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Federal Highway Administration

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MANUAL FOR SELECTING

Safety Improvements on High Risk Rural Roads

TECHNICAL REPORT DOCUMENTATION PAGE

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16. Abstract

This manual provides information on the costs and benefits of safety treatments on high-risk rural roads (HRRR). Agencies can use this manual to determine the following information on the treatments: Safety benefits; Cost-effectiveness comparison of safety treatments; Applicability of treatment deployment with respect to identified need; and Initial and reoccurring maintenance costs associated with countermeasure installation. In addition, this manual provides information on the decision-making process necessary to identify treatments.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS

AADT	Average Annual Daily Traffic
ADHS	Appalachian Development Highway System
ADT	Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
BCR	Benefit-Cost Ratio
CMF	Crash Modification Factor
COG	Council of Governments
CRF	Crash Reduction Factor
D-CS	Detection-Control System
DOT	Department of Transportation
FHWA	Federal Highway Administration
FLMA	Federal Land Management Agency
FLTP	Federal Lands Transportation Program
FMCSA	Federal Motor Carrier Safety Administration
HAWK	High Intensity Activated Crosswalk
HRRR	High Risk Rural Roads
HRRRP	High Risk Rural Roads Program
HSIP	Highway Safety Improvement Program
HSM	Highway Safety Manual
HSP	Highway Safety Plan
ITS	Intelligent Transportation Systems
km/h	kilometers per hour
LED	Light Emitting Diode
LTAP	Local Technical Assistance Program
MAP-21	Moving Ahead for Progress in the 21st Century Act
mph	miles per hour
MPO	Metropolitan Planning Organization
MUTCD	Manual on Uniform Traffic Control Devices
NACE	National Association of County Engineers
NACO	National Association of Counties
NCHRP	National Cooperative Highway Research Program
NHI	National Highway Institute
NHPP	National Highway Performance Program
NHS	National Highway System
NHTSA	National Highway Transportation Safety Administration
RPC	Regional Planning Commission
RPO	Regional Planning Organization
RRFB	Rectangular Rapid Flash Beacon
RSA	Roadway Safety Audit
SAFETEA-LU	Safe, Accountable, Flexible Efficient Transportation Equity Act: A Legacy for Users
SHSP	Strategic Highway Safety Plan
SLOSSS	Suggested List of Surveillance Study Sites
SP&R	State Planning & Research
STIP	Statewide Transportation Improvement Program
STP	Surface Transportation Program
TAP	Transportation Alternatives Program
TIP	Transportation Improvement Program
TTAP	Tribal Technical Assistance Program
TTP	Tribal Transportation Program
TWLTL	Two-Way Left Turn Lane
USC	United States Code
USDOT	United States Department of Transportation
VMT	Vehicle Miles Traveled
vpd	vehicles per day

EXECUTIVE SUMMARY

Transportation agencies across the United States use many treatments to improve safety on high risk rural roads (HRRR). This manual provides information and criteria associated with those improvements including the following:

- Safety benefits;
- Cost-effectiveness comparison of safety treatments;
- Applicability of treatment deployment with respect to identified need;
- Initial and reoccurring maintenance costs associated with treatment installation; and
- Decision-making process for treatment selection.

With the large number of safety treatments available, it can be challenging for practitioners to select the most effective treatment to implement with limited funds. This manual is intended to assist an agency in understanding the effectiveness of safety improvements on HRRR to aid in the treatment selection process.

Practitioners may use this manual to understand the potential use and applicable deployment locations for each treatment presented. The HRRR Treatment Matrix sorts through treatment selection and deployment criteria to identify potential improvements for a site. The manual includes overviews of safety program management, potential funding sources and funding processes, and provides decision-making tools for selecting appropriate safety treatments for given crash types and roadway characteristics.

1. INTRODUCTION

This manual provides information on the costs and benefits of safety treatments on high risk rural roads (HRRR). Agencies can use this manual to determine the following information related to the treatments:

- Safety benefits;
- Cost-effectiveness comparison of safety treatments;
- Applicability of treatment deployment with respect to identified need; and
- Initial and reoccurring maintenance costs associated with countermeasure installation.

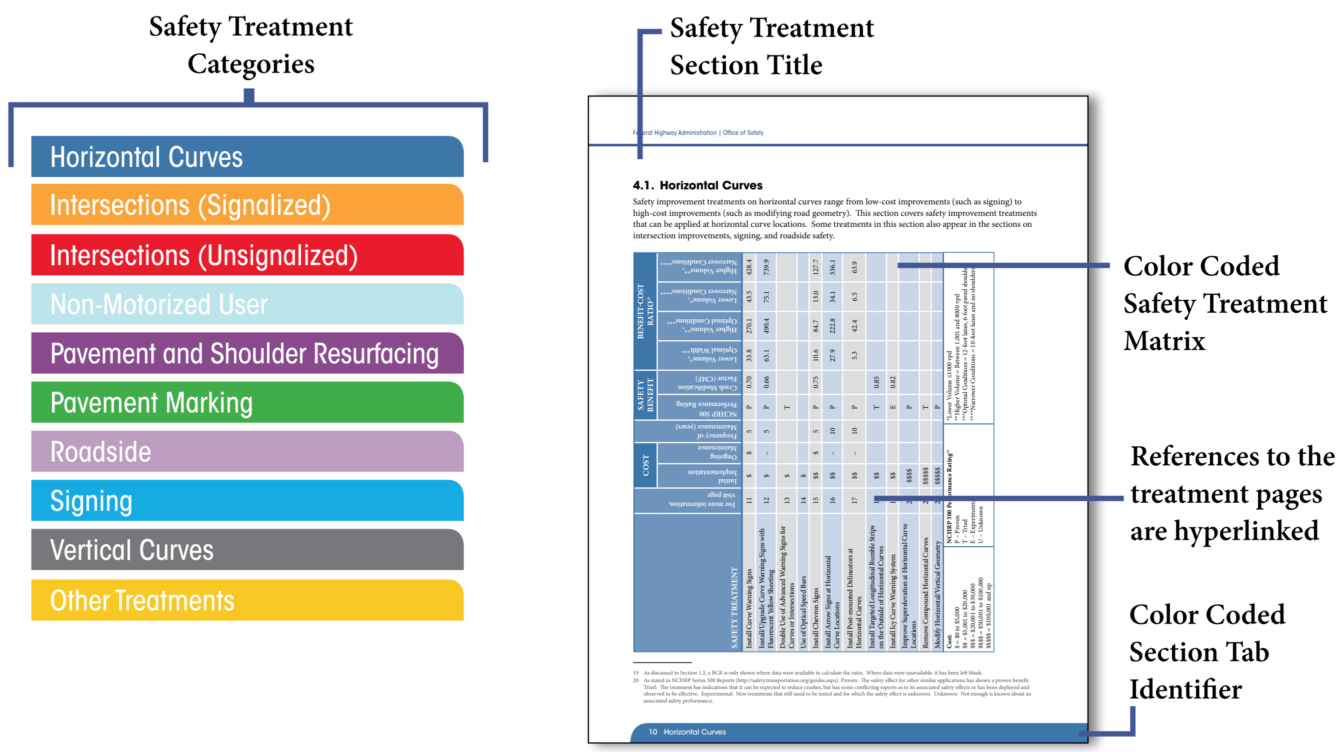
In addition, this manual provides information on the decision-making process necessary to identify treatments.

1.1. Purpose

With limited data specific to HRRR, it can be challenging for agencies to effectively use limited funds for treatments on HRRR. The purpose of this manual is to provide a comparison between the cost-effectiveness of safety treatments on HRRR, identify where the treatments may be more effectively used, and present initial and ongoing costs associated with installation. The objective is to assist agencies in finding effective ways to efficiently allocate safety improvement funds on HRRR to achieve a greater reduction in the number and severity of rural roadway crashes.

1.2. How to Use This Manual

This manual is organized to assist in selection of safety treatments based on roadway feature type (e.g., horizontal curves). The treatments are organized into 10 categories such that treatments can be compared at like locations. The safety treatments are separated into the following sections according to the corresponding roadway feature type and correlate to a color coded tab at the bottom of the page:



At the beginning of each treatment category section, a treatment matrix provides an overview of benefits and costs associated with each safety improvement in the section. The matrix may be used to help narrow the list of potential treatments by sorting through criteria specific to the practitioner's needs and available resources. For example, if a practitioner would like to identify an intersection treatment with a maximum initial cost, the matrix can be used to narrow the treatments to only those falling within the maximum range. Figure 1 shows an abbreviated version of the Horizontal Curve Treatment Matrix.

Table 1. Example Treatment Matrix

SAFETY TREATMENT	For more information, visit page	COST		Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO[19]			
		Initial Implementation	Ongoing Maintenance		NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Width***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Install Curve Warning Signs	11	$	$	5	P	0.70	33.8	270.1	43.5	428.4
Install/Upgrade Curve Warning Signs with Fluorescent Yellow Sheeting	12	$	–	5	P	0.66	63.1	490.4	75.1	739.9

Cost: $ = $0 to $5,000 $$ = $5,001 to $20,000 $$$ = $20,001 to $50,000 $$$$ = $50,001 to $100,000 $$$$$ = $100,001 and up	**NCHRP 500 Performance Rating**[20] P – Proven T – Tried E – Experimental U – Unknown	*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd ***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders ****Narrower Conditions = 10-foot lanes and no shoulders

The users of this manual can follow the decision flow charts in Chapter 6 to determine a range of treatment options based on the resources available to implement a treatment. This manual does not provide a full comprehensive list of every treatment available, and is only a guide to assist an agency in determining a potential range of treatments. An agency should always use an engineering study to determine if a specific treatment would be ideal at a location due to the site characteristics, agency standards, local driving laws, and other factors. In addition, the manual is focused on infrastructure safety improvements. It does not include enforcement, education, or emergency medical services treatments.

This manual only addresses treatments on HRRR, which are limited to rural collectors and rural local roads. While rural roads also include Interstate highways and arterials, those roadways are not addressed in this manual.

Treatment costs were identified through a survey of State, local, and Tribal agencies with experience applying safety treatments on HRRR. Resulting treatments costs were averaged and may not be representative of costs required to employ the treatments at each applicable location or costs incurred by each agency.

For each treatment where cost information was provided by agencies in the survey, a benefit cost ratio (BCR) is shown. A BCR value greater than 1.0 reflects a return on investment. For example, a BCR of 2.5 suggests that for every one dollar spent, a $2.50 benefit can be expected. Additional information related to how BCRs for safety treatments are calculated can be found in Section 6.4.

When responding to the survey, agencies did not always provide benefit or cost information for each safety treatment. In these cases, benefits, costs, or BCRs were not included in the HRRR Treatment Matrix.

2. HIGH RISK RURAL ROADS OVERVIEW

High risk rural roads include rural collectors and rural local roads.[1] The fatality rate on rural collectors and rural local roads is more than 1.5 times higher than the fatality rate on urban collectors and local roads, as shown in Table 1.[2]

Table 2. 2010 Rural vs. Urban Collector and Local Road VMT and Fatality Rate Comparison

RURAL			URBAN		
VMT*	Fatalities	Fatality Rate**	VMT*	Fatalities	Fatality Rate**
357,351	5,169	1.45	451,285	4,056	0.90

VMT = vehicle miles traveled
* In Millions ** Per 100 Million VMT
Example: To obtain the rural fatality rate, 1.45=(5,169*100)/357,351

2.1. High Risk Rural Road Safety

The higher roadway fatality rate on rural roadways is the result of many factors, including the following:

The physical characteristics of the roadways. Many rural roadways on both the State and local systems lack shoulders and clear zones that provide an area of recovery for roadway departures, which is the most prevalent crash type on these roadways.

Behavioral issues such as higher speeds, reduced seat belt use, and higher rates of impaired driving.[3] On rural routes, the ability to drive at a higher speed is not limited by the congestion found in urban areas. Motorists in rural areas are also more likely to drive while under the influence of alcohol and drugs. Rural areas also exhibit lower seat belt use than urban areas by nearly 20 percent.[4]

Increased Emergency Medical Services response time to incidents. When a severe crash occurs, the time it takes for victims to receive medical care is sometimes a determining factor of the severity of crash-caused injuries. In particular, the "golden hour" (one hour immediately following a roadway crash) is especially important when

1 Per the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA:LU) Title 23 Sec. 148 "Highway Safety Improvement Program" and Moving Ahead for Progress in the 21st Century (MAP-21) Title 23 Sec. 1112 "Highway Safety Improvement Program."

2 U.S. Department of Transportation, National Highway Traffic Safety Administration, "Traffic Safety Facts 2010," Rural and Urban Comparison 2010 Data. July 2012. Available at: http://www-nrd.nhtsa.dot.gov/Pubs/811637.pdf.

3 Chandler, B. and R. Anderson, "Implementing the High Risk Rural Roads Program," March 2010. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa10012/fhwasa10012.pdf.

4 Strine, T.W., L.F. Beck , J. Bolen, C. Okoro, S. Dhingra, and L. Balluz, "Geographic and Sociodemographic Variation in Self-reported Seat Belt Use in the United States," Accident Analysis & Prevention, 2010 July; 42(4): 1066-71. Epub 2010 Jan 4.

a crash occurs. Due to the reduced likelihood of passers-by witnessing a crash or its effects in rural areas, the distance emergency medical responders often must travel, and the distance between a crash location and the location of a trauma center, the risk of severe injury and fatality outcomes due to crashes on rural roads is high.

Challenges with limited data, safety expertise, and funding. The challenges of identifying safety improvements are due in part to the limited data available and varying levels of expertise of local agencies. Rural road issues compete for funding against the need for safety and expansion of urban road systems.

Each of these factors present challenges towards solving the fatal and severe crash problem on HRRR.

2.2. Challenges of Applying Treatments to HRRR

Nearly 80 percent of HRRR are found on the locally owned road system.[5] As of 2012, there were 89,004 local government units in the United States[6] that vary in the size of the engineering staff (including many jurisdictions with no engineering experience) and their expertise in making safety decisions. The financial responsibility for installing safety treatments in many locations is borne by the local agency, and competing community priorities may affect investment for upgrades in roadway safety.

Because local agencies maintain many of the HRRR, their challenges are important and include the following:

Insufficient Funding. Local transportation agencies often lack the funds needed to implement projects. Local agencies are often unfamiliar with the requirements of the State's Federal-aid funding application process, procurement process, and Federal-aid requirements related to construction. In other cases a local agency may not be able to pay for the required matching funds or finance the upfront cost of the project prior to reimbursement. In addition, competition from the large number of local agencies for State or Federal funds can sometimes make it difficult to secure necessary safety funding.

- **Potential solutions:** It is important to establish effective means of communication and coordination between the local agencies and State DOTs so that local agencies can engage the State to best target available funds. Coordination between State and local agencies can include the State training local agencies about available funds for HRRR and educating them on how to apply.

Lack of Technical Expertise. Many local agencies have found it difficult to identify and select safety treatments, as local agencies are often structured differently than the State DOT and may not have a dedicated safety program with funding or dedicated staff. A single local agency staff member with responsibility for roadway safety may also play several roles within the local agency. When safety technical expertise is limited, local agencies may be unable to select the most appropriate solutions.

- **Potential solutions:** Local Technical Assistance Program (LTAP)- and Tribal Technical Assistance Program (TTAP)-led training and technical workshops covering low-cost safety improvements on HRRR and HSIP processes can support HRRR efforts by offering technical training to local and Tribal agencies related to safety data and safety management programs and by providing information on problem identification and safety improvement implementation.

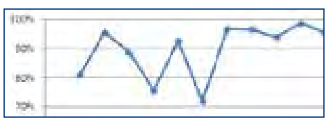
5 FHWA, *Developing Safety Plans: A Manual for Local Rural Road Owners*, FHWA-SA-12-017 (Washington, DC: March 2012). Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa12017/.

6 U.S. Census Bureau. "2012 Census of Governments," July 2012. Available at: http://www2.census.gov/govs/cog/2012/formatted_prelim_counts_23jul2012_2.pdf.

In addition to the potential solutions listed previously, several State and local agencies have developed innovative contracting strategies to apply funding quickly and efficiently on high risk rural roads. These agencies have taken the following actions:

- Used public forces for labor and bulk materials purchases to more efficiently use funds on HRRR.
- Initiated on-call contracts that have decreased the amount of time that elapses between project selection and completion.
- Augmented DOT staffing with outside resources for data analysis, problem identification, project selection, and administration.[7]
- Used special safety program coordinators at the State DOT district and local levels.
- Maintained websites with helpful HRRR-related information for locals.

For additional information related to funding resources and process, see Sections 5.2 and 5.3. More discussion related to identifying HRRR safety issues, even with limited data, is found in Sections 3.1 and 3.2, while assistance in navigating the process for identifying appropriate safety treatments is in Section 6.



Lack of Data. In addition to a lack of funds and technical expertise can be a lack of understanding of which roadway and crash data are important to capture and how to go about the collection and evaluation process.

- **Potential solutions:** Agencies can use the limited data available, regardless of how small or incomplete the data set, to help determine a course of action. Data may include finite numerical values (quantitative data) or may come from conversations with law enforcement personnel and field staff to determine the types, contributing circumstances, and times of crashes that occur at specific locations (qualitative data). While specific volume data may not be available, agencies may be able to prioritize corridor-wide implementation by dividing roadways into low-, medium-, and high-volume categories.

3. IDENTIFYING SAFETY TREATMENTS

This chapter discusses several tools that can be used to identify and select safety treatments and presents the differences between the traditional methods of treating "spot" locations versus a systemic approach.

3.1. Tools for Identifying HRRR Safety Issues

Technical expertise is cited as one of the most significant obstacles facing agencies when attempting to identify and implement safety treatments. Fortunately, many safety tools and opportunities for training exist for State and local transportation agencies. This section describes safety tools to assist with safety needs identification, use of available data—however limited—to make informed decisions with respect to selecting treatments, and additional resources and training opportunities.

7 FHWA, *Implementing the High Risk Rural Roads Program*, "Chapter 4. State Practices for Implementation," FHWA-SA-10-012 (Washington, DC: March 2010). Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa10012/chap_4.cfm.

Highway Safety Manual

The Highway Safety Manual (HSM) "Frequently Asked Questions" page describes the manual as providing:

> "... practitioners with information and tools to consider safety when making decisions related to design and operation of roadways. The HSM assists practitioners in selecting countermeasures and prioritizing projects, comparing alternatives, and quantifying and predicting the safety performance of roadway elements considered in planning, design, construction, maintenance, and operation."[8]

The HSM uses data to estimate the safety impacts of incorporating safety features for existing roads or future projects by determining the impacts of design and other decisions on the expected safety performance of a facility.

Safety Analyst

The **Safety Analyst** tool assists in making site-specific safety improvement recommendations that involve physical modifications to the roadway, either through systemic or spot location applications. As spot locations are being examined, the tool can help to identify crash patterns at specific locations and determine whether those crash types are overrepresented and the frequency at which crashes occur. The tool can help to identify opportunities for systemic solutions by identifying overrepresented crashes and clusters for highway segments or intersection types.[9]

Safety Analyst has the following capabilities to aid practitioners in each step of the safety management process, from needs identification to implementation and evaluation:

- A system-wide screening tool identifies potential sites for safety improvements.
- A diagnostic tool detects the nature of safety problems at specific sites.
- A countermeasure selection tool assists users in selecting safety treatments to reduce crash frequency and severity at spot locations.
- An economic appraisal tool performs a financial assessment of a specific countermeasure or several alternative countermeasures for a specific site.
- A priority ranking tool provides a prioritized listing of sites and proposed improvements based on benefit and cost estimates determined by the economic appraisal tool.
- The evaluation tool assists practitioners in conducting before-and-after evaluations of implemented safety improvements.

Crash Modification Factor (CMF) Clearinghouse

The CMF Clearinghouse website[10] provides a collection of calculated crash modification factors practitioners can apply to estimate the benefits of specific safety treatments. The website can be used by searching for a particular treatment name, which can be further refined by crash type or severity, roadway or intersection type, area type (e.g., urban, suburban, rural), and intersection geometry. Each safety improvement in the clearinghouse shows a CMF and Crash Reduction Factor (CRF), in addition to the quality or rating of the CMF. The quality rating indicates the quality or confidence in the results of the study producing the CMF.[11] CMFs and CRFs are accompanied with details of the research conducted to develop the CMF.

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8 AASHTO, "Highway Safety Manual-Related Frequently Asked Questions (FAQs)," last modified June 14, 2013, http://www.highwaysafetymanual.org/support.aspx.
9 **Safety Analyst** website, accessed October 9, 2013. http://www.safetyanalyst.org/.
10 CMF Clearinghouse website, accessed October 9, 2013. http://www.cmfclearinghouse.org.
11 CMF Clearinghouse website, "About the Star Quality Rating," accessed October 9, 2013. http://www.cmfclearinghouse.org/sqr.cfm.

Road Safety Audits

A Road Safety Audit (RSA) is the formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users.[12] RSAs can be integrated into the project development process for new roads and intersections, on existing roads and intersections, and for future or existing work zones.

For HRRR, the multidisciplinary team's expertise can include those familiar with rural issues, law enforcement officers, emergency service providers, human factors experts, and engineering fields including design, traffic safety, operations and maintenance, and others. The team assesses site-specific conditions and recommends improvements based on the team's road safety expertise in each member's respective fields.

RSAs can help to reduce crash severity and frequency while accounting for all road users. If performed during the design phase, RSAs serve as a proactive approach to improving safety before construction begins.

Training

Opportunities for and depth of training vary based on the agency's need. Practitioners can inquire about training based on their own specific needs beginning with the following resources:

- **Local Technical Assistance Programs (LTAP) and Tribal Technical Assistance Programs (TTAP).** LTAPs and TTAPs are a great technical resource and regularly provide training opportunities on many program areas. For more information, a visit to the national LTAP website can direct practitioners toward the LTAP or TTAP in their area.[13]
- **Highway Safety Manual.** The HSM website Training Page has information on HSM courses currently available.[14] The National Highway Institute (NHI) offers courses related to the HSM.[15] For more information State and local departments of transportation can contact their FHWA Division Office for training assistance.
- **Road Safety Audits.** FHWA provides technical assistance and trainings for RSAs. For more information, see FHWA's RSA website.[16]
- **National Association of County Engineers (NACE) and National Association of Counties (NACO).** NACE and NACO convene regularly, on both regional and national levels. The association is a forum for county engineers and staff to discuss safety and other issues related to the local road system. More information can be found on the NACE and NACO websites.[17,18]

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12 FHWA Road Safety Audit website. Accessed October 9, 2013. http://safety.fhwa.dot.gov/rsa/.
13 Local and Tribal Technical Assistance Program website, accessed December 3, 2013. http://www.ltap.org/.
14 Highway Safety Manual Training website, accessed December 3, 2013. http://www.highwaysafetymanual.org/Pages/Training.aspx.
15 National Highway Institute website, accessed December 3, 2013. https://www.nhi.fhwa.dot.gov/default.aspx.
16 FHWA Road Safety Audit website, accessed December 3, 2013. http://safety.fhwa.dot.gov/rsa.
17 National Association of County Engineers website, accessed December 3, 2013. http://www.countyengineers.org.
18 National Association of Counties website, accessed December 3, 2013. http://www.naco.org.

3.2. Systemic Implementation and Spot Location Treatments

A challenge in addressing safety in rural areas is that crashes tend to be widely dispersed geographically. The high number of lane miles and the dispersed nature of crashes make it difficult to target specific locations for assessment and improvement. Therefore, applying a systemic approach to addressing safety issues is a beneficial method for proactively addressing widespread safety concerns and cost-effectively minimizing crash potential.

Rather than focus on specific crash locations, a systemic approach targets common risk factors in crashes throughout the roadway network. A systemic improvement is widely implemented based on high-risk roadway features that are correlated with particular crash types rather than location-based crash frequency. The systemic problem identification entails a system-wide crash analysis targeting specific crash characteristics at the system level.

Systemic solutions can reduce overall severe crashes of certain types in a jurisdiction more effectively than choosing a small number of spot locations. This approach allows an agency to compensate for incomplete and lower quality crash history or roadway data, as it is less vital for that information to be perfect when many locations or segments are addressed with low-cost treatments.

With the systemic approach, implementation must be widespread enough to make a region-wide impact. Additionally, it can sometimes be difficult to convince stakeholders to apply safety treatments (even if low-cost) at locations that do not have a history of crashes.

Traditionally, a common approach has been to identify “black spots,” or locations with the highest crash frequency. While specific implementation sites are easily identified using roadway and crash data, this approach does not adequately deal with the randomness of the location of fatal and severe injury crashes. The traditional approach does not directly account for the most prevalent risk types associated with system-wide crashes.

This manual presents safety treatments that can be applied systemically, specifically at spot locations, or using both implementation methods.

For additional information on spot location and systemic safety treatment installations, please visit the following resources:

- **A Systemic Approach to Safety:** Using Risk to Drive Action.
  Available at: http://safety.fhwa.dot.gov/systemic/index.htm
- **Roadway Safety Information Analysis:** A Manual for Local Rural Road Owners.
  Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasaxx1210/index.cfm

4. SELECTING SAFETY TREATMENTS

This chapter features safety improvements used on HRRR that were identified by a survey of State, local, and Tribal agencies. The treatments are separated by section under the following categories. Each category has a color coded tab on the bottom of the page to assist with locating specific sections:

- Horizontal Curves
- Intersections (Signalized)
- Intersections (Unsignalized)
- Non-Motorized User
- Pavement and Shoulder Resurfacing
- Pavement Marking
- Roadside
- Signing
- Vertical Curves
- Other Treatments

Applicability of "Urban" Treatments to HRRR

Several agencies identified treatments used on high risk rural roads even though the treatments are typically viewed as treatments used in urban areas. In these cases, the functional classification of a HRRR did not change when the road passed through a small city or town and was still classified as rural. These treatments include, but are not limited to:

- Shared-used paths adjacent to the roadway;
- Shoulders for non-motorized users;
- Exclusive bicycle lanes;
- Bicycle trail grade separation structures;
- Sidewalks;
- Crosswalks at targeted locations;
- Pedestrian hybrid beacons (or high intensity activated crosswalk, known as HAWK)
- Rectangular rapid flash beacons;
- Staggered and raised median islands;
- Curb extensions; and
- Pedestrian signal heads added to existing signalized intersections.

4.1. Horizontal Curves

Safety improvement treatments on horizontal curves range from low-cost improvements (such as signing) to high-cost improvements (such as modifying road geometry). This section covers safety improvement treatments that can be applied at horizontal curve locations. Some treatments in this section also appear in the sections on intersection improvements, signing, and roadside safety.

SAFETY TREATMENT	For more information, visit page	COST			SAFETY BENEFIT		BENEFIT-COST RATIO[19]			
		Initial Implementation	Ongoing Maintenance	Frequency of Maintenance (years)	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Install Curve Warning Signs	11	$	$	5	P	0.70	33.8	270.1	43.5	428.4
Install/Upgrade Curve Warning Signs with Fluorescent Yellow Sheeting	12	$	–	5	P	0.66	63.1	490.4	75.1	739.9
Double Use of Advanced Warning Signs for Curves or Intersections	13	$			T					
Use of Optical Speed Bars	14	$								
Install Chevron Signs	15	$$	$	5	P	0.75	10.6	84.7	13.0	127.7
Install Arrow Signs at Horizontal Curve Locations	16	$$	–	10	P		27.9	222.8	34.1	336.1
Install Post-Mounted Delineators at Horizontal Curves	17	$$	–	10	P		5.3	42.4	6.5	63.9
Install Targeted Longitudinal Rumble Strips on the Outside of Horizontal Curves	18	$$			T	0.85				
Install Icy Curve Warning System	19	$$			E	0.82				
Improve Superelevation at Horizontal Curve Locations	20	$$$$			P					
Remove Compound Horizontal Curves	21	$$$$$			T					
Modify Horizontal/Vertical Geometry	22	$$$$$			P					

Cost:
$ = $0 to $5,000
$$ = $5,001 to $20,000
$$$ = $20,001 to $50,000
$$$$ = $50,001 to $100,000
$$$$$ = $100,001 and up

NCHRP 500 Performance Rating[20]
P – Proven
T – Tried
E – Experimental
U – Unknown

*Lower Volume ≤1000 vpd
**Higher Volume = Between 1,001 and 8000 vpd
***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders
****Narrower Conditions = 10-foot lanes and no shoulders

19 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, it has been left blank.

20 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Install Curve Warning Signs

Some of the most serious crashes on rural roads occur at horizontal curves. Horizontal alignment signs, informally called curve warning signs, can improve safety by alerting drivers to changes in roadway geometry that may not be apparent or expected. These signs provide visual information for the driver about the nature of the curve they are approaching, letting them know whether it's a gradual curve, a sharp turn, a hairpin turn, or some combination. Different types of curve warning signs are identified in the MUTCD.

Where to Use: Curve warning signs should be applied to any curve or turn with a history of roadway departure crashes and curves or turns with similar geometry or traffic volumes yet to experience crashes. According to the 2009 MUTCD, warning signs are required on curves or turns where the advisory speed is 10 mph less than the posted speed.

Studies have shown that reductions in crashes due to the installation of curve warning signs are more prominent at locations with higher traffic volumes, sharper curves, or hazardous roadsides.

Install Curve Warning Signs - **Initial Investment:** $2,400 - **Cost of Maintenance:** $1,280 - **Frequency of Maintenance:** 5 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	33.8	Proven	0.70
Higher Volume Optimal Conditions	207.1	Proven	0.70
Lower Volume Narrower Conditions	43.5	Proven	0.70
Higher Volume Narrower Conditions	428.4	Proven	0.70

Top Recommended Resources:

1. University of California, Berkley, Institute of Transportation Studies, Technology Transfer Program, *Tech Transfer Newsletter*, "Signs for Curves and Turns." Available at: http://www.techtransfer.berkeley.edu/newsletter/08-2/signs-for-curves-and-turns.php.
2. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Install/Upgrade Curve Warning Signs with Fluorescent Yellow Sheeting

Fluorescent yellow sheeting can improve the effectiveness of curve warning and delineation signs by increasing the conspicuity, or prominent visibility, of the sign, especially during dark conditions.

Where to Use: Connecticut DOT used fluorescent yellow sheeting to improve signing at horizontal curves between 2002 and 2006. These curves were selected through a regular program called the Suggested List of Surveillance Study Sites (SLOSSS), which uses crash data, traffic volumes, and roadway characteristics to identify intersections and road segments with higher than expected crash rates.

Install/Upgrade Curve Warning Signs with Fluorescent Yellow Sheeting - **Initial Investment:** $1,280 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 5 years (2 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	63.1	Proven	0.66
Higher Volume Optimal Conditions	490.4	Proven	0.66
Lower Volume Narrower Conditions	75.1	Proven	0.66
Higher Volume Narrower Conditions	739.9	Proven	0.66

Top Recommended Resource:

1. FHWA, *Safety Evaluation of Improved Curve Delineation*, September 2009. Available at: http://www.fhwa.dot.gov/publications/research/safety/09045/09045.pdf

Double Use of Advanced Warning Signs for Curves or Intersections

Doubling the use of either Intersection Ahead warning signs or Curve Ahead warning signs (i.e., on the left and right) is recommended for locations where the crash rates have not been reduced after installation of a single advanced warning sign.

Where to Use: This treatment may be used at locations where crashes indicate that motorists do not heed existing advanced warning signs and additional conspicuity is needed.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Double Use of Advanced Warning Signs	$0 to $5,000	Tried

Top Recommended Resource:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

Use of Optical Speed Bars

Optical speed bars are transverse stripes spaced at gradually decreasing distances. The rationale for using them is to increase drivers' perception of speed and cause them to reduce speed, which can be helpful near intersections or horizontal curves. The Optical speed bar name comes from this intended visual effect on drivers' speed as they react to the spacing of the painted lines. These white transverse stripes are 18 inches long and 12 inches wide. The preferred material is thermoplastic because of the exposure to traffic volume over time.

Where to Use: This treatment may be used at locations where speed reductions are needed, such as near intersections and horizontal curves.

Safety Treatment	Initial Implementation Cost
Use of Optical Speed Bars	$0 to $5,000

Top Recommended Resource:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

Install Chevron Signs

Chevron signs (or curve delineation signs) indicate to drivers the alignment of the roadway when they are within the actual horizontal alignment of a curve. The signs show the shape and degree of curvature, and they guide drivers through the entire curve or turn.

Where to Use: Chevrons should be installed at any curve or turn with a history of roadway departure crashes and at curves or turns with similar geometry or traffic volume yet to experience crashes. According to the 2009 MUTCD, alignment delineation (or a single-directional large arrow) is required on curves or turns where the advisory speed is 15 mph less than the posted speed limit. They can be installed at locations where no chevrons currently exist, or to supplement chevrons that are already in place.

Install Chevron Signs - **Initial Investment:** $7,200 - **Cost of Maintenance:** $3,600 - **Frequency of Maintenance:** 5 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	10.6	Proven	0.75
Higher Volume Optimal Conditions	84.7	Proven	0.75
Lower Volume Narrower Conditions	13.0	Proven	0.75
Higher Volume Narrower Conditions	127.7	Proven	0.75

Top Recommended Resource:

1. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Install Arrow Signs at Horizontal Curve Locations

The One-Direction Large Arrow sign is used to define a change in horizontal alignment. It can be used alone or to supplement other curve warning signs, such as chevrons.

Where to Use: The sign is typically placed on the outside of the curve directly in line with the approaching tangent section. The MUTCD guidance regarding the application of this sign is to install either the One-Direction Large Arrow sign or the Chevron Alignment sign when the Hairpin Curve sign or the Loop sign is installed. Based on standard practice, this sign is limited to sharper curves (turns). It should not be used when there is no advisory speed plaque.

Install Arrow Signs at Horizontal Curve Locations - **Initial Investment:** $5,600 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume Optimal Conditions	27.9	Proven
Higher Volume Optimal Conditions	222.8	Proven
Lower Volume Narrower Conditions	34.1	Proven
Higher Volume Narrower Conditions	336.1	Proven

Top Recommended Resource:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

Install Post-Mounted Delineators at Horizontal Curves

When used within horizontal curves, post-mounted delineators with retroreflective sheeting the full length of the post improves driver lane position both at the entry to the curve and at its midpoint.

Where to Use: For best results, post-mounted delineators are to be installed on each chevron support post and coupled with edge line and center line pavement markings.

Install Post-Mounted Delineators at Horizontal Curves - **Initial Investment:** $5,600 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume Optimal Conditions	5.3	Proven
Higher Volume Optimal Conditions	42.4	Proven
Lower Volume Narrower Conditions	6.5	Proven
Higher Volume Narrower Conditions	63.9	Proven

Top Recommended Resource:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

Install Targeted Longitudinal Rumble Strips on the Outside of Horizontal Curves

Shoulder or edge line milled rumble strips can be used on roads with a history of roadway departure crashes. While it is recommended that rumble strips be applied systematically along an entire route instead of only at spot locations, where appropriate, they can be used on the outside of horizontal curves and the tangent leading to the curves.

Where to Use: This treatment may be used at horizontal curve locations with a high frequency of roadway departure crashes.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Targeted Longitudinal Rumble Strips on the Outside of Horizontal Curves	$5,001 to $20,000	Tried	0.85

Top Recommended Resource:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

Install Icy Curve Warning System

Icy curve warning systems may be installed at problematic areas where ice formation frequently recurs. Using in-pavement weather sensors, icy curve warning signs are activated to alert motorists of upcoming icy conditions.

Where to Use: This treatment may be useful in locations that experience recurring icy conditions, such as horizontal curves located in mountain passes.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Icy Curve Warning System	$5,001 to $20,000	Experimental	0.82

Top Recommended Resource:

1. Ye, Z., D. Veneziano, and I. Turnbull, *Safety Effects of Icy Curve Warning Systems*, 2012. Available at: http://www.westernstates.org/projects/coats/Documents/TRB2012/Fredonyer%20ICWS_TRB%20Safety%20Paper_2012-1-23_FINAL.pdf.

Improve Superelevation at Horizontal Curve Locations

Superelevation is the rotation of the pavement on the approach to and through a horizontal curve and is intended to assist the driver in negotiating the curve by counteracting the lateral acceleration produced by tracking. In other words, the road is designed so that the pavement rises as it curves, offsetting the horizontal sideways momentum of the approaching vehicle.

Where to Use: Superelevation is expressed as a decimal representing the ratio of the pavement slope to width, ranging from 0 to 0.12 feet. The adopted criteria allow for the use of maximum superelevation rates from 0.04 to 0.12. Maximum superelevation rates for design are established by policy by each State. Selection of a maximum superelevation rate is based on several variables, such as climate, terrain, highway location (urban vs. rural), and frequency of very slow-moving vehicles. Specific guidance on superelevation rates can be found in *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2011 and *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, AASHTO, 2001.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Improve Superelevation at Horizontal Curve Locations	$50,001 to $100,000	Proven

Top Recommended Resources:

1. FHWA, *Mitigating Strategies for Design Exceptions*, July 2007. Available at: http://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/.
2. NCHRP Project 17-18(3), *Strategy 15.2 A12: Improve or Restore Superelevation (P)*. Available at: http://safety.transportation.org/htmlguides/horz_crvs/default.htm.
3. AASHTO, *Guidelines for Geometric Design of Very Low-volume Local Roads (ADT 400)*, January 2001.
4. AASHTO, *A Policy on Geometric Design of Highways and Streets*, November 2011.

Remove Compound Horizontal Curves

Drivers typically expect a single steering setting while negotiating a horizontal curve. Replacing compound curves with a single radius curve better adheres to driver expectations.

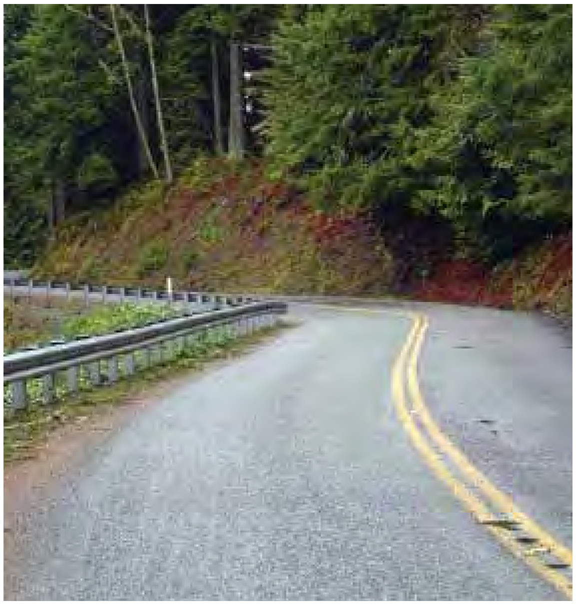
Where to Use: This treatment may be used on HRRR with locations of compound horizontal curves that experience a high frequency of roadway departure crashes. This treatment is especially applicable where other treatments have been applied at the curve location and have not been successful in reducing crashes.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Remove Compound Horizontal Curves	$100,001 and up	Tried

Top Recommended Resource:

1. NCHRP Project 17-18(3), *Strategy 15.2 A13: Modify Horizontal Alignment (P)*. Available at: http://safety.transportation.org/htmlguides/horz_crvs/default.htm.

Modify Horizontal/Vertical Geometry



Horizontal and vertical geometry may be reconstructed in a variety of ways. For example, horizontal and vertical curves may benefit from increased radii, thereby increasing sight distance. Modifying road geometry may also include eliminating horizontal or vertical curves and providing a more direct alignment.

Where to Use: This treatment may be used at locations where improved sight distance is needed and at locations that experience head-on collisions and run-off-road crashes.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Modify Horizontal/Vertical Geometry	$100,001 and up	Proven

Top Recommended Resource:

1. NCHRP Project 17-18(3), *Strategy 15.2 A13: Modify Horizontal Alignment (P)*. Available at: http://safety.transportation.org/htmlguides/horz_crvs/default.htm.

4.2. Intersections (Signalized)

Signalized intersection-specific safety treatments assist drivers in recognizing they are at or approaching signal-controlled intersecting routes, provide storage for turning traffic,[21] and give positive guidance to motorists through the intersection.

SAFETY TREATMENT	For more information, visit page	COST		Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT- COST RATIO[22]	
		Initial Implementation	Ongoing Maintenance		NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*	Higher Volume**
Improve Traffic Signal Visibility (Larger Diameter Lens or Install Back Plate)	24	$			P	0.85		
Provide Intersection Lighting	25	$$	$	1	P	0.41-0.88	26.9	93.8
Install Pedestrian Signal Heads to Existing Signalized Intersections	26	$$			P			
Provide Flashing Beacons at Intersection Approaches	27	$$$	$	2	P		11.0	38.2
Use Raised Median to Restrict Turning Movements	28	$$$-$$$$			P	0.61-1.09		
Install Priority Control Systems for Emergency Vehicles	29	$$$-$$$$			T			
Provide Advanced Dilemma Zone Detection for Rural High Speed Signalized Approaches	30	$$$-$$$$			P	0.61		
Implement J-Turns Along a Signalized Corridor	31	$$$$	$	10	P		45.4	159.1
Install Acceleration or Deceleration Lanes	32	$$$$			P			
Install Right Turn Lane	33	$$$$$	$$	10	P	0.77-0.96	4.9	16.9
Install Left Turn Lane	34	$$$$$	$$	10	P	0.50-0.80	4.1	14.1
Install Offset (or Channelized) Left Turn Lane	35	$$$$$	$$	10	P	0.80	4.1	14.1
Convert a Traditional Signalized Intersection into a Roundabout	36	$$$$$	$$$	10	P	0.26-0.82	4.8	16.6
Reconstruct At-Grade Intersection to Create an Interchange	37	$$$$$	$$$	10	P	0.43-0.64	0.1	0.4
Cost: $ = $0 to $5,000 $$ = $5,001 to $20,000 $$$ = $20,001 to $50,000 $$$$ = $50,001 to $100,000 $$$$$ = $100,001 and up	**NCHRP 500 Performance Rating**[23] P – Proven T – Tried E – Experimental U – Unknown				*Lower Volume ≤1000 vpd **Higher Volume = Between 1,001 and 8000 vpd			

21 Turn lane storage is the length of turn lane provided based on anticipated traffic needs.

22 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, the BCR has been left blank.

23 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Improve Traffic Signal Visibility (Larger Diameter Lens or Install Back Plate)

Enhancing the visibility of traffic signals can help to eliminate red-light running and associated crashes. Enhancements may include installing signal lenses with a larger diameter and using reflective back plates.

Where to Use: This treatment may be used when crash types such as red-light running indicate that visibility of traffic signal is an issue.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Improve Traffic Signal Visibility	$2,000	Proven	0.85

Top Recommended Resource:

1. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Provide Intersection Lighting

Many intersection crashes during late-night and early-morning hours occur due to poor visibility, which results in drivers being unable to see conflicting traffic, other road users, or—specifically in the case of unsignalized intersections—the presence of the intersection itself. At night in rural areas, the only source of lighting for roadways is often provided by vehicle headlights. Roadway lighting allows for greater visibility of the intersection, which makes the intersection more conspicuous to motorists and provides aid in helping drivers determine their paths through the intersection by making signs and markings more visible.

Where to Use: Lighting should be provided at signalized or unsignalized intersections, particularly those with a high instance of dark crashes. Rear-end, right-angle, or turning crashes on the major road approaches to an unsignalized intersection may indicate that approaching drivers are unaware of the presence of the intersection.

Provide Intersection Lighting - **Initial Investment:** $20,000 - **Cost of Maintenance:** $500 - **Frequency of Maintenance:** 1 year	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Signalized Intersections	26.9	Proven	0.41–0.88
Higher Volume Signalized Intersections	93.8	Proven	0.41–0.88

Top Recommended Resource:

1. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Install Pedestrian Signal Heads to Existing Signalized Intersections

Pedestrian signal heads provide special types of traffic signal indications exclusively intended for controlling pedestrian traffic. These signal indications consist of the illuminated symbols of a walking person (symbolizing Walk) and an upraised hand (symbolizing Don't Walk).

Where to Use: This treatment is applicable where pedestrian traffic exists at signalized intersections.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Pedestrian Signal Heads to Existing Signalized Intersections	$5,001 to $20,000	Proven

Top Recommended Resources:

1. FHWA, *Manual on Uniform Traffic Control Devices*, "Chapter 4E. Pedestrian Control Features," December 2009. Available at: http://mutcd.fhwa.dot.gov/pdfs/2009r1r2/mutcd2009r1r2edition.pdf.
2. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Provide Flashing Beacons at Intersection Approaches

Flashing beacons provide a visible signal to the presence of an intersection and can be very effective in rural areas where there may be long stretches between intersections as well as in locations where nighttime intersection visibility is an issue.

Where to Use: Flashing beacons can be installed prior to signalized intersections with patterns of right-angle crashes related to lack of driver awareness of the upcoming signalized intersection. The beacons can be installed atop Advance Signal Ahead signs.

Provide Flashing Beacons at Intersection Approaches - **Initial Investment:** $25,000 - **Cost of Maintenance:** $1,000 - **Frequency of Maintenance:** 2 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume Signalized Intersections	11.0	Proven
Higher Volume Signalized Intersections	38.2	Proven

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, “Chapter 4. Countermeasures,” January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/ch4.cfm.

Use Raised Median to Restrict Turning Movements

Raised medians can be helpful in limiting access and restricting turning movements within the functional limits of intersections, thereby reducing conflicts between through traffic and turning vehicles.

Where to Use: This treatment may be used at locations where access to streets, businesses, homes, and other properties falls within the intersection functional area.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Use Raised Median to Restrict Turning Movements	$20,001 to $100,000	Proven	0.61–1.09

Top Recommended Resource:

1. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Install Priority Control Systems for Emergency Vehicles

Emergency priority control systems are designed to give emergency response vehicles a green indication on their approach to a signalized intersection while providing a red light to conflicting approaches.

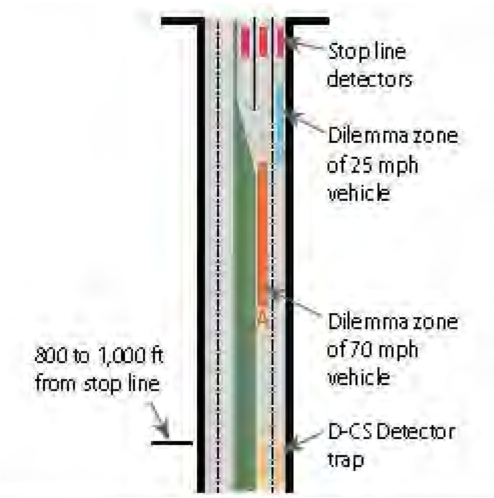
Where to Use: This system may be most beneficial where vehicles approaching a green signal cannot see emergency vehicles approaching on the intersecting roadway because of line-of-sight problems with nearby buildings, vegetation, or hills.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Priority Control Systems for Emergency Vehicles	$20,001 to $100,000	Tried

Top Recommended Resources:

1. FHWA, *Traffic Signal Preemption for Emergency Vehicles: A Cross-Cutting Study*, January 2006. Available at: http://www.gtt.com/wp-content/uploads/Traffic-signal-preemption-for-emergency-vehicles-A-cross-cutting-study.pdf.
2. FHWA, *Traffic Signal Timing Manual*, "Chapter 9," June 2008. Available at: http://ops.fhwa.dot.gov/publications/fhwahop08024/chapter9.htm

Provide Advanced Dilemma Zone Detection for Rural High Speed Signalized Approaches



Note: The sign shown may not be consistent with the latest version of the MUTCD.

Advanced dilemma zone detection systems enhance safety at signalized intersections by modifying traffic control signal timing to reduce the number of drivers that may have difficulty deciding whether to stop or proceed during a yellow phase. This may reduce rear-end crashes associated with unsafe stopping and angle crashes due to illegally continuing into the intersection during the red phase.

Where to Use: This treatment may be used at locations with a high frequency of crashes associated with the traffic signal phase change (e.g., rear-end and angle crashes) and high frequencies of red-light violations. Additional benefits of this treatment include reducing delay and stop frequency on the major road and maintaining or reducing overall intersection delay.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Provide Advanced Dilemma Zone Detection for Rural High Speed Signalized Approaches	$20,001 to $100,000	Proven	0.61

Top Recommended Resource:

1. FHWA, *Advanced Dilemma-Zone Detection System*, May 2009. Available at: http://safety.fhwa.dot.gov/intersection/resources/techsum/fhwasa09008/.

Implement J-Turns Along a Signalized Corridor

The J-turn intersection is characterized by the prohibition of left turn and through movements from side street approaches as permitted in conventional designs. The J-turn intersection accommodates these movements by requiring drivers to turn right onto the main road and then make a U-turn maneuver at a one-way median opening 400 to 1,000 feet after the intersection. Left turns from the main road approaches are executed in a manner similar to left turns at conventional intersections and are unchanged in this design. Left turn movements from the major road could also be removed at primarily rural unsignalized J-turn designs.

Where to Use: J-turn intersections are typically implemented as part of a corridor treatment; however, they can be used at isolated intersections. Unsignalized J-turn intersections preserve corridor capacity and can be installed without the adverse effects of signal control. Scenarios where J-turn intersections are most applicable include the following:

- Relatively low to medium side-street through volumes and heavy left turn volumes from the major road.
- The minor road total volume to total intersection volume ratio is typically less than or equal to 0.20.
- Areas where median widths are greater than 40 feet. For narrower medians, loons or bulb-outs on the shoulders need to be constructed.

For intersections with very high left turn and through volumes from the side road approaches, the J-turn intersection design is not the optimal choice.

Implement J-Turns Along a Signalized Corridor - **Initial Investment:** $100,000 - **Cost of Maintenance:** $5,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume Signalized Intersections	45.4	Proven
Higher Volume Signalized Intersections	159.1	Proven

Top Recommended Resource:

1. FHWA, *Restricted Crossing U-Turn Intersection*, October 2009. Available at: http://www.fhwa.dot.gov/publications/research/safety/09059/09059.pdf.

Install Acceleration or Deceleration Lanes

Drivers turning onto an uncongested highway generally accelerate until they approach the desired open-road speed. When acceleration by entering traffic takes place directly on the traveled way, it may disrupt the flow of through traffic. To minimize this operational problem due to right- or left turning traffic at highway intersections, acceleration lanes may be used.

An acceleration lane is an auxiliary or speed-change lane that allows vehicles to accelerate to highway speeds before entering the through traffic lanes of a highway. Acceleration lanes should be of sufficient length to permit adjustments in speeds of both through and entering vehicles so that the driver of the entering vehicle can accelerate and maneuver into that gap before reaching the end of the acceleration lane.

Additionally, the purpose of a parallel deceleration lane is to provide drivers exiting or turning from the road with an opportunity to slow down to a more reasonable speed prior to turning.

Where to Use: This treatment may be used at unsignalized intersections on highways that experience a high proportion of rear-end crashes related to the speed differential caused by vehicles turning left or right onto or from the highway. They may also be used where intersection sight distance is inadequate or where there are high volumes of trucks or recreational vehicles entering or exiting the highway.

Acceleration or deceleration lanes can be added as median acceleration/deceleration lanes, as installed at several locations in Missouri, or as lanes next to the shoulder for vehicles entering or exiting the roadway on the right side, as installed in Kentucky.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Acceleration or Deceleration Lanes	$100,000	Proven

Top Recommended Resources:

1. FHWA. *NCHRP Report 500 / Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*, “Strategy B9. Provide Right-Turn Acceleration Lanes at Intersections,” July 2003. Available at: http://safety.fhwa.dot.gov/intersection/resources/intsafestratbro/ub9.cfm.
2. FHWA. *NCHRP Report 500 / Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*, “Strategy B5. Provide Left-Turn Acceleration Lanes at Intersections,” July 2003. Available at: http://safety.fhwa.dot.gov/intersection/resources/intsafestratbro/ub5.cfm.

Install Right Turn Lane

Providing a right turn lane at an intersection can reduce rear-end crashes by allowing vehicles to proceed through the intersection without having to stop or slow down for vehicles making a right turn. Assuming turn lanes are of adequate length, vehicles will not be stopped in the travel lanes; this allows for through traffic to continue without stopping for vehicles turning at an intersection.

Where to Use: Right turn lanes should be constructed at intersections with a high frequency of rear-end crashes resulting from conflicts between (1) vehicles turning right and following vehicles, and (2) vehicles turning right and through vehicles coming from the left on the cross street.

Install Right Turn Lane - **Initial Investment:** $400,000 - **Cost of Maintenance:** $20,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Signalized Intersections	4.9	Proven	0.77–0.96
Higher Volume Signalized Intersections	16.9	Proven	0.77–0.96

Top Recommended Resources:

1. FHWA, *Techbrief: Safety Effectiveness of Intersection Left- and Right-Turn Lanes*, 2002. Available at: http://www.fhwa.dot.gov/publications/research/safety/02103/02103techbrief.pdf
2. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Install Left Turn Lane

Left turn lanes are used as auxiliary lanes for storage or to accommodate left turning vehicles with decreasing speed as they approach the intersection. Installing left turn lanes can reduce rear-end crashes by allowing vehicles to proceed through the intersection without having to stop or slow down for vehicles waiting to make a left turn.

Where to Use: The AASHTO Green Book recommends that left turning traffic be removed from the through lanes whenever practical, and that left turn lanes should be provided at street intersections along major arterials and collector roads wherever left turns are permitted. Consideration of left turn lanes has traditionally been based on such factors as the number of through lanes, speeds, left turn volumes, opposing through volumes, and/or left turning crashes.

Intersections with a high frequency of crashes resulting from the conflicts between (1) vehicles turning left and following vehicles, and (2) vehicles turning left and opposing through vehicles are also candidates for the installation of left turn lanes.

Practitioners should consider installing left turn lanes for the major road approaches to improve safety at 3- and 4-leg intersections with two-way stop control on the minor road at locations where significant turning volumes exist or where there is a history of turn-related crashes.

Install Left Turn Lane - **Initial Investment:** $400,000 - **Cost of Maintenance:** $20,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Signalized Intersections	4.1	Proven	0.50–0.80
Higher Volume Signalized Intersections	14.1	Proven	0.50–0.80

Top Recommended Resources:

1. FHWA, *Signalized Intersections Informational Guide,* July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.
2. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.

Install Offset (or Channelized) Left Turn Lane

Offset left turn lanes provide the left turning motorist a line of sight to opposing through vehicles. Instead of attempting to look around opposing left turning vehicles, the motorist can clearly see oncoming traffic.

Where to Use: Offset left turn lanes should be used at unsignalized 4-leg intersections with a high frequency of crashes between vehicles turning left and opposing through vehicles. This treatment can be applied at intersections on divided highways with medians wide enough to provide the appropriate positive offset, and also on approaches without medians if sufficient width exists.

Install Offset (or Channelized) Left Turn Lane - **Initial Investment:** $250,000 - **Cost of Maintenance:** $1,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Signalized Intersections	4.1	Proven	0.80
Higher Volume Signalized Intersections	14.1	Proven	0.80

Top Recommended Resource:

1. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Convert a Traditional Signalized Intersection into a Roundabout

The modern roundabout is a type of circular intersection defined by the basic operational principle that entering traffic yields to vehicles on the circulatory roadway. Key design principles achieve deflection of entering traffic by channelization at the entrance and deflection around a center island. Roundabout intersections eliminate a number of vehicle conflict points typically associated with traditional intersections. A 4-leg, single-lane roundabout has 75 percent fewer vehicle conflict points than a traditional stop-controlled intersection. Roundabouts also enhance safety by reducing vehicle speeds both in and through the intersection and by changing the crash type from angle to sideswipe, which typically results in less severe crashes.

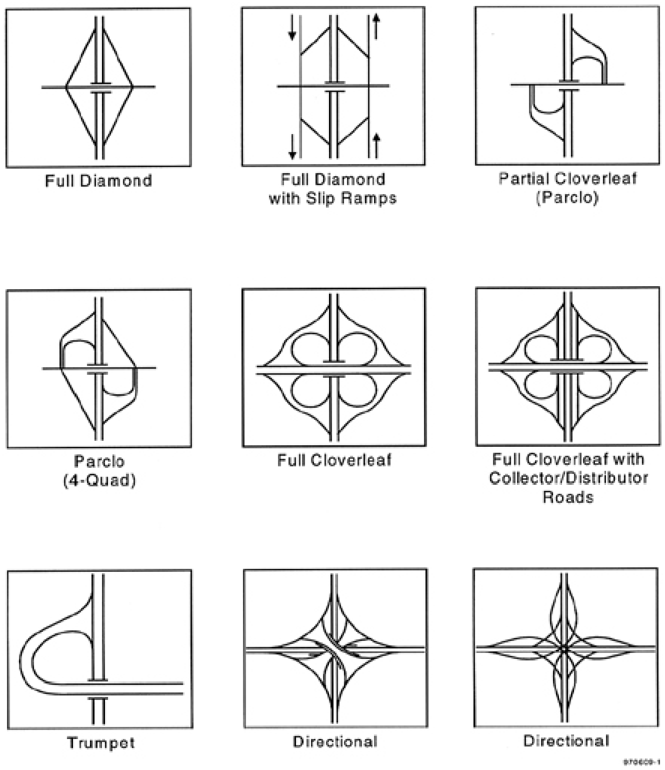
Where to Use: Roundabouts are the preferred safety alternative for a wide range of intersections. Although they may not be appropriate in all circumstances, they may be considered as an alternative for all proposed new intersections on federally-funded highway projects. Roundabouts should also be considered for all existing intersections that have been identified as needing major safety or operational improvements. This would include freeway interchange ramp terminals and rural intersections.

Convert a Traditional Signalized Intersection into a Roundabout - **Initial Investment:** $400,000 - **Cost of Maintenance:** $40,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Signalized Intersections	4.8	Proven	0.26–0.82
Higher Volume Signalized Intersections	16.6	Proven	0.26–0.82

Top Recommended Resources:

1. FHWA, "Guidance Memorandum on Consideration and Implementation of Proven Safety Countermeasures," 2010. Available at: http://safety.fhwa.dot.gov/policy/memo071008/.
2. FHWA, *Intersection Safety Case Study: Minnesota Roundabout—A Scott County Success Story*, February 2010. Available at: http://safety.fhwa.dot.gov/intersection/resources/casestudies/fhwasa09013/.

Reconstruct At-Grade Intersection to Create an Interchange



In removing an existing at-grade intersection and navigating traffic through an interchange, the through movements on the major street are physically separated from the other turning movements, which are typically served by one or two intersections (ramp terminals) on the minor street. The interchange may take several forms: a diamond interchange, a single point urban interchange, and a compressed diamond interchange. Each interchange type has independent safety implications.

Where to Use: This improvement may be applicable to 4-leg intersections with high volumes on the through street and a high number of angle crashes.

Reconstruct At-Grade Intersection to Create an Interchange - **Initial Investment:** $10,000,00 - **Cost of Maintenance:** $40,000 - **Frequency of Maintenance:** 10 years **Calculations include a salvage value of $1,000,000*	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Low Volume Signalized Intersections	0.1	Proven	0.43–0.64
Higher Volume Signalized Intersections	0.4	Proven	0.43–0.64

Top Recommended Resources:

1. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.
2. FHWA, *Rural Public Transportation Technologies: User Needs and Applications FR1-798*, July 1997. Available at: http://www.fhwa.dot.gov/publications/research/safety/97106/ch01/ch01.cfm.

4.3. Intersections (Unsignalized)

Intersection-specific safety treatments assist drivers in recognizing they are at or approaching an unsignalized intersection, provide storage for turning traffic,[24] and give positive guidance to motorists through the intersection. Among others, improvements cited in this section include Railway-Highway Grade Crossing treatments.

SAFETY TREATMENT	For more information, visit page	COST		Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO[25]			
							4-LEG INTERSECTIONS		3-LEG INTERSECTIONS	
		Initial Implementation	Ongoing Maintenance		NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*	Higher Volume**	Lower Volume*	Higher Volume**
Relocate an Existing Stop Bar on Minor Approach	40	$			T					
Install Stop Ahead Pavement Markings	41	$			P	0.44-0.69				
Install Advanced Intersection Warning Signs	42	$			P					
Provide a Stop Bar on Minor-Road Approaches	43	$	–	5	P		337.7	1175.8	287.1	1484.1
Improve Sight Distance within Sight Triangle	44	$	$	5	P	0.44-0.89	157.3	547.8	66.9	345.7
Provide Upcoming Road Names on Advanced Warning Signs	45	$			T	0.90-0.99				
Install Retroreflective Strips on Sign Posts	46	$			T					
Upgrade to Larger Stop Signs	47	$			P					
Double Use of Stop Signs	48	$			T					
Improve Sight Distance and Conspicuity at Railroad Grade Crossings	49	$			T					
Install a Splitter Island	50	$$			T					
Channelization of Major and Minor Roads (Physical or Painted)	51	$$			P					
Provide Intersection Lighting	52	$$	$	1	P		23.1	80.6	10.5	54.2
Install Dynamic Advanced Intersection Warning System	53	$$			P	0.10-0.76				
Upgrade Existing Railroad Crossing Hardware and Warning Systems	54	$$-$$$			P	0.55				
Implement Lane Narrowing through Rumble Strips and Painted Median at Rural Stop-Controlled Approaches	55	$$-$$$			T	0.60-0.80				

24 Turn lane storage is the length of turn lane provided based on anticipated traffic needs.

25 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, the BCR has been left blank.

SAFETY TREATMENT	For more information, visit page	COST		Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO[25]			
							4-LEG INTERSECTIONS		3-LEG INTERSECTIONS	
		Initial Implementation	Ongoing Maintenance		NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*	Higher Volume**	Lower Volume*	Higher Volume**
Provide Flashing Beacons at Intersection Approaches	56	$$$	$	2	P	0.85	16.3	56.8	6.8	35.8
Convert Minor-Road Stop Control to All-Way Stop Control	57	$$$	$	10	P	0.30	77.2	268.8	32.8	169.7
Convert a Traditional Stop-Controlled Intersection into a J-Turn Intersection	58	$$$-$$$$	$	10	P	0.0-0.91	46.4	161.4	n/a	n/a
Use Raised Median to Restrict Turning Movements	59	$$$-$$$$			P					
Install Acceleration or Deceleration Lanes	60	$$$-$$$$			P					
Install Railroad Crossing Hardware and Warning Systems Where They Currently Do Not Exist	61	$$$-$$$$			P	0.75				
Convert a 4-Leg Intersection into Two 3-Leg Intersections (Offset T-Intersections)	62	$$$$			P	0.70				
Install Bypass Lane	63	$$$$	$$	10	P		11.6	40.6	5.0	25.6
Modify Horizontal and/or Vertical Geometry	64	$$$$$			P					
Improve Horizontal Intersection Alignment or Skew	65	$$$$$	–	–	P		1.0	7.9	1.0	7.9
Install Traffic Signals	66	$$$$$	$$	1	P	0.23-1.58	15.4	53.8	6.9	35.5
Install Right Turn Lane	67	$$$$$	$$	10	P		16.0	55.9	6.8	35.3
Install Left Turn Lane	68	$$$$$	$$	10	P		6.0	20.8	3.7	18.9
Install Offset (or Channelized) Left Turn Lane	69	$$$$$	$$	10	P		6.0	20.8	3.7	18.9
Install a Roundabout (From Stop-Controlled)	70	$$$$$	$$$	10	P	0.54-1.11	4.8	16.8		
Remove or Separate an Existing Railroad Grade Crossing	71	$$$$$			P					

Cost:
$ = $0 to $5,000
$$ = $5,001 to $20,000
$$$ = $20,001 to $50,000
$$$$ = $50,001 to $100,000
$$$$$ = $100,001 and up

NCHRP 500 Performance Rating[26]
P – Proven
T – Tried
E – Experimental
U – Unknown

*Lower Volume ≤1000 vpd
**Higher Volume = Between 1,001 and 8000 vpd

26 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Relocate an Existing Stop Bar on Minor Approach

A minor approach may have an existing stop bar that is located where vehicles stopping at the bar have limited sight distance at the intersection. The stop bar may be relocated closer to the intersection at a point where the stopped vehicle would have better sight distance for approaching traffic.

Where to Use: This treatment may be used at locations where existing sight distance may be obstructed or where sight distance may be significantly improved by moving the stop bar.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Relocate an Existing Stop Bar on Minor Approach	$0 to $5,000	Tried

Top Recommended Resource:

1. FHWA. *NCHRP Report 500 / Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*, "Strategy E4. Provide a Stop Bar (or Provide a Wider Stop Bar) on Minor Road Approaches," July 2003. Available at: http://safety.fhwa.dot.gov/intersection/resources/intsafestratbro/ue4.cfm.

Install Stop Ahead Pavement Markings

Providing pavement markings with supplementary messages (such as Stop Ahead) can help alert drivers on the stop-controlled approach to the presence of an intersection.

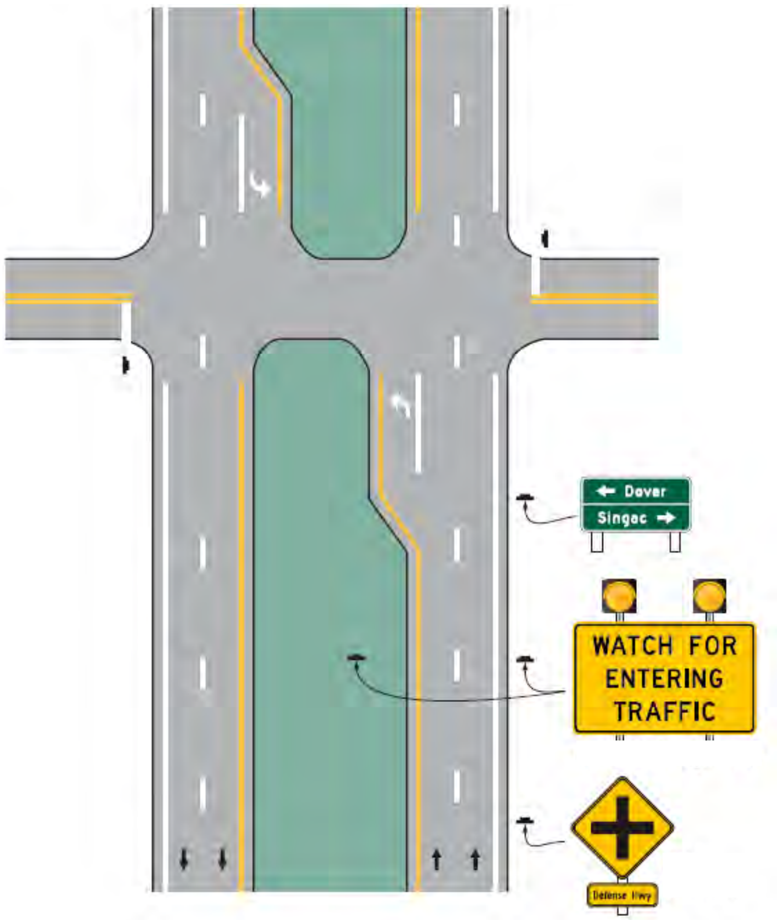
Where to Use: It is likely that Stop Ahead pavement markings will be most effective at locations with a high frequency of target collisions (i.e., right-angle and rear-end), particularly where driver awareness may be an issue.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Stop Ahead Pavement Markings	$0 to $5,000	Proven	0.44–0.69

Top Recommended Resource:

1. FHWA, *Techbrief: Safety Evaluation of STOP AHEAD Pavement Markings*, March 2008. Available at: http://www.fhwa.dot.gov/publications/research/safety/08045/index.cfm.

Install Advanced Intersection Warning Signs



Advanced intersection warning signs can help alert drivers to the presence of an intersection ahead. Signs can be placed with sufficient distance prior to the intersection to allow drivers to perceive and react. They can also be installed on both sides of the roadway to solicit greater awareness.

Where to Use: Advanced intersection warning signs are to be applied predominantly on single through lane, high-crash, stop-controlled State intersections in both rural and urban areas. They may also be applied on dual through lane, high-crash, stop-controlled intersections with lower traffic volumes (less than about 25,000 average annual daily traffic (AADT)) where the use of J-treatments is not appropriate and the frequency of acceptable gaps for entering traffic is such that long waiting and higher risk taking are present at the intersection.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Advanced Intersection Warning Signs	$0 to $5,000	Proven

Top Recommended Resources:

1. FHWA, *Example Intersection Safety Implementation Plan*, 2009.
2. FHWA, *Stop-Controlled Intersection Safety: Through Route Activated Warning Systems*, February 2011. Available at: http://safety.fhwa.dot.gov/intersection/resources/fhwasa11015/traws.pdf.

Provide a Stop Bar on Minor-Road Approaches

Providing visible stop bars on the minor road approach to an unsignalized intersection can help direct the attention of drivers to the presence of the intersection.

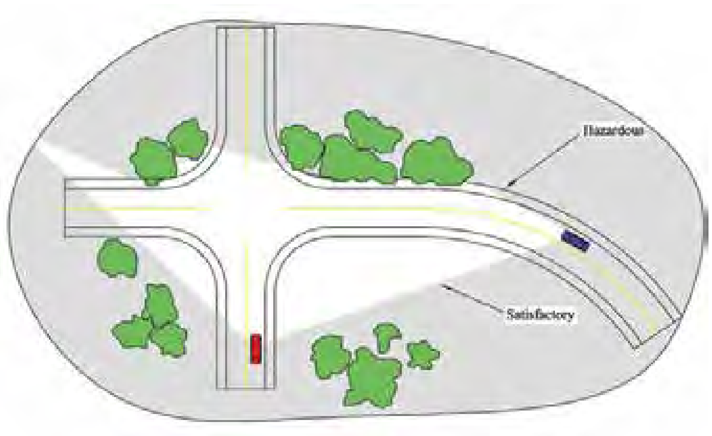
Where to Use: Minor road approaches where conditions allow the stop bar to be seen by an approaching driver at a significant distance from the intersection. Locations should be identified by patterns of crashes related to lack of driver recognition of the intersection.

Provide a Stop Bar on Minor-Road Approaches - **Initial Investment:** $1,000 (4ST), $500 (3ST) - **Cost of Maintenance:** $0 - **Frequency of Maintenance:** 5 years (4 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume 4-Way Intersections	337.7	Proven
Higher Volume 4-Way Intersections	1175.8	Proven
Lower Volume 3-Leg Intersections	287.1	Proven
Higher Volume 3-Leg Intersections	1484.1	Proven

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.

Improve Sight Distance within Sight Triangle



By removing sight distance restrictions (e.g., vegetation, parked vehicles, signs, buildings) from the sight triangles at stop or yield-controlled intersection approaches, drivers will be able see approaching vehicles on the main line without obstruction and therefore make better decisions about entering the intersection safely.

Where to Use: This treatment may be used at unsignalized intersections with restricted sight distance and patterns of crashes related to lack of sight distance where sight distance can be improved by clearing roadside obstructions without major construction.

Improve Sight Distance within Sight Triangle - **Initial Investment:** $4,500 - **Cost of Maintenance:** $1,000 - **Frequency of Maintenance:** 5 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume 4-Way Intersections	157.3	Proven	0.44–0.89
Higher Volume 4-Way Intersections	547.8	Proven	0.44–0.89
Lower Volume 3-Leg Intersections	66.9	Proven	0.44–0.89
Higher Volume 3-Leg Intersections	345.7	Proven	0.44–0.89

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.

Provide Upcoming Road Names on Advanced Warning Signs

At locations where Intersection Ahead warning signs are used, it is recommended that street name plaques be placed underneath the upcoming street sign. These street name plaques provide the driver with additional information about the street so he or she can make an early decision regarding potential turning movements.

Where to Use: This treatment may be used at locations where crashes could potentially be reduced by providing advanced turn information.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Provide Upcoming Road Names on Advanced Warning Signs	$0 to $5,000	Tried	0.90–0.99

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.

Install Retroreflective Strips on Sign Posts

The use of retroreflective strips on sign posts may be beneficial when there is a need to draw additional attention to the signs, especially at night. Reflective strips may be added to Stop signs, curve or intersection warning signs, regulatory or guidance signs, etc.

Where to Use: The MUTCD provides the following guidance for the use of reflective strips on sign posts: "The material must be at least 2 inches wide and must be placed the full length of the post, from the sign to within 2 feet above the horizontal surface into which the sign is fixed. In addition, the color of the material must match the background color of the sign except that the color of the strip for Yield and Do Not Enter signs must be red."

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Retroreflective Strips on Sign Posts	$0 to $5,000	Tried

Top Recommended Resource:

1. FHWA, "Intersection Safety Implementation Plan Workshop," presentation, July 2009. Available at: http://safety.fhwa.dot.gov/intersection/resources/ex_wksp_pres0109/.

Upgrade to Larger Stop Signs

A high number of crashes relate to the driver's inability or failure to see the Stop sign at stop-controlled intersections. To improve recognition of the signs, larger Stop signs can be installed. Sizes can range from 30 inches, to 36 inches, to 48 inches and larger, if needed.

Where to Use: While roadway classification and speed can help determine proper Stop sign size, larger sizes may be used when crash types indicate that Stop sign visibility may be an issue.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Upgrade to Larger Stop Signs	$0 to $5,000	Proven

Top Recommended Resource:

1. FHWA, *Stop Sign-Controlled Intersections: Enhanced Signs and Markings—A Winston-Salem Success Story*, November 2009. Available at: http://safety.fhwa.dot.gov/intersection/resources/casestudies/fhwasa09010/.

Double Use of Stop Signs

Two Stop signs (mounted left and right) can be used to call greater attention to the need for motorists to stop at an intersection. The first Stop sign is installed at the traditional right side location; a second is recommended in the median (if available) of the approach. To accommodate this left-mounted Stop sign, a small mountable curb is suggested. This curb and associated pavement markings provide the motorist with additional information that he or she is entering an intersection.

Where to Use: This treatment may be used at locations where crashes indicate that motorists do not obey existing Stop signs and additional intersection conspicuity is needed.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Double Use of Stop Signs	$0 to $5,000	Tried

Top Recommended Resources:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.
2. FHWA, *Stop Sign-Controlled Intersections: Enhanced Signs and Markings—A Winston-Salem Success Story*, November 2009. Available at: http://safety.fhwa.dot.gov/intersection/resources/casestudies/fhwasa09010/.

Improve Sight Distance and Conspicuity at Railroad Grade Crossings

Where passive warning devices are used at railroad crossings, improvements in vertical alignment or through removing vegetation and other obstructions can help to provide increased sight distance. Conspicuity of the intersection may be helped by providing brighter sign sheeting or upgrading to larger signs.

Where to Use: This treatment is appropriate for use at all railroad grade crossings.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Improve Sight Distance and Conspicuity at Railroad Grade Crossings	$0 to $5,000	Tried

Top Recommended Resource:

1. FHWA, *Railroad-Highway Grade Crossing Handbook*, Revised Second Edition, August 2007. Available at: http://safety.fhwa.dot.gov/xings/com_roaduser/07010/.

Install a Splitter Island

A splitter island separates traffic moving in opposite directions of travel. A splitter island that is installed on the minor approach creates a physical separation between other vehicles that are turning onto the minor road. In addition, the installation of a splitter island allows for a second Stop sign to be mounted in the median to make the intersection more conspicuous.

Where to Use: Splitter islands should be applied to minor road approaches of unsignalized intersections where the presence of the intersection or the Stop sign is not readily visible to approaching motorists. The strategy is particularly appropriate for intersections where the speeds on the minor road are high.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install a Splitter Island	$5,001 to $20,000	Tried

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.

Channelization of Major and Minor Roads (Physical or Painted)

The installation of channelizing separator islands at stop-controlled intersection approaches can accommodate redundancy of the Stop sign and increase driver compliance with the Stop sign.

Where to Use: This practice has greater potential for effectiveness on intersections of high-speed roadways; however, they can also be applied to intersections with lower posted speed limits.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Channelization of Major and Minor Roads (Physical or Painted)	$5,001 to $20,000	Proven

Top Recommended Resource:

1. FHWA, *Summary Report: Two Low-Cost Safety Concepts for Two-Way STOP-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roadways*, December 2008. Available at: http://www.fhwa.dot.gov/publications/research/safety/08063/.

Provide Intersection Lighting

Many intersection crashes during late-night and early-morning hours occur due to drivers being unable to see conflicting traffic, other road users, or—specifically in the case of unsignalized intersections—the presence of the intersection itself. At night in rural areas, the only source of lighting for roadways is often provided by vehicle headlights. Roadway lighting allows for greater visibility of the intersection, making signs and markings more visible and helping drivers determine a safe path through the intersection.

Where to Use: Lighting should be provided at signalized or unsignalized intersections, particularly those with a high instance of dark crashes. Rear-end, right-angle, or turning crashes on the major road approaches to an unsignalized intersection may indicate that approaching drivers are unaware of the presence of the intersection.

Provide Intersection Lighting - **Initial Investment:** $20,000 - **Cost of Maintenance:** $500 - **Frequency of Maintenance:** 1 year	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume 4-Way Intersections	23.1	Proven
Higher Volume 4-Way Intersections	80.6	Proven
Lower Volume 3-Leg Intersections	10.5	Proven
Higher Volume 3-Leg Intersections	54.2	Proven

Top Recommended Resources:

1. FHWA. *NCHRP Report 500 / Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*, "Strategy E2. Improve Visibility of the Intersection by Providing Lighting," July 2003. Available at: http://safety.fhwa.dot.gov/intersection/resources/intsafestratbro/ue2.cfm.
2. Minnesota DOT, *Safety Impacts of Street Lighting at Isolated Rural Intersections—Part II*, September 2006. Available at: http://www.intrans.iastate.edu/reports/rural_lighting_FINAL.pdf.

Install Dynamic Advanced Intersection Warning System

Infrastructure-based Intelligent Transportation System (ITS) technologies can be used to significantly improve the safety at stop-controlled intersections. These systems provide enhanced safety warning information for approaching drivers compared to passive warning systems. A dynamic advanced intersection warning system can provide:

- Enhanced warning to the through driver that there is a vehicle on a cross road stop approach that may enter the intersection.
- Enhanced warning to drivers on a stop approach that their trajectory speed is high and that they may run the Stop sign.
- Enhanced warning to through drivers that they are traveling at too high an intersection entry speed and advising them to slow down.
- Enhanced warning to drivers on the stop approach of entering vehicles on the through approach, inferring potential unsafe gaps.

Where to Use: This treatment may be provided at intersections that experience severe intersection-related crashes due to speed, low visibility, or insufficient gaps.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Dynamic Advanced Intersection Warning System	$5,001 to $20,000	Proven	0.10–0.76

Top Recommended Resource:

1. FHWA, *Stop-Controlled Intersection Safety: Through Route Activated Warning Systems*, February 2011. Available at: http://safety.fhwa.dot.gov/intersection/resources/fhwasa11015/traws.pdf.

Upgrade Existing Railroad Crossing Hardware and Warning Systems

The installation of enhanced railroad crossing hardware and warning systems not only notifies motorists as to the presence of an approaching train but can limit their ability to proceed through the intersection through the use of gates and other devices.

Where to Use: This treatment is applicable where additional notification and/or the ability to limit drivers from proceeding through the crossing is needed.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Upgrade Existing Railroad Crossing Hardware and Warning Systems	$5,001 to $50,000	Proven	0.55

Top Recommended Resource:

1. FHWA, *Railroad-Highway Grade Crossing Handbook*, Revised Second Edition, August 2007. Available at: http://safety.fhwa.dot.gov/xings/com_roaduser/07010/.

Implement Lane Narrowing through Rumble Strips and Painted Median at Rural Stop-Controlled Approaches

Lane narrowing features the introduction of rumble strips on the outside shoulders and in a painted yellow median island on the major road approaches. The objective of lane narrowing is to induce drivers on major roads to reduce approach speeds at intersections by effectively reducing the lane width.

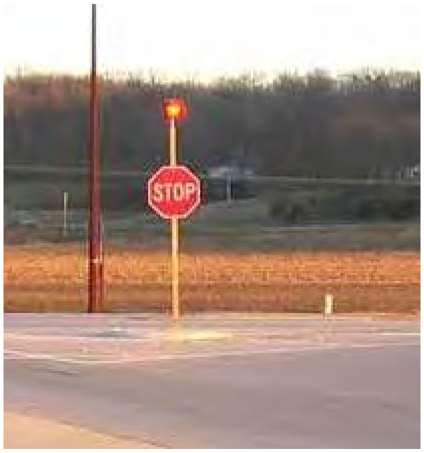
Where to Use: This practice has greater potential for effectiveness for intersections on high-speed roadways. However, the treatment can also be applied to intersections with lower posted speed limits.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Implement Lane Narrowing through Rumble Strips and Painted Median at Rural Stop-Controlled Approaches	$5,001 to $50,000	Tried	0.60–0.80

Top Recommended Resource:

1. FHWA, *Railroad-Highway Grade Crossing Handbook*, Revised Second Edition, August 2007. Available at: http://safety.fhwa.dot.gov/xings/com_roaduser/07010/.

Provide Flashing Beacons at Intersection Approaches



Flashing beacons provide a visible signal indicating the presence of an intersection and can be very effective in rural areas where there may be long stretches between intersections. They may also improve safety at locations where nighttime visibility of intersections is an issue.

Where to Use: Flashing beacons can be installed at unsignalized intersections with patterns of right-angle crashes related to lack of driver awareness of the intersection on an uncontrolled approach and lack of driver awareness of the Stop sign on a stop-controlled approach. The beacons can be installed either atop Stop signs or Advance Intersection Warning Signs, where applicable.

Provide Flashing Beacons at Intersection Approaches - **Initial Investment:** $25,000 - **Cost of Maintenance:** $1,000 - **Frequency of Maintenance:** 2 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume 4-Way Intersections	16.3	Proven	0.85
Higher Volume 4-Way Intersections	56.8	Proven	0.85
Lower Volume 3-Leg Intersections	6.8	Proven	0.85
Higher Volume 3-Leg Intersections	35.8	Proven	0.85

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, "Chapter 4. Countermeasures," January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/ch4.cfm.

Convert Minor Road Stop Control to All-Way Stop Control

At locations where there is a pattern of high-severity frontal impact crashes, all-way stop control can be implemented quickly by installing Stop signs on the unrestricted approach. It is important to ensure adequate sight distance for all stop conditions and to consult the MUTCD for proper installation guidelines.

Where to Use: This treatment can be installed at locations where there is a pattern of high severity frontal impact crashes.

Convert Minor Road Stop Control to All-Way Stop Control - **Initial Investment:** $30,000 - **Cost of Maintenance:** $5,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume 4-Way Intersections	77.2	Proven	0.30
Higher Volume 4-Way Intersections	268.8	Proven	0.30
Lower Volume 3-Leg Intersections	32.8	Proven	0.30
Higher Volume 3-Leg Intersections	169.7	Proven	0.30

Top Recommended Resource:

1. FHWA. *NCHRP Report 500 / Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*, "Strategy F2. Provide All-Way Stop Control at Appropriate Intersections," July 2003. Available at: http://safety.fhwa.dot.gov/intersection/resources/intsafestratbro/uf2.cfm.

Convert a Traditional Stop-Controlled Intersection into a J-Turn Intersection

The J-turn intersection is characterized by the prohibition of left turn and through movements from side street approaches as permitted in conventional designs. The J-turn intersection accommodates these movements by requiring drivers to turn right onto the main road and then make a U-turn maneuver at a one-way median opening 400 to 1,000 feet after the intersection. Left turns from the main road approaches are executed in a manner similar to left turns at conventional intersections and are unchanged in this design. Left turn movements from the major road could also be removed at primarily rural unsignalized J-turn designs.

Where to Use: J-turn intersections are typically implemented as part of a corridor treatment; however, they can be used at isolated intersections. Unsignalized J-turn intersections preserve corridor capacity and can be installed without the adverse effects of signal control. Scenarios where J-turn intersections are most applicable include the following:

- Relatively low to medium side-street through volumes and heavy left turn volumes from the major road.
- The minor road total volume to total intersection volume ratio is typically less than or equal to 0.20.
- Areas where median widths are greater than 40 feet. For narrower medians, loons or bulb-outs on the shoulders need to be constructed.

For intersections with very high left turn and through volumes from the side road approaches, the J-turn intersection design is not the optimum choice.

Convert a Traditional Stop-Controlled Intersection into a J-Turn Intersection - **Initial Investment:** $50,000-$100,000 - **Cost of Maintenance:** $5,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume 4-Way Intersections	46.1	Proven	0.0–0.91
Higher Volume 4-Way Intersections	161.4	Proven	0.0–0.91
Lower Volume 3-Leg Intersections	n/a	Proven	0.0–0.91
Higher Volume 3-Leg Intersections	n/a	Proven	0.0–0.91

Top Recommended Resource:

1. FHWA, *Restricted Crossing U-Turn Intersection*, October 2009. Available at: http://www.fhwa.dot.gov/publications/research/safety/09059/09059.pdf.

Use Raised Median to Restrict Turning Movements

Raised medians can be helpful in limiting access and restricting turning movements within the functional limits of intersections, thereby reducing conflicts between through traffic and turning vehicles.

Where to Use: This treatment may be used at locations where access to streets, businesses, homes, and other properties falls within the intersection functional area.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Use Raised Median to Restrict Turning Movements	$20,001 to $100,000	Proven

Top Recommended Resource:

1. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Install Acceleration or Deceleration Lanes

Drivers turning onto an uncongested highway generally accelerate until they approach the desired open-road speed. When the entering traffic accelerates within the traveled way, it has the potential to disrupt the flow of through traffic. To minimize this operational problem due to right or left turning traffic at divided highway intersections, acceleration lanes may be used.

An acceleration lane is an auxiliary or speed-change lane that allows vehicles to accelerate to highway speeds before entering the through traffic lanes of a highway. Acceleration lanes should be of sufficient length to permit adjustments in speeds of both through and entering vehicles so that the driver of the entering vehicle can maneuver into that gap before reaching the end of the acceleration lane. Additionally, the purpose of a parallel deceleration lane is to provide drivers exiting or turning from the road with an opportunity to slow down to a more reasonable speed prior to turning.

Where to Use: This treatment may be used at unsignalized intersections on divided highways that experience a high proportion of rear-end crashes related to the speed differential caused by vehicles turning left or right onto or from the highway. They may also be used where intersection sight distance is inadequate or where there are high volumes of trucks or recreational vehicles entering or exiting the divided highway.

Acceleration or deceleration lanes can be added as median acceleration or deceleration lanes—as installed at several locations in Missouri—or as lanes next to the shoulder for vehicles entering or exiting the roadway on the right side—as installed in Kentucky.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Acceleration or Deceleration Lanes	\$20,001 to \$100,000	Proven

Top Recommended Resources:

1. FHWA, *NCHRP Report 500 / Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*, "Strategy B9. Provide Right-Turn Acceleration Lanes at Intersections," 2003. Available at: http://safety.fhwa.dot.gov/intersection/resources/intsafestratbro/ub9.cfm
2. FHWA, *NCHRP Report 500 / Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*, "Strategy B5. Provide Left-Turn Acceleration Lanes at Intersections," 2003. Available at: http://safety.fhwa.dot.gov/intersection/resources/intsafestratbro/ub9.cfm

Install Railroad Crossing Hardware and Warning Systems Where They Currently Do Not Exist

By installing railroad crossing hardware and warning devices, motorists are notified as to the presence of an approaching train and can make an informed decision whether to cross.

Where to Use: This treatment may be applied where railroad crossings exist with no form of warning device.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Railroad Crossing Hardware and Warning Systems Where They Currently Do Not Exist	$20,001 to $100,000	Proven	0.75

Top Recommended Resource:

1. FHWA, *Railroad-Highway Grade Crossing Handbook*, Revised Second Edition, August 2007. Available at: http://safety.fhwa.dot.gov/xings/com_roaduser/07010/.

Convert a 4-Leg Intersection into Two 3-Leg Intersections (Offset T-Intersections)

For some 4-leg intersections with very low through volumes on the cross street, one method of improving safety may be to convert the intersection to two T-intersections. This conversion can be accomplished by realigning the two cross-street approaches an appreciable distance along the major road, thus creating separate intersections that operate relatively independently of one another.

Where to Use: This improvement may be applicable to 4-leg intersections with very low through volumes on the cross street, yet with a relatively high number of unusually severe collisions.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Convert a 4-Leg Intersection into Two 3-Leg Intersections (Offset T-Intersections)	$50,001 to $100,000	Proven	0.70

Top Recommended Resource:

1. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Install Bypass Lane

Installation of this treatment is accomplished by adding bypass lanes using the shoulder at intersections. The bypass lanes are intended for vehicles to continue through the intersection without having to stop for traffic making left turns.

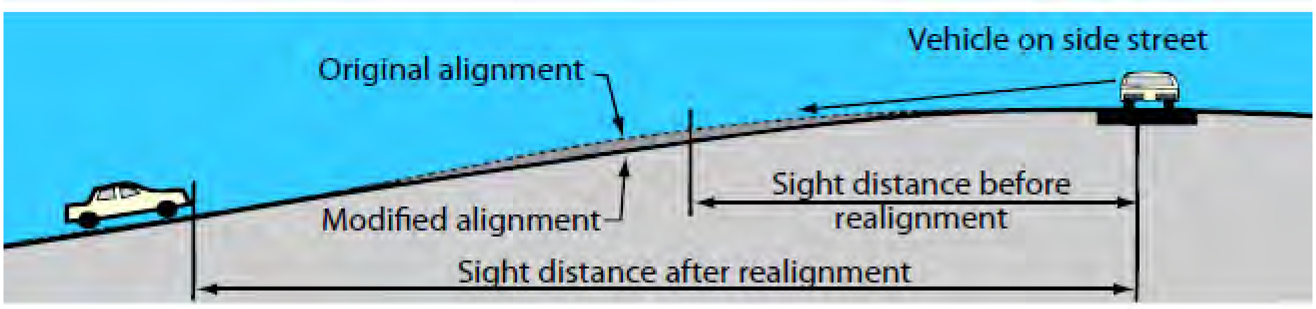
Where to Use: Bypass lanes should be used at 3-leg intersections on two-lane highways with moderate through and turning volumes, especially intersections that have rear-end collisions involving vehicles waiting to turn left from the mainline.

Install Bypass Lane - **Initial Investment:** \$75,000 - **Cost of Maintenance:** \$20,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume 4-Way Intersections	11.6	Proven
Higher Volume 4-Way Intersections	40.6	Proven
Lower Volume 3-Leg Intersections	5.0	Proven
Higher Volume 3-Leg Intersections	25.6	Proven

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.

Modify Horizontal and/or Vertical Geometry



Although changing alignment is a high-cost treatment, in some cases sight distance is restricted by horizontal and vertical curvature. Straightening a roadway will increase sight distance and allow for better visibility of other vehicles and the intersection itself.

Where to Use: This treatment may be used at unsignalized intersections with restricted sight distance due to horizontal and/or vertical geometry and with patterns of crashes related to that lack of sight distance that cannot be ameliorated by less expensive methods.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Modify Horizontal and/or Vertical Geometry	$100,001 and up	Proven

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.

Improve Horizontal Intersection Alignment or Skew

Reducing or eliminating the skew at intersection approaches helps address problems like vehicle alignment, long exposure in the intersection, and potential driver confusion. Intersection skew treatments include pavement markings, channelizing islands, and realignment.

Where to Use: This treatment may be used at unsignalized intersections with a high frequency of crashes resulting from insufficient intersection sight distance and awkward sight lines at a skewed intersection.

Improve Horizontal Intersection Alignment or Skew - **Initial Investment:** $300,000 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** n/a	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume Optimal Conditions	1.0	Proven
Higher Volume Optimal Conditions	7.9	Proven

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.

Install Traffic Signals

Traffic signals help to assign right-of-way to traffic movements and have been shown to reduce the severity of total collisions experienced at intersections. The MUTCD lists eight warrants for the placement of traffic signals, which should be reviewed as installation of this treatment is considered. The safety benefit of signalizing an unsignalized intersection is a function of the crash history by crash type, the traffic entering the intersection on the major and minor approaches, and whether the intersection is a 3-leg T-intersection or a conventional 4-leg intersection.

Where to Use: Traffic signals can be installed at intersections that experience a high frequency of right-angle collisions with adequate sight distance to that intersection from all approaches. Signalization may be particularly effective where the ratio of right-angle to rear-end crashes is high.

Install Traffic Signals - **Initial Investment:** $150,000 - **Cost of Maintenance:** $8,000 - **Frequency of Maintenance:** 1 year	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume 4-Way Intersections	15.4	Proven	0.23–1.58
Higher Volume 4-Way Intersections	53.8	Proven	0.23–1.58
Lower Volume 3-Leg Intersections	6.9	Proven	0.23–1.58
Higher Volume 3-Leg Intersections	35.5	Proven	0.23–1.58

Top Recommended Resource:

1. AASHTO, *NCHRP Report 617: Accident Modification Factors for Traffic Engineering and ITS Improvements*, July 2008. Available at: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_617.pdf.

Install Right Turn Lane

Providing a right turn lane at an intersection can reduce rear-end crashes by allowing vehicles to proceed through the intersection without having to stop or slow down for vehicles making a right turn. Assuming turn lanes are of adequate length, vehicles will not be stopped in the travel lanes; this allows for through traffic to continue without stopping for vehicles turning at an intersection.

Where to Use: Right turn lanes should be constructed at unsignalized intersections with a high frequency of rear-end crashes resulting from conflicts between (1) vehicles turning right and following vehicles, and (2) vehicles turning right and through vehicles coming from the left on the cross street.

Install Right Turn Lane - **Initial Investment:** $400,000 - **Cost of Maintenance:** $20,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume 4-Way Intersections	16.0	Proven
Higher Volume 4-Way Intersections	55.9	Proven
Lower Volume 3-Leg Intersections	6.8	Proven
Higher Volume 3-Leg Intersections	35.3	Proven

Top Recommended Resources:

1. FHWA, *Techbrief: Safety Effectiveness of Intersection Left- and Right-Turn Lanes*, 2002. Available at: http://www.fhwa.dot.gov/publications/research/safety/02103/02103techbrief.pdf
2. FHWA, *Safety Effectiveness of Intersection Left- and Right-Turn Lanes*, July 2002. Available at: http://www.fhwa.dot.gov/publications/research/safety/02089/02089.pdf.

Install Left Turn Lane

Left turn lanes are auxiliary lanes for storage or to accommodate the decreasing speed of left turning vehicles as they approach the intersection speed change of left turning vehicles. Installing left turn lanes at an intersection can reduce rear-end crashes by allowing vehicles to proceed through the intersection without having to stop or slow down for vehicles waiting to make a left turn.

Where to Use: The AASHTO Green Book recommends that left turning traffic be removed from the through lanes whenever practical, and that left turn lanes should be provided at street intersections along major arterials and collector roads wherever left turns are permitted. Consideration of left turn lanes has traditionally been based on such factors as the number of through lanes, speeds, left turn volumes, opposing through volumes, and/or left turning crashes.

Intersections with a high frequency of crashes resulting from the conflicts between (1) vehicles turning left and following vehicles, and (2) vehicles turning left and opposing through vehicles are also candidates for the installation of left turn lanes.

Practitioners should consider installing left turn lanes for the major road approaches to improve safety at 3- and 4-leg intersections with two-way stop control on the minor road at locations where significant turning volumes exist or where there is a history of turn-related crashes.

Install Left Turn Lane **- Initial Investment:** $400,000 **- Cost of Maintenance:** $20,000 **- Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume 4-Way Intersections	6.0	Proven
Higher Volume 4-Way Intersections	20.8	Proven
Lower Volume 3-Leg Intersections	3.7	Proven
Higher Volume 3-Leg Intersections	18.9	Proven

Top Recommended Resource:

1. AASHTO, *NCHRP Report 617: Accident Modification Factors for Traffic Engineering and ITS Improvements*, July 2008. Available at: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_617.pdf.

Install Offset (or Channelized) Left Turn Lane

Offset left turn lanes provide the left turning motorist a line of sight to opposing through vehicles. Instead of attempting to look around opposing left turning vehicles, the motorist can clearly see oncoming traffic.

Where to Use: Offset left turn lanes should be used at unsignalized 4-leg intersections with a high frequency of crashes between vehicles turning left and opposing through vehicles. This treatment can be applied at intersections on divided highways with medians wide enough to provide the appropriate positive offset, and also on approaches without medians if sufficient width exists.

Install Offset (or Channelized) Left Turn Lane - **Initial Investment:** $400,000 - **Cost of Maintenance:** $20,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume 4-Way Intersections	6.0	Proven
Higher Volume 4-Way Intersections	20.8	Proven
Lower Volume 3-Leg Intersections	3.7	Proven
Higher Volume 3-Leg Intersections	18.9	Proven

Top Recommended Resource:

1. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Install a Roundabout (From Stop-Controlled)

The modern roundabout is a type of circular intersection defined by the basic operational principle that entering traffic yields to vehicles on the circulatory roadway. Key design principles achieve deflection of entering traffic by channelization at the entrance and deflection around a center island. Roundabout intersections eliminate a number of vehicle conflict points typically associated with traditional intersections. A 4-leg, single-lane roundabout has 75 percent fewer vehicle conflict points than a traditional stop-controlled intersection. Roundabouts also enhance safety by reducing vehicle speeds both in and through the intersection and by changing the crash type from angle to sideswipe, which typically results in less severe crashes.

Where to Use: Roundabouts are the preferred safety alternative for a wide range of intersections. Although they may not be appropriate in all circumstances, they may be considered as an alternative for all proposed new intersections on federally funded highway projects. Roundabouts should also be considered for all existing intersections that have been identified as needing major safety or operational improvements. This would include freeway interchange ramp terminals and rural intersections.

Install a Roundabout (From Stop-Controlled) - **Initial Investment:** $400,000 - **Cost of Maintenance:** $40,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume 4-Way Intersections	4.8	Proven	0.54–1.11
Higher Volume 4-Way Intersections	16.8	Proven	0.54–1.11
Lower Volume 3-Leg Intersections	n/a	Proven	0.54–1.11
Higher Volume 3-Leg Intersections	n/a	Proven	0.54–1.11

Top Recommended Resources:

1. FHWA, "Guidance Memorandum on Consideration and Implementation of Proven Safety Countermeasures," July 2010. Available at: http://safety.fhwa.dot.gov/policy/memo071008/.
2. FHWA, *Intersection Safety Case Study: Minnesota Roundabout—A Scott County Success Story*, February 2010. Available at: http://safety.fhwa.dot.gov/intersection/resources/casestudies/fhwasa09013/.

Remove or Separate an Existing Railroad Grade Crossing

Conflicts between road users and trains can be reduced by completely eliminating a crossing or separating it from vehicular traffic. This will likely divert traffic to another grade crossing, whether it is a grade-separated structure or another at-grade intersection.

Where to Use: This treatment may be applicable where a high frequency of severe vehicle-rail crashes occur and at locations where more suitable alternative crossings are available.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Remove or Separate an Existing Railroad Grade Crossing	$100,001 and up	Proven

Top Recommended Resource:

1. FHWA, *Railroad-Highway Grade Crossing Handbook - Revised Second Edition*, 2007. Available at: http://safety.fhwa.dot.gov/xings/com_roaduser/07010/

4.4. Non-motorized User

Non-motorized users generally consist of cyclists and pedestrians but also include equestrian, horse-drawn buggies, in-line skaters, and other methods. Their needs must be addressed due to increased risks they encounter on rural roads. Rural pedestrian crashes are nearly twice as likely to result in a fatality and rural bicycle crashes are three times as likely to result in a fatality compared to urban crashes.[27] Risky riding and walking behaviors may indicate that the transportation infrastructure does not adequately address the safety and mobility needs of non-motorized users.

		COST			SAFETY BENEFIT		BENEFIT-COST RATIO[28]			
SAFETY TREATMENT	For more information, visit page	Initial Implementation	Ongoing Maintenance	Frequency of Maintenance (years)	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrow Conditions****	Higher Volume**, Narrow Conditions****
Provide Crosswalks at Targeted Locations	73	$			P & T					
Install Pedestrian Signal Heads to Existing Signalized Intersections	74	$$			P					
Construct Wildlife Fencing	75	$$			T					
Install Rectangular Rapid Flash Beacons (RRFBs)	76	$$			P					
Build Sidewalks	77	$$-$$$			P					
Construct Adjacent Shared-Use Paths	78	$$-$$$			P					
Construct Shared-Use Paved Shoulders for Horse & Buggy Road Users or Bicyclists	79	$$-$$$			T					
Construct Exclusive Bicycle Lanes	80	$$-$$$			T					
Install Curb Extensions	81	$$$			T					
Install or Modify Culverts to Accommodate Wildlife Crossing	82	$$$-$$$$			T					
Install Pedestrian Hybrid Beacons or High intensity Activated Crosswalks (HAWK)	83	$$$-$$$$			P	0.712				
Construct Bicycle Trail Grade Separation Structures	84	$$$$$			P					

Cost:
$ = $0 to $5,000
$$ = $5,001 to $20,000
$$$ = $20,001 to $50,000
$$$$ = $50,001 to $100,000
$$$$$ = $100,001 and up

NCHRP 500 Performance Rating[29]
P – Proven
T – Tried
E – Experimental
U – Unknown

*Lower Volume ≤1000 vpd
**Higher Volume = Between 1,001 and 8000 vpd
***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders
****Narrower Conditions = 10-foot lanes and no shoulders

27 UNC Highway Safety Research Center, *Factors Contributing to Pedestrian and Bicycle Crashes on Rural Highways – Final Report*, http://www.hsisinfo.org/pdf/HSIS-Rural-PedBike-Final-Report.pdf

28 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, the BCR has been left blank.

29 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Provide Crosswalks at Targeted Locations

Crosswalks help call attention to pedestrians crossing a road and provide a defined location in which to do so.

Where to use: Marked pedestrian crosswalks may be used to delineate preferred pedestrian paths across roadways under the following conditions:

- At locations with stop signs or traffic signals to direct pedestrians to those crossing locations and to prevent vehicular traffic from blocking the pedestrian path when stopping for a stop sign or red light.
- At nonsignalized street crossing locations in designated school zones. Use of adult crossing guards, school signs and markings, and/or traffic signals with pedestrian signals (when warranted) should be considered in conjunction with the marked crosswalk, as needed.
- At nonsignalized locations where engineering judgment dictates that the number of motor vehicle lanes, pedestrian exposure, average daily traffic (ADT), posted speed limit, and geometry of the location would make the use of specially designated crosswalks desirable for traffic/pedestrian safety and mobility.

Marked crosswalks alone (i.e., without traffic-calming treatments, traffic signals and pedestrian signals when warranted, or other substantial crossing improvement) are insufficient and should not be used under the following conditions:

- Where the speed limit exceeds 64.4 km/h (40 mi/h).
- On a roadway with four or more lanes without a raised median or crossing island that has (or will soon have) an ADT of 12,000 or greater.
- On a roadway with four or more lanes with a raised median or crossing island that has (or soon will have) an ADT of 15,000 or greater.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Provide Crosswalks at Targeted Locations	$0 to $5,000	Proven & Tried

Top Recommended Resource:

1. FHWA, *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines*, September 2005. Available at: http://www.fhwa.dot.gov/publications/research/safety/04100/04.cfm.

Install Pedestrian Signal Heads to Existing Signalized Intersections

Pedestrian signal heads provide special types of traffic signal indications exclusively intended for controlling pedestrian traffic. These signal indications consist of the illuminated symbols of a walking person (symbolizing Walk) and an upraised hand (symbolizing Don't Walk).

Where to Use: This treatment is applicable where pedestrian traffic exists at signalized intersections.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Pedestrian Signal Heads to Existing Signalized Intersections	$5,001 to $20,000	Proven

Top Recommended Resources:

1. FHWA, *Manual on Uniform Traffic Control Devices*, "Chapter 4E. Pedestrian Control Features," December 2009. Available at: http://mutcd.fhwa.dot.gov/pdfs/2009r1r2/mutcd2009r1r2edition.pdf.
2. FHWA, *Signalized Intersections Informational Guide*, July 2013. Available at: http://safety.fhwa.dot.gov/intersection/signalized/13027/index.cfm.

Construct Wildlife Fencing

Wildlife fences help to prevent livestock and wildlife from straying onto highways.

Where to Use: Wildlife fence may be constructed along the right-of-way at locations with expansive open plains, paths that are known to be a crossing area, or locations that experience a moderately high frequency of crashes involving wildlife. Several States give guidance on how and where to properly construct wildlife fencing.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Construct Wildlife Fencing	$5,001 to $20,000	Tried

Install Rectangular Rapid Flash Beacons

Rectangular Rapid Flash Beacons (RRFBs) are user-actuated amber Light Emitting Diodes (LEDs) that supplement warning signs at unsignalized intersections or mid-block crosswalks. They can be activated by pedestrians manually by a push button or passively by a pedestrian detection system. RRFBs can enhance safety by reducing crashes between vehicles and pedestrians at unsignalized intersections and mid-block pedestrian crossings by increasing driver awareness of potential pedestrian conflicts. RRFBs are also referred to as LED Rapid-Flash System, Stutter Flash or LED Beacons.

Where to use: RRFBs may be installed on either two-lane or multi-lane roadways at unsignlized intersections and mid-block pedestrian crossings.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Rectangular Rapid Flash Beacons	$5,001 to $20,000	Proven

Top Recommended Resource:

1. FHWA, "Rectangular Rapid Flash Beacons (RRFB)," May 2009. Available at: http://safety.fhwa.dot.gov/intersection/resources/techsum/fhwasa09009/fhwasa09009.pdf.

Build Sidewalks

Providing sidewalks and associated accommodations for pedestrians along heavily traveled corridors gives refuge for pedestrians and helps to enhance roadway operations, mobility, and safety. This treatment is especially useful at locations with heavy pedestrian volumes, such as business districts, schools, and community centers.

Where to Use: This treatment should be considered when heavy pedestrian volumes exist along a corridor or specific location, impacting the safety of all road users.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Build Sidewalks	$5,001 to $50,000	Proven

Construct Adjacent Shared-Use Paths

A shared-use path serves as part of a transportation circulation system and supports multiple recreation opportunities, such as walking, bicycling, and in-line skating. A shared-use path typically has a surface that is asphalt, concrete, or firmly packed crushed aggregate. The 2012 AASHTO Guide for the Development of Bicycle Facilities defines a shared-use path as being physically separated from motor vehicular traffic with an open space or barrier. Shared-use paths should always be designed to include pedestrians even if the primary anticipated users are bicyclists.

Where to Use: This treatment can be used when a high volume of non-motorized traffic exists along a corridor, such as along designated hiking trails or known bicycle routes.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Construct Adjacent Shared-Use Paths	$5,001 to $50,000	Proven

Top Recommended Resources:

1. FHWA, *Designing Sidewalks and Trails for Access, Part I of II: Review of Existing Guidelines and Practices*, July 1999. Available at: http://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/sidewalks/.
2. FHWA, *Designing Sidewalks and Trails for Access, Part II of II: Best Practices Design Guide*, September 2001. Available at: http://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/sidewalk2/pdf.cfm.
3. AASHTO, *Guide for the Development of Bicycle Facilities, 4th Edition*, June 2012.

Construct Shared-Use Paved Shoulders for Horse & Buggy Road Users or Bicyclists

HRRR located near communities where horse and buggies are used in conjunction with motorized transportation may experience abrupt disruptions in traffic flow as faster moving vehicles overtake slower traffic; the same is true for HRRR that are known bicycle routes. Providing a paved shoulder adjacent to the travel way with sufficient width to accommodate alternate modes of transportation can help separate slower moving traffic from the travel lane.

Where to Use: This treatment may be used at locations where slower moving traffic is known to exist frequently, such as bicycle routes and locations with horse and buggy users, and that experience a high frequency of crashes associated with the alternate modes of traffic coming in contact with motorized traffic.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Construct Shared-Use Paved Shoulders for Horse & Buggy Road Users or Bicyclists	$5,001 to $50,000	Tried

Top Recommended Resources:

1. FHWA, *Non-Motorized User Safety: A Manual for Local Rural Road Owners*, November 2012. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa010413/nonmotorize.pdf.
2. AASHTO, *Guide for the Development of Bicycle Facilities, 4th Edition*, June 2012.

Construct Exclusive Bicycle Lanes

Bike lanes are defined as a portion of the roadway that has been designated by striping, signing, and pavement marking for the preferential or exclusive use by bicyclists. Bicycle lanes make the movements of both motorists and bicyclists more predictable and, as with other bicycle facilities, there are advantages to all road users in striping them on the roadway.

Where to Use: This treatment can be used when a high volume of bicycle traffic exists along a corridor, such as known State- or nation-wide bicycle routes.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Construct Exclusive Bicycle Lanes	$5,001 to $50,000	Tried

Top Recommended Resources:

1. FHWA, Pedestrian and Bicycle Information Center, “Bike Lanes.” Available at: http://www.bicyclinginfo.org/engineering/facilities-bikelanes.cfm.
2. FHWA, *Bicycle Facilities and the Manual on Uniform Traffic Control Devices*, February 28, 2014. Available at: http://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/design_guidance/mutcd_bike.cfm.

Install Curb Extensions

Curb extensions extend the sidewalk or curb line out into the parking lane, which reduces the effective street width. Curb extensions significantly improve pedestrian crossings by reducing the pedestrian crossing distance, improving the ability of pedestrians and motorists to see each other, and reducing the time that pedestrians are in the street.

Where to Use: Curb extensions should typically be used where there is a parking lane and where transit and cyclists will be traveling outside the curb edge for the length of the street.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Curb Extensions	$20,001 to $50,000	Tried

Install or Modify Culverts to Accommodate Wildlife Crossing

A mix of underpasses, bridge extensions, culvert installations, and culvert modifications can be used to facilitate wildlife movement and reduce collisions on HRRR associated with wildlife.

Where to Use: Culverts may be used to accommodate wildlife crossings at locations with expansive open plains, paths that are known to be a crossing area, or locations that experience a moderately high frequency of crashes involving wildlife. Several States provide guidance on how and where to properly construct wildlife fencing.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install or Modify Culverts to Accommodate Wildlife Crossing	$20,001 to $100,000	Tried

Install Pedestrian Hybrid Beacons or High Intensity Activated Crosswalk (HAWK)

The HAWK is a pedestrian activated beacon located on the roadside and on mast arms over major approaches to an intersection. The HAWK signal head consists of two red lenses over a single yellow lens. It displays a red indication to drivers when activated, which creates a gap for pedestrians to cross a major roadway. The HAWK is not illuminated until it is activated by a pedestrian, triggering the warning flashing yellow lens on the major street. After a set amount of time, the indication changes to a solid yellow light to inform drivers to prepare to stop. The beacon then displays a dual solid red light to drivers on the major street and a walking person symbol to pedestrians. At the conclusion of the walk phase, the beacon displays an alternating flashing red light to drivers, and pedestrians are shown an upraised hand symbol with a countdown display informing them of the time left to cross.

Where to use: This treatment may be used at locations with a high number of pedestrian crashes where additional visibility of pedestrian crossings is needed.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Pedestrian Hybrid Beacons or High Intensity Activated Crosswalk (HAWK)	\$20,001 to \$100,000	Proven	0.712

Top Recommended Resource:

1. FHWA, *Safety Effectiveness of the HAWK Pedestrian Crossing Treatment*, July 2010. Available at: http://www.fhwa.dot.gov/publications/research/safety/10042/index.cfm.

Construct Bicycle Trail Grade Separation Structures

This treatment can be an elevated or subterranean structure that minimizes or eliminates conflicts with motorized vehicles. Bicycle trail grade-separated structures allow for passage over otherwise un-navigable or difficultly-traversed locations such as waterways, rail, limited access freeways, or high-volume intersections.

Where to Use: This treatment can be used at locations where safe passage of bicycles is difficult due to terrain, traffic volume, or geographic obstacles.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Construct Bicycle Trail Grade Separation Structures	$100,001 and up	Proven

4.5. Pavement and Shoulder Resurfacing

Pavement and shoulder resurfacing and widening infrastructure safety treatments may improve a vehicle's ability to remain on the roadway. This occurs by increasing the paved area for use by a vehicle, providing warning when a vehicle is leaving the driving lane, or improving the friction to reduce hydroplaning and loss of vehicle control.

SAFETY TREATMENT	For more information, visit page	COST			SAFETY BENEFIT		BENEFIT-COST RATIO[30]			
		Initial Implementation	Ongoing Maintenance	Frequency of Maintenance (years)	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Install a Safety Edge	86	$	–	20	P	0.85-0.92	33.4	267.2	40.9	403.2
Install Center Line Rumble Strips	87	$	–	10	P	0.75-0.85	21.3	170.6	26.1	257.5
Install Edge Line or Shoulder Rumble Strips	88	$	–	10	P	0.78-0.90	58.6	469.0	71.8	707.7
Install Transverse Rumble Strips	89	$			P	0.76-0.91				
Regrade or Recondition Gravel Lanes	90	$-$$			T					
Install Targeted Longitudinal Rumble Strips at Key Locations (Such as on the Outside of Horizontal Curves Only)	91	$$-$$$			T	0.85				
Install or Maintain a Graded Shoulder	92	$$-$$$			P	0.52				
Provide Turnout Areas	93	$$-$$$			T					
Improve Pavement Friction/Increase Skid Resistance	94	$$$$	–	10	P	0.25-0.60	3.3	26.7	4.1	40.3
Add Paved Shoulder	95	$$$$$	$$	2	P	0.86	n/a	n/a	0.5	4.5
Widen Existing Travel Lanes by Two Feet or Less per Lane	96	$$$$$	$$$	10	P	0.95	n/a	n/a	0.3	2.8
Install Passing or Climbing Lanes	97	$$$$$	$$$	10	P		0.3	2.3	0.4	3.5
Increase Shoulder Width	98	$$$$$			P	0.90-0.97				
Improve Superelevation at Horizontal Curve Locations	99	$$$$$			P					

Cost:
$ = $0 to $5,000
$$ = $5,001 to $20,000
$$$ = $20,001 to $50,000
$$$$ = $50,001 to $100,000
$$$$$ = $100,001 and up

NCHRP 500 Performance Rating[31]
P – Proven
T – Tried
E – Experimental
U – Unknown

*Lower Volume ≤1000 vpd
**Higher Volume = Between 1,001 and 8000 vpd
***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders
****Narrower Conditions = 10-foot lanes and no shoulders

30 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, the BCR has been left blank.

31 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Install a Safety Edge

When a vehicle leaves the traveled way and encounters a pavement-shoulder drop-off, it can be difficult for the driver to return safely to the roadway. A safety edge is a treatment intended to minimize drop-off-related crashes. With this treatment, the pavement edge is sloped at an angle (30-35 degrees) to make it easier for a driver to safely reenter the roadway after inadvertently driving onto the shoulder. This treatment is designed to be a standard policy for any overlay project.

Where to Use: Each State should implement policies and procedures to incorporate the Safety Edge where pavement and non-pavement surfaces interface on all paving and resurfacing projects with surface differentials of 2.5 inches or more. The differentials should be measured from the pavement surface to the adjacent non-pavement surface, accounting for grading along the pavement edge during construction and including existing drop-offs. The Safety Edge is appropriately used at locations where pavement edge drop-offs occur through everyday use, particularly on rural roads with unpaved shoulders.

Note: In general, the Safety Edge is used the entire length of a project, rather than only in locations where a drop-off exists for a short distance.

Install a Safety Edge - **Initial Investment:** $2,145 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 20 years	Benefit-Cost Ratio	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Lower Volume Optimal Conditions	33.4	Proven	0.85–0.92
Higher Volume Optimal Conditions	267.2	Proven	0.85–0.92
Lower Volume Narrower Conditions	40.9	Proven	0.85–0.92
Higher Volume Narrower Conditions	403.2	Proven	0.85–0.92

Top Recommended Resources:

1. FHWA, *Summary Report: Safety Evaluation of the Safety Edge Treatment*, February 2011. Available at: http://www.fhwa.dot.gov/publications/research/safety/hsis/11025/11025.pdf.
2. FHWA, "Proven Safety Countermeasures: Safety Edge," January 2012. Available at: http://safety.fhwa.dot.gov/provencountermeasures/fhwa_sa_12_010.htm.
3. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Install Center Line Rumble Strips

Rumble strips are raised 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. Rumble strips may be installed on the center line of undivided highways, on the roadway shoulder, or on the roadway surface (transverse rumble strips).

Where to Use: Center line rumble strips can be used on virtually any roadway—especially those with a history of head-on crashes. It is recommended that rumble strips be applied systematically along an entire route instead of only at spot locations. For all rumble strips, pavement condition should be sufficient to accept milled rumble strips.

Rumble strips should be provided on all new rural freeways and on all new rural two-lane highways with travel speeds of 50 mph or greater. In addition, State 3R and 4R policies should consider installation of center line rumble strips on rural two-lane road projects where the lane plus shoulder width beyond the rumble strip will be at least 13 feet wide; particularly roadways with higher traffic volumes, poor geometrics, or a history of head-on and opposite-direction sideswipe crashes.

Install Center Line Rumble Strips - **Initial Investment:** $5,000 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 10 years (2 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	21.3	Proven	0.75–0.85
Higher Volume Optimal Conditions	170.6	Proven	0.75–0.85
Lower Volume Narrower Conditions	26.1	Proven	0.75–0.85
Higher Volume Narrower Conditions	257.5	Proven	0.75–0.85

Top Recommended Resources:

1. FHWA, “Proven Safety Countermeasures: Longitudinal Rumble Strips and Stripes on 2-Lane Roads,” April 2012. Available at: http://safety.fhwa.dot.gov/provencountermeasures/fhwa_sa_12_008.htm.
2. FHWA, “Promoting the Implementation of Proven Safety Countermeasures,” memorandum. January 12, 2012. Available at: http://safety.fhwa.dot.gov/provencountermeasures/pc_memo.htm.
3. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Install Edge Line or Shoulder Rumble Strips

Rumble strips are raised 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. Rumble strips may be installed on the center line of undivided highways, on the roadway shoulder, or on the roadway surface (transverse rumble strips).

Where to Use: Shoulder milled rumble strips should be used on roads with a history of roadway departure crashes. It is recommended that rumble strips be applied systematically along an entire route instead of only at spot locations. For all rumble strips, pavement condition should be sufficient to accept milled rumble strips.

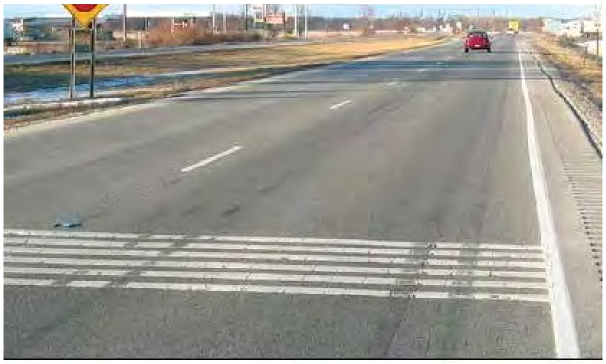
Rumble strips should be provided on all new rural freeways and on all new rural two-lane highways with travel speeds of 50 mph or greater. In addition, State 3R and 4R policies should consider installation of continuous shoulder rumble strips on all rural freeways and on all rural two-lane highways with travel speeds of 50 mph or above (or as agreed to by the Division and the State) and/or a history of roadway departure crashes, where the remaining shoulder width beyond the rumble strip will be 4 feet or greater, paved or unpaved.

Install Edge Line or Shoulder Rumble Strips - **Initial Investment:** $3,000 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 10 years (2 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	58.6	Proven	0.78–0.90
Higher Volume Optimal Conditions	469.0	Proven	0.78–0.90
Lower Volume Narrower Conditions	71.8	Proven	0.78–0.90
Higher Volume Narrower Conditions	707.7	Proven	0.78–0.90

Top Recommended Resources:

1. FHWA, “Proven Safety Countermeasures: Longitudinal Rumble Strips and Stripes on 2-Lane Roads,” April 2012. Available at: http://safety.fhwa.dot.gov/provencountermeasures/fhwa_sa_12_008.htm.
2. FHWA, “Promoting the Implementation of Proven Safety Countermeasures,” memorandum. January 12, 2012. Available at: http://safety.fhwa.dot.gov/provencountermeasures/pc_memo.htm.
3. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Install Transverse Rumble Strips



Rumble strips are raised or grooved patterns on the roadway that provide both an audible warning (rumbling sound) and physical vibration to alert drivers of an upcoming intersection, curve, or other geometry change. Rumble strips may be installed on the center line of undivided highways, on the roadway shoulder, or on the roadway surface (transverse rumble strips).

Where to Use: Transverse rumble strips have been used by some agencies to warn drivers in rural areas that they are approaching an intersection, a horizontal curve, or reduced speeds.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Transverse Rumble Strips	$0 to $5,000	Proven	0.76–0.91

Top Recommended Resources:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.
2. FHWA, "Proven Safety Countermeasures: Longitudinal Rumble Strips and Stripes on 2-Lane Roads," April 2012. Available at: http://safety.fhwa.dot.gov/provencountermeasures/fhwa_sa_12_008.htm.
3. FHWA, "Promoting the Implementation of Proven Safety Countermeasures," memorandum. January 12, 2012. Available at: http://safety.fhwa.dot.gov/provencountermeasures/pc_memo.htm.
4. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Regrade or Recondition Gravel Lanes

Maintaining a proper grade on gravel roads helps to remove rutting, shape the road to allow for proper drainage, smooth the driving surface, and bring the road surface up to bridge approaches or low water crossing approaches. Each of these considerations helps improve safety for those traveling along the route.

Where to Use: This treatment should be considered as routine maintenance on all unpaved roadways.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Regrade or Recondition Gravel Lanes	$0 to $20,000	Tried

Top Recommended Resource:

1. Huntington, G., "Road Geometry, Surface Materials Are Key to Safety on Gravel Roads," *Safety Compass* 6, No. 2 (2012), 4-5.

Install Targeted Longitudinal Rumble Strips at Key Locations (Such as on the Outside of Horizontal Curves Only)

Shoulder or edge line milled rumble strips can be used on roads with a history of roadway departure crashes. While it is recommended that rumble strips be applied systematically along an entire route instead of only at spot locations, where appropriate, they can be used on the outside of horizontal curves and the tangents leading to the curves.

Where to Use: Horizontal curve locations with a high frequency of roadway departure crashes.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Targeted Longitudinal Rumble Strips at Key Locations (Such as on the Outside of Horizontal Curves Only)	$5,001 to $50,000	Tried	0.85

Top Recommended Resources:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.
2. FHWA, "Proven Safety Countermeasures: Longitudinal Rumble Strips and Stripes on 2-Lane Roads," April 2012. Available at: http://safety.fhwa.dot.gov/provencountermeasures/fhwa_sa_12_008.htm.

Install or Maintain a Graded Shoulder

Installing an earth or graded shoulder adjacent to the travel lane provides a recovery area for vehicles should they depart the roadway. The shoulder serves as an opportunity for the driver to correct their direction of travel by either re-entering the roadway or serving as a buffer before traversing the sideslope.

Where to Use: This treatment may be used at locations where no shoulders exist and/or where roadway departure crashes frequently occur.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install or Maintain a Graded Shoulder	$5,001 to $50,000	Proven	0.52

Top Recommended Resource:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

Provide Turnout Areas

Turnout areas are additional pavement beyond the travel way used for slower moving traffic to allow following traffic to pass.

Where to Use: This treatment may be used in low-volume rural locations where farm equipment and other slow moving vehicles are common. Because turnout areas can cause extreme speed differentials, they should not be installed at locations with high traffic volumes.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Provide Turnout Areas	$5,001 to $50,000	Tried

Improve Pavement Friction/Increase Skid Resistance

Vehicles often leave the road due to lack of friction—especially in wet conditions when water between the tires and pavement could cause hydroplaning. Pavement friction treatments can reduce the number of wet-road crashes by improving friction at specific locations.

Where to Use: Treatments such as epoxy-based, micro-surface, or chip seal overlays can address spot locations (e.g., a single curve, interchange ramp, bridge, or short roadway section). Friction treatments should be applied at locations with severe slick conditions that could benefit from increased friction.

Improve Pavement Friction/Increase Skid Resistance - **Initial Investment:** $53,335 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 10 years (2 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	3.3	Proven	0.25–0.60
Higher Volume Optimal Conditions	26.7	Proven	0.25–0.60
Lower Volume Narrower Conditions	4.1	Proven	0.25–0.60
Higher Volume Narrower Conditions	40.3	Proven	0.25–0.60

Top Recommended Resource:

1. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Add Paved Shoulder

The addition of a paved shoulder to an existing road can help to reduce run-off-road crashes. Benefits can be realized for any HRRR without paved shoulders regardless of existing lane pavement width. Adding a paved shoulder within horizontal curve sections may help agencies maximize use of the treatment while minimizing costs as opposed to adding paved shoulders to an entire corridor.

Where to Use: This treatment may be used on any HRRR without a paved shoulder.

Add Paved Shoulder - **Initial Investment:** $400,000 - **Cost of Maintenance:** $20,000 - **Frequency of Maintenance:** 2 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	n/a	Proven	0.86
Higher Volume Optimal Conditions	n/a	Proven	0.86
Lower Volume Narrower Conditions	0.5	Proven	0.86
Higher Volume Narrower Conditions	4.5	Proven	0.86

Top Recommended Resource:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

Widen Existing Travel Lanes by Two Feet or Less per Lane

Increasing lane width on HRRR from 9- or 10-feet wide to 11- or 12-feet wide can result in up to a 50 percent reduction in crashes. Drivers on rural two-lane highways may shift closer to the center line as they become less comfortable next to a narrow shoulder. At other times, they may shift closer to the shoulder edge and are at greater risk of driving off the paved portion of the roadway as they meet oncoming traffic. Lane widening in horizontal curve sections may help agencies maximize use of the treatment while minimizing costs as opposed to widening lanes through an entire corridor.

Where to Use: This treatment may be used at locations where the width of travel lane is less than 12 feet.

Widen Existing Travel Lanes by Two Feet or Less per Lane - **Initial Investment:** $500,000 - **Cost of Maintenance:** $25,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	n/a	Proven	0.95
Higher Volume Optimal Conditions	n/a	Proven	0.95
Lower Volume Narrower Conditions	0.3	Proven	0.95
Higher Volume Narrower Conditions	2.8	Proven	0.95

Top Recommended Resource:

1. FHWA, *Mitigation Strategies for Design Exceptions*, "Chapter 3. The 13 Controlling Criteria," July 2013. Available at: http://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/chapter3/3_lanewidth.htm.

Install Passing or Climbing Lanes

Passing or climbing lanes are auxiliary lanes that are provided in short segments to accommodate the passage of single-directional traffic.

Where to Use: This treatment can be provided where additional capacity is needed, in segment locations where head-on collisions occur as a result of passing vehicles, or locations where particularly slow moving traffic exists.

Install Passing or Climbing Lanes - **Initial Investment:** $1,000,000 - **Cost of Maintenance:** $50,000 - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume Optimal Conditions	0.3	Proven
Higher Volume Optimal Conditions	2.3	Proven
Lower Volume Narrower Conditions	0.4	Proven
Higher Volume Narrower Conditions	3.5	Proven

Increase Shoulder Width

Increasing shoulder width may offer the following benefits:

- Provide an area for drivers to maneuver to avoid crashes;
- Increase safety by providing a stable, clear recovery area for drivers who have left the travel lane;
- Improve stopping sight distance at horizontal curves by providing an offset to objects such as barrier and bridge piers;
- Improve bicycle accommodations; and
- Provide space for emergency storage of disabled vehicles.

The benefits seen by increasing shoulder width vary based on before and after conditions, road classification, speed, and the presence of multiple road user types. Increasing shoulder width within horizontal curve sections may help agencies maximize use of the treatment while minimizing costs as opposed to widening shoulders along an entire corridor.

Where to Use: For narrow pavement widths, it is beneficial to provide narrower lanes with wider shoulders at low AADTs (less than 1,000 vpd), while the configuration with 12-foot lanes and no shoulders appears to be most beneficial for large AADTs (greater than 1,000 vpd).

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Increase Shoulder Width	$100,000 and up	Proven	0.90–0.97

Top Recommended Resource:

1. FHWA, *Safety Evaluation of Lane and Shoulder Width Combinations on Rural, Two-Lane, Undivided Roads*, June 2009. Available at: http://www.fhwa.dot.gov/publications/research/safety/09031/09031.pdf.

Improve Superelevation at Horizontal Curve Locations

Superelevation is the rotation of the pavement on the approach to and through a horizontal curve and is intended to assist the driver in negotiating the curve by counteracting the lateral acceleration produced by tracking. In other words, the road is designed so that the pavement rises as it curves, offsetting the horizontal sideways momentum of the approaching vehicle.

Where to Use: Superelevation is expressed as a decimal representing the ratio of the pavement slope to width, ranging from 0 to 0.12 feet. The adopted criteria allow for the use of maximum superelevation rates from 0.04 to 0.12. Maximum superelevation rates for design are established by policy by each State. Selection of a maximum superelevation rate is based on several variables, such as climate, terrain, highway location (urban vs. rural), and frequency of very slow-moving vehicles. Specific guidance on superelevation rates can be found in AASHTO's *A Policy on Geometric Design of Highways and Streets* and *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Improve Superelevation at Horizontal Curve Locations	$100,000 and up	Proven

Top Recommended Resources:

1. FHWA, *Mitigating Strategies for Design Exceptions*, July 2007. Available at: http://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/.
2. AASHTO, *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*, January 2001.
3. AASHTO, *A Policy on Geometric Design of Highways and Streets*, November 2011.

4.6. Pavement Marking

Pavement markings provide directional guidance and sometimes inconspicuous warnings as drivers approach intersections and horizontal curves. Over time, these markings may fade, or increases in traffic volume may warrant pavement markings where none existed previously. This section covers safety improvement treatments that can be applied in the form of pavement marking procedures. Some treatments in this section also appear in the sections on intersection improvements, horizontal curve improvements, and roadside safety.

SAFETY TREATMENT	For more information, visit page	COST			SAFETY BENEFIT		BENEFIT-COST RATIO[32]			
		Initial Implementation	Ongoing Maintenance	Frequency of Maintenance (years)	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Provide a Stop Bar on Minor Road Approaches	101	$	$	5	P		337.7	1175.8	287.1	1484.1
Install Stop Ahead Pavement Markings	102	$			P	0.44-0.69				
Relocate an Existing Stop Bar on Minor Approach	103	$			T					
Use of Optical Speed Bars	104	$								
Install Raised Pavement Markers	105	$-$$			T	≤0.76				
Install Edge Line Markings	106	$$	–	5	P	0.56-0.62	27.9	222.8	34.1	336.1
Install Center Line Markings	107	$$	–	5	P	0.67	35.1	281.0	43.0	424.0
Install Wider Pavement Markings (With or Without Rumble Strips)	108	$$			E	0.65-0.96				
Implement Lane Narrowing Through Rumble Strips and Painted Median at Rural Stop-controlled Approaches	109	$$-$$$			T	0.60-0.80				
Install Center Line and Edge Line Markings	110	$$$	–	5	P		16.5	132.1	20.2	199.3
Convert a Four-Lane Two-Way Road into a Three-Lane Road With One Lane in Each Direction of Travel Plus a Continuous Two-Way Left Turn Lane (Road Diet)	111	$$$-$$$$			P	0.71-0.95				
Convert a Four-Lane Two-Way Road into a Five-Lane Road with Two Lanes in Each Direction of Travel Plus a Continuous Two-Way Left Turn Lane OR Convert a Two-Lane Two-Way Road into a Three-Lane Road Plus a Continuous Two-Way Left Turn Lane	112	$$$-$$$$			T					

Cost:
$ = $0 to $5,000
$$ = $5,001 to $20,000
$$$ = $20,001 to $50,000
$$$$ = $50,001 to $100,000
$$$$$ = $100,001 and up

NCHRP 500 Performance Rating[33]
P – Proven
T – Tried
E – Experimental
U – Unknown

*Lower Volume ≤1000 vpd
**Higher Volume = Between 1,001 and 8000 vpd
***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders
****Narrower Conditions = 10-foot lanes and no shoulders

32 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, the BCR has been left blank.

33 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Provide a Stop Bar on Minor Road Approaches

Providing visible stop bars on minor road approaches to unsignalized intersections can help direct the attention of drivers to the presence of the intersection.

Where to Use: Apply on minor road approaches where conditions allow the stop bar to be seen by an approaching driver at a significant distance from the intersection. Locations should be identified by patterns of crashes related to lack of driver recognition of the intersection.

Provide a Stop Bar on Minor Road Approaches - **Initial Investment:** $1,000 (4-Way), $500 (3-Leg) - **Cost of Maintenance:** $0 - **Frequency of Maintenance:** 5 years (4 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume 4-Way Intersections	337.7	Proven
Higher Volume 4-Way Intersections	1175.8	Proven
Lower Volume 3-Leg Intersections	287.1	Proven
Higher Volume 3-Leg Intersections	1484.1	Proven

Top Recommended Resource:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.

Install Stop Ahead Pavement Markings

Providing pavement markings with supplementary messages (such as Stop Ahead) can help alert drivers on the stop-controlled approach to the presence of an intersection.

Where to Use: It is likely that Stop Ahead pavement markings will be most effective at locations with a high frequency of target collisions (i.e., right-angle and rear-end), particularly where driver awareness may be an issue.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Stop Ahead Pavement Markings	$0 to $5,000	Proven	0.44–0.69

Top Recommended Resource:

1. FHWA, *Techbrief: Safety Evaluation of STOP AHEAD Pavement Markings*, March 2008. Available at: http://www.fhwa.dot.gov/publications/research/safety/08045/index.cfm.

Relocate an Existing Stop Bar on Minor Approach

A minor approach may have an existing stop bar that is located where vehicles stopping at the bar have limited sight distance at the intersection. The stop bar may be relocated closer to the intersection at a point where the stopped vehicle would have better sight distance for approaching traffic.

Where to Use: This treatment may be used at locations where existing sight distance may obstructed or where sight distance may be significantly improved by moving the stop bar.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Relocate an Existing Stop Bar on Minor Approach	$0 to $5,000	Tried

Top Recommended Resource:

1. FHWA. *NCHRP Report 500 / Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*, "Strategy E4. Provide a Stop Bar (or Provide a Wider Stop Bar) on Minor Road Approaches," July 2003. Available at: http://safety.fhwa.dot.gov/intersection/resources/intsafestratbro/ue4.cfm.

Use of Optical Speed Bars

Optical Speed Bars are transverse stripes spaced at gradually decreasing distances. The rationale for using them is to increase drivers' perception of speed and cause them to reduce speed, which can be helpful near intersections or horizontal curves. The Optical Speed Bar name comes from this intended visual effect on drivers' speed as they react to the spacing of the painted lines. These white transverse stripes are 18 inches long and 12 inches wide. The preferred material is thermoplastic because of the exposure to traffic volume over time.

Where to Use: This treatment may be used at locations where speed reductions are needed such as near intersections and horizontal curves.

Safety Treatment	Initial Implementation Cost
Use of Optical Speed Bars	$0 to $5,000

Top Recommended Resource:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

Install Raised Pavement Markers

Raised pavement markers are designed to supplement the delineation provided by pavement markings. During certain conditions, particularly on wet roads in the dark, motorists may have difficulty determining the location of the center line and edge line pavement markings, increasing the likelihood of roadway departure. By installing raised pavement markers, the pavement markings are much more prominent in adverse weather conditions, providing important information to the driver.

Where to Use: Raised pavement markers should be installed on routes with sufficient pavement quality to hold the devices in place. The type of raised pavement marker to install is dependent on regional climate. For example, in areas that experience snowfall, snow plowable RPMs should be used.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Raised Pavement Markers	\$0 to \$20,000	Tried	≤ 0.76

Top Recommended Resource:

1. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Install Edge Line Markings

Edge line markings separate the travel lane from the shoulder and communicate the intended roadway alignment and travel path to the driver. The MUTCD states that edge line markings must be white. A standard edge line marking is 4 inches, and wider edge line markings can range from 4 inches to 8 inches in width.

Where to Use: According to Massachusetts DOT guidance, edge lines shall be placed on paved rural arterials with a traveled way of 20 feet or more and an ADT of 6,000 vpd or greater.

Install Edge Line Markings - **Initial Investment:** $16,000 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 5 years (2 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	27.9	Proven	0.56–0.62
Higher Volume Optimal Conditions	222.8	Proven	0.56–0.62
Lower Volume Narrower Conditions	34.1	Proven	0.56–0.62
Higher Volume Narrower Conditions	336.1	Proven	0.56–0.62

Top Recommended Resources:

1. Massachusetts DOT, *Pavement Markings: Centerlines and Edgelines*, January 2008. Available at: http://www.mhd.state.ma.us/safetytoolbox/downloads/PavementMarkings_CL_EL.pdf.
2. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Install Center Line Markings

Center line markings separate two opposing traffic streams on a roadway, guide the road user, and delineate travel lanes. The MUTCD states that center line markings must be yellow. A single solid center line is used to discourage crossing, a double line prohibits crossing, and a broken center line is used to indicate a passing zone.

Where to Use: According to Massachusetts DOT guidance, center lines are required on all paved urban arterials and collectors that have a traveled way of 20 feet or more in width and an ADT volume of 6,000 vpd or greater.

Install Center Line Markings - **Initial Investment:** $16,000 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 5 years (2 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	35.1	Proven	0.67
Higher Volume Optimal Conditions	281.0	Proven	0.67
Lower Volume Narrower Conditions	43.0	Proven	0.67
Higher Volume Narrower Conditions	424.0	Proven	0.67

Top Recommended Resources:

1. Massachusetts DOT, *Pavement Markings: Centerlines and Edgelines*, January 2008. Available at: http://www.mhd.state.ma.us/safetytoolbox/downloads/PavementMarkings_CL_EL.pdf.
2. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Install Wider Pavement Markings (With or Without Rumble Strips)


Pavement markings provide continuous information to road users related to the roadway alignment, vehicle positioning, and other important driving-related tasks. Edge line width has been found to statistically lower nighttime fatal and injury crashes. A standard edge line marking is 4 inches, and wider edge line markings can range from 4 inches to 8 inches in width.

Where to Use: This treatment may be beneficial for locations that experience run-off-road and opposite-direction crashes that occur at night or on curves.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Wider Pavement Markings (With or Without Rumble Strips)	\$5,001 to \$20,000	Experimental	0.65–0.96

Top Recommended Resource:

1. Carlson, P., E. Park, and C. Anderson, "The Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research," Paper No. 09-0488, August 2008.

Implement Lane Narrowing Through Rumble Strips and Painted Median at Rural Stop-Controlled Approaches

Lane narrowing features the introduction of rumble strips on the outside shoulders and in a painted yellow median island on the major road approaches. The objective of lane narrowing is to induce drivers on major roads to reduce approach speeds at intersections by effectively reducing the lane width.

Where to Use: This practice has greater potential for effectiveness for intersections on high-speed roadways. However, the treatment can also be applied to intersections with lower posted speed limits.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Implement Lane Narrowing Through Rumble Strips and Painted Median at Rural Stop-Controlled Approaches	$5,001 to $50,000	Tried	0.60–0.80

Top Recommended Resource:

1. FHWA, *Summary Report: Two Low-Cost Safety Concepts for Two-Way STOP-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roadways*, December 2008. Available at: http://www.fhwa.dot.gov/publications/research/safety/08063/.

Install Center Line and Edge Line Markings

This treatment refers to installing both center line and edge line markings on a roadway.

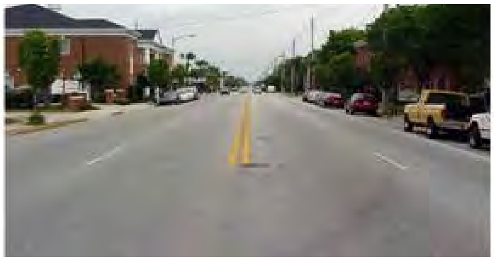
Where to Use: Any road with a history of run-off-road-right, head-on, opposite-direction-sideswipe, or run-off-road-left crashes is a candidate for this treatment. Depending on the width of the roadway, various combinations of edge line and/or center line pavement markings may be the most appropriate.

Install Center Line and Edge Line Markings - **Initial Investment:** $32,000 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 5 years (2 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**
Lower Volume Optimal Conditions	16.5	Proven
Higher Volume Optimal Conditions	132.1	Proven
Lower Volume Narrower Conditions	20.2	Proven
Higher Volume Narrower Conditions	199.3	Proven

Top Recommended Resource:

1. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Convert a Four-Lane Two-Way Road into a Three-Lane Road With One Lane in Each Direction of Travel Plus a Continuous Two-Way Left Turn Lane (Road Diet)



A road diet involves converting an undivided four-lane roadway into three lanes made up of two through lanes and a center Two-Way Left Turn Lane (TWLTL). The reduction of lanes allows the roadway to be reallocated for other uses such as bike lanes, pedestrian crossing islands, and/or parking. Road diets have multiple safety and operational benefits for vehicles as well as pedestrians, such as:

- Decreasing vehicle travel lanes for pedestrians to cross, therefore reducing the multiple-threat crash (when one vehicle stops for a pedestrian in a travel lane on a multi-lane road, but the motorist in the next lane does not, resulting in a crash) for pedestrians;
- Providing room for a pedestrian crossing island;
- Improving safety for bicyclists when bike lanes are added (such lanes also create a buffer space between pedestrians and vehicles);
- Providing the opportunity for on-street parking (also a buffer between pedestrians and vehicles);
- Reducing rear-end and side-swipe crashes; and
- Improving speed limit compliance and decreasing crash severity when crashes do occur.

Where to Use: Road diets can be low cost if planned in conjunction with reconstruction or simple overlay projects, since a road diet mostly consists of restriping. Roadways with Average Daily Traffic (ADT) of 20,000 or less may be good candidates for a road diet and should be evaluated for feasibility. It has been shown that roads with 15,000 ADT or less had very good results in the areas of safety, operations, and livability. Driveway density, transit routes, the number and design of intersections along the corridor, as well as operational characteristics are some considerations to be evaluated before deciding to implement a road diet.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Convert a Four-Lane Two-Way Road into a Three-Lane Road With One Lane in Each Direction of Travel Plus a Continuous Two-Way Left Turn Lane (Road Diet)	$20,001 to $100,000	Proven	0.71–0.95

Top Recommended Resource:

1. FHWA, *Proven Safety Countermeasures: Road Diet (Roadway Reconfiguration)*, December 2011. Available at: http://safety.fhwa.dot.gov/provencountermeasures/fhwa_sa_12_013.htm.

Convert a Four-Lane Two-Way Road into a Five-Lane Road with Two Lanes in Each Direction of Travel Plus a Continuous Two-Way Left Turn Lane OR Convert a Two-Lane Two-Way Road into a Three-Lane Road Plus a Continuous Two-Way Left Turn Lane

A Two-Way Left Turn Lane (TWLTL) is a lane placed between opposing lanes of traffic for the purpose of allowing traffic from either direction to make left turns off of a roadway.

TWLTLs remove left turning vehicles from the through lanes, which can reduce delay to through vehicles and can lead to a reduction in rear-end and sideswipe collisions. Second, TWLTLs provide spatial separation between opposing lanes of traffic, which can lead to a reduction in head-on collisions. The TWLTLs can also function as a lane for emergency vehicles.

Where to Use: Current and future operational conditions such as capacity and level of service, safety conditions, traffic volumes (including trucks), and left turn volumes, along with type of land use, future development, and driveway and intersection densities should be considered before implementation.

Lower cost installations of TWLTLs can be a cost-effective treatment for two-lane rural locations, especially those with a high frequency of rear-end collisions involving a lead vehicle desiring to make a turn.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Convert a Four-Lane Two-Way Road into a Five-Lane Road with Two Lanes in Each Direction of Travel Plus a Continuous Two-Way Left Turn Lane OR Convert a Two-Lane Two-Way Road into a Three-Lane Road Plus a Continuous Two-Way Left Turn Lane	$20,001 to $100,000	Tried

Top Recommended Resources:

1. Iowa DOT. *Design Manual*, “Chapter 6,” December 2010. Available at: http://www.iowadot.gov/design/dmanual/manual.html.
2. FHWA, *Safety Evaluation of Installing Center Two-Way Left Turn Lanes on Two-Lane Roads*, March 2007. Available at: http://www.fhwa.dot.gov/publications/research/safety/08042/08042.pdf.

4.7. Roadside

Improvements cited in this section include removal of hazards, redesigning obstacles, relocating obstacles, reducing impact severity with breakaway devices, shielding obstacles, or delineation. These are common hazards on rural roadways. Some treatments in this section also appear in the sections on pavement and shoulder treatments.

SAFETY TREATMENT	For more information, visit page	COST: Initial Implementation	COST: Ongoing Maintenance	Frequency of Maintenance (years)	SAFETY BENEFIT: NCHRP 500 Performance Rating	SAFETY BENEFIT: Crash Modification Factor (CMF)	BENEFIT-COST RATIO[34]: Lower Volume*, Optimal Conditions***	BENEFIT-COST RATIO[34]: Higher Volume**, Optimal Conditions***	BENEFIT-COST RATIO[34]: Lower Volume*, Narrower Conditions****	BENEFIT-COST RATIO[34]: Higher Volume**, Narrower Conditions****
Install a Safety Edge	114	$	–	20	P	0.85-0.92	33.4	267.2	40.9	403.2
Improve Sight Distance by Controlling Roadside Vegetation	115	$-$$			T					
Convert Culvert Headwalls to Traversable End Treatments	116	$-$$			P					
Remove Guardrail	117	$-$$			U					
Install or Maintain a Graded Shoulder	118	$$$			P	0.52				
Relocate Select Hazardous Utility Poles	119	$$$-$$$$			P	≤0.71				
Install Median Guardrail	120	$$$-$$$$								
Modify End Treatments of Existing Guardrail	121	$$$-$$$$			P					
Install Impact Attenuation Devices at Select Roadside Hazard Locations (Such as Exposed Bridge Columns)	122	$$$-$$$$			P	0.31-0.54				
Remove or Shield Obstacles in Clear Zone	123	$$$$	$$	5	P	≤0.71	3.3	26.7	4.6	45.2
Increase Shoulder Width	124	$$$$-$$$$$			P	0.90-0.97				
Widen Existing Median or Construct Median	125	$$$$-$$$$$			P					
Install Median Cable Barrier	126	$$$-$$$$			P	0.71				
Flatten Road Sideslope	127	$$$$$	–	10	P	0.58	n/a	n/a	0.2	1.9
Create or Increase Clear Zone	128	$$$$$	–	–	P	0.56-0.87	1.0	7.9	1.5	14.6
Add Paved Shoulder	129	$$$$$	$$	2	P	0.86	n/a	n/a	0.5	4.5
Install Concrete Median Barrier	130	$$$$$			P					

Cost:
$ = $0 to $5,000
$$ = $5,001 to $20,000
$$$ = $20,001 to $50,000
$$$$ = $50,001 to $100,000
$$$$$ = $100,001 and up

NCHRP 500 Performance Rating[35]
P – Proven
T – Tried
E – Experimental
U – Unknown

*Lower Volume ≤1000 vpd
**Higher Volume = Between 1,001 and 8000 vpd
***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders
****Narrower Conditions = 10-foot lanes and no shoulders

34 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, the BCR has been left blank.

35 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Install a Safety Edge

When a vehicle leaves the traveled way and encounters a pavement-shoulder drop-off, it can be difficult for the driver to return safely to the roadway. They often overcorrect when returning to the pavement and subsequently lose control and run off the road. A safety edge is a treatment intended to minimize drop-off-related crashes. With this treatment, the pavement edge is sloped at an angle (30-35 degrees) to make it easier for a driver to safely re-enter the roadway after inadvertently driving onto the shoulder. This treatment is designed to be a standard policy for any overlay project.

Where to Use: Each State should implement policies and procedures to incorporate the Safety Edge where pavement and non-pavement surfaces interface on all paving and resurfacing projects with surface differentials of 2.5 inches or more. The differentials should be measured from the pavement surface to the adjacent non-pavement surface, accounting for grading along the pavement edge during construction and including existing drop-offs. The Safety Edge is appropriately used at locations where pavement edge drop-offs occur through everyday use, particularly on rural roads with unpaved shoulders.

Note: In general, the Safety Edge is used the entire length of a project, rather than only in locations where a drop-off exists for a short distance.

Install a Safety Edge - **Initial Investment:** $2,145 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 20 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	33.4	Proven	0.85–0.92
Higher Volume Optimal Conditions	267.2	Proven	0.85–0.92
Lower Volume Narrower Conditions	40.9	Proven	0.85–0.92
Higher Volume Narrower Conditions	403.2	Proven	0.85–0.92

Top Recommended Resources:

1. FHWA, *Summary Report: Safety Evaluation of the Safety Edge Treatment*, February 2011. Available at: http://www.fhwa.dot.gov/publications/research/safety/hsis/11025/11025.pdf.
2. FHWA, "Proven Safety Countermeasures: Safety Edge," January 2012. Available at: http://safety.fhwa.dot.gov/provencountermeasures/fhwa_sa_12_010.htm.
3. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Improve Sight Distance by Controlling Roadside Vegetation

Vegetation control helps lessen the likelihood of fixed-object crashes. Proper maintenance of tall grass, weeds, brush, and tree limbs and can help improve drivers' sight distance of the road ahead, traffic control devices, approaching vehicles, wildlife and livestock, and pedestrians and bicycles.

Where to Use: This treatment is appropriate to use at all locations, especially those in rural areas where vegetation growth is high.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Improve Sight Distance by Controlling Roadside Vegetation	$0 to $20,000	Tried

Top Recommended Resource:

1. FHWA, *Vegetation Control For Safety: A Guide for Local Highway and Street Maintenance Personnel*, August 2008. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa07018/vegetationfv1108.pdf.

Convert Culvert Headwalls to Traversable End Treatments

Culvert headwalls may act as a fixed object once vehicles leave the roadway. By installing traversable culvert end treatments, vehicles may be able to drive over them without rolling over or experiencing an abrupt change in speed.

Where to Use: This treatment is applicable for locations where culvert headwalls are perpendicular to and lie in close proximity to the traveled way.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Convert Culvert Headwalls to Traversable End Treatments	$0 to $20,000	Proven

Top Recommended Resource:

1. FHWA, *Maintenance of Drainage Features for Safety: A Guide for Local Street and Highway Maintenance Personnel,* July 2009. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa09024/fhwasa09024.pdf.

Remove Guardrail

Removal of guardrail that no longer provides a safety benefit can help eliminate a roadside obstacle. Each removal should be evaluated on a case-by-case basis.

Where to Use: This treatment may be used at locations where guardrails no longer provide a safety benefit (e.g., locations where sideslopes have been improved behind the guardrail or where roadside obstacles have been removed).

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Remove Guardrail	$0 to $20,000	Unknown

Install or Maintain a Graded Shoulder

Installing a stabilized earth or graded shoulder adjacent to the travel lane provides a recovery area for vehicles if they should depart the road. The shoulder provides as an opportunity for drivers to correct their direction of travel by re-entering the roadway. It may also serve as a buffer before traversing the sideslope.

Where to Use: This treatment may be used at locations where no shoulders exist and/or where roadway departure crashes frequently occur.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install or Maintain a Graded Shoulder	$20,001 to $50,000	Proven	0.52

Relocate Select Hazardous Utility Poles

Relocating or removing utility poles from within the clear zone alleviates the potential for fixed-object crashes. If utility poles cannot be completely eliminated from within the clear zone, efforts can be made to either relocate the poles to a greater offset from the road or delineated.

Where to Use: This treatment may be used at locations where utility pole fixed-object crashes occur or are more likely to occur due to the proximity of the poles to the roadway, such as along the outside of horizontal curves.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Relocate Select Hazardous Utility Poles	\$20,001 to \$100,000	Proven	≤ 0.71

Top Recommended Resource:

1. Transportation Research Board. *NCHRP Report 500 / Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 8: A Guide for Reducing Collisions Involving Utility Poles*, June 2004. Available at: http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_500v8.pdf.

Install Median Guardrail

The installation of median guardrail is most suitable for use in traversable medians having no or little change in grade and cross slope. While these systems may not reduce the frequency of crashes due to roadway departure, they can help prevent a lane-departure crash from becoming a head-on collision.

Where to Use: This treatment may be used on divided highways with 20,000 ADT or greater that have a system-wide history of cross-median crashes. Highways with medians less than 50 feet wide. The treatment should be applied systemically using logical end points, not at specific locations.

Safety Treatment	Initial Implementation Cost
Install Median Guardrail	$20,001 to $100,000

Top Recommended Resource:

1. FHWA, *Median Barriers*, September 2010. Available at: http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/ctrmeasures/median_barriers/.

Modify End Treatments of Existing Guardrail

The installation of a crashworthy end treatment can be used to prevent impact with guardrail ends by safely decelerating the vehicle or by safety redirecting it around the object of concern.

Where to Use: This treatment may be used at guardrail locations that have experienced severe crashes or have not performed as desired when hit. Also, any currently-installed “turn-down” or blunt guardrail ends.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Modify End Treatments of Existing Guardrail	$20,001 to $100,000	Proven

Install Impact Attenuation Devices at Select Roadside Hazard Locations (Such as Exposed Bridge Columns)

An impact attenuator, also known as a crash cushion or crash attenuator, is a device intended to reduce the damage to vehicles, motorists, and structures as a result of a motor vehicle collision. Attenuators may be installed to protect bridge columns and other narrow roadside obstacles.

Where to Use: This treatment may be used at locations where roadside hazards are relatively close to the road, or where fixed object crashes have occurred.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Impact Attenuation Devices at Select Roadside Hazard Locations (Such as Exposed Bridge Columns)	$20,001 to $100,000	Proven	0.31–0.54

Remove or Shield Obstacles in Clear Zone

Removing, redesigning, marking, or relocating fixed objects within the clear zone reduces the likelihood of a crash. If a crash occurs, adding breakaway features, crash cushions, or redirection devices reduces crash severity.

Where to Use: Depending on the type and location of the obstacle, several methods to improve the clear zone exist.

These include:

1. Removing the obstacle;

2. Redesigning the obstacle so it can be safely traversed;

3. Relocating the obstacle to a point where it is less likely to be struck;

4. Reducing impact severity by using an appropriate breakaway device;

5. Protecting the driver by redirecting the errant vehicle with guardrail or reducing the severity of the crash with an impact attenuation device; and

7. Marking the object to provide motorist information.

Remove or Shield Obstacles in Clear Zone - **Initial Investment:** $70,000 - **Cost of Maintenance:** $7,000 - **Frequency of Maintenance:** 5 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	3.3	Proven	≤ 0.71
Higher Volume Optimal Conditions	26.7	Proven	≤ 0.71
Lower Volume Narrower Conditions	4.6	Proven	≤ 0.71
Higher Volume Narrower Conditions	45.2	Proven	≤ 0.71

Top Recommended Resources:

1. FHWA, *Toolbox of Countermeasures and Their Potential Effectiveness for Roadway Departure Crashes*, August 2008. Available at: http://safety.fhwa.dot.gov/tools/crf/resources/briefs/rdwydepartissue.cfm.
2. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Increase Shoulder Width

Increasing shoulder width may offer the following benefits:

- Provide an area for drivers to maneuver to avoid crashes;
- Increase safety by providing a stable, clear recovery area for drivers who have left the travel lane;
- Improve stopping sight distance at horizontal curves by providing an offset to objects such as barrier and bridge piers;
- Provide shelf for snow in northern climates;
- Improve bicycle accommodation; and
- Provide space for emergency storage of disabled vehicles

The benefits seen by increasing shoulder width vary based on before and after conditions, road classification, speed, and the presence of multiple road user types. Increasing shoulder width within horizontal curve sections may help agencies maximize use of the treatment while minimizing costs, as opposed to adding widening shoulders to an entire corridor.

Where to Use: For narrow pavement widths, it is beneficial to provide narrower lanes with wider shoulders at low AADTs (less than 1,000 vpd), while the configuration with 12-foot lanes and no shoulders appears to be most beneficial for large AADTs (greater than 1,000 vpd).

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Increase Shoulder Width	$50,001 to $100,000	Proven	0.90–0.97

Top Recommended Resource:

1. FHWA, *Safety Evaluation of Lane and Shoulder Width Combinations on Rural, Two-Lane, Undivided Roads*, June 2009. Available at: http://www.fhwa.dot.gov/publications/research/safety/09031/09031.pdf.

Widen Existing Median or Construct Median

Use of these treatments helps to provide additional lateral distance between opposing traffic.

Where to Use: This treatment may be applicable when high frequencies of head-on collisions exist.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Widen Existing Median or Construct Median	$50,001 to $100,000	Proven

Install Median Cable Barrier

Median cable barrier systems are considered the most versatile and forgiving barrier systems available for reducing the severity of median crossover crashes. While these systems may not reduce the frequency of crashes due to roadway departure, they can help prevent a lane-departure crash from becoming a head-on collision.

Where to Use: This treatment may be used on divided highways that have a system-wide history of cross-median crashes and highways with medians less than 50 feet wide. The treatment should be applied systemically using logical end points, not at specific locations.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Median Cable Barrier	$120,000	Proven	0.71

Top Recommended Resource:

1. FHWA, *Median Barriers*. Available at: http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/ctrmeasures/median_barriers/

Flatten Road Sideslope

By reducing the amount of road sideslope, vehicles are better able to recover after leaving the travelway. The flatter the slope, the more traversable the sideslope becomes.

Where to Use: This treatment may be used at locations that have experienced overturn crashes, on the outside of curves with small radii, where the sideslope has a slope of greater than 3:1.

Flatten Road Sideslope - **Initial Investment:** $1,000,000 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 10 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	n/a	Proven	0.58
Higher Volume Optimal Conditions	n/a	Proven	0.58
Lower Volume Narrower Conditions	0.2	Proven	0.58
Higher Volume Narrower Conditions	1.9	Proven	0.58

Top Recommended Resources:

1. FHWA, *Toolbox of Countermeasures and Their Potential Effectiveness for Roadway Departure Crashes*, August 2008. Available at: http://safety.fhwa.dot.gov/tools/crf/resources/briefs/rdwydepartissue.cfm.
2. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Create or Increase Clear Zone

A clear zone is an unobstructed, traversable roadside area that allows a driver to stop safely or regain control of a vehicle that has left the roadway. The width of the clear zone should be based on risk (also called exposure). Key factors in assessing risk include traffic volumes, speeds, and slopes, in accordance to the AASHTO Roadside Design guide. Clear roadsides consider both fixed objects and terrain that may cause vehicles to rollover. Creating or increasing clear zones within horizontal curve sections may help agencies maximize use of the treatment while minimizing costs, as opposed to providing a clear zone throughout an entire corridor.

Where to Use: A clear zone should be developed on every roadway where space is available. In situations where public right-of-way is limited, steps should be taken to request assistance from property owners or seek volunteer easements, as appropriate.

Create or Increase Clear Zone - **Initial Investment:** $300,000 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** n/a	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	1.0	Proven	0.56–0.87
Higher Volume Optimal Conditions	7.9	Proven	0.56–0.87
Lower Volume Narrower Conditions	1.5	Proven	0.56–0.87
Higher Volume Narrower Conditions	14.6	Proven	0.56–0.87

Top Recommended Resources:

1. FHWA, *Clear Zones*, Available at: http://safety.fhwa.dot.gov/roadway_dept/clear_zones/
2. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.
3. AASHTO, *Roadside Design Guide*, September 2011.

Add Paved Shoulder

The addition of a paved shoulder to an existing road can help to reduce run-off-road crashes. Benefits can be realized for any HRRR without paved shoulders, regardless of existing lane pavement width. Adding a paved shoulder within horizontal curve sections may help agencies maximize use of the treatment while minimizing costs as opposed to adding paved shoulders to an entire corridor.

Where to Use: This treatment may be used on any HRRR without a paved shoulder.

Add Paved Shoulder - **Initial Investment:** $400,000 - **Cost of Maintenance:** $20,000 - **Frequency of Maintenance:** 2 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	n/a	Proven	0.86
Higher Volume Optimal Conditions	n/a	Proven	0.86
Lower Volume Narrower Conditions	0.5	Proven	0.86
Higher Volume Narrower Conditions	4.5	Proven	0.86

Install Concrete Median Barriers

Concrete median barriers are longitudinal barriers used to separate opposing directions of traffic. While these systems may not reduce the frequency of crashes due to roadway departure, they can help prevent a lane-departure crash from becoming a head-on collision.

Where to Use: Concrete median barriers can be used in urban or rural locations that experience frequent head-on collisions when:

- Constructing a median is not possible, and
- There exists sufficient distance between opposing travel lanes to install the barrier

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Concrete Median Barriers	$100,001 and up	Proven

4.8. Signing

Improved signing and sign conspicuity can provide warnings to drivers as they approach potentially hazardous scenarios, such as intersections and horizontal curves. Some treatments in this section also appear in the sections on intersection improvements and horizontal curve improvements.

SAFETY TREATMENT	For more information, visit page	COST			SAFETY BENEFIT		BENEFIT-COST RATIO[36]			
		Initial Implementation	Ongoing Maintenance	Frequency of Maintenance (years)	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Install/Upgrade Curve Warning Signs with Fluorescent Yellow Sheeting	132	$	–	5	P	0.66	63.1	490.4	75.1	739.9
Install Curve Warning Signs	133	$	$	5	P	0.70	33.8	270.1	43.5	428.4
Install Retroreflective Strips on Sign Posts	134	$			T					
Double Use of Advanced Warning Signs for Curves or Intersections	135	$			T					
Provide Upcoming Road Names on Advanced Warning Signs	136	$			T	0.90-0.99				
Install Advanced Intersection Warning Signs	137	$			T					
Upgrade to Larger Stop Signs	138	$			P					
Double Use of Stop Signs	139	$			T					
Use of Supplemental Warning Signs	140	$			T					
Install Chevron Signs	141	$$	$	5	P	0.75	10.6	84.7	13.0	127.7

Cost:
$ = $0 to $5,000
$$ = $5,001 to $20,000
$$$ = $20,001 to $50,000
$$$$ = $50,001 to $100,000
$$$$$ = $100,001 and up

NCHRP 500 Performance Rating[37]
P – Proven
T – Tried
E – Experimental
U – Unknown

*Lower Volume ≤1000 vpd
**Higher Volume = Between 1,001 and 8000 vpd
***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders
****Narrower Conditions = 10-foot lanes and no shoulders

36 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, the BCR has been left blank.

37 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Install/Upgrade Curve Warning Signs with Fluorescent Yellow Sheeting

Fluorescent yellow sheeting can improve the effectiveness of curve warning and delineation signs by increasing the conspicuity of the sign, especially during dark conditions.

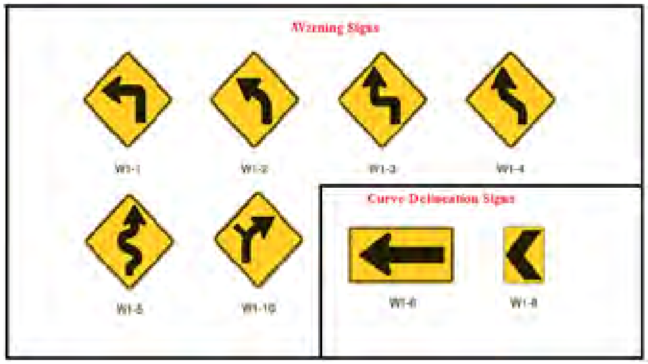
Where to Use: Connecticut DOT used fluorescent yellow sheeting to improve signing at horizontal curves between 2002 and 2006. These curves were selected through a regular program called the Suggested List of Surveillance Study Sites (SLOSSS), which uses crash data, traffic volumes, and roadway characteristics to identify intersections and road segments with higher than expected crash rates.

Install/Upgrade Curve Warning Signs with Fluorescent Yellow Sheeting - **Initial Investment:** $1,280 - **Cost of Maintenance:** n/a - **Frequency of Maintenance:** 5 years (2 applications)	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	63.1	Proven	0.66
Higher Volume Optimal Conditions	490.4	Proven	0.66
Lower Volume Narrower Conditions	75.1	Proven	0.66
Higher Volume Narrower Conditions	739.9	Proven	0.66

Top Recommended Resources:

1. FHWA, *Safety Evaluation of Improved Curve Delineation*, September 2009. Available at: http://www.fhwa.dot.gov/publications/research/safety/09045/09045.pdf
2. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

Install Curve Warning Signs



Some of the most serious crashes on rural roads occur at horizontal curves. Horizontal alignment signs, informally called curve warning signs, can improve safety by alerting drivers to changes in roadway geometry that may not be apparent or expected. These signs provide visual information for the driver about the nature of the curve they are approaching, letting them know whether it's a gradual curve, a sharp turn, a hairpin turn, or some combination. Different types of curve warning signs are identified in the MUTCD.

Where to Use: Curve warning signs should be applied to any curve or turn with a history of roadway departure crashes and curves or turns with similar geometry or traffic volume yet to experience crashes. According to the 2009 MUTCD, warning signs are required on curves or turns where the advisory speed is 10 mph less than the posted speed.

Studies have shown that reductions in crashes due to the installation of curve warning signs are more prominent at locations with higher traffic volumes, sharper curves, or hazardous roadsides.

Install Curve Warning Signs - **Initial Investment:** $2,400 - **Cost of Maintenance:** $1,280 - **Frequency of Maintenance:** 5 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	33.8	Proven	0.70
Higher Volume Optimal Conditions	270.1	Proven	0.70
Lower Volume Narrower Conditions	43.5	Proven	0.70
Higher Volume Narrower Conditions	428.4	Proven	0.70

Top Recommended Resources:

1. University of California, Berkley, Institute of Transportation Studies, Technology Transfer Program, *Tech Transfer Newsletter*, "Signs for Curves and Turns." Available at: http://www.techtransfer.berkeley.edu/newsletter/08-2/signs-for-curves-and-turns.php.
2. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

Install Retroreflective Strips on Sign Posts

The use of retroreflective strips on sign posts may be beneficial when there is a need to draw additional attention to the signs, especially at night. Reflective strips may be added to Stop signs, curve or intersection warning signs, regulatory or guidance signs, etc.

Where to Use: The MUTCD provides the following guidance for the use of reflective strips on sign posts: "the material must be at least 2 inches wide and must be placed the full length of the post from the sign to within 2 feet above the horizontal surface into which the sign is fixed. In addition, the color of the material must match the background color of the sign except that the color of the strip for Yield and Do Not Enter signs must be red."

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Retroreflective Strips on Sign Posts	$0 to $5,000	Tried

Top Recommended Resource:

1. FHWA, "Intersection Safety Implementation Plan Workshop," presentation, July 2009. Available at: http://safety.fhwa.dot.gov/intersection/resources/ex_wksp_pres0109/.

Double Use of Advanced Warning Signs for Curves or Intersections

Doubling the use of either Intersection Ahead warning signs or Curve Ahead warning signs (on the left and right) is recommended for locations where the crash rate has not been reduced after installation of a single advanced warning sign.

Where to Use: This treatment may be used at locations where crashes indicate that motorists do not heed existing advanced warning signs and additional conspicuity is needed.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Double Use of Advanced Warning Signs for Curves or Intersections	$0 to $5,000	Tried

Top Recommended Resource:

1. FHWA, *Low Cost Treatments for Horizontal Curve Safety*, December 2006. Available at: http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/.

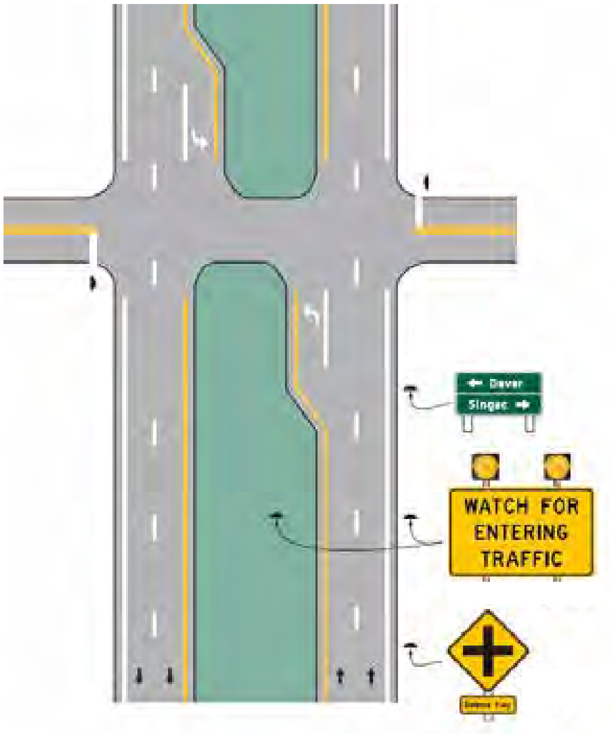
Provide Upcoming Road Names on Advanced Warning Signs

At locations where Intersection Ahead warning signs are used, it is recommended that street name signs be placed underneath each intersection warning sign. These street name plaques provide the driver with additional information about the street the motorist is approaching so he or she can make an early decision regarding potential turning movements.

Where to Use: This treatment may be used at locations where crashes could potentially be reduced by providing advanced turn information.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Provide Upcoming Road Names on Advanced Warning Signs	$0 to $5,000	Tried	0.90–0.99

Install Advanced Intersection Warning Signs



Advanced intersection warning signs can help alert drivers to the upcoming presence of an intersection. Signs can be placed with sufficient distance prior to the intersection to allow drivers to perceive and react and can be installed on both sides of the roadway to solicit greater awareness.

Where to Use: Advanced intersection warning signs are to be applied predominantly on single through lane, high-crash, stop-controlled State intersections in both rural and urban areas. They may also be applied on dual through lane, high-crash, stop-controlled intersections with lower traffic volumes (less than about 25,000 average annual daily traffic (AADT)) where the use of J-treatments are not appropriate and the frequency of acceptable gaps for entering traffic is such that long waiting and higher risk taking are not present at the intersection.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Advanced Intersection Warning Signs	$0 to $5,000	Tried

Top Recommended Resource:

1. FHWA, *Stop-Controlled Intersection Safety: Through Route Activated Warning Systems*, February 2011. Available at: http://safety.fhwa.dot.gov/intersection/resources/fhwasa11015/traws.pdf.

Upgrade to Larger Stop Signs

A high number of crashes relate to the driver's inability or failure to see the Stop sign at stop-controlled intersections. To improve recognition of the signs, larger Stop signs can be installed. Sizes can range from 30 inches, to 36 inches, to 48 inches and larger, if needed.

Where to Use: While roadway classification and speed can help determine proper Stop sign size, larger sizes may be used when crash types indicate that Stop sign visibility may be an issue.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Upgrade to Larger Stop Signs	$0 to $5,000	Proven

Top Recommended Resource:

1. FHWA, *Stop Sign-Controlled Intersections: Enhanced Signs and Markings—A Winston-Salem Success Story*, November 2009. Available at: http://safety.fhwa.dot.gov/intersection/resources/casestudies/fhwasa09010/.

Double Use of Stop Signs

Two Stop signs (mounted left and right) can be used to call greater attention to the need for motorists to stop at an intersection. The first Stop sign is installed at the traditional right side location; a second is recommended in the median (if available) of the approach. To accommodate this left-mounted Stop sign, a small mountable curb is suggested. This curb and associated pavement markings provide the motorist with additional information that he or she is entering an intersection.

Where to Use: This treatment may be used at locations where crashes indicate that motorists do not obey existing Stop signs and additional intersection conspicuity is needed.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Double Use of Stop Signs	$0 to $5,000	Tried

Top Recommended Resources:

1. FHWA, *Intersection Safety: A Manual for Local Rural Road Owners*, January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1108/fhwasa1108.pdf.
2. FHWA, *Stop Sign-Controlled Intersections: Enhanced Signs and Markings—A Winston-Salem Success Story*, November 2009. Available at: http://safety.fhwa.dot.gov/intersection/resources/casestudies/fhwasa09010/.

Use of Supplemental Warning Signs

When specialized conditions exist, supplemental warning signs may be used to notify road users of the possibility that slower and more susceptible road users may be ahead. Examples include Share The Road, Trail Crossing, and Equestrian Crossing signs.

Where to Use: These signs may be used whenever road users need to be notified that slower traffic crosses the roadway or exists on or very near the roadway.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Use of Supplemental Warning Signs	$0 to $5,000	Tried

Install Chevron Signs

Chevron signs (or curve delineation signs) indicate to drivers the alignment of the roadway when they are within the actual horizontal alignment of a curve. The signs show the shape and degree of curvature and guide drivers through the entire curve or turn.

Where to Use: Chevrons should be installed at any curve or turn with a history of roadway departure crashes and curves or turns with similar geometry or traffic volume that have yet to experience crashes. According to the 2009 MUTCD, alignment delineation (or a one direction large arrow) is required on curves or turns where the advisory speed is 15 mph less than the posted speed limit. They can be installed at locations where no chevrons currently exist or to supplement those that are already in place.

Install Chevron Signs - **Initial Investment:** $7,200 - **Cost of Maintenance:** $3,600 - **Frequency of Maintenance:** 5 years	**Benefit-Cost Ratio**	**NCHRP 500 Performance Rating**	**Crash Modification Factor (CMF)**
Lower Volume Optimal Conditions	10.6	Proven	0.75
Higher Volume Optimal Conditions	84.7	Proven	0.75
Lower Volume Narrower Conditions	13.0	Proven	0.75
Higher Volume Narrower Conditions	127.7	Proven	0.75

Top Recommended Resource:

1. FHWA, *Roadway Departure Safety: A Manual for Local Rural Road Owners,* January 2011. Available at: http://safety.fhwa.dot.gov/local_rural/training/fhwasa1109/fhwasa1109.pdf.

4.9. Vertical Curves

Safety improvement treatments on vertical curves range from low-cost improvements (such as signing) to high-cost improvements (such as modifying road geometry). This section covers safety improvement treatments that can be applied at vertical curve locations. Some treatments in this section also appear in the sections on intersection improvements, signing, and roadside safety.

SAFETY TREATMENT	For more information, visit page	COST		Frequency of Maintenance (years)	SAFETY BENEFIT		BENEFIT-COST RATIO[38]			
		Initial Implementation	Ongoing Maintenance		NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Conditions***	Higher Volume**, Optimal Conditions***	Lower Volume*, Narrower Conditions****	Higher Volume**, Narrower Conditions****
Install Advanced Intersection Warning Signs	143	$			P					
Install Dynamic Advanced Intersection Warning System	144	$$			P	0.10-0.76				
Modify Horizontal/Vertical Geometry	145	$$$$$			P					
Relocate Driveways, Entrances, and Intersections	146	$$$$			T					

Cost:
$ = $0 to $5,000
$$ = $5,001 to $20,000
$$$ = $20,001 to $50,000
$$$$ = $50,001 to $100,000
$$$$$ = $100,001 and up

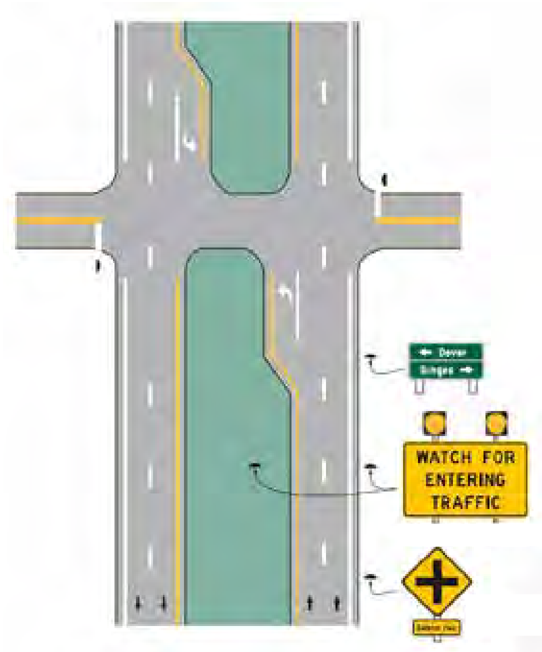
NCHRP 500 Performance Rating[39]
P – Proven
T – Tried
E – Experimental
U – Unknown

*Lower Volume ≤1000 vpd
**Higher Volume = Between 1,001 and 8000 vpd
***Optimal Conditions = 12-foot lanes, 6-foot paved shoulders
****Narrower Conditions = 10-foot lanes and no shoulders

38 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, the BCR has been left blank.

39 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Install Advanced Intersection Warning Signs



Advanced intersection warning signs can help alert drivers to the presence of an intersection ahead. Signs can be placed with sufficient distance prior to the intersection to allow drivers to perceive and react and can be installed on both sides of the roadway to solicit greater awareness. Advanced intersection signing can be used to improve notice of upcoming intersections where vertical curves impede visibility to the intersection.

Where to Use: Advanced intersection warning signs are to be applied predominantly on single through lane, high-crash, stop-controlled State intersections in both rural and urban areas. They may also be applied on dual through lane, high-crash, stop-controlled intersections with lower traffic volumes (less than about 25,000 average annual daily traffic (AADT)) where the use of J-treatments are not appropriate and the frequency of acceptable gaps for entering traffic is such that long waiting and higher risk taking are present at the intersection.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Install Advanced Intersection Warning Signs	$0 to $5,000	Proven

Top Recommended Resource:

1. FHWA, *Stop-Controlled Intersection Safety: Through Route Activated Warning Systems*, February 2011. Available at: http://safety.fhwa.dot.gov/intersection/resources/fhwasa11015/traws.pdf.

Install Dynamic Advanced Intersection Warning System

Infrastructure-based Intelligent Transportation System (ITS) technologies can be used to significantly improve the safety at stop-controlled intersections with visibility limited by vertical curves. These systems provide enhanced safety warning information for approaching drivers compared to passive warning systems. A dynamic advanced intersection warning system can provide:

- Enhanced warning to the through driver that there is a vehicle on a cross road stop approach that may enter the intersection.
- Enhanced warning to drivers on a stop approach that their trajectory speed is high and that they may run the Stop sign.
- Enhanced warning to through drivers that they are traveling at too high an intersection entry speed and advising them to slow down.
- Enhanced warning to drivers on the stop approach of entering vehicles on the through approach, inferring potential unsafe gaps.

Where to Use: This treatment may be provided at intersections that experience severe intersection-related crashes due to speed, low visibility, or insufficient gaps.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)
Install Dynamic Advanced Intersection Warning System	$5,001 to $20,000	Proven	0.10–0.76

Top Recommended Resource:

1. FHWA, *Stop-Controlled Intersection Safety: Through Route Activated Warning Systems*, February 2011. Available at: http://safety.fhwa.dot.gov/intersection/resources/fhwasa11015/traws.pdf.

Modify Horizontal/Vertical Geometry

Horizontal and vertical geometry may be reconstructed in a variety of ways. For example, horizontal and vertical curves may benefit from increased radii, thereby increasing sight distance. Modifying road geometry may also include eliminating horizontal or vertical curves and providing a more direct alignment.

Where to Use: This treatment may be used at locations where improved sight distance is needed and at locations that experience head-on and run-off-road crashes. This treatment can also be used at unsignalized intersections with restricted sight distance due to horizontal or vertical geometry and those with patterns of crashes related to that lack of sight distance that cannot be ameliorated by less expensive methods.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Modify Horizontal/Vertical Geometry	$100,001 and up	Proven

Relocate Driveways, Entrances, and Intersections

Relocating or removing private and public driveways, commercial entrances, and road or street intersections just beyond the crest of vertical curves in the direction of travel isn't always feasible but does ensure that conflicts at locations with limited sight distances are removed or remediated.

Where to use: This treatment may be used near vertical curve crests where sight distance to driveways, entrances, or intersections is limited or obstructed.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Relocate Driveways, Entrances, and Intersections	$100,001 and up	Tried

4.10. Other Treatments

Treatments in this section may be applied at specific locations to improvement safety and do not fit into any of the previous categories.

SAFETY TREATMENT	For more information, visit page	COST			SAFETY BENEFIT		BENEFIT-COST RATIO[40]			
		Initial Implementation	Ongoing Maintenance	Frequency of Maintenance (years)	NCHRP 500 Performance Rating	Crash Modification Factor (CMF)	Lower Volume*, Optimal Condition***	Higher Volume**, Optimal Condition***	Lower Volume*, Narrower Condition****	Higher Volume**, Narrower Condition****
Mitigate Ground Water to Prevent Ponding and/or Icing	148	$$$-$$$$			E					
Widen Functionally Obsolete Bridges	149	$$$$$								

Cost:
$ = $0 to $5,000
$$ = $5,001 to $20,000
$$$ = $20,001 to $50,000
$$$$ = $50,001 to $100,000
$$$$$ = $100,001 and up

NCHRP 500 Performance Rating[41]
P – Proven
T – Tried
E – Experimental
U – Unknown

*Lower Volume ≤1000 vpd
**Higher Volume = Between 1,001 and 8000 vpd
***Optimal Condition = 12-foot lanes, 6-foot paved shoulders
****Narrower Condition = 10-foot lanes and no shoulders

40 As discussed in Section 1.2, a BCR is only shown where data were available to calculate the ratio. Where data were unavailable, the BCR has been left blank.

41 As stated in NCHRP Series 500 Reports (http://safety.transportation.org/guides.aspx). Proven: The safety effect for other similar applications has shown a proven benefit. Tried: The treatment has indications that it can be expected to reduce crashes, but has some conflicting reports as to its associated safety effects or has been deployed and observed to be effective. Experimental: New treatments that still need to be tested and for which the safety effect is unknown. Unknown: Not enough is known about an associated safety performance.

Mitigate Ground Water to Prevent Ponding and/or Icing

Good site drainage is needed to keep ponding and icing from occurring. This can be accomplished through a change in runoff conditions, whether by increasing the storm drainage capacity, re-grading ditches for better flow, or making changes to the roadway superelevation.

Where to Use: This treatment is applicable at locations where roadway ponding occurs.

Safety Treatment	Initial Implementation Cost	NCHRP 500 Performance Rating
Mitigate Ground Water to Prevent Ponding and/or Icing	$20,001 to $100,000	Experimental

Widen Functionally Obsolete Bridges

Widening narrow bridges on HRRR that are unable to accommodate traffic, either as a one-lane two-way operation or lanes too narrow to accommodate two-way traffic, may help to prevent head-on and sideswipe collisions.

Where to Use: This treatment can be used at locations that experience a high frequency of head-on or sideswipe collisions due to narrow lane width or one-lane two-way operations.

Safety Treatment	Initial Implementation Cost
Widen Functionally Obsolete Bridges	$100,001 and up

5. SAFETY MANAGEMENT, THE FUNDING PROCESS, AND FUNDING SOURCES

Safety Management includes overall program direction and project prioritization, funding identification, project development, project implementation, and evaluation.

5.1. Safety Management

5.1.1. Safety Project Prioritization and Development

To prioritize and identify projects for funding, safety professionals must determine comparison criteria for this purpose. In many cases an economic appraisal is used to provide a fair comparison among projects competing for safety funds. In a basic economic appraisal, an analyst will calculate the monetary cost of the treatment and the estimated monetary value of the benefits, such as reduced number and severity of crashes. The analyst can then calculate a benefit-to-cost ratio for each potential project to compare their relative effectiveness.[42]

In addition to the calculated value, other prioritization criteria may include:

- Connecting the treatment to State Strategic Highway Safety Plan strategies;
- Leveraged funding through cost sharing with other agencies (or other similar methods that decrease treatment cost);
- Local needs of MPOs, RPCs, or local roadway agencies;
- Benefits of combining safety and non-safety funding sources (e.g., adding rumble strips to an already-funded, non-safety project); and
- Public perception of safety treatments.

5.1.2. Initial and Ongoing Treatment Costs

When selecting safety improvements to deploy, practitioners should weigh the treatments among several criteria: estimated safety benefit, feasibility or applicability of installing the treatment at a specific site or sites, how to fund the initial installation and ongoing maintenance costs while considering the ranges of those costs, and how often the treatment will need routine maintenance in order to maintain the safety benefits associated with deployment.

Typically, the initial installation of safety treatments can be financed through dedicated safety funds in additional to other funding sources used for highway construction and reconstruction. However, ongoing maintenance costs associated with the initial installation become the responsibility of the agency and are typically funded through internal operations and maintenance budgets.

Recurring maintenance costs should be considered and weighed as practitioners decide among potential treatments to deploy on HRRR. The HRRR Treatment Matrix located in this manual presents the initial deployment cost and recurring maintenance costs associated with safety treatments presented in Chapter 4 to aid in the decision-making process.

42 AASHTO, Highway Safety Manual, First Edition, 2010.

5.2. The Funding Process

State DOTs typically program safety (and other transportation) projects through their multi-year Statewide Transportation Improvement Program (STIP). A State's Planning Division is often the leader of this process, so safety-focused staff must provide project recommendations for potential funding. Specific policies, procedures, and practices vary widely by State.

Non-State agencies, such as counties, municipalities, and Tribal entities, work through regional planning commissions (RPCs), regional planning organizations (RPO), councils of government (COGs), or metropolitan planning organizations (MPOs) to identify, plan, and program transportation safety projects. Each RPC, RPO, COG, and MPO develops a Transportation Improvement Program (TIP) in conjunction with the State DOT that cites the region or area's top transportation priorities for new projects. Transportation safety projects are typically a portion of the TIP.

5.3. Legislation and Funding Sources

A number of sources for funding are available at the Federal, State, and local levels. Processes vary widely from State-to-State and year-to-year based on the current level of funding and legislation, so the best sources of information in an individual State is the State DOT Safety Engineer, State DOT Local Programs Office, FHWA Division Office, and LTAP Center.

The following sections provide background information regarding current legislation and funding sources at the time of this writing. All are subject to change.

5.3.1. Legislation and Federal Funding Sources

In 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) established the HSIP as a core Federal-aid funding program. As part of the HSIP, SAFETEA-LU introduced a set-aside provision, the High Risk Rural Roads Program (HRRRP). The HRRRP provided $90 million as an annual set-aside from a State's HSIP apportionment and was developed to help States implement solutions on the lower functional classes of rural roadways, a segment of the system often overlooked.[43]

On July 6, 2012, President Barak Obama signed into law P.L. 112-141, the Moving Ahead for Progress in the 21st Century Act (MAP-21). MAP-21 continues the Highway Safety Improvement Program with nearly double the funding from SAFETEA-LU. MAP-21 removes the HRRRP set-aside provision and also revises the definition of "High Risk Rural Road," but continues the inclusion of construction and operational improvements on HRRR as eligible HSIP projects.[44] While the $90 million set-aside for HRRR was not continued, MAP-21 contains a special rule[45] requiring obligation of funds for HRRR projects if the fatality rate on rural roads in a State is increasing. If the special rule applies to a State for a fiscal year, it must obligate projects on HRRR of an amount equal to at least 200 percent of the amount of funds the State received for FY 2009 for the HRRRP.[46]

43 23 U.S.C. §148(a)(1) defines a "high risk rural road" as: "…any roadway functionally classified as a rural major or minor collector or a rural local road (a) on which the accident rate for fatalities and incapacitating injuries exceeds the statewide average for those functional classes of roadway; or (b) that will likely have increases in traffic volume that are likely to create an accident rate for fatalities and incapacitating injuries that exceeds the statewide average for those functional classes of roadway."

44 Section 1112 of MAP-21 changed the definition of a "high risk rural road" in 23 USC 148(a)(1) to: "any roadway functionally classified as a rural major or minor collector or a rural local road with significant safety risks, as defined by a State in accordance with an updated State strategic highway safety plan."

45 23 U.S.C. 148(g)(1)

46 FHWA, "Highway Safety Improvement Program, MAP-21 High Risk Rural Roads Guidance."

There are multiple funding resources that can be used to fund recommendations for HRRR projects, depending on the nature of the suggestion. Funding for safety projects may come from a variety of Federal, State, and local sources. Some of the programs include:[47]

- **Highway Safety Improvement Program (HSIP)** – The HSIP emphasizes a data-driven, strategic approach to improving highway safety on all public roads and focuses on performance. The foundation for this approach is a safety data system, which each State is required to have to identify key safety problems, establish their relative severity, and then adopt strategic and performance-based goals to maximize safety. Every State is required to develop a Strategic Highway Safety Plan (SHSP) that lays out strategies to address these key safety problems. The HSIP has average annual funding of $2.4 billion, including $220 million per year for the Railway-Highway Crossing Program.

  For more information, refer to the HSIP Fact Sheet: http://www.fhwa.dot.gov/map21/hsip.cfm

- **23 U.S.C. 130: Railway-Highway Crossing Program (Section 130)** – The program funds safety improvements to eliminate hazards at public railway-highway grade crossings. This includes projects on HRRR and could be a potential funding source. This program is funded with a $220 million set-aside of the Highway Safety Improvement Program (HSIP).
- **Surface Transportation Program (STP)** – The STP provides an annual average of $10 billion in flexible funding that may be used by States and localities for projects to preserve or improve conditions and performance on any Federal-aid highway, bridge projects on any public road, facilities for non-motorized transportation, transit capital projects and public bus terminals, and facilities.

  For more information, refer to the STP Fact Sheet: http://www.fhwa.dot.gov/map21/stp.cfm

- **Transportation Alternatives Program (TAP)** – MAP-21 established a new program to provide for a variety of alternative transportation projects that were previously eligible activities under separately funded programs. This program is funded at a level equal to two percent of the total of all MAP-21 authorized Federal-aid highway and highway research funds, with the amount for each State set aside from the State's formula apportionments. For HRRR, this funding may be utilized for the Safe Routes to School Program.

  For more information, refer to the TAP Fact Sheet: http://www.fhwa.dot.gov/map21/tap.cfm

- **Federal Lands and Tribal Transportation Programs** – MAP-21 continues to acknowledge the importance of access to Federal and Tribal lands. Recognizing the need for all public Federal and Tribal transportation facilities to be treated under uniform policies similar to the policies that apply to Federal-aid highways and other public transportation facilities, MAP-21 creates a unified program for Federal lands transportation facilities, Federal lands access transportation facilities, and Tribal transportation facilities.

  For more information, refer to the Tribal Transportation Program (TTP) Fact Sheet: http://www.fhwa.dot.gov/map21/ttp.cfm

- **Federal Lands Transportation Program** – The program provides $300 million annually for projects that improve access within the Federal estate, such as national forests and national recreation areas, on infrastructure owned by the Federal government. This program combines the former Park Roads and Refuge Roads programs, and adds three new Federal Land Management Agency (FLMA) partners. A portion of the funds will support traditional partner agencies at current funding levels, with new partners competing for a modest portion.

  For more information, refer to the Federal Lands Transportation Program (FLTP) Fact Sheet: http://www.fhwa.dot.gov/map21/fltp.cfm.

47 FHWA, Moving Ahead for Progress in the 21st Century Act (MAP-21), A Summary of Highway Provisions. Available at: http://www.fhwa.dot.gov/map21/summaryinfo.cfm.

- **Federal Lands Access Program** – The program provides $250 million annually for projects that improve access to the Federal estate on infrastructure owned by States and local governments. Replacing and expanding the Forest Highways program, projects providing access to any Federal lands are eligible for this new comprehensive program. Funds are distributed by formula based on recreational visitation, Federal land area, Federal public road mileage, and the number of Federal public bridges.
- **Tribal Transportation Program** – This program provides $450 million annually for projects that improve access to and within Tribal lands. This program generally continues the existing Indian Reservation Roads program, while adding new set-asides for Tribal bridge projects (in lieu of the existing Indian Reservation Road Bridge program) and Tribal safety projects. It continues to provide set-asides for program management and oversight and Tribal transportation planning.
- **Tribal High Priority Projects Program** – This program is a discretionary program modeled on an earlier program that was funded by set-asides from the Indian Reservation Roads Program. MAP-21 provides $30 million per year from the General fund (subject to appropriation) for this new program.

  For more information, refer to the Tribal High Priority Projects Program Fact Sheet: http://www.fhwa.dot.gov/map21/thpp.cfm
- **Appalachian Development Highway System (ADHS)** – The ADHS program is continued, but without separate funding. Portions that are on the NHS are eligible for National Highway Performance Program (NHPP) funding, and ADHS routes, including local access roads, are eligible for STP funding. To encourage the completion of the ADHS, States are required to submit plans for completion of the system and an increased Federal share is provided.

  For more information, refer to the ADHS Fact Sheet: http://www.fhwa.dot.gov/map21/adhs.cfm
- **Bridge and Tunnel Inspection** – The program provides for continued improvement to bridge and tunnel conditions essential to protect the safety of the traveling public and allow for the efficient movement of people and goods on which the U.S. economy relies. MAP-21 requires inspection and inventory of highway bridges and tunnels on public roads. No dedicated funds are provided for inspections, but it is an eligible use of NHPP, STP, HSIP, FHWA administrative, Tribal Transportation, and Research funds. MAP-21 authorizes $400 million per year for the following six programs: Highway Research and Development, Technology and Innovation Deployment, Training and Education, Intelligent Transportation Systems, University Transportation Research, and the Bureau of Transportation Statistics.

  For more information, refer to the Bridge and Tunnel Inspection Fact Sheet: http://www.fhwa.dot.gov/map21/bti.cfm
- **Research and Technology Development and Deployment** – MAP-21 provides $115 million per year for the Highway Research and Development program. Research areas include highway safety, infrastructure integrity, planning and environment, highway operations, exploratory advanced research, and the Turner-Fairbank Highway Research Center.
- **Technology Innovation and Deployment Program** – The program provides $62.5 million per year to accelerate implementation and delivery of new innovations and technologies that result from highway research and development to benefit all aspects of highway transportation. At least $12 million per year of these funds must be used to accelerate the deployment and implementation of pavement technology.
- **Training and Education** – MAP-21 authorizes $24 million per year for continuation of training and education programs, including the National Highway Institute, the Local Technical Assistance Program (LTAP), the Tribal Technical Assistance Program (TTAP), the Dwight D. Eisenhower Transportation Fellowships, the Garrett A. Morgan Technology and Transportation Education Program, the Transportation Education Development Program, and the Freight Capacity Building Program. Also funded from the Training and Education funds are the competitively selected centers for transportation excellence in the areas of the environment, surface transportation safety, rural safety, and project finance. The Federal share for LTAP and TTAP centers remains at 50 percent and 100 percent respectively.

- **State Planning and Research (SP&R)** – MAP-21 continues the SP&R, as a two percent takedown of four core programs: National Highway Performance Program, Surface Transportation Program, Congestion Mitigation Air Quality program, and Highway Safety Improvement Program. At least 25 percent of these funds have to be used for research purposes.

  For more information, refer to the State Planning and Research (SP&R) Fact Sheet: http://www.fhwa.dot.gov.map21/spr.cfm

In addition to the major highway program funding sources, other Federal safety resources may assist with HSIP implementation. These grant programs are administered by NHTSA and FMCSA and can be used to assist with law enforcement efforts and improve traffic record data collection, data systems, and hazard elimination. The funding includes:[48,49]

- **23 U.S.C. 154 and 164 Transfer Funds** – States in which Federal-aid highway funds are transferred based on noncompliance with 23 U.S.C. 154 Open Container Requirements or 23 U.S.C. 164 Minimum Penalties for Repeat Offenders for Driving While Intoxicated or Under the Influence can use the transfer funds on approved projects for alcohol-impaired driving countermeasures or direct the funds to State/local law enforcement to increase impaired driving enforcement. States also may elect to use the funds for hazard elimination activities eligible under 23 U.S.C. 152.
- **23 U.S.C. 402: State and Community Highway Safety Grants** – Supports a full range of highway safety behavioral programs, including alcohol countermeasures, occupant protection, police traffic services (e.g., enforcement), emergency medical services, traffic records, motorcycle safety pedestrian and bicycle safety, non-construction aspects of road safety, and speed enforcement and management programs. A minimum of 40 percent of a State's Section 402 funds must be expended by local governments, or be used for the benefit of local governments. To receive Federal highway safety grant funds, State Highway Safety Offices must submit an annual Highway Safety Plan (HSP) to the NHTSA.

5.3.2. Other Funding Sources

In some States the DOT sets aside a certain amount of safety funding for State and local rural road projects. Funding sources and amounts vary from State to State, so the best resources for finding out more in a particular State are the State DOT Safety Engineer, FHWA Division Office, and LTAP Center. For example, safety efforts in Iowa on State and local roads are funded with a combination of Federal and State funds. A portion of their Road Use Tax Fund (0.5% as of 2005) has been set aside for safety projects. This gives Iowa about $7 million of State funds per year—on top of their Federal safety funding—to address the State's most pressing safety needs. Previous projects have included experimental pavement marking, data software development, the small town signing program, and research projects at local universities.[50]

5.4. Evaluation

Evaluation of safety treatments is a necessary step in the safety management process. Calculating effectiveness provides safety officials with the information needed to determine if the treatment(s) should be used in similar situations in the future.

48 FHWA, Highway Safety Improvement Program Manual. Available at: http://safety.fhwa.dot.gov/hsip/resources/fhwasa09029/sec5.cfm

49 Iowa Department of Transportation, "National Priority Safety Programs Under MAP-21, Section 405." Available at: http://www.iowadot.gov/pol_leg_services/federalregister-notices/NHTSA%20Sec.%20405%20regulatory%20analysis.pdf

50 Chandler, B., Midwest Safety Scanning Tour, Missouri Department of Transportation, 2005. Available at: http://www.modot.org/safety/Safety_Engineering/documents/2005SafetyScanningTour.pdf

Pre- and post-installation crash history and a record of treatment installations support performance assessment of each safety treatment. It is important to keep a current list of installed treatments with associated details to support these analyses. Periodic assessments will help drive decisions about whether each treatment contributed to safety improvements and why they were successful.

Required information may include crash history data (with associated details related to the treatment—crash type, frequency, severity); public input and complaints; and observations from maintenance crews or law enforcement.

Once calculated, the quantified benefits of certain treatments can be used to develop crash modification factors (CMF) to improve the analysis during project prioritization and selection.[51]

6. NAVIGATING THE SAFETY TREATMENTS

The HRRR safety treatments summarized in this manual can be systematically considered; however, only a subset of the large number of candidate treatments can potentially help to reduce crashes for a given location. One approach for selecting safety enhancements is to identify study sites, perform a descriptive statistical safety diagnosis, execute a treatment analysis, evaluate economic feasibility, and prioritize and select promising improvements suitable for consideration. The contents of this manual can be used to perform this type of assessment. The following sections briefly review each of these key steps that will enable the selection of potential safety enhancements for a study location.

6.1. Identify Study Sites

The safety treatments summarized in this manual are specifically targeted for HRRR locations and assumed to apply to two-lane highways with varying traffic volume and road characteristics. Prior to initiating the safety assessment, practitioners should identify the specific sites or site types for which the analysis will be applied. In many cases, the study may focus only on an intersection while in other cases the analysis could be targeted to a corridor or a systemic modification. Consequently, it is important in this first step to clearly identify where the analysis will apply and why this location has been selected for consideration. Figure 1 (Flowchart A) introduces an overall approach to this safety enhancement analysis. Once the study location and focus has been established, the next step is to perform a preliminary safety diagnosis.

For discussion related to spot versus systemic treatment application, see Chapter 3.2.

6.2. Perform Safety Diagnosis

The steps for the initial safety diagnosis are depicted in Figure 2 (Flowchart B). The user should develop a series of descriptive statistics regarding safety at the study location(s). In an effort to provide a statistically robust evaluation, crash data that extends across a period of 3-5 years should be used for these summaries. Crash data should be compiled so that a summary of crash frequencies per year for total crashes as well as fatal and injury only crashes can be used in subsequent analysis. In addition, crash information should be summarized by crash types. This crash type information will be used as a key diagnostic input in subsequent tasks.

51 FHWA, Road Safety Information Analysis: A Manual for Local Rural Road Owners, FHWA-SA-11-10 (Washington, DC, 2011).

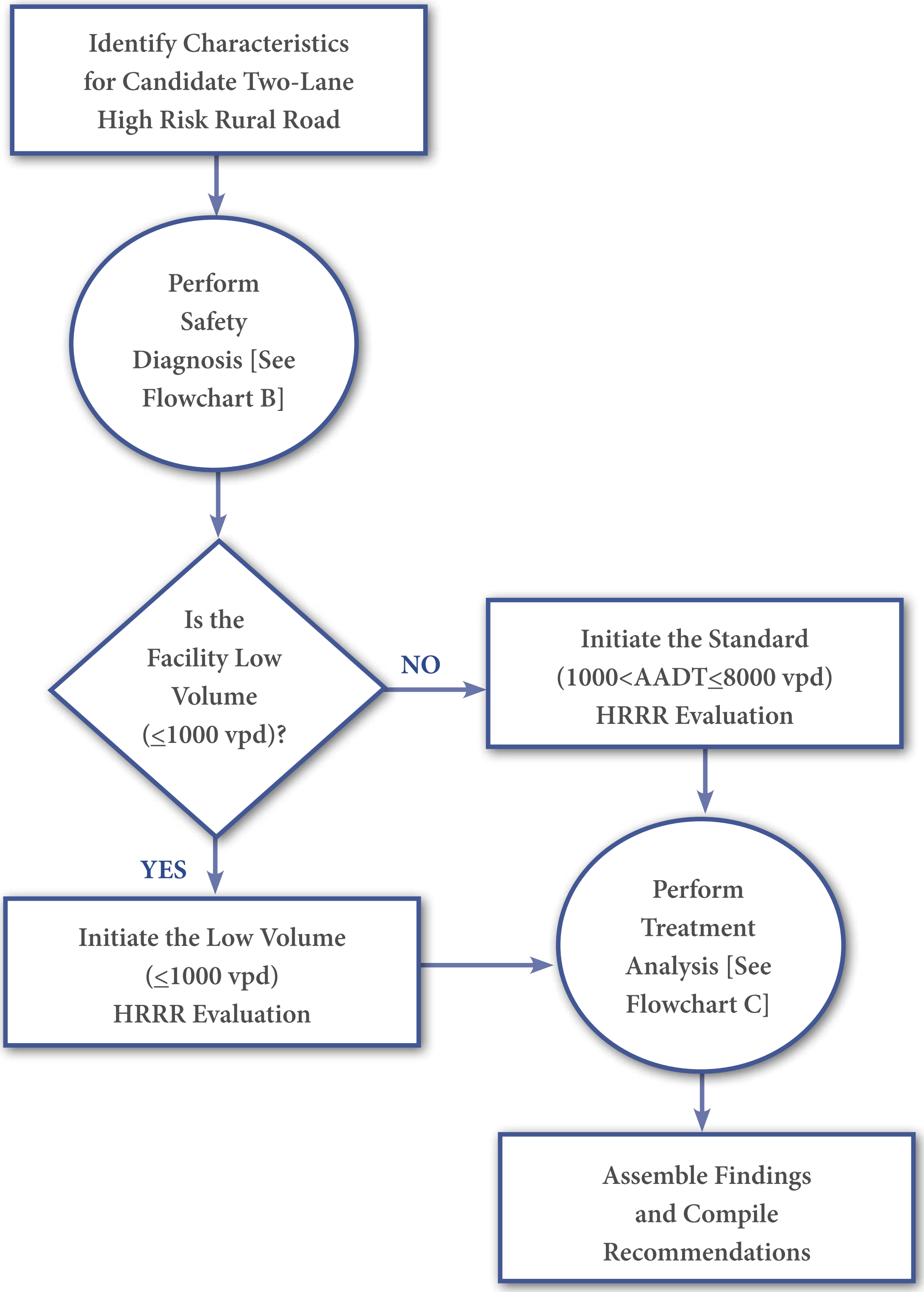


Figure 1. Flowchart A – HRRR Safety Enhancement Analysis

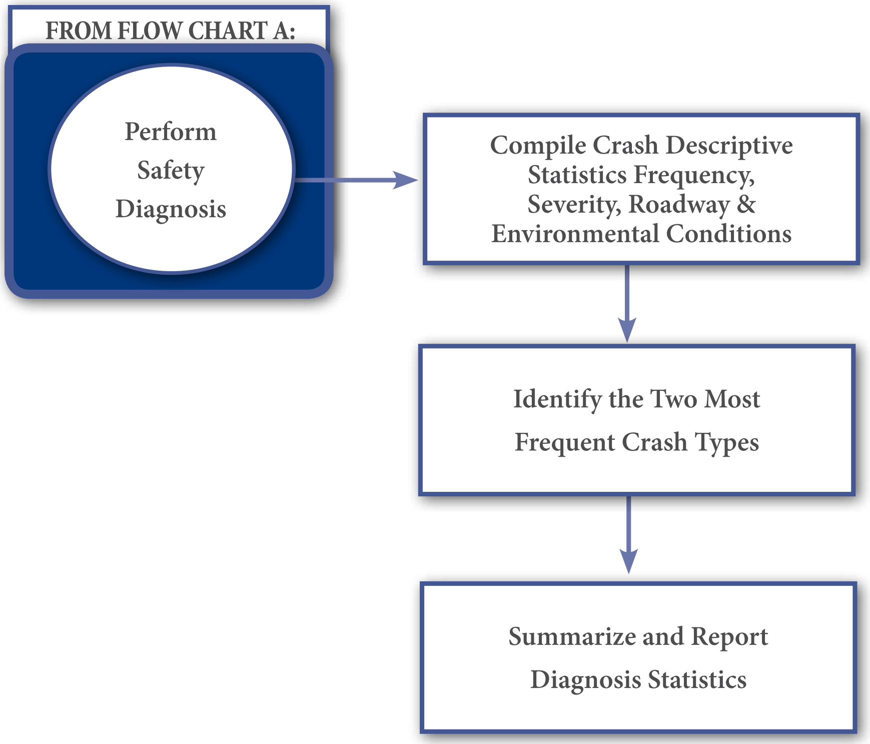


Figure 2. Flowchart B – Safety Diagnosis

The crash types should be divided into the following general categories and proportional values should be assigned based on total crashes or fatal plus injury crashes (depending on the objective of the safety enhancement effort):

- Rear-end
- Angle
- Head-on
- Fixed object
- Out-of-control
- Other
- Sideswipe
- Turning
- Run-off-road
- Animal
- Work zone

Following the development of the crash type summary for the study site, the user should identify the two or more most common crash types that occurred for the severity type targeted for reduction. If the intent is to reduce the number of fatal plus serious injury crashes, then the two or more crash types most often involved in that subset of crashes should be identified. If, on the other hand, the intent is to reduce total crashes or crashes of a specific nature, then the two most significant crash types for this group of crashes should be selected.

During the safety diagnosis step, the user should also compile information that may be contributing to the crash condition. This would include physical road features and traffic volume. In addition, unusual features identified by examining the crash history may be noted. These could include an unexpected number of crashes at dawn or dusk, inclement weather crashes, or similar.

6.3. Initiate Treatment Analysis

It may be likely that the preliminary improvement selection criteria are availability of funding, either for the initial installation or for ongoing maintenance. Additionally, the economic feasibility of a specific treatment is strongly influenced by traffic exposure at a location. Consequently, the treatments provided in this manual are further divided into lower volume (assumed to be represented by AADT=1000 vpd) and higher volume (assumed to be represented by AADT=8000 vpd) treatments. In general, the lower volume locations are also characterized by relaxed design standards such as narrower lanes and shoulders. As a result, prior to initiating the treatment analysis the user needs to clearly define which traffic volume threshold best applies to the study location. As shown in Figure 1 (Flowchart A), facilities with more than 1000 vpd are considered "Standard" or higher volume and evaluated separately from their lower volume counterparts. Figure 3 (Flowchart C) demonstrates the treatment analysis steps that can be applied to either traffic volume threshold.

Each facility should be divided into a category of intersection or segment. For locations that include entire corridors or systemic improvements, the characteristics of the prevailing targeted crash types will help determine the facility type of interest. This manual includes the following 10 general categories for the potential safety treatments:

- Horizontal curves
- Unsignalized intersections
- Pavement marking
- Roadside infrastructure
- Vertical curves
- Signalized intersections
- Signing
- Pavement and shoulder resurfacing and widening
- Non-motorized user
- Others

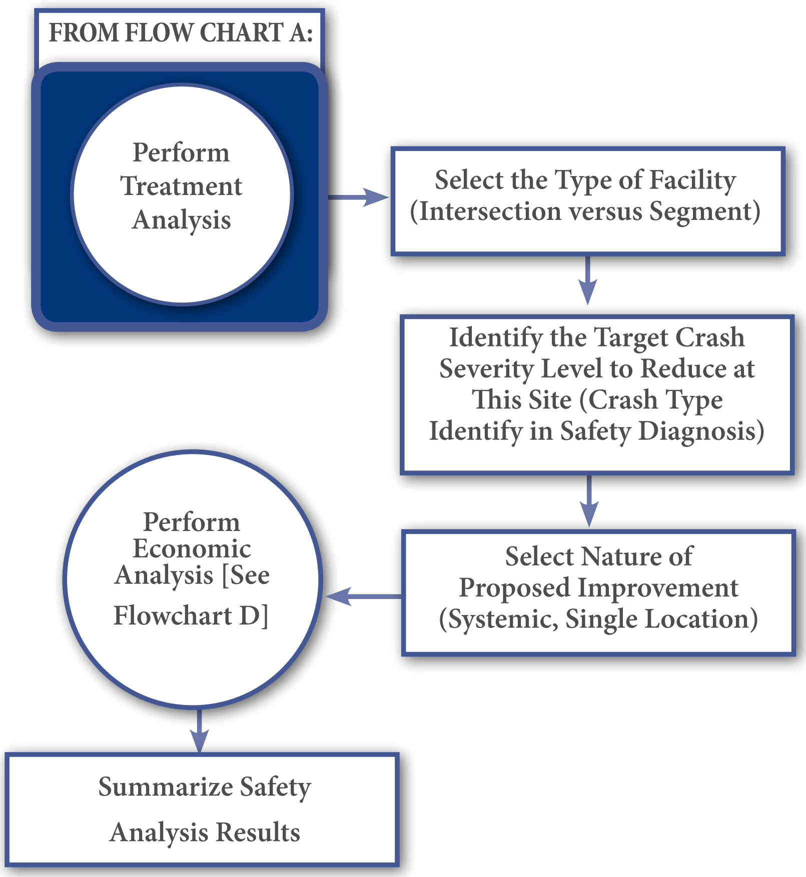


Figure 3. Flowchart C – Treatment Analysis

In many cases, an individual treatment can be included in more than one of these 10 categories. As an example, installing advanced intersection warning signs would be included in both the intersection category as well as the signing category. Within each category, the treatments tend to be further reduced into infrastructure-based treatments, traffic control treatments, and other enhancements.

Based on the two most significant crash types previously identified in the safety diagnosis, potential treatments can be identified; however, before the treatment analysis can be completed, the user should also consider the economic feasibility of a treatment for the specific study location. For example, one possible improvement that may be identified is widening a shoulder. If the study site already has a shoulder that is reasonably wide, this candidate treatment may not be practical if a different treatment can more substantially help to reduce crashes resulting in a more economically justified treatment selection. Therefore, the final step in the treatment analysis is to initiate the economic assessment for the subset of treatments identified.

6.4. Perform Economic Analysis

The benefit-cost ratio is one common method for evaluating the economic feasibility of a treatment. In addition, issues such as substantial initial investments, short life cycles, and extensive treatment maintenance must be considered to determine practical application of a treatment. The benefit-cost ratio is a numeric value that helps to capture these influences. A benefit-cost ratio value of 2.0, for example, suggests that there would be a $2 return for every $1 invested. For more information on how to calculate a benefit-cost ratio, see FHWA's Benefit-Cost Analyses Guidance for TIGER Grant Applicants.[52]

In addition to the benefit-cost ratio are other potential economic metrics. Two of these candidate cost-effectiveness values in the user guide include the equivalent annual dollars spent for fatal plus injury crashes prevented and the net annual benefit. This manual includes these economic values for each of the candidate treatments.

Of course, many safety enhancement projects are constrained by targeted funds that must be used for specific purposes or that are systemic rather than site specific. Figure 4 (Flowchart D) summarizes the basic steps required to perform the economic analysis component of the treatment selection process.

In many cases, a maximum initial investment can be a driving force in the selection of feasible treatments. The practitioner should first identify this maximum value and determine if there are any funding constraints associated with the available resources or candidate improvements. Once these economic analysis questions are answered, the practitioner can then evaluate the previously identified list of potential treatments and determine their associated economic assessment values. This information can then be used to develop a list of priorities.

Many agencies will restrict the economic analysis priority selection to a specific economic metric, so the practitioner will need to identify if this constraint applies. As an example, some agencies solely use the benefit-cost ratio for final economic decisions.

52 FHWA's Benefit-Cost Analyses Guidance for TIGER Grant Applicants. Available at: http://www.dot.gov/tiger/guidance.

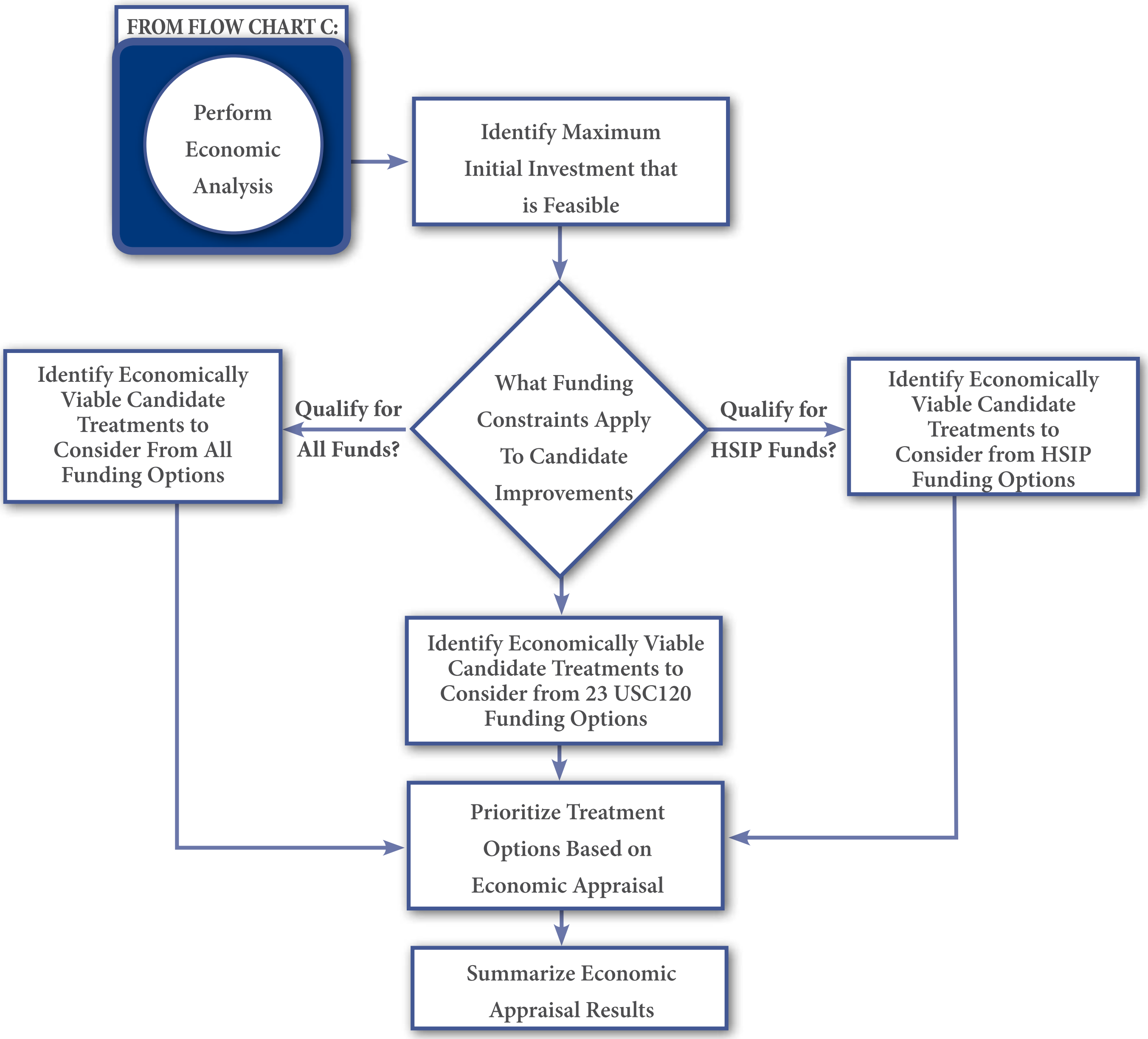


Figure 4. Flowchart D – Economic Analysis

6.5. Summarize Recommendations

Following these safety enhancement analysis steps, the user should have a short, prioritized list of candidate safety treatments. It is important to note that the intent of this HRRR safety analysis is to identify potential safety enhancements for additional consideration. Consequently, transportation agencies would then use this information as one key input into a final safety project study. Additional issues that should be considered and that are not captured as part of this analysis include, but are not limited to, potential impacts to the roadway capacity, air quality, contextually sensitive characteristics, local or regional construction preferences, and local driving laws and regulations. A final engineering study is necessary to capture these broader issues associated with a specific improvement project.

GLOSSARY

Local Technical Assistance Program (LTAP) – In each State, a LTAP center and/or a Tribal Technical Assistance Program Center can provide technical information and training for local governments and agencies that own and maintain public roads. These centers are partially funded by the Federal Highway Administration (FHWA) and provide resources to local agencies and Tribal governments.

Roadway Feature Type – Characteristics of the roadway present at a specific site. For the purposes of this document, roadway feature types may include an intersection, a roadside, horizontal curves, driving lane or shoulder, etc.

Safety Treatment or Improvement – A treatment that, once installed, helps to improve a defined safety need.

Tribal Technical Assistance Programs (TTAP) – The TTAP is a training and technology transfer resource for Native American tribes in the United States and is funded by the FHWA and the Bureau of Indian Affairs. Through technology transfer and training, research, and cultural consideration, the TTAP aims to distribute technical assistance and training activities at the Tribal level; help implement administrative procedures and new transportation technology at the Tribal level; provide training and assistance in transportation planning and economic development; and develop educational programs to encourage and motivate interest in transportation careers among Native American students.[53]

53 LTAP/TTAP website. Accessed October 14, 2013. http://www.ltap.org/about/ttap.php

For More Information

Visit http://safety.fhwa.dot.gov/hsip/hrrr/manual

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