install a Barrier.** With regard to installing a barrier, RSAP (see Section 8.4.5.2) allows the designer to evaluate any number of barriers that can be used to shield the hazard. Through this method, the following can be evaluated:

    - The effects of average daily traffic,
    - Offset of barrier or hazard,
    - Size of barrier or hazard, and
    - The relative severity of the barrier or the hazard.

    For low-volume, low-speed roads, strict adherence to the guardrail warrants shown in the *Roadside Design Guide* are frequently not practical or cost-effective. See the *FLH Barrier Guide* for more information.

    Characteristics that affect barrier needs include the following:

    - Roads closed in winter and during periods of hazardous climatic conditions,
    - Roads closed at dark,
    - Vehicle speed,
    - Length or other vehicle restrictions, and
    - Roads with access limited to passenger-carrying vehicles.

    Another consideration affecting the use of barriers is for areas that have unusual environmental sensitivity (e.g., endangered plants and animals, major historic and scenic resources).

    Always remember that a barrier is itself a significant hazard and is more likely to be hit than the hazard it is intended to protect. Therefore, the relative severity, costs and frequency of crashes must be considered.

    Although the warrants cover a wide range of roadside conditions, special cases or conditions will arise for which there is no clear choice. These cases must be evaluated on an individual basis, and, in the final analysis, must usually be solved by engineering judgment.

3. **Sign or Delineate Hazard**. Signing or delineating a hazard is typically cost-effective on low-volume and/or low-speed facilities, or where the probability of crashes is low.

4. **Do Nothing**. Use this option only after determining that other alternatives are not cost-effective in reducing the risk of crashes.

8.5.3.2 Type Selection

Once it has been determined that a barrier is needed, type selection will be made. While the most predominant type of roadside barrier used on Federal Lands' projects is metal W-beam guardrail, the designer needs to be cognizant of various selection criteria for roadside barriers. Exhibit 8.5–A lists the various criteria that should be considered.

Exhibit 8.5–A SELECTION CRITERIA FOR ROADSIDE BARRIERS

Characteristic	Considerations
Deflection	Space available behind barrier must be adequate to permit dynamic deflection of barriers.
Strength and Safety	System should contain and redirect vehicle at design conditions. System should be as safe as possible considering costs and other considerations.
Maintenance	Collision maintenance. Routine maintenance. Environmental conditions. Inventory of spare parts.
Compatibility	Can system be transitioned to other barriers? Can system be terminated properly?
Costs	Initial costs. Maintenance costs. Crash cost to motorist.
Field Experience	Documented evidence of barrier's performance in the field.
Aesthetics	Barrier should have a pleasing appearance.
Promising New Designs	It may be desirable to install new systems on an experimental basis.

Refer to the *Roadside Design Guide* and the FHWA Roadside Hardware website for design criteria of the various systems.

The FLH has conducted crash tests using the National Cooperative Highway Research Reports (NCHRP) 230 and 350 criteria to evaluate aesthetic barrier systems. Research efforts are in progress to identify and crash-test other systems for possible use on FLH Program projects.

The owner agency generally selects the type of roadside barrier. It is the designer's responsibility to ensure that the selected barrier has been tested and approved for use and designed to function where installed.

The FLH policy requiring barrier systems to meet the requirements of NCHRP-350 is provided below:

1. **Routes on the NHS**. The following applies:

   - *State and local routes*. **As required by FHWA, it is the policy of the FLH to use only roadside safety hardware that meets NCHRP 350 criteria. No exceptions are permitted, except for specific hardware items receiving delays or temporary waivers granted by the FHWA, Office of Safety Design (HSA-10).**

   - *National Park Service (NPS) routes.* **It is also the policy of the FLH that all roadside safety hardware shall meet NCHRP 350 criteria on NPS routes.**

   A request for acceptance of aesthetic barrier systems previously accepted under NCHRP 230 may be submitted to the Office of Safety Design for consideration. The Office of Safety Design may determine that the barrier is acceptable under NCHRP 350 criteria without retesting if the test result data under NCHRP 230, or results from similar systems tested under NCHRP 350, indicate the system is likely to meet NCHRP 350 criteria.

2. **Routes not on the NHS**. The FLH should comply with the owning agency's policies on roadside safety hardware on non-NHS routes. The owning agency's policies will be referenced as the reasons for permitting barrier systems that do not meet NCHRP 350 criteria. **However, no barrier systems shall be used that have not passed NCHRP 230 criteria. If the agency has no policy, FLH shall specify roadside safety hardware that meets NCHRP 350 criteria.** Although there is no regulatory requirement, the FHWA strongly encourages safety hardware used on non-NHS routes to meet NCHRP 350 criteria.

   - *State and local routes*. Due to particular issues (e.g., maintenance of barrier systems), State or local agencies may require barrier systems that do not meet NCHRP 350 criteria. **The FLH Divisions shall ensure the owning agencies are aware that proposed systems do not meet NCHRP 350 criteria before complying with the owning agencies' requests. The decision and reasons for specifying barrier systems that do not meet NCHRP 350 criteria must be documented as a formal design exception.**

   - *NPS routes*. **All barrier systems shall meet NCHRP 350 criteria. The decision to use barrier systems that do not meet NCHRP 350 criteria must be documented as a formal design exception.**

Roadside safety hardware meeting NCHRP 350 criteria are currently being accepted by the Office of Safety Design following a review of data submitted by the vendor or the developer of the system. Updated lists of approved barrier systems are maintained by the FHWA. If no acceptable non-proprietary barrier terminal systems and transitions are available that meet the project needs, at least three acceptable proprietary systems (if available) shall be permitted as options in the contract.

8.5.3.3 Design Procedures

Once the need for barrier has been determined, the designer must determine the length and location for the barrier. The following discussion outlines the significant elements for locating and designing roadside barriers. However, the designer should refer to the *Roadside Design Guide* for specific details and limiting criteria for layout and use of the barrier selected, along with the *FLH Barrier Guide* for low volume and low speed road applications.

8.5.3.3.1 Length of Barrier

The length of need is equal to the length of the area of concern parallel to the roadway, plus the length of the approach barrier on the upstream side (and downstream side, if needed), plus a safety end treatment. Exhibit 8.5–B depicts approach barrier layouts for both adjacent traffic and opposing traffic. Refer to the *RDG* for descriptions of the variables shown in these layouts.

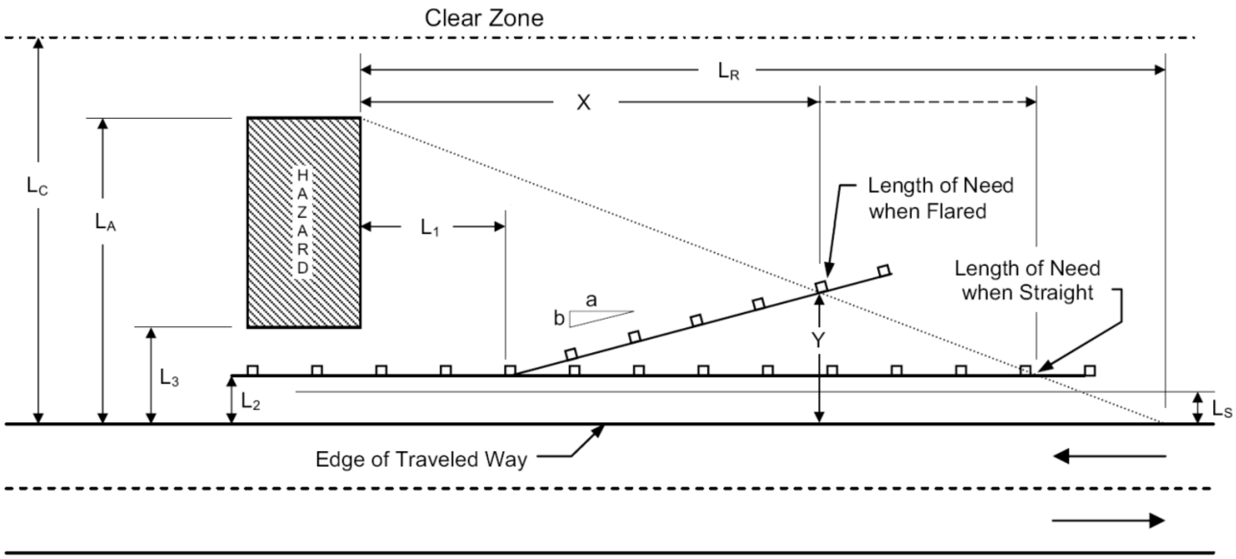
Where slopes outside of the graded shoulder are flat enough, the barrier approach should be flared or the guardrail installation should be located outside of the graded shoulder to minimize the length of need. More commonly, where slopes are steeper, the barrier will run along the shoulder.

8.5.3.3.2 Location of Barrier

The location of a barrier may be one of the following:

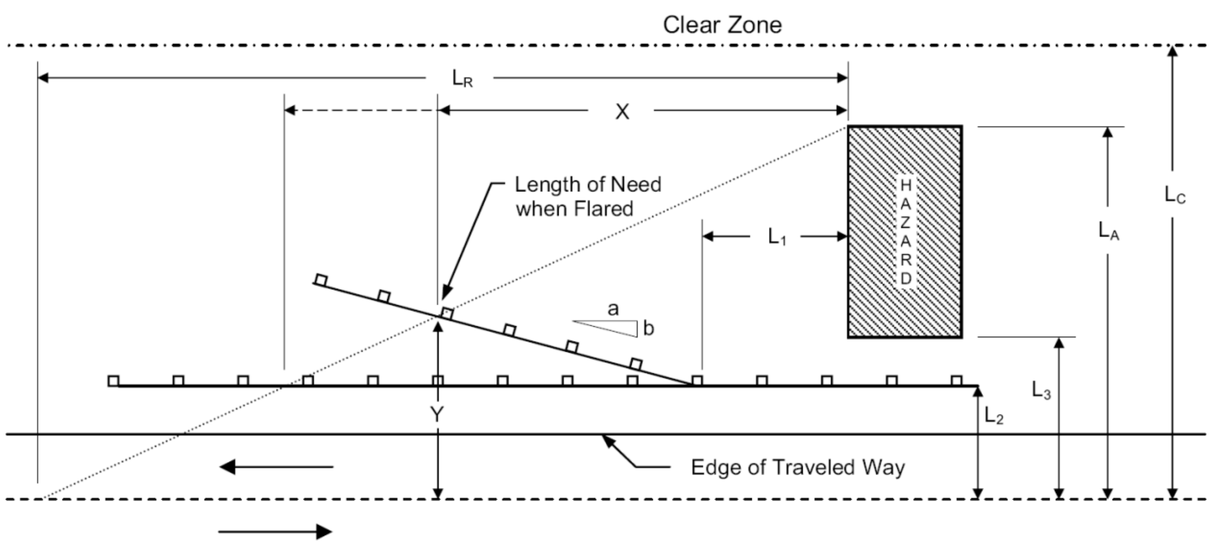
1. **Adjacent to the Graded Shoulder**. Designers should be aware that barrier installations require widening of the shoulder to provide adequate soil support. In addition, special attention is required at barrier terminals to ensure that widened areas are graded correctly so that the terminal will function properly.
2. **Back of the Graded Shoulder**. Where barriers are located in back of the graded shoulder or when barriers are flared back of the shoulder edge, slopes in front of the barrier shall be 1V:10H or flatter. Also, the algebraic difference between the shoulder slope and the slope in front of the guardrail should not be greater than 8 percent.
3. **Adjacent to a Retaining Wall Face**. When barriers are located near the edge of a retaining wall, there may not be adequate support behind the barrier for the embedded posts to properly sustain the impact loading and may require project-specific design. For example, the supports may need to be founded in a cantilever-spread footing and require a special structural design. For these situations, both the structural and highway safety engineers need to review the proposed installation.

Exhibit 8.5–B GUARDRAIL LENGTH REQUIREMENTS



Approach Barrier Layout for Adjacent Traffic

Note: For a description of the layout features and the associated equations to design these installations, refer to the Roadside Design Guide.



Approach Barrier Layout for Opposing Traffic

8.5.3.3.3 Barrier/Curb Combinations

The following briefly describes barrier/curb combinations:

1. **All Barrier/Curb Combinations**. Concrete curb and gutter, header curb or other rigid-type curb used in combination with a barrier should be avoided whenever possible.

Curbs should not be used in front of barriers unless the combination has been successfully crash-tested.

2. **Guardrail/Curb Combinations**. Where there are no other feasible alternatives to guardrail/curb combinations, the face-of-curb should be located behind or flush with the face of guardrail. However, crash tests have shown some guardrail/curb combinations with curbs located flush with the face of the guardrail can cause vaulting due to deflection of the rail. Therefore, curbs higher than 4 in [100 mm] should not be used with guardrail unless:

   - The guardrail/curb combination has been successfully crash-tested, or
   - The rail is adequately reinforced (stiffened) to reduce its deflection.

   On low-speed roads, use of a reinforced rail may not be cost-effective. These locations are best analyzed on a case-by-case basis, taking actual or anticipated operating speeds into account and considering the consequences of vehicular penetration.

The *Roadside Design Guide* and the *FLH Barrier Guide* contain additional information on curb and barrier/curb combinations.

8.5.3.3.4 Shy Distance

Barriers are themselves items that must be avoided. Placed at the edge of the roadway, most drivers will provide an extra cushion of separation from the barrier to ensure that neither their vehicle nor the barrier is damaged. This separation is called the shy distance and it varies with respect to speed and the size of the obstacle. It is defined as the distance from the edge of the traveled way beyond which the typical driver will not perceive a roadside object as an immediate obstacle. Placed any closer to the edge of the roadway, the driver may feel compelled to either change the vehicle's placement or reduce its speed.

As a rule of thumb, barrier should be placed an additional 2 ft [0.6 m] beyond the edge of the prevailing shoulder to retain the driver's perception of a constant width roadway. A more detailed discussion is available in the AASHTO *Roadside Design Guide*, Section 5.6, which provides additional information on what the suggested shy distance should be, based on various design speeds and obstacle offsets.

8.5.3.3.5 Transitions

Once a barrier is selected for a site application, use that type of barrier to protect the motorist throughout the length of the hazard. Occasionally, there is a need to transition from one type of barrier to another. This condition is typical at bridge locations, where the roadway barrier may be a flexible W-Beam system and the bridge incorporating a rigid concrete barrier. The key concern in changing from one type of barrier to another is the possible impact at the transition point. Review Section 8.5.3.4 to ensure the design addresses pocketing concerns. Transition sections should provide gradually increasing lateral stiffness to properly join two different barrier materials.

8.5.3.4 Bridge Railings

Selection of the appropriate barrier both on and approaching the bridge structure requires cooperation between the bridge and roadway disciplines. In addition, attention to aesthetics, maintenance, and its ability to deflect an errant vehicle must all be evaluated before the type of railing is selected. While the selection of the barrier used on the structure itself is generally determined by the Structural Engineer following the design guidelines provided in Section 10.4.4, the type of transition used between the bridge barrier and the roadway barrier approaching the structure can vary.

Barriers on bridge structures must be rigid enough to deflect the errant vehicle without leaving the edge of the bridge deck. To provide this rigidity on the structure, the barrier system on the bridge deck may be anchored to cast-in-place concrete barriers located at or beyond the abutments. These anchors serve as a transition as they provide an attachment point between the bridge railing and the approach roadway barrier transition terminal. One example of this transition is the thrie-to-W-beam transition which is used on many bridge rail retrofit jobs. Currently there is no standard drawing/detail for these installations; however, they are very common throughout FLH with details available from suppliers and many DOT sites.

On many projects, existing bridges have inadequate bridge or transition railings. When replacing structurally obsolete bridges, railing replacement should meet current standards. When bridge railings are structurally adequate but functionally obsolete, engineering analysis should be performed to determine the recommended action on a case-by-case basis.

Special attention should be given to the proper attachment of the transition railing with the bridge railing or parapet. The railing connection should develop the full tensile strength of the rail element and be designed to prevent possible pocketing or snagging of a vehicle on the end of the bridge parapet. The bridge plans should generally include special drawings of these connection details. Transition guardrail should satisfy the minimum length of need to develop its full tensile strength capacity. Besides the FHWA Roadside Hardware website, a resource that is recommended for information on various guardrail transitions is FHWA Technical Advisory T 5040.34, which provides some sample designs for attachment to modified and unmodified concrete safety shape bridge rails, wingwalls or parapets.

The terminal end should extend outside the lateral clear zone or be provided with a crash worthy terminal, protected by a crash cushion or buried in a cut slope. In rare occasions, there are site constraints that don’t provide enough room in advance of the bridge barrier to construct the necessary approach barrier, or the standard flexible to rigid barrier transition. Examples could include parking lots and turnouts located immediately adjacent to the bridge abutment. In these locations, the designer should consider extending the rigid barrier beyond the bridge and terminating the barrier properly outside the clear zone within the parking lot or turnout, or consider providing a crash cushion or impact attenuator in advance of the bridge barrier. Wrapping a standard flexible barrier around an approach without the necessary rigid transition will allow the errant vehicle to deflect the face of the flexible barrier, resulting in the vehicle directly impacting the bridge barrier with results similar to having no approach protection at all. There are guidelines for installing curved guardrails that have been crash tested, see the Standard Drawings and the *RDG* for more information.

8.5.4 CRASH CUSHIONS AND END TREATMENTS

Crash cushions shield errant vehicles from impacting fixed rigid hazards (e.g., an intersection of bridge parapets at a gore area) by smoothly decelerating the vehicle to a stop condition when hit head on. Also, it is desirable for the crash cushion to redirect a vehicle when hit from the side by functioning in a manner similar to a longitudinal barrier.

End treatments are devices that are designed to treat the end of a longitudinal barrier. The end treatment may function by:

- Decelerating a vehicle to a safe stop in a relatively short distance,
- Permitting controlled penetration of the vehicle behind the device,
- Containing and redirecting the vehicle, or
- A combination of any of the above.

These devices may be located in roadway medians, gore areas or along the roadside. These devices have been developed for specific applications (e.g., limited shoulder width, temporary construction installations, high frequency impact sites, the protection of wide hazards, and the protection of fixed features that protrude into the clear zone).

8.5.4.1 Determination of Need

As with longitudinal barriers, the first consideration with regard to a rigid object or a hazardous condition is to evaluate the feasibility of removing the obstruction, relocating it or making it breakaway. When these options are not feasible, the next step is to determine whether or not some type of barrier is warranted by analyzing the cost effectiveness as described in Section 8.4.5.2. The cost-effective procedure can be used to evaluate both longitudinal barriers as well as crash cushions.

8.5.4.2 Types of Treatments

The *Roadside Design Guide* presents several approved crash cushions and end treatments. Updated lists of approved crash cushions and end treatments are maintained by the FHWA. Crash test criteria can be found in NCHRP Report 350.

8.5.4.3 Design Procedures

Standard Drawings or manufacturer's designs, or both, should be followed when crash cushions or end treatments are needed. The road cross-section design must take into account the width, offset, and flare of the end treatment or crash cushion.

8.5.5 TRAFFIC CALMING

Travelers are often concerned about excessive traffic volumes and speeds on local streets. Local streets are intended to serve the adjacent land use at slow speeds, yet they are often designed so that high-speed travel is accommodated. Traffic calming measures are sometimes considered, primarily in residential neighborhoods, to address demonstrated safety problems caused by excessive vehicle speeds and conflicts with pedestrians, bicyclists, and school children. Well designed traffic calming devices effectively reduce traffic speeds and volumes while maintaining local access to adjacent facilities and turnouts. Refer to Section 9.3.1.13.3 for more information and guidance.

Public involvement is needed for residents, businesses, planners and engineers to understand the issues and agree with the proposed changes. The benefits of traffic calming, especially for pedestrians and bicyclists include:

- Reduced traffic speeds and volumes allow bicyclists to share the road with vehicles;
- Quieter streets and increased ease of crossing enhance the pedestrian environment;
- Lower traffic speeds increase safety (high speeds are responsible for many pedestrian fatalities); and
- In park and forest settings, lower traffic speeds enhance the visitor experience in a natural setting.

8.5.5.1 Managing Speeds

Managing traffic speeds can be accomplished through physical constraints on the roadway or by creating an “illusion of less space.” Motorists typically drive at a speed they perceive as safe; this is usually related to the road design, especially available width. Refer to Section 9.3.1.14 for self-explaining, self-enforcing road concepts.

One way to achieve the lower speed is to provide various physical constraints. The following are some examples:

1. **Narrow Streets or Travel Lanes**. Narrow (minimum) cross sections can effectively reduce speeds, as most drivers adjust their speed to the available lane width. Narrow streets also reduce construction and maintenance costs. See the AASHTO *Guide for Achieving Flexibility* for information about lane width issues and mitigation.
2. **Speed Humps** (not speed bumps). If well designed, speed humps allow a vehicle to proceed over the hump at the intended speed with minimal discomfort, but driving over the hump at higher speeds will rock the vehicle. The hump is designed with a reversing curve at each end, and a level area in the middle long enough to accommodate most wheelbases.
3. **Chokers** (i.e, curb extensions, bulb-outs, neckdowns). Chokers constrict the street width and reduce the pedestrian crossing distance.

Another means to reduce speeds is to provide the illusion of limited space. Examples of this technique include:

1. **Creating Vertical Lines**. By forcing some natural or barrier elements closer to the roadway edge, the roadway will appear narrower than it is. This can be accomplished with longitudinal barriers, curbs, or trees and landscaping.
2. **Coloring or Texturing Bike Lanes**. Drivers see only the travel lanes as available road space, so the roadway appears narrower than it is. Painting the road surface is expensive; lower-cost methods include:
   - Paving travel lanes with concrete and bike lanes with asphalt, or the reverse;
   - Slurry-sealing or chip-sealing the roadway and not the bike lanes; and
   - Incorporating dyes into concrete or asphalt.
3. **Chicanes**. By alternating on-street parking, landscaping or other physical features from one side of the road to the other, the driver does not see an uninterrupted stretch of road. The roadway width remains adequate for two cars to travel.

8.5.5.2 Roundabouts

Roundabouts are a common form of intersection control used throughout the world. Until recently, many State and local agencies throughout the United States have been hesitant to recommend and install roundabouts due to a lack of objective nationwide guidelines on planning, performance and design of roundabouts. The FHWA publication *Roundabouts: An Informational Guide*, explains some principles of good design and indicates potential tradeoffs of roundabouts, along with addressing the following topics:

- Definition of a roundabout and what distinguishes roundabouts from traffic circles;
- Methodology for identifying appropriate sites for roundabouts and the range of conditions for which roundabouts offer optimal performance;
- Methodology for estimating roundabout capacity and delay;
- Design principles and standards to which roundabouts should conform, including applicable national standards (e.g., the AASHTO *Policy on Geometric Design of Highways and Streets*, the *Manual on Uniform Traffic Control Devices)*;
- Consideration for all modes, including heavy vehicles, buses, fixed route transit, bicycles, pedestrians and emergency vehicles;
- Guidelines for operational features (e.g., signing, pavement markings, illumination, landscaping); and
- Public acceptance and legal issues associated with roundabouts.

8.5.6 EVALUATION OF THE DESIGN FOR WEATHER CONDITIONS

Most of the time, a roadway surface is dry and will allow a vehicle to respond in a predictable manner while the driver is negotiating stops, curves and lane changes. The engineer should also take into account what will happen to the roadway surface during inclement weather activities as well, especially if these activities recur every season. Vehicles traveling on impaired road surfaces often lose traction. With a loss of traction comes a loss of control of the vehicle. The problem is exacerbated when out-of-control vehicles on impaired roads frequently end up crossing the centerline and colliding head-on with oncoming vehicles. The oncoming vehicle has limited defensive capabilities as their tire friction and opportunity to respond is also impaired.

The following sections discuss recurring activities and some precautions that should be considered as the design is developed.

8.5.6.1 Skid Resistance

During field reviews of the road, if any patch of slick or damaged asphalt is observed, this will prohibit proper friction between the vehicles tires and the roadway during inclement weather. The surface should be repaired and covered with a friction course or wearing course.

For information regarding skid resistance on unpaved roads, see the design guidelines in the AASHTO *Guidelines for Geometric Design of Very Low-Volume Local Roads*.

8.5.6.2 Black Ice

Black ice is typically formed due to snow melt running across the roadway surface during the day, and freezing on the roadway or bridge surface at night. Some of this can only be mitigated with proper snow maintenance activities (e.g., plows pushing the snow completely off of the roadway surface and into a ditch). As a designer, there are elements of design that can minimize the occurrence of snowmelt from crossing the roadway. These include:

- In areas where there is no ditch, consider the installation of concrete barriers to prevent runoff from reaching the roadway surface.
- Clear trees sufficiently away from the roadway, ensuring no shadows are present on the pavement that would retain ice on the roadway in spots rather than melting and draining away.
- Avoid abrupt horizontal curves in areas where ice may form, especially on bridge decks, as these surfaces stay frozen the longest.

8.5.6.3 Snowpack and Snow Storage

To prevent black ice from occurring, there must be adequate storage for plowed snow to be contained off of the roadway prism while it melts. The designer must consider not only the capacity to handle the melted water in the runoff, but the area required to contain the snow mass while it melts. Finally, if the slopes adjacent to these storage areas can be cleared sufficiently to allow late-day sun, the site would benefit from quicker melting times.

8.5.6.4 Fog

When fog occurs on the roadway, visibility distance is hindered. This in turn impacts traffic flow through reduced travel speed, which leads to increased speed variance between drivers, delayed travel time and ultimately increased collision risk. The operational impacts of fog hinge on driver capabilities/behavior, road treatment strategy, access control, and speed limit control. Specific mitigation measures for fog are not readily available. Some possible methods of dealing with low visibility conditions include:

- Advisory strategies to provide information on predicted and prevailing conditions. Such systems typically involve the installation of low visibility warning systems that use computer systems to predict foggy conditions. The system can alert traffic managers for deployment of additional safety forces to the roadway, turn off overhead lighting to reduce glare, and warn motorists of the conditions and to drive appropriately.
- Control strategies to regulate traffic flow and roadway capacity. Examples could be to close or reduce capacity of roadways frequently experiencing foggy conditions.
- Treatment strategies to provide roadway elements to mitigate weather impacts. Examples can include installation of raised or recessed pavement markers, rumble strips, or profiled pavement markings to better define the roadway limits and direction to the driver.

The benefits of road weather management strategies include improved safety due to reduced crash risk, increased mobility due to restored capacity, reduced delays, and more uniform traffic flow. Other benefits include increased productivity due to reduced labor, treatment material, and equipment costs.

8.5.6.5 Bridge Conditions

One of the most challenging elements to consider as part of bridge design is the force of nature, specifically the weather. Rain, ice, and wind can each have a substantial influence on the stability of a structure. Bridge designs have evolved to improve upon experienced failures of the past. Iron has replaced wood; steel has replaced iron; and pre-stressed concrete has replaced steel in many locations. Each new material or design technique builds off the lessons from the past. Weather-related problems, however, have yet to be completely eliminated. Cases of weather-related failure on bridges far outnumber those of design-related failures. To this day, there is no specific construction material or bridge design that can completely eliminate or mitigate these effects. When evaluating an existing bridge site, consider the site elements that will not likely exist during the inspection period, such as the following:

- Runoff: With respect to rainfall and runoff, the best solution involves diverting all runoff before it can access the bridge structure. For water that is captured on the bridge deck, ensure the water can be diverted off of the deck without causing ponding or more than allowable spread on the travel way. In some rural areas on low volume roads, runoff may be allowed to sheet flow directly off of the structure and into the drainageway or water body that is being crossed (confirm this is acceptable with the environmental agencies). This solution ensures no ponding can occur on the deck at any point. If the water must be conveyed off the structure, ensure no sags or “birdbaths” exist on the deck that could capture the runoff. Finally, with very long structures, if the runoff must be captured within a drainage system, the pipes must not only have the capacity to carry the runoff from the structure, they must also be maintainable and free from obstructions during all types of weather. The pipes should be accessible to have sediments and debris removed, and insulated against possible freezing if located in colder climates (as this is very difficult and expensive, these systems are typically not used in colder climates).

- Hazardous Spills: With inclement weather, the possibility of hazardous or undesirable materials being drained into sensitive waters is another bridge concern. Depending on the local environmental requirements, two mitigation measures may be required for this condition: (1) the runoff must be routed into a drainage structure that can filter out the first flush contaminants (using a absorbent filter for example); or (2) diverting the runoff from the bridge into a containment basin that can retain spills and runoff before entering a protected waterway.
- Snow and Ice: In cold climates, bridges typically are the first segments of the roadway surface that will freeze up. In these climates, structures should be designed to be straight with minimal grades. If they must incorporate horizontal curves, it is best that the curve be started in advance of the bridge, with the full superelevation developed in advance of the structure. Sag vertical curves must be avoided as the runoff will typically freeze and accumulate at the low point. As noted above, conveying drainage runoff through a pipe system during snow conditions usually results in frozen pipes that clog. Some pipes freeze solid and expand, slitting the pipe material and making it useless once the snow melts.
- Debris: Bridges and drainage facilities alike are designed to convey a design volume through a given opening. Over time, debris can accumulate at the entrance of the structure, reducing the capacity of the structure. Similar to a drainage inlet, the opening to the structure must be free of debris, and free from materials that may trap debris.

8.5.6.6 Barrier and Bridge Rail Considerations

Roadside and bridge barriers are typically designed independent of drainage systems. When the site gets inundated with rain or snow, the interrelation between these two design elements becomes more apparent. Evaluate the impacts of snow and rain on the barriers in the following scenarios:

- Permeable vs. non-permeable barrier designs in snow areas: When snow is removed from the roadway surface and placed behind the barrier, will the runoff from the stored snow cross through the barrier (i.e., on superelevated roadway sections with W-Beam rail sections), or be directed behind the rail to swales or other conveyance facilities. Of primary concern is that if the snow removed in the early morning is piled behind the barrier, will it melt during the day only to create a patch of black ice when it freezes again in the evening?
- Plow conditions: Will the maintenance equipment for the roadway have the ability to push snow along or through the barrier, or throw snow over the barrier? If materials can only be pushed, there must be opportunities to dispose of the snow in open areas, or the shoulders will be used for snow storage.

8.6 TRAFFIC ANALYSIS

A traffic analysis is an evaluation of the roadway's projected demand and the effects of that demand on the capacity of either the existing or proposed facility.

The analysis of the traffic on a transportation facility is a fundamental concern of transportation engineering. There are essentially two components of traffic analysis:

1. **Demand**. The traffic load that will use the facility (projected traffic volumes).
2. **Supply**. The ability of the roadway to handle the traffic load or the roadway's capacity.

8.6.1 TRAFFIC DEMAND

One of the real complexities of the transportation problem is the inability to accurately predict and control the level of demand for the system or the service. Transportation demand is generally related to social and economic influences. Transportation demand generally relates to commuters or visitors that result in other activities that may eventually lead to a physical load (e.g., the passage of vehicles over a section of roadway or a street).

A multitude of factors can contribute to the level of transportation demand, and are summarized in the following sections.

8.6.1.1 Average Annual Daily Traffic (AADT)

The foundation of demand is based on the current traffic counts of a facility. The measurement of traffic is generally considered to be in terms of the flow of vehicles. The flow is typically expressed in terms of vehicles per unit of time.

Some commonly used units of measurement for traffic flow are vehicles per day, vehicles per hour, passengers per day, etc. The common measurements of traffic flow are vehicles per day (veh/day) or vehicles per hour (veh/hr). A good reliable indicator of the general level of traffic activity on a street or a roadway is the Average Annual Daily Traffic (AADT). This is the total annual traffic at a highway location divided by the number of days of the year. If the facility is not open all year long, then traffic volumes will only be described in seasonal averages.

8.6.1.2 Seasonal Variations

Many facilities have varying traffic volumes throughout the year. These seasonal fluctuations can vary greatly, but they are generally very predictable. Seasonal peaks are particularly important to recreational facilities. To make adequate projections, traffic counts must be acquired throughout the year at regular intervals. These counts will generate a pattern that can be used to project the Average Daily Traffic (ADT) for any given season.

8.6.1.3 Peak Hour/Design Volumes

Average daily traffic counts (collected for continuous 24-hr periods) are the typical source of traffic volume information. Designing the facility to meet the average daily traffic can result in significant delays during the higher use periods. The highest hourly volume that occurs in a given day is called the Peak Hourly Volume (PHV). The Design Hourly Volume (DHV) is the standard for estimating the peak traffic loads during the day for design. It is based on the 30th highest PHV of the year. This volume can be determined using Equation 8.6(1):

$$DHV = AADT \times K \qquad \text{Equation 8.6(1)}$$

Where:

DHV = Design Hourly Volume in the design year

AADT = Average Annual Daily Traffic (vehicles per day) in the design year; see Section 8.6.1.1

K = Design Hour Factor (the proportion of daily traffic traveling during the design hour expressed as a decimal); see Section 8.6.1.6

8.6.1.4 Trends (Past and Projected)

To determine trends affecting transportation facilities, it is important to review past and recent history to have a reasonable idea of what to expect in the future. The more historical information that can be provided and evaluated, the better and more accurate the projection will be. In addition to volumes, it is also important to determine where patrons are coming from, be they local, statewide, regional, national, international, or a mix.

Local Growth / Population Trends. For most county and state facilities, the respective DOT keeps historic records of traffic counts for various types of roadways. If no major developments are to occur that would change the trends to the traffic numbers, simply plotting the historic rates will produce a growth factor that can be used for estimating future traffic volumes. If the roadway being improved is to serve a new facility, or if the existing facility will be experiencing significant development improvements, these historic rates may need to be increased. Discussions with local planners at both the County and State transportation jurisdictions can usually provide insights to such matters. Typical values range from 1.5% to 3% while values as high as 4% are only experienced in areas with significant new development or unusually high growth.

Park Visitor Attendance History/Projections. For all national park facilities, the NPS keeps records of both visitor and traffic counts that can be used to evaluate trends and form a basis for projections.

Intersection Turning Movement Projections. At some entrance or intersection locations, it is also essential to evaluate where patrons are arriving from (directional), so determining origin and destination is also important. To determine the adequacy of an intersection, AM, PM, or weekend peak hour turning movements may be needed to evaluate the efficiency of an intersection. This information is not typically available from an existing database, but must be gathered by counting the traffic at a given intersection. Once this information is determined, the same growth rate used to project the future, overall traffic needs of the roadway can be applied to the turning movements at the intersection.

8.6.1.5 Classifications

Transportation demand certainly varies between different types of roadways. Roadways are characterized by determining their functional classification. The functional classification of a particular roadway establishes a range of design speeds and also defines a range of design parameters. Classification is normally determined during the planning and programming phase, and it is verified with consideration of additional data as part of the conceptual engineering studies. Refer to Section 9.3.1.2 for guidance on functional classification, as well as FHWA Functional Classification Guidelines.

8.6.1.6 Traffic Factors (K, D, T)

Several factors are used to evaluate the traffic flow. The three most common factors provided include the Design Hour Factor (K), the Directional Split Factor (D) and the Heavy Vehicle Factor (T). These factors are usually determined on the basis of regional or route-specific characteristics.

K Factor: The Design Hour Volume is typically the 30^{th} highest hourly volume experienced in a year. The factor used to express this volume as a percentage of the annual average daily traffic is defined as the K-Factor [Design Hour Volume = AADT × (K-Factor)]. If no specific information is provided, the typical K factor for a rural facility is 12 to 15 percent, and 10 to 12 percent for an urban facility.

D Factor: This factor accounts for the directional distribution of the traffic. Values generally range from 0.54 to 0.59 and are used to convert average daily traffic to directional peak hour traffic. If this factor is unknown or cannot be easily determined, a default D-factor of 55 percent may be used (expressed as 0.55). Note that for one-way streets, the D-factor becomes 1.0 since 100 percent of the traffic is traveling in the same direction.

T Factor: Roadway capacity is reduced as the number of large trucks, recreation vehicles, and buses increase. The T-Factor (Heavy Vehicle Factor) is used in calculating the level of service (LOS) of a roadway based on the percentage of heavy vehicles. If the relative proportions of RVs, trucks and buses are not known, the heavy vehicles can be considered trucks when determining passenger-car equivalents. If this factor is unknown or cannot be easily determined, a default T-factor of 5 percent may be used in urban areas and 10 percent in rural areas.

8.6.1.7 Turning Movements

In order to determine if an intersection or interchange will work at a given Level of Service (LOS, see Section 8.6.2.1), it is necessary to utilize peak hour turning traffic volumes at the specific site to be analyzed. These turning traffic volumes (typically AM and PM peak hours) are usually based on actual volume counts made at the existing intersection, and can be projected for the future using the same growth rates used in traffic projections (typically, 20 years out). Traffic at intersections is generally divided into left-turn, through, and right-turn traffic volumes. The designer can then use these traffic volumes to perform a capacity analysis and resulting LOS to determine how many left-turn, through, or right-turning traffic lanes (or combined left-turn and through lanes, or combined through and right-turn lanes) are needed.

If traffic counts are collected to determine the effectiveness of current or proposed geometry, the traffic counts should be done in 15 minute increments in both the morning and afternoon heavy use periods. In that way, a Peak Hour Factor can be established and used to determine the intersection LOS. The Peak Hour Factor (PHF) is the ratio of hourly demand to four times the peak 15-minute demand [Highest sum of 4 consecutive 15-minute periods / (4 × highest 15-minute flow rate)]. This ratio typically ranges from 0.75 to 0.95. The higher values tend to occur as demand approaches capacity on the facility. Default values of 0.88 for rural areas and 0.92 for urban areas may be used in the absence of local data.

8.6.1.8 Speed and Delay Data

Speed and Delay can be measured or calculated to help determine Level of Service (LOS, see Section 8.6.2.1). Free-flowing roadways (such as freeways) are impacted by increasing traffic volumes and density, with reduced speeds typically resulting as traffic volumes increase. Traffic speeds can be determined by using speed measuring devices (such as radar or surface instruments) or by the “floating car” method. The floating car method involves driving at the general speed of most traffic and making several passes (at least 3) on the segment of roadway being measured. In that manner, a representative example of current traffic speeds can be obtained.

Intersections that are controlled by traffic control devices (such as a traffic signal or a Stop sign) are not free flowing facilities, so the LOS is determined by average traffic delays (and not average speeds). Traffic delays can be measured by several different approaches, including stop watches, video tape, traffic detectors, etc. Traffic delay can be measured in two different manners, stopped-delay and control-delay. Stopped delay is the time a vehicle is actually stopped due to a traffic control device. Control device includes the time of slowing, stopping, and accelerating to normal speeds, and typically is approximately 30% higher than just the stopped delay (at a traffic signal).

8.6.1.9 Conflict Study Data

Conflicts are traffic events involving two or more vehicles where one or both take evasive action to avoid a collision. Conflicts can be identified as a potential conflict, where the paths of two cars cross and a collision “may” occur, such as a left-turning vehicle in one direction crossing the path of an opposing through traffic vehicle at an intersection.

Conflicts can also be measured to determine how many actual conflicts occur over a given period of time at an intersection. Traffic conflict studies provide an effective way to measure traffic safety, supplement crash studies in estimating the potential for accidents at a given intersection, and can measure the effectiveness of a given geometry or traffic control device.

Conflicts can also be considered at vehicle interactions which “may” lead to crashes. For a conflict to occur, traffic must be on a collision course (attempting to occupy the same space/same time). The action of the first user places the secondary user on a collision course unless corrective action is taken. If corrective action is not taken, or inadequate or inappropriate action is taken, the result would be a near-miss or an accident, resulting in a “conflict.”

Conflict studies typically involve using trained observers or devices such as video taping to be able to methodically identify and catalog traffic conflicts.

8.6.1.10 Presentation of Traffic Data (Data required for Highway Design Standards Form)

The complexity of the traffic data collected varies by the site and project requirements. For every project, there is a minimum amount of traffic data that is desired for every project. This information is typically collected at the onset of the project development process, and summarized in the Highway Design Standards Form (see Section 9.1.3). This information is generally presented in a tabular format similar to Exhibit 8.6–A.

8.6.2 HIGHWAY CAPACITY

The method used for describing and determining capacity and traffic operating conditions is outlined in the *Highway Capacity Manual* (HCM).

8.6.2.1 Level of Service

Level of Service (LOS) is defined as a qualitative measure of operational conditions within a traffic stream and the perception by motorists. Six levels of service, LOS A through LOS F, are used to designate different operating conditions in terms of such factors as speed, travel time, freedom to maneuver, traffic interruptions, comfort, and convenience. Safety is not included in the measures that establish service levels.

There are several analytical methods presented in the HCM to determine the LOS of a roadway or intersection.

Most design or planning efforts typically strive for service flow rates of LOS C in rural areas, and LOS D in urban areas in the design year.

Exhibit 8.6–A HIGHWAY DESIGN STANDARDS FORM TRAFFIC DATA

		ADT				
TRAFFIC	**YEAR**	**AVERAGE**	**SEASONAL**	**DHV**	**PERCENT TRUCKS**	**D**
Current	(1)	(3)	(5)	(7)	(8)	(9)
Design	(2)	(4)	(6)			

Note: The procedures for determining the data within each of the fields listed above are summarized as follows:

1. Current Year: This is the current year, the year the design development is occurring.
2. Design Year: This is typically a projection that is 20 years from the anticipated completion of construction.
3. Current Year ADT: Current Year Average Daily Traffic. The value is typically provided by the land manager. For example, current and historic traffic data is available for all NPS roads from the Eastern Federal Lands web site. Values for forest and county roads are typically available from State or County transportation departments. Some minor facilities may not have frequent traffic counts, and estimates or site counts are required to determine the current traffic volumes.
4. Design Year ADT: Estimate the volume of traffic in the design year by determining the average annual growth that will occur for the facility (as discussed in Section 8.6.1.4), and applying a standard annual growth formula to determine the future traffic demands [i.e., Design Year ADT = (Current Year ADT) × (1+ Annual Growth in decimal percent)^(number of years between current and design year)]
5. If the facility has heavy seasonal shifts in visitor traffic, determine the SADT per Section 8.6.1.2.
6. Similar to (4) above, extend the current seasonal values into the future by the anticipated growth rate.
7. The design hourly volume (DHV) is described in Section 8.6.1.3, and is equal to the AADT × K-Factor.
8. Determine the percentage of heavy vehicles such as trucks, RVs and buses, as noted in Section 8.6.1.6.
9. Determine the directional split factor, as noted in Section 8.6.1.6.

8.7 TRAFFIC DESIGN

The safe and efficient movement of traffic through the highway project necessitates that designers review the proposed design from a traffic operations standpoint. The designer needs to be alert for situations that involve alterations in the driver's behavior or changes in driver attention. During the design phase, the designer should attempt to perceive the final roadway as it will appear to the motorist anticipating the necessary traffic control devices. Traffic control devices are intended to provide the user with sufficient advance information so the highway can be driven safely. Through the proper application of design standards, the number of motorist decision points will be minimized. There will, however, always be a need for appropriate permanent traffic control devices to inform, regulate and/or warn the motorist. A review of the safety analysis will generally identify areas of existing operational problems.

Field reviews during construction are encouraged to substantiate if the original perceived operational characteristics of the project were germane and to provide timely adjustments during construction should they be warranted. After construction is completed and the project is opened to traffic, an evaluation should be made of the traffic control devices to determine their adequacy and if they are functioning as planned.

See Section 9.3 for traffic design topics not covered in the following sections.

8.7.1 SIGNING AND DELINEATION

The *Manual on Uniform Traffic Control Devices (MUTCD*) is the national standard for signing, signalization, channelization and pavement markings for all public roads in the United States. The Standard Highway Sign (*SHS*) book, the *NPS UniGuide Standards*, the *Forest Service Sign Manual*, and state DOT manuals provide additional design criteria, methods and charts for design.

All traffic control devices shall be in accordance with the MUTCD. Compliance with the requirements of the MUTCD for all traffic control devices is mandatory and includes the following:

- Use;
- Placement;
- Uniformity;
- Maintenance;
- Color;
- Size;
- Shape;
- Legend;
- Retroreflectivity; and
- Removal, when not applicable.

The main message of the MUTCD is the importance of uniformity. Substantial adherence to the *MUTCD* is required on all public roads. However, some owner agencies have supplements or have developed similar manuals (e.g., the NPS Sign Manual), that must also be considered when designing and constructing roads under their jurisdiction. The ITE *Traffic Control Devices Handbook* supplements the MUTCD by providing basic information and criteria to address most questions that are relative to traffic control devices and their applications.

Highway users are dependent on traffic-control devices (i.e., signs, markings, signals) for information, warning and guidance. Uniform, high-quality devices are important for the safe, efficient use and public acceptance of any road regardless of the width, alignment and structural design.

Any traffic control device should meet five basic requirements:

- Fulfill a need;
- Command attention;
- Convey a clear, simple meaning;
- Command respect from road users; and
- Give adequate time for proper response.

The following aspects should be carefully considered in order to maximize the ability of the traffic control device to meet the five requirements listed above:

- Design,
- Placement and operation,
- Maintenance, and
- Uniformity.

Consideration should be given to these requirements and aspects during the design stage to ensure that the required number of devices can be minimized and properly placed. In addition, local variations in laws and ordinances must be complied with when installing traffic control devices (i.e., all regulatory traffic control devices shall be supported by laws, ordinances, or regulations).

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

8.7.1.1 Signing

The above cited references provide the designer with the information required to properly select the appropriate signing.

The authority for regulatory signing rests with the maintaining/regulating agency. Likewise, the client agency may have specific concerns regarding warning or informational signs. The designer's responsibility is to identify all signs required and review them with the appropriate agencies during project development.

Some owner agencies may have established sign plans for particular routes or regions; these plans should be requested and reviewed during project development. For example, the NPS Director's Order 52C, *Park Signs*, requires each park to have an established sign plan. These plans should be reviewed together with crash statistics and any available safety studies to ensure continued appropriateness whenever additional construction work takes place.

8.7.1.1.1 Sign Supports

Sign supports should be designed in accordance with the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals*. Owner agency practice, in accordance with the above standards, may dictate the types of materials to be used. **Sign supports and luminaires left unprotected by a barrier system and located within the clear zone shall be breakaway or yielding and meet the requirements of NCHRP 350.** See the FHWA lists of breakaway hardware for approved designs.

8.7.1.1.2 Sign Design

Any site-specific signs that are developed must be evaluated to ensure the lettering is large enough to be both visible and legible at the distance and speed that the user is traveling. Lettering sizes varies with the design speed. This information is found in the *MUTCD*, *SHS*, *NPS UniGuide Standards*, or other owner agency documents.

The MUTCD requires that traffic signs be illuminated or retroreflective to enhance nighttime visibility. The retroreflective sheeting on sign panels gradually deterioerates over time making signs less visible. Within the project limits, signs must be evaluated for appropriate levels of retroreflectivity (See MUTCD 2A.08). It is recommended that all permanent regulatory (black on white/ white on red), warning (black on yellow), and destination and directional guide (white on green or brown) be replaced with new panels conforming to the MUTCD. All other signs (e.g., parking, trails, information, etc.) should be evaluated on a project by project basis to determine the need for replacement.

8.7.1.2 Pavement Markings

Pavement markings have definite and important functions to perform in a proper scheme of traffic control. In some cases, they are used to supplement the regulations or warnings of other devices (e.g., traffic signs, signals). In other instances, they are used alone and produce results that cannot be obtained by the use of any other device. In these cases, they serve as a very effective means of conveying certain regulations and warnings that could not otherwise be made clearly understandable.

Pavement markings have definite limitations. They can be obliterated by snow, may not be clearly visible when wet and may not be very durable when subjected to heavy traffic. In spite of these limitations, they have the advantage, under favorable conditions, of conveying warnings or information to the driver without diverting the driver's attention from the roadway.

8.7.1.2.1 General Application

Each standard marking shall be used only to convey the meaning prescribed for it in the *MUTCD*. Before any newly paved highway, surfaced detour or temporary route is opened to traffic all necessary markings must be in place.

Remove or obliterate markings no longer applicable, or which may create confusion for the motorist, as soon as practicable. Painting over markings is not an acceptable method of obliteration. Markings must be retroreflective.

All markings shall be placed in accordance with the *MUTCD*.

8.7.1.2.2 Pavement Marking Materials

The standard material used for pavement markings is a conventional or waterborne paint with retroreflective beads. All other pavement-marking materials are considered to be upgraded materials. To upgrade, consideration must be given to material performance, material cost, traffic volume and type, climatic conditions, availability of materials and installation equipment (both for initial installation and maintenance). Only when an upgraded material is established to be more cost-effective than the standard material can the upgraded material be used. The following guidelines may be used for upgrading the striping material in lieu of an economic evaluation:

1. **Epoxy and Polyester Materials**. Epoxy thermoplastic (ETP), epoxy and polyester materials may be specified for centerlines, lane lines and edge lines under any of following conditions:
   - The average daily lane volume is in excess of 1000;
   - Because of environmental, traffic or climatic conditions, it is necessary to restripe with paint two or more times a year, or epoxy every two years; or
   - The location is not proposed or scheduled for sealing or resurfacing within the next three years.
2. **Thermoplastic and Preformed Plastic Materials**. Thermoplastic and preformed plastic type materials may be allowed for centerlines, lane lines and edge lines when one of the following conditions are met:
   - The average daily lane volume is in excess of 5000;
   - The location is not proposed or scheduled for sealing or resurfacing within the next five years; or
   - The pavement markings are considered critical (e.g., intersections, lane drops).

These upgraded materials may be specified under lower traffic conditions where directed by the owning agency or where there is a need to emphasize transitions, channelization or special markings (e.g., stop lines and crosswalks). Before specifying these materials, additional consideration should be given to justify the added costs of these materials if it will be less than three years before the pavement is scheduled for sealing or resurfacing.

8.7.1.3 Raised Pavement Markers

Raised pavement markers (RPMs) are intended to be used as a positioning guide or to supplement or substitute for pavement markings. RPMs can be retroreflectorized or nonretroreflectorized, and they may be mounted on the pavement surface or recessed. The color of the RPMs shall conform to the color of the pavement markings for which they supplement or substitute.

The appropriate type of RPMs and/or snow-plowable recessed low profile markers should be considered for the following:

- Intersection channelization,
- Directional left-turn lanes,
- High hazard/crash locations,
- Areas of frequent inclement weather, and
- Gore areas and approaches to deceleration lanes.

Retroreflective RPMs have one or more retroreflective lenses and a base. They may be used in conjunction with, or as a substitute for, pavement markings. Nonretroreflective RPMs should not be used alone, but can supplement pavement markings or retroreflective RPMs.

8.7.1.4 Rumble Strips

Roadway departure fatalities account for almost half of all traffic fatalities and include run-off-road (ROR) and head-on fatalities. The main causes of these crashes are driver inattention, drowsiness, and carelessness. Noise and vibration produced by rumble strips are effective alarms for drivers who are leaving the roadway. They are also helpful in areas where motorists battle rain, fog, snow or dust.

Rumble strips are raised (by using RPMs) or grooved patterns on the roadway that provide both an audible warning (rumbling sound) and a physical vibration to alert drivers that they are leaving the driving lane. In addition to warning inattentive drivers, rumble strips help drivers stay on the road during inclement weather when visibility is poor. Some States paint stripes over the rumble strips (i.e., rumble stripes) to make them visible.

There are three types of rumble strips. The most common type is the continuous shoulder rumble strip (CSRS). These are located on the road shoulder to prevent roadway departure crashes on expressways, interstates, parkways and two-lane rural roadways that have high numbers of single-vehicle crashes. Centerline rumble strips are used on some two-lane rural highways to prevent head-on and sideswipe type collisions. Transverse rumble strips are installed on approaches to intersections, toll plazas, horizontal curves, and work zones.

See the FHWA Rumble Strips website for more information on rumble strips.

8.7.2 TRAFFIC SIGNALS

Traffic control signals are devices that control vehicular and pedestrian traffic by assigning the right-of-way to various movements for certain pre-timed or traffic-actuated intervals of time. Traffic control signals are one of the key elements in the function of many urban streets and of some rural intersections. The planned signal system for a facility should be integrated with the design to achieve optimum safety, operation, capacity and efficiency. Careful consideration should be given in plan development to intersection and access locations, horizontal and vertical curvature, pedestrian requirements and geometric schematics to ensure the best possible signal progression, speeds and phasing. In addition to the initial installation, future needs should also be evaluated.

The design of traffic signal devices and warrants for their use are covered in the *MUTCD*. Consult additional reference sources when designing signalized intersections and other traffic control systems not covered by the *MUTCD*. The ITE *Traffic Control Devices Handbook* provides the fundamental procedures for proper analysis and design of traffic control systems as well as the *Highway Capacity Manual*.

Owner agencies or State highway agencies are good sources for design assistance, particularly in the area of equipment compatibility and electrical design.

8.7.3 ILLUMINATION

Highway illumination helps promote safe and orderly movement of traffic at night, and reduces the probability of crashes due to insufficient visibility. Roadway lighting design is complex enough that computer software analysis tools are generally needed in order to take into consideration roadway geometry (horizontal and vertical), the impact of one illumination source upon another, and the various illumination results caused by varying the type of lighting source and the vertical and horizontal aspects of lighting caused by the height and location of the illumination source(s). Also, the impacts of lighting pollution needs to be taken into consideration, as residential areas and the ability to see the night sky can be impacted by the design of highway illumination.

Intersection illumination is generally provided to improve night-time safety conditions for drivers, pedestrians and bicyclists.

Sign illumination is used to ensure legibility of overhead signs during night-time conditions. A sign may be illuminated externally or internally.

Tunnel lighting requires a great deal of attention and analysis. The greatest impacts to drivers in tunnels occur during the daytime and impact drivers greater than during night-time conditions, as the eye must adapt from bright to dark and then to bright again.

The steps in lighting design generally include:

- Familiarity with the project and design requirements.
- Selection of general types of fixtures and poles to be used.
- Locating the fixtures.
- Performing computations to assure compliance with design criteria.

The computational aspects of lighting design typically involve these criteria:

- Luminance (cd/m^2) – indicates the relative brightness of a roadway after considering the amount reflected from the pavement by a given light source

- Illuminance (Lux) – is the measurement of light incident on the roadway from a given light source.
- Small Target Visibility – is affected by the luminance of the target, the background, the adjacent surroundings, and glare.
- Lighting Pollution – or uplighting, is the amount of light that is directed upwards rather than down towards the roadway, and is affected by the inclusion of cutoff or semi-cutoff lighting fixtures which limits the amount of uplighting.
- Light Trespass – is the amount of unwanted lighting in areas such as residential neighborhoods.

Practitioners have various documents that they can utilize when designing highway lighting, AASHTO's *Roadway Lighting Design Guide* (2005) being one of the more popular. This guide contains recommended warrants for lighting and various lighting design criteria which can be used as a guide when conducting lighting analysis and preparing lighting designs.

8.7.4 HIGHWAY-RAIL GRADE CROSSINGS

The function of traffic control at highway-rail grade crossings is to permit reasonably safe and efficient operation of both rail and highway traffic at highway-rail grade crossings. See Part 8 of the *MUTCD* for more information on traffic control for these types of intersections. For guidance on the geometric design of railroad-highway grade crossings refer to Section 9.3.15.

The appropriate traffic control system used to provide crossing protection at a highway-rail grade crossing should be determined by an engineering study involving both the road agency and the railroad company. Crossing protection is either passive or active, as described in the following sections.

8.7.4.1 Passive Crossing Protection

Passive crossing protection includes signing, pavement markings and, if applicable, grade crossing illumination. Signing used at railroad grade crossings should include the following:

- A railroad crossing sign commonly identified as the Crossbuck sign (R15-1). The Crossbuck sign shall have a strip of retroreflective white material on the back of each blade, except where Crossbucks have been installed back-to-back. The Crossbuck sign post shall also have a retroreflective strip on both sides, facing traffic. The railroad is typically responsible for placement and maintenance of Crossbuck signs. Improvements may need to be made as part of the highway project.
- An auxiliary railroad crossing sign (R15-2) of an inverted T-shape mounted below the Crossbuck sign to show the number of tracks when two or more tracks are between the signs.
- An advance railroad warning sign (W10 series).

- An exempt railroad crossing sign (R15-3) as a supplemental sign (when authorized by law or regulation) mounted below the Crossbuck. The railroad advance warning signs may also be supplemented with an exempt sign (W10-1a).
- A DO NOT STOP ON TRACKS sign (R8-8).

Pavement markings placed in advance of a grade crossing on all paved approaches must consist of railroad pavement markings, NO PASSING markings for two-lane roads and stop lines, if needed.

If an engineering study is conducted and determines that better nighttime visibility of the crossing is needed, consider installing illumination at and adjacent to the Highway-rail grade crossing. Consider lighting where train speeds are low, where crossings become blocked for long periods, or where crash history shows that motorists experience difficulty in seeing the crossing, trains or control devices during hours of darkness.

8.7.4.2 Active Crossing Protection

Active crossing protection consists of post-mounted and/or cantilever flashing light signals and, where warranted, the addition of automatic gates. Bells or other audible warning devices may be included in the assembly.

There is no single standard system of active traffic control devices universally applicable for grade crossings. Perform an engineering study to determine the type of active traffic control system that is appropriate to consider. Refer to State standards for the level of crossing protection needed. If State standards do not apply, Exhibit 8.7–A may be used to help determine the level of crossing protection to provide.

Use the signals shown in the current edition of the *MUTCD* and the *Railroad-Highway Grade Crossing Handbook (FHWA-SA-07-010)* for active crossing signal installations. The locations of signals and automatic gates are shown in the *MUTCD.* A railroad signal may be a point hazard that warrants the use of a traffic barrier or a crash cushion. Install all traffic barriers (see Section 8.5.3) or crash cushions (see Section 8.5.4) outside the minimum railroad clearance as shown in the MUTCD.

Exhibit 8.7–A GUIDELINES FOR RAILROAD CROSSING PROTECTION

Type of Highway	Exposure Factor[1]	Type of Railroad Facility	
		Non-Mainline	Mainline
Two Lane	Under 1500 1500 to 5000 5000 to 50 000 Over 50 000	Retroreflective Signs Flashing Lights Automatic Gates[2] Separation	Flashing Lights Flashing Lights Automatic Gates[2] Separation
Multilane	Under 50 000 Over 50 000	Automatic Gates Separation	Automatic Gates Separation
All Fully Controlled Access	In all cases	Separation	Separation

Notes:

1. Exposure Factor = Trains per day x vehicle ADT.
2. Automatic Gates to be used in urban areas and flashing lights in rural areas, unless conditions warrant otherwise.

8.7.5 INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

Intelligent Transportation Systems (ITS) are wired or wireless communication based information and electronics technologies that relieve traffic congestion and improve roadway safety. ITS generally includes one or more of the following types of systems (with examples):

- Arterial Management
  - ◊ Coordination of traffic signals
  - ◊ Signal preemption for emergency vehicles
  - ◊ Adaptive or advanced signal systems (real-time)
  - ◊ Special event capabilities
  - ◊ Reversible lanes
  - ◊ Dynamic message signs
- Freeway Management
  - ◊ Ramp meters
  - ◊ Dynamic message signs
  - ◊ Vehicle detection
  - ◊ CCTV cameras
  - ◊ HOV
  - ◊ Special events, emergencies
  - ◊ Identify detour routes (electronic trailblazers)

- Traffic Management or Operations Centers (TMC or TOC)
    - ◊ Central facilities for ITS system operations
    - ◊ Electronic wall maps
    - ◊ CCTV images
    - ◊ Computer operator stations
    - ◊ Coordination with police and emergency responders
- Transit Management
    - ◊ Surveillance
    - ◊ Signal Priority
    - ◊ Dynamic Routing
    - ◊ Information Dissemination
- Incident Management
    - ◊ Surveillance and Detection
    - ◊ Mobilization and Response
    - ◊ Information Dissemination
    - ◊ Clearance/Recovery
- Emergency Management
    - ◊ Hazmat Management
    - ◊ Emergency Medical
    - ◊ Response and Recovery
- Electronic Payment
    - ◊ Tolls
    - ◊ Transit
    - ◊ Parking
    - ◊ Multi-use
- Traveler Information
    - ◊ Pre-trip (Web, Kiosks, other)
    - ◊ En-Route (511, In-Vehicle, Other)
    - ◊ Tourism and Events
- Information Management
    - ◊ Archiving Data (for planning, operations, research, administration)
- Crash Prevention
    - ◊ Road Geometry Warning (Ramp Rollover)
    - ◊ Highway-Rail Crossings
    - ◊ Intersection, pedestrian, bicycle, animal warning systems
- Roadway Operations
    - ◊ Construction/Maintenance Information (web and DMS's)
    - ◊ Asset Management
    - ◊ Work Zone Management

- Road Weather
  - ◊ Surveillance and Prediction
  - ◊ Response and Treatment
  - ◊ Traffic Control
  - ◊ Information Dissemination
- Commercial Vehicle Operations
  - ◊ Tracking
  - ◊ Terminal/Border Crossings
- Intelligent Vehicles
  - ◊ Collision Avoidance
  - ◊ Collision Notification
  - ◊ Driver Assistance

ITS analysis involves utilizing the National ITS Architecture which is a common framework for planning, project definition, and integration of ITS systems. The ITS Architecture is a basis for defining the required functions, physical entities, or information flows required to operate and integrate the various ITS systems.

8.8 TEMPORARY TRAFFIC CONTROL (TTC)

Construction activity presents many traffic control problems that must be addressed by the designer. Regardless of whether the project is open or closed to public traffic, some form of construction traffic control will be required. A plan directed to the safe and expeditious movement of traffic through construction and to the safety of the work force performing those operations is defined as a TTC Plan.

It is FLH policy that a TTC plan be designed and incorporated into all projects.

8.8.1 TEMPORARY TRAFFIC CONTROL (TTC) PLAN DEVELOPMENT

The purpose of the TTC plan is to anticipate and describe those traffic control measures that will be necessary during project construction and to outline coordination needs with owner agencies and the public.

TTC plans will vary in scope and complexity depending upon the type and volume of traffic and the nature of the construction project. At an early stage in the project development, the development of the TTC plan should begin and a determination made of the nature and volume of current and predicted traffic. All interested agencies should be involved throughout the development of the TTC plan. For projects with low-traffic volumes or that otherwise have few traffic hazards or conflicts, the TTC plan may be quite simple.

For projects that have one or more of the following characteristics, the TTC plan will normally be more complex:

- High-volume or high-speed traffic;
- Rush hour or seasonal traffic patterns;
- Heavy use by bicycles, pedestrians or disabled persons;
- Changing work conditions or other conditions that would be confusing to the traveling public;
- Hazards due to nighttime operations;
- Detours or complex traffic patterns; and/or
- Closely spaced intersections, interchanges or other decision points.

In developing the TTC plan, consider the items in Exhibit 8.8–A as needed. These items may be used as a checklist in either developing or reviewing the adequacy of traffic control plans.

All TTC plan features, which are obligations on the part of the contractor, shall be included in the plans and specifications. When necessary, appropriate project-specific or standard typical traffic schemes shall be included in the plans.

Exhibit 8.8–A TEMPORARY TRAFFIC CONTROL PLAN CHECKLIST

Temporary Traffic Control Plan Items	
1.	Estimated traffic volumes, vehicle types, and direction of travel
2.	Traffic speeds
3.	Required number of travel lanes
4.	Traffic control layouts including signing, markings, channelization devices, traffic signals, traffic delineators, barriers, and detour schemes
5.	Restrictions on work periods such as rush hours, holidays, special events, nights, and weekends
6.	Characteristics of adjacent highway segments
7.	Requirements for partial completion and opening sections to traffic
8.	Maneuvering space available for traffic (public and work equipment)
9.	Requirements for installing, maintaining, moving, or removing traffic control devices
10.	Turns or cross movements required by traffic
11.	Restrictions on contractor hauling or moving materials
12.	Provisions for accommodating adjacent businesses or residential areas
13.	Any special requirements for the contractor's traffic safety coordinator
14.	Requirements for after hours surveillance or on-call personnel
15.	Special requirements for nighttime operations
16.	Restrictions on parking vehicles, storing materials, and the contractor's equipment
17.	Special provisions on pedestrian or bicycle movements
18.	Provision for accommodating regularly scheduled services such as postal vehicles and school buses.
19.	Maximum delays (time, queue length, etc.)

The *MUTCD* must be used as a standard for signs, striping and other traffic control devices. Because of the general nature of the MUTCD, it will usually be necessary to use supplemental information.

The contract PS&E must include the minimum requirements for controlling traffic through the construction work zones. The TTC plan as contained in the contract must be adopted by the contractor unless an alternate TTC plan is developed by the contractor and approved by the engineer prior to beginning construction operations.

Include traffic control provisions in the PS&E distribution made to other offices and agencies for review before advertising in order that these other parties may have an opportunity to review the provisions for adequacy and coordination.

Payment for TTC plan activities will usually be made by individual bid items for services, traffic control devices, signing, etc. For projects with only light traffic where traffic control procedures are minimal, payment may be incidental to other items of work, or paid for on a lump-sum basis.

There may be certain traffic control information that is of value to the project engineer but should not be included in the contract. In this case, this type of information should be documented and copies provided to the appropriate construction project engineer as described in Section 9.6.6. This information may include the following:

- The need for public relations (e.g., notifications to the local news media);
- Any special agreements reached with other agencies relating to traffic control or traffic management;
- Crash reporting requirements; and
- Any special guidance on traffic management for the project engineer.

8.8.2 TEMPORARY TRAFFIC CONTROL (TTC) PAVEMENT MARKINGS

The TTC plan should reflect FLH policy that pavement markings conforming to full *MUTCD* standards shall be installed as quickly as practical in the construction process. Special standards described below are available to accommodate the periods of time before installation of permanent markings is practical.

8.8.2.1 Definitions

1. **Temporary Pavement Markings**. Either interim or standard markings installed prior to the installation of permanent markings.
2. **Interim Markings**. Interim markings are special, reduced dimension, temporary centerline and lane line markings, which are permitted by *MUTCD* Section 6F.72 or raised pavement markers permitted by Section 6F.73. Interim markings are permitted on new pavement lifts when additional pavement lifts or standard markings are to be installed within two weeks. Interim markings must conform to the color and retroreflective requirements of the *MUTCD*.
3. **Standard Markings**. Standard markings are centerline, lane line, and no-passing zone markings that comply fully with the dimensional, color and retroreflective requirements of

the *MUTCD*. Standard markings may be either temporary or permanent, although permanent markings typically have additional contractual requirements.

4. **Vehicle Positioning Guides**. Temporary raised pavement markers, installed on centerline and lane lines immediately after paving but prior to the installation of temporary or permanent pavement markings. See *MUTCD* Section 6F.73 and the *FP-XX* for more information.

5. **Severe Curvature**. Roads with a design speed of 35 mph [55 km/h] or less, or curves with speeds of at least 10 mph [15 km/h] less than the design speed for the remainder of the road.

8.8.2.2 Unmarked Pavement

Section 6F.72 of the *MUTCD* permits a limited period of unmarked pavement prior to the required installation of temporary or permanent markings. The traffic volume as outlined in Section 8.8.2.4 and Section 8.8.2.5 defines the time limitations. During this period, it is recommended that adequate delineation and signing be provided as follows:

- Vehicle positioning guides shall be installed on centerline and lane lines at a maximum spacing of N (N = cycle length, usually 40 ft [12 m]) in combination with appropriate signs, channelizing devices and other delineation. Spacing should be reduced to 0.5 N in severe curvature situations.
- A W8-12 “NO CENTER STRIPE” sign shall be placed at the beginning of each unmarked section, and after each major intersection or entrance ramp. In addition, an R4-1 “DO NOT PASS” sign shall be installed at the beginning of the project and approximately every mile [1.6 km] thereafter. At the end of each zone, an R4-2 “PASS WITH CARE” sign shall be used.
- The R4-1 sign at the beginning of each zone may be supplemented by a W14-3 “NO PASSING ZONE” sign.

8.8.2.3 Marked Pavement

Temporary markings are required if the time limitations as described for unmarked pavement are exceeded and it remains impractical to install permanent markings. Temporary markings should be standard markings, unless the specific time limitations of temporary markings can be met. The following are special standards for temporary markings:

1. **Centerlines and Lane Lines**. *MUTCD* Section 6F.72 requires interim broken-line pavement markings to be 2 ft [0.6 m] stripes on 40 ft [12 m] cycles or 2 ft [0.6 m] stripes on 20 ft [6 m] cycles in severe curves. When 30 percent or more of the road is designated as meeting the criterion for severe curvature, the entire road may be striped on a 20 ft [6 m] cycle. Temporary raised pavement markers may be substituted for broken line segments, and solid lines, in accordance with spacing described in the *FP-XX*.

2. **Edge Lines**. Temporary edge lines are not required, except in the case of a winter shutdown or extended delay of six weeks or more in the completion of paving and

installation of permanent markings. Temporary edge lines meeting the requirements of the *MUTCD* must be installed on those roads where edge lines were present prior to construction and permanent edge lines are specified in the contract.

8.8.2.4 Time Limitations — Roads with the ADT < 1000

Where average daily traffic does not exceed 1000 veh/day, and where the installation of permanent markings is not practical or possible immediately prior to opening the road to traffic, the following applies:

- For a scheduled duration of not more than two weeks after opening of a new lift of pavement, the minimum requirements of Section 8.8.2.2 apply.
- As an option to unmarked pavement during the same two-week time frame, temporary centerline markings meeting the standards of interim markings as defined in Section 8.8.2.3 are permitted.
- For a scheduled duration of more than two weeks after the opening of a new lift of pavement, the minimum requirements of standard markings as defined in Section 8.8.2.1 apply; as well as the requirements for edge lines in Section 8.8.2.3.

8.8.2.5 Time Limitations — Roads with the ADT > 1000

Where the average daily traffic exceeds 1000 veh/day, and where the installation of permanent pavement markings is not practical immediately prior to opening the road to traffic, the following applies:

- For a scheduled duration of not more than three days after the opening of a new lift of pavement, the minimum requirements of Section 8.8.2.2 apply.
- For a scheduled duration of not more than two weeks after opening a new lift of pavement, the minimum requirements of interim markings as defined in Section 8.8.2.1.
- For scheduled duration of more than two weeks after opening a new lift of pavement, the minimum requirements of standard markings as defined in Section 8.8.2.1 as well as the requirements for edge lines in Section 8.8.2.3 apply.

8.8.2.6 No Existing Markings

Where the existing road, prior to construction, has no markings, then temporary markings are not required prior to completion of the work. However, if the construction is nearly complete, including one or more lifts of pavement materials, and has upgraded the geometrics and increased prevailing speeds, temporary markings are required in accordance with Section 8.8.2.3.

8.8.2.7 One-Lane Paving

Where only one lane of a two-lane road is being paved during construction and the second lane is paved the following day (permitted by the *FP-XX* depending on lift thicknesses), the paving must be offset so that the existing markings are not obscured or temporary markings must be installed on the one lane mat prior to opening it to traffic. In addition, a W8-11 “UNEVEN LANES” sign should be used in this situation.

8.8.2.8 Special Pavement Markings

The need for temporary school zone, railroad, cross walk, stop line and other special pavement markings must be evaluated on a case-by-case basis during the design process. Markings that are deemed warranted must be included in the contract. Bicycle and pedestrian traffic, limited sight distance and other potential hazards should also be considered during the design process as well as traffic volume and the duration of construction.

8.8.2.9 Diversions and Detours

Paved temporary roads and detours that carry other than low-volume traffic, or are to be used in excess of two weeks, must receive the standard markings in accordance with the *MUTCD*. When two-way traffic is detoured onto what would ordinarily be a one-way road, or what may appear to be a one-way road, signing must be supplemented with W6-3 “TWO-WAY TRAFFIC” signs at maximum intervals of 1 mile [1.6 km].

8.8.2.10 State Standards

Designers should be cognizant of prevailing State standards (i.e., more stringent standards) and make adjustments to FLH requirements, wherever appropriate.

8.8.2.11 Contract Items

Contract requirements and contract items should be structured to assure safety while not subsidizing or encouraging delays, inefficiencies and excessive use of temporary markings and related traffic control.

Vehicle positioning guides are not considered centerline markings. They may be paid for as vehicle positioning guides or considered a subsidiary obligation. Additional signing and/or channelization devices necessary during periods of unmarked pavement should be anticipated and included in the TTC plan.

Because the *FP-XX* prohibits painted temporary markings on the final lift of pavement, it may be appropriate to include a contract item for temporary markings for lifts other than the final lift, but not for the final lift. This will minimize the cost of the temporary markings item and encourage the contractor to schedule permanent markings on the final lift in a timely manner.

8.8.2.12 Contract Provisions

It is important to structure contracts so that major overruns and unnecessary government liability for short-term markings will not occur if the contractor elects to perform the paving and marking differently than the designer assumed. The following are general guidelines that must be reevaluated on a case-by-case basis:

- There should be sufficient quantities of temporary markings to accommodate each lift of paving materials anticipated during construction.
- The contractor should be given the option of furnishing painted markings, reflective tape or temporary raised pavement markers. The bid item should include removal when required. Generally, painted short-term markings are cheapest and are appropriate immediately behind the paving operation on intermediate lifts. The temporary raised pavement markers are more practical on final lifts since they are easily removable prior to installing permanent markings, and are usually less expensive than reflective tape on roads with extensive no-passing zones.
- The Government is not obligated to pay for two systems on the same lift. If the time limit for temporary interim markings expires due to poor scheduling, and the contractor has to install temporary standard markings, then the upgrade should be at the contractor's expense.
- For large projects, it is intended that the time limitations on temporary interim markings will force the contractor to complete manageable sections of the project through permanent striping, rather than have the entire project partially complete for an unacceptably long period of time.

8.8.3 TEMPORARY TRAFFIC CONTROL (TTC) CHANNELIZING DEVICES

The preferred channelizing device for any application involving both day and night usage is the drum. If clearance or width problems preclude the use of drums, other devices (e.g., vertical panels, barricades, tubular markers) may be substituted. All devices must meet current crashworthiness standards.

The TTC plan should address and contain appropriate standards defining the expected condition of the traveled way and the needs of the public through the duration of the project. Specific situations that should be addressed through the use of appropriate signing and channelizing devices in each TTC plan include the following:

1. **Delineating Isolated Hazards**. Delineate hazards such as partially completed guardrail, catch basins, and major dropoffs.
2. **Protecting Workers**. Protect workers by separating traffic from an active work site.
3. **Separating Opposing Lanes.** Separate opposing lanes of traffic in confined or detour situations.
4. **Tapers and Transitions.** Tapers and transitions guide traffic from one lane to another, on or off a detour, facilitate a merge, lane narrowing or a one-lane flagging situation.
5. **Delineating Continuous Hazards.** Delineate continuous hazards such as shoulder dropoffs.
6. **Delineating the Traveled Way.** Delineate the traveled way through a work zone when no specific hazards are present. This is often appropriate for low-volume roads where

no detour or temporary pavement surface is provided, and traffic must be routed through the work zone. Once the permanent channelizing cues (e.g., delineators or pavement markings) are removed, temporary delineation must be provided, especially for nighttime traffic.

7. **Portable Changeable Message Signs**. Provide current information on the current or future work, any work-related delays or detours, and how to maneuver through the construction site. Portable Changeable Message Signs (PCMS) used for TTC are also called variable message signs (VMS) and should be used as a supplement to and not as a substitute for conventional signs and pavement markings. See *MUTCD* 6F.55 for more information.

   In an age where the motorist feels that they are entitled to as much advance notice of any interruptions to their travel plans, these devices have become very supportive as an outreach device, as well as a safety device.

8. **Temporary Traffic Signals**. Control road user (public and project-related) movements through TCC zones for extended periods of time instead using of a flagging operation. Temporary traffic control signals are typically used in situations such as temporary haul road crossings, one-way operations on roads or bridges, and intersections.

   Temporary signals can be installed using embedded poles, with overhead steel cables providing the support of the signal heads, or there can be mobile traffic signals delivered to the site, complete with controllers and interconnects. These compact units are transported similar to PCMS, and are placed on opposing corners of the intersection or at either end of a one-way operation, and some models provide both side and overhead signal heads. See *MUTCD* 6F.80 for more information.

8.8.4 TEMPORARY TRAFFIC CONTROL (TTC) BARRIERS/END TREATMENTS

Depending on traffic volume, speed, duration of condition, geometrics and related risk assessment factors, Items in Section 8.8.3 may warrant the use of a temporary concrete barrier. In high-risk situations, such as retaining wall construction or large culvert installations, channelizing devices should not be used alone where a positive barrier is warranted.

8.8.5 TRAFFIC DELAYS

Since many FLH projects are constructed in congested tourist locations, addressing the delays to the traveler in the TTC plan is almost as important as the TTC devices themselves. Between the plans and the SCRs, the designer must work with the land management agency and local emergency services personnel to establish desirable and acceptable delays to the public during construction. If only short (15-minute) closures are anticipated, they must still be agreed to with the resource agencies in advance of the advertisement, and clearly conveyed to the contractor through the construction documents.

The TTC plan should clearly identify all restrictions to traffic closures. These restrictions should address activities on holidays or weekends or perhaps between noon on Friday through Sunday night through an entire summer season. Coordination with the FLH construction personnel on holiday and other shut-downs should also be addressed. If extended public closures will be necessary, consider specifying closures during low-usage times such as midday, evenings, or just before/after a road may be closed for the winter. On some projects, the use of incentives or lane rental is an appropriate consideration to limit the impacts from delays.

Occasionally, it is not the time that is the critical factor of a closure, but the impacts of the queued traffic that must be addressed. On some roads, only a few cars will be stopped over a 30-minute closure, while other highways experience delays that impact thousands. Working closely with the resource agency over the many variations in the construction restrictions will ensure that confusion and conflicts will be minimized during the construction itself.

8.8.6 EMERGENCY RESPONSE CONSIDERATIONS

Delays to the traveling public may be unavoidable in order to complete the construction of a project. Delays to emergency services personnel could have severe consequences if these restrictions are not discussed and resolved in advance of the construction activities. Include with the development of the TTC plan and construction sequencing plan a discussion with local emergency response personnel. Their concerns may be resolved with simple advance notification of any closed traffic operations. In some areas, they may need to mobilize response crews on both sides of the closed roadway to maintain adequate service.