

2.0 Run-Off-Road Research Needs

2.1 Introduction

There were more than one million run-off-road (ROR) crashes in the United States in 2002, of which 387,000 caused injury and 15,458 were fatal. A ROR crash occurs when a single vehicle leaves the traveled lanes and encroaches on the shoulder, the median, or the roadside and either collides with an object, overturns, or both. ROR crashes do not include situations in which a collision that occurred on the roadway resulted in a vehicle leaving the roadway or situations in which a vehicle crosses the centerline and crashes into a vehicle traveling in the opposite direction. However, these crash types are relevant because they often involve the same circumstances as ROR crashes.

The factors that contribute to vehicles leaving the roadway are varied and include inattention, drowsiness, use of drugs or alcohol, speeding, steering overcorrection, vehicle failure, and on-road avoidance maneuvers or collisions, among others. Road conditions can also contribute to ROR crashes. These include adverse weather, poor visibility, inadequate signing, and poor pavements, among others. Road type is also a factor in ROR crashes, with 85 percent occurring on non-freeways and 66 percent occurring on rural roads (Najm, Koopman, Boyle, & Smith, 2002).

ROR crashes most often occur with fixed objects such as trees, shrubs, poles, curbs, guard rails, and embankments. Trees, shrubs, and poles account for 43 percent of all fatal fixed object crashes. Curbs, culverts, and ditches account for an additional 20 percent of fatal fixed object crashes. ROR crashes can also occur with non-fixed objects such as parked vehicles and pedestrians. Collisions with parked vehicles accounted for about 336,000 crashes in 2002, but were less likely to be severe than collisions with most fixed objects. Vehicle rollovers are the most severe ROR crash type. About 64 percent of rollovers result in injury or death.

In recent years, many improvements have been made to reduce the likelihood and severity of ROR crashes. These improvements affect roadway infrastructure, signing, roadside design, and vehicle characteristics. Nonetheless, ROR crashes continue to occur at a substantial rate. Although ROR crashes accounted for less than 17 percent of all nonfatal police-reported crashes, they accounted for more than 40 percent of all fatal crashes. Although some of this difference may be accounted for by inconsistent rates of police reporting for different crash types, this statistic indicates that ROR crashes are more often fatal than on-road crashes. There are two primary explanations for this. First, many roadside objects such as trees and utility poles tend to cause more serious damage when struck than unfixed objects such as other vehicles. Second, vehicles that run off the road sometimes roll over. According to 1999 FARS data, 19 percent of fatal ROR crashes involved a rollover as the first harmful event and 41 percent of fatal ROR crashes involved a rollover as the most harmful event.

There are three general areas in which improvements can be made to reduce the ROR problem:

1. *Prevent the vehicle from leaving the roadway.* Although the primary responsibility to prevent vehicles from leaving the roadway falls upon motorists themselves, transportation officials can provide an environment that helps motorists to drive more safely. General improvements that can reduce the likelihood of vehicles leaving the roadway include repaving and resurfacing, installing rumble strips, improving curve and edgeline delineation, and improving signage and roadway markings. Additionally, in-vehicle systems that provide a warning to drivers when they encroach on the roadside are currently being tested.
2. *Prevent the vehicle from striking a roadside object or rolling over.* The most effective way to prevent a vehicle from striking a roadside object is to provide a clear zone free of obstructions. However, it is rarely possible to clear all obstructions. Alternatively, traffic engineers can focus on removing only the most hazardous objects. Rollovers can be reduced by improving ditch and slope design and by using roadside surface materials that minimize tripping (the event in which the rollover is initiated) and maximize motorists' ability to maintain or regain control of the vehicle.
3. *Minimize crash severity.* The two factors that have the greatest influence on crash severity are vehicle speed and the features of the struck object. Roadside should be designed using surfaces, slopes, and clear zones that allow the vehicle to decelerate as much as possible before encountering roadside objects. Additionally, many roadside objects can be made more forgiving. Hazardous objects that cannot be removed or replaced can be shielded using attenuation devices such as guard rails or crash cushions. In locations where new trees will be planted on the roadside, smaller, less hazardous species can be chosen.

Although research and practice have contributed substantially to safety improvements in all three of these areas, there are many potential improvements that have not been investigated or implemented to the extent that their contribution to ROR crash reduction can be known. The purpose of this white paper is to recommend programs of priority research to investigate innovative and unproven approaches to reduce the ROR crash problem.

The Future Strategic Highway Research Partnership's (F-SHRP) vision for roadside safety is "a highway system where drivers rarely leave the road; but when they do, the vehicle and roadside work together to protect vehicle occupants and pedestrians from serious harm" (McGinnis, 2001). This vision emphasizes the interrelation of the three areas described above. Campbell, Lepofsky, and Bittner (2003) note that two current NCHRP projects are being conducted to better understand the factors that influence ROR crash severity, so "In light of these projects, the F-SHRP Safety Research Plan is focused on understanding the initial road departure event." In concert with the goals stated by F-SHRP, this white paper focuses on the fundamental understanding of the underlying human and situational factors that are associated with ROR crashes. Such knowledge is a necessary foundation for the development of countermeasures, and will be especially helpful in targeting countermeasures to the locations and situations where they will be most cost-effective.

2.2 Run-Off-Road Research Topics

Category	Project Title	Type of Research	Likelihood of success (1-5 scale)	Duration (months)	Cost (in millions)
Run-Off-Road	ROR 1: Use of Rumble Strips on Non-Freeways	Applied	5	36	1
Run-Off-Road	ROR 2: Development of a System of TCDs to Reduce ROR Crashes at Curves	Applied	4	18	1
Run-Off-Road	ROR 3: Optimizing the Net Benefits of Delineation	Applied	4	36	1
Run-Off-Road	ROR 4: Development and Application of a Roadside Inventory Database	Advanced	3	24+	1.5

Table 2.2.1

2.3 Knowledge Strongholds and Gaps

This section presents a brief overview of strategies to reduce the likelihood and severity of ROR crashes. The purpose of this overview is to distinguish strategies that have a known effect (knowledge strongholds) from strategies that are not well understood, but may have a positive effect (knowledge gaps). More thorough evaluation and discussion of many of these strategies can be found in sources from which this summary draws substantially. These include AASHTO's *Roadside Design Guide*, NCHRP Report 500 Volume 6: *A Guide for Addressing Run-Off-Road Collisions* (Neuman, et al., 2003), *Strategic Plan for Improving Roadside Safety* (McGinnis, 2001), *Detailed Planning for Research on Making a Significant Improvement in Highway Safety: Study 2 – Safety* (Campbell et al., 2003).

Curve Design. The effects of curves on ROR crashes are generally well-documented. Vehicles are 1.5 to 4 times more likely to leave the roadway on curves than straight roadway sections (Glennon, Newman, & Leish, 1985; cited in Neuman et al., 2003) and crash likelihood generally increases with curve sharpness. However, little is known about the speeds and angles at which vehicles tend to run off the road on curves, how these characteristics differ on straight road segments, and what effects they may have on crash likelihood and severity. Furthermore, additional research is needed to determine why driver errors continue to occur on curves, often despite the presence of TCDs.

Surfacing Materials. Skid-resistant surfaces help to prevent vehicles from losing traction and control. Skid-resistance is often most important when roads are wet. New York State

established criteria for resurfacing roadway sections based on the proportion of crashes in wet and dry weather. Following treatment, wet-weather crashes at the resurfaced locations decreased 50 percent. *NCHRP Report 486* (Harwood, Kohlman Rabbani, Richard, McGee, & Gittings, 2003) provides guidelines on how to select the most cost effective locations to resurface and to decide if geometric improvements such as shoulder paving should be made during the resurfacing effort.

Shoulder Design. A paved shoulder that is free of objects can provide a “margin of error” for drivers that allows them leave the traveled roadway without losing control or striking a roadside object. Shoulder width has an inverse relationship with crash likelihood. The Federal Highway Administration has established accident modification factors (AMFs) to predict the crash reduction that would be associated by a given increase in shoulder width or an upgrade of shoulder surfacing (Harwood, Council, Hauer, Hughes, & Vogt, 2000). Although the effects of shoulder width and materials are well-established, the effect of edgedrop height (the vertical dropoff where the edge of the shoulder meets the roadside) is not. It is generally assumed that the larger the edgedrop is, the more difficult it is for a driver to safely return to the roadway once one or more tires have exceeded the edgedrop. However, there is insufficient data to back up this assumption.

Rumble Strips. Shoulder rumble strips have been shown to substantially decrease the likelihood of ROR crashes on freeways with paved shoulders. However, much less is known about the effects that shoulder rumble strips may have on nonfreeways, many of which have smaller shoulders and smaller clear zones than freeways. There is also little known about the effects of rumble strips on roads with no shoulder or an unpaved shoulder. Potential treatments for these roads include rumble strips on the edgeline or in the middle of the lane. Midlane rumble strips are intended to rumble when the vehicle’s wheels closest to the centerline move too close to the edge of the roadway. Centerline rumble strips, which have been recently investigated by Kansas Department of Transportation and the Insurance Institute for Highway Safety (IIHS) may also have the potential to reduce the likelihood of vehicles crossing the centerline and colliding with oncoming traffic.

Signage. Signage can be used to warn drivers of upcoming curves, hills, and other features that may be associated with ROR crashes. The MUTCD currently provides guidelines for signs to indicate the direction of curves and the safe speed. Innovative signage using ITS technology may also help to control vehicle speed. For example, a speed detection system can be installed a sign prior to a sharp curve that provides a “Slow Down” message to vehicles entering the curve at an unsafe speed. ITS can also be used to create a variable speed limit system that can be adjusted according to road or weather conditions.

Pavement Markings and Roadway Delineation. The primary purpose of roadway delineation as it relates to ROR crashes is to provide drivers with advance information about the path of the roadway ahead. The MUTCD provides extensive and detailed guidance on pavement markings. It also often provides more than one marking option to engineers, and these options may differ in terms of safety benefits and costs to implement. For example, there is evidence that raised pavement markers (RPMs) to supplement edgelines can improve delineation and thereby reduce ROR crashes, but the benefits of RPMs may depend upon the type of roadway where they are

installed. More research is needed to determine which pavement marking options are most effective, and most cost effective, for a variety of roadway conditions.

Slope and Ditch Design. There are two primary goals of slope and ditch design: 1) allow the driver to maintain control of the vehicle and 2) minimize the likelihood of a rollover. Maintaining control of an errant vehicle increases the likelihood of safely returning to the roadway or coming to a stop without striking an object or rolling over. Crash testing, simulation, and crash statistics have helped researchers to create a comprehensive picture of why rollovers occur. Off-road rollovers most often occur when a vehicle strikes an object while skidding laterally. In nearly a third of single-vehicle rollovers, the first object struck is a ditch or embankment. In general, ROR crashes are more likely to occur on wider and flatter slopes with surface materials or objects that can trip a skidding vehicle. AASHTO's *Roadside Design Guide* (2002) recommends safe clear zone distances according to side slope steepness, design speed, and design ADT. Although safe slope and ditch design have been established, improving existing roadways can be difficult and expensive. It is therefore a research priority to target slope and ditch improvements to locations where they can provide the greatest safety benefit.

Roadside Crash Hazards. The simplest way to ensure that vehicles do not collide with roadside hazards is to remove all hazards within a reasonable distance of the roadway. AASHTO's *Roadside Design Guide* (2002) provides guidance on recommended clear zone distance for various roadway types. However, it is not always possible to create safe clear zones, especially on nonfreeways where trees, curbs, posts, and an assortment of other hazards are often located adjacent to the roadway. For a variety of reasons, removal of hazardous objects is often not an option. Alternatives to removal include installing less hazardous barriers and attenuation systems (e.g., guard rails and crash cushions) and replacing hazardous objects with less hazardous alternatives (e.g., breakaway signs and poles). *NCHRP Report 350* (Ross, Sicking, Zimmer, & Michie, 1993) provides guidelines for crash testing and in-service evaluation of various highway safety features. Another alternative to object removal is improved delineation of roadside objects using reflective markings. Section 3C.03 of the MUTCD provides guidance on markings for objects and other hazards, such as drop-offs, adjacent to the roadway. However, it may be possible to develop innovative delineation markings that are more effective than the standard markings.

Summary of Knowledge Strongholds and Gaps. Thanks to decades of research, highway engineers have an arsenal of ROR countermeasures available for implementation. Guidelines documents have been developed that specify how, and under what conditions, countermeasures should be implemented. Crash databases, crash testing, and simulations are being used to document how and why ROR crashes occur. One of the most recent advances in ROR crash prevention and mitigation is the development of analysis programs that can be used to target roadside improvements to the locations where they are most needed.

Although ROR research has progressed substantially, there is still much to be learned. Many roadway and roadside improvements have been studied individually, but very few studies have focused on how ROR countermeasures function as a system. Past research has also not provided a strong basis for understanding the driver behavioral events that result in ROR crashes and the human factors considerations that relate to these causes. Although statistics describe the

situations associated with ROR crashes (e.g., speeding, alcohol/drug intoxication, slick roadway) less is known about the specific driver actions that cause (or fail to prevent) ROR crashes. F-SHRP notes that most collisions are to some extent caused by driver errors; therefore understanding the driver's actions in the moments before and during the ROR crash is critical to understanding why ROR crashes occur and how they can be prevented and mitigated (Campbell et al., 2003).

2.4 Critical Future Highway Issues

The highway environment is not static. The future may bring changes in travel patterns, traffic characteristics, driver demographics, driver behavior, vehicle characteristics, communications technologies, and other factors. As the transportation system evolves, established knowledge and practice may become dated as new problems and opportunities arise. Researchers should be aware of likely changes so that appropriate conditions can be included in their detailed study plans. As Campbell et al. (2003) noted, the “changing traffic environment both complicates and heightens the need for fundamental traffic safety research.” This section highlights those potential changes that are most relevant to ROR crashes. It draws on issues identified in F-SHRP reports and other sources. Issues are grouped under three general headings: changes among drivers; changes in vehicles; and changes in the highway environment.

Changes Among Drivers

Aging Population: As members of the baby boom generation enter their sixties and seventies, older drivers are likely to represent an increasingly substantial percentage of the driving public. Staplin, Lococo, Byington, and Harkey (2001) have discussed how standards and practice for sight distance, horizontal and vertical alignment, and associated TCDs are based on driver performance capabilities that are affected by age. These capabilities include diminished visual performance, slower reaction time, attentional deficits, poorer physical vehicle control capability, and less accurate perceptual judgments. Current practice may not adequately meet the needs of older drivers, and Staplin et al. provide some guidelines for design, delineation, and signage that better accommodate the older driver. Future practice related to ROR crashes should take the increased older driver population into account. Proposed research that includes driver perception and response considerations must include adequate representation of older drivers and new practices must match their capabilities

Aggressive Driving: Aggressive driving is a current hot topic in highway safety, but has proven difficult to study empirically (Llaneras & Lerner, 1999). Part of the difficulty can be attributed to the lack of clear definitions of aggressive acts. For example, red light-running may be done aggressively to beat the light or accidentally as a result of driver inattention or misjudgment of signal timing. As highways become increasingly crowded, it is likely that aggressive driving will become more common and it is important to understand its causes and effects. For instance, speeding is a common precursor to ROR crashes, but less is known about the effects of speeders on surrounding traffic. Other aggressive behaviors that may play a role in ROR crashes include frequent or erratic lane changes, cutting off other drivers, tailgating, and aggressive interactions (i.e., road rage). There are many challenges inherent in understanding drivers'

intentions and motivations, but future research may reveal why aggressive behaviors occur, how they relate to ROR crashes, and how they can be prevented.

Changes in Vehicles

In-Vehicle Distractions: Technologies such as entertainment systems, navigation systems, and handheld devices such as cell phones are becoming increasingly common in vehicles (Llaneras & Singer, 2002). Empirical evidence suggests that in-vehicle distractions can have a negative effect on driver performance, including lane-keeping, perception-reaction time, and eyes-off-road time. The universe of in-vehicle devices is growing rapidly and the distractions that put drivers at risk in the future may not be the same as the distractions drivers currently face. Driver distraction may have implications for traffic control devices. Visual cues will be less effective, so acoustic or tactile signals may be important. Much depends on future device designs, accessibility, and regulation. Although in-vehicle devices are likely to become increasingly common in vehicles, designs that reduce driver workload and prevent drivers from using them at inopportune times may contribute to safer device use.

Hazard Warnings and Alerts: With improvements in vehicle sensing technologies, hazard warnings and alerts are becoming feasible for wide scale deployment. Many vehicle manufacturers currently offer proximity sensors on their vehicles, and more advanced systems are under development. Future systems may help to prevent ROR crashes by using a combination of GPS, GIS map databases, and vehicle sensors to determine the appropriate speed for an upcoming section of road and warn drivers who are encroaching on an edgeline or centerline. In fact, the recently developed Road Departure Crash Warning (RDCW) system includes both a speed warning component and a lane departure component (University of Michigan Transportation Research Institute, Visteon Corporation, & AssistWare Technologies, Inc, 2003). The use of hazard warnings and alerts may hold great promise for reducing ROR crashes, but a number of important questions need to be answered. First, research must be conducted to choose the most appropriate warning modalities and features. Second, warnings algorithms must be calibrated to maximize real warnings while minimizing nuisance warnings (false alarms). Finally, special consideration must be given when multiple warning systems are present in the same vehicle (e.g., lane departure, speed warning, proximity alert). Drivers must be able to immediately recognize the meaning of a warning if they are to respond quickly and appropriately. The National Highway Traffic Safety Administration (NHTSA) is currently developing and testing alerts for use under conditions of multiple warnings issued individually and concurrently.

Driving Automation: Systems that automate portions of the driver's task are just beginning to penetrate the vehicle fleet. These systems sense the roadway environment and intelligently respond to changing conditions. Automation can be employed for driver convenience or for imminent crash avoidance. Although a variety of automation systems have been developed or simulated, adaptive cruise control (ACC) is the only system that is currently available as a manufacturer option in passenger cars. Automation for imminent crash avoidance involves many of the same issues as hazard warnings and alerts, but these systems go one step further by taking some degree of vehicle control away from the driver. Fundamental questions regarding the use of automation for imminent crash avoidance are yet to be answered. For example, how should alerts and warnings be integrated with automation and at what point should control be

taken away from the driver? The answers to these questions will likely depend on the specific system in use and the nature of the imminent crash scenario. Although automated crash avoidance may have the advantage of instantaneous response, the nature of the vehicle response may not always be appropriate for the specific threat. Furthermore, little is known about how drivers react when vehicle control is taken from them. With regard to automation for driver convenience, the primary concern is that drivers may become complacent or over reliant and fail to properly monitor the environment or respond to changing conditions. An additional concern is drivers who are unsure of the degree of automation (e.g., Will ACC respond to stopped traffic ahead?)

Crash Detection and Reporting: The basis of crash detection and reporting systems is an event data recorder (EDR). EDRs, which are commonly referred to as “black boxes,” collect information about vehicle motion, inputs, outputs, and system functionality. EDRs are sometimes installed by vehicle manufacturers to aid in vehicle diagnostics, but in the case of a crash, data collected immediately before the crash can be used to reconstruct the crash scenario. Crash reconstructions can help researchers to understand the cause of the crash, the events that cause harm, and what countermeasures may have prevented or mitigated the crash. EDRs can be configured to detect a crash if some criterion is met, such as an extreme deceleration or an airbag deployment. Although current EDRs capture some useful information, additional data such as vehicle trajectory, deceleration, and lateral motion would be valuable in helping to reconstruct crashes. With additional data, EDRs could even be used to record close calls, as indicated by antilock brake activation, lateral vehicle motion, or extreme steering inputs. NCHRP Project 17-24, entitled *Use of Event Data Recorder (EDR) Technology for Roadside Crash Data Analysis*, which will be completed in June 2004, will recommend a minimum set of EDR data to address roadside safety. As EDRs become more common in vehicles, crash reconstructions may provide an increasingly clear picture of why crashes occur and how they can be prevented. In addition to aiding in crash reconstruction, EDRs can also be used to report crashes. If the EDR detects vehicle characteristics that indicate that a crash has occurred, a wireless communication device can be used to report the crash. When used with a GPS unit, the vehicle’s location can be reported to emergency services, even if the victim is not capable of communicating. The OnStar system in some General Motors vehicles provides this service. Automatic crash reporting is especially useful for ROR crashes because they often occur in rural areas where there may not be bystanders to report the crash.

Vehicle Compatibility with Roadside Hardware and Features: The requirements for roadside hardware (e.g., guardrails, signage) and roadside features (e.g., side slope, shoulder treatments, clear zones) are related to features of the errant vehicle. The current vehicle fleet is very diverse, and includes automobiles, motorcycles, SUVs, vans, light trucks, and heavy trucks of various sorts. These vehicles differ in size and weight, stability characteristics, handling, braking, and may also be traveling at a range of speeds. Designing roadway and roadside features to be compatible with the full range of vehicles is a current challenge. This problem undoubtedly will continue into the future and the characteristics of the vehicle fleet may change in a variety of ways. The particular changes may be difficult to predict and may be influenced by economic, technology, environmental, and policy considerations. In addition to changes in vehicle size, there may be new types of passenger and commercial vehicles as well as non-traditional downsized personal transportation products. Alternative fuels and alternative power systems

may influence vehicle size and handling characteristics. Vehicle control and stability systems, such as steer-by-wire, brake-by-wire, or intelligent suspensions, may influence performance related to ROR crashes. Various degrees of machine intelligence and automation may also affect crashes. Intelligent cruise control and driver assist systems are currently developing examples. While predicting the evolution of the vehicle fleet decades from now may be difficult, it seems likely that diversity will continue to present challenges for design of the roadway and roadside to optimally mitigate ROR crashes.

Changes in the Highway Environment

Increased Traffic Volumes: Motorists traveled 2.83 trillion miles on US highways in 2002, up from 2.25 trillion in 1992 and 1.60 trillion in 1982. As the number of vehicle-miles driven increases, traffic volumes are likely to increase on many roads. Increased attention should be given to the effects of traffic volume, especially as average daily traffic begins to exceed design capacity. Increasing traffic volume is likely to have a complex effect on ROR crash likelihood and may also vary by road type. Research is needed to determine the effects of increased traffic volume on ROR crashes and to help choose appropriate countermeasures if highway improvements are needed.

Intelligent Signing: Most roadway communications to the motorist, such as signs and markings, are fixed. Even those displays that are variable (changeable message signs [CMS]) are generally changed by direct intervention of a human controller. However, it is likely that future highways will take more advantage of intelligent systems to communicate warnings to the motorist. Roadway based sensors, processors, and communications, used in conjunction with display technologies such as CMS or in-vehicle display panels, can be used to dynamically communicate changing situations to motorists. Intelligent sign systems have been demonstrated or implemented for such applications as speed control, work zone messages, and route guidance. Intelligent systems have potential application to ROR crashes. They may be used to detect and warn about hazardous conditions, such as wet/icy road surfaces, queued traffic, work zones, or obstacles. They may be used to indicate safe speeds based on current conditions. They may also be used to provide targeted messages to individual drivers. For example, a message might be provided to a driver approaching a curve at too high a speed, and might even consider vehicle characteristics (e.g., size, weight). To date, there have been few efforts directed specifically at ROR crashes, although there are examples such as curve warnings when the road is wet or icy (Brisbane & Vasiliou, 2002) and freeway exit ramp warnings to large trucks if high speeds and potential instability are sensed (Strickland & McGee, 1997). More research will be needed on the benefits, drawbacks, and cost effectiveness of intelligent roadway systems directed at ROR problems.

2.5 Research Recommendations

Comment from R+T Partnership Steering Committee

Ongoing and Proposed Projects – It's not possible to tell what recent ongoing or proposed projects were reviewed (e.g., F-SHRP and NCHRP 17-11). Some other examples include: For ROR 1, "Crash Reductions Following Installation of Centerline Rumble Strips on Rural Two-Lane Roads" published by the Insurance Institute for Highway Safety (IIHS) should be

referenced. With the results of this study, there doesn't appear to be a significant need to do more research in this area. Ongoing NCHRP 3-61 project, "Communicating Changes in Horizontal Alignment," has similar objectives to ROR 2. The ROR 2 write-up should explicitly acknowledge and address the relationship with this ongoing project. Also, there's the NCHRP 5-17 project "Safety Evaluation of Permanent Raised Pavement Markers" currently being completed.

Response from White Paper authors

Comments from the R&T Partnership Steering Committee were thoroughly reviewed and the responses have been fully integrated into this revised chapter. The responses were not provided on a question-by-question basis (we had not interpreted the request in this way), but rather woven appropriately throughout the text discussion and recommendations.

Comment from R&T Partnership Steering Committee

Speed - The authors mention speeding as one of the contributory factors to ROR crashes but do not address the need to manage speed in the subsequent reasoning. Yet speed affects both the frequency and the severity of ROR crashes. Therefore, research into speed choice and speed control ought to be given consideration.

Comment from R&T Partnership Steering Committee

Median Barriers - The safety effects of median barriers are still unclear so research on this topic should be explored.

Comment from R&T Partnership Steering Committee

Curve Design and Safety - There are still a number of unresolved issues pertaining to curve design and safety. What are the relationships of tangent length, superelevation, pavement widening, lane/shoulder values, etc. with safety? The effects of curvature on multi-lane roads may be quite different than for two-lane roads, but requires more research. In regards to delineation treatments for curves, changing unsafe behaviors by traffic control devices has low probability. Instead, broaden to include research on effects of shoulder paving, widening, and for other factors.

Comment from R&T Partnership Steering Committee

Shoulder Widths - The relationship of shoulder widths and safety is still unclear. Therefore, more research is needed.

Comment from R&T Partnership Steering Committee

Understanding Driver Behavior - The authors of the papers indicate that past research has not provided a strong basis for understanding the driver behavioral events that result in ROR crashes and the human factors considerations that relate to these causes. However, there is no reasoned

description of how better “understanding the driver behavioral events that result in ROR crashes and the human factors considerations that relate to these causes” would lead to cost-effective countermeasures. A general understanding of the main factors already exists. As noted early on in their white paper: “The factors that contribute to vehicles leaving the roadway are varied and include inattention, drowsiness, use of drugs or alcohol, speeding, steering overcorrection, vehicle failure, and on-road avoidance maneuvers or collisions, among others.” Nor is there a particular shortage of research on inattention, drowsiness, alcohol, etc.

Comment from R&T Partnership Steering Committee

Visibility - The paper identifies that visibility (or lack thereof) and visibility issues (signage and pavement markings) are factors that should be evaluated. However, the potential for improved lighting, both in terms of absolute levels and optimal use of lighting, are not considered. While the data tend to support the claim that improved visibility, through the use of fixed roadway lighting, will result in a reduced crash rate and reduces the severity of crashes, additional research needs to be completed to calculate the actual impact of a lighting system for different highway types and intersections.

Comment from R&T Partnership Steering Committee

Crash Testing and Simulation Work - While the authors noted three areas of ROR improvements on page 4, all this work seems to be oriented to preventing the vehicle from leaving the road, with nothing on preventing crashes with roadside objects or lessening the severity of rollovers or crashes with objects. If FHWA is going to continue to fund crash test and simulation work, someone needs to look closely at these two areas and determine what the major research needs are.

Research recommendations for four high-priority topic areas follow. A primary objective of this white paper was to identify a selected set of key research topics and develop these into formal research problem statements. Numerous possibilities for addressing ROR problems exist, and the set of four recommended topics should not be seen as comprehensively covering all of the issues and approaches. Rather, taking F-SHRP criteria into account, it represents a judgment about the advanced and applied research topics that appear particularly promising in advancing knowledge in a way that will support future efforts in ROR crash reduction.

In developing these recommendations, we have drawn on existing suggestions for research as well our own review of the problem. Documents that provide substantial insight into roadside safety issues include *NCHRP Report 500, Volume 6: A Guide for Addressing Run-Off-Road Collisions* (Neuman et al., 2003); *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* (Ross, Sicking, Zimmer, & Michie, 1993); *Research-Gap Identification Background Issues: Human Factors* (Hanscom, 2002); and *AASHTO's Roadside Design Guide* (AASHTO, 2002)

The magnitude of the ROR problem has also made this crash type a focus within a number of recent studies, workshops, and conferences. Many of these efforts have produced lists of

research needs for ROR. Among these efforts have been: NCHRP's *Strategic Plan for Improving Roadside Safety* (McGinnis, 2001); *Safety Research Agenda Planning Conference* (Research and Technology Partnership, 2002); and Future Strategic Highway Research Program's (F-SHRP) *Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life* (2001). As a result, dozens of suggestions for research topics already exist. These range from highly specific, narrow recommendations (e.g., effect of 4-inch vs. 6-inch edge line) to general targeting of broad issues (e.g., vehicle/roadside interaction). Appendix A provides the roadside safety research topics proposed by various researchers, committees, and workshop groups. In developing the research project recommendations that follow, we have tried to integrate many of these issues into systematic programs of research activity that deal comprehensively with the major issues.

ROR 1. Use of Rumble Strips on Non-Freeways

Comment from R&T Partnership Steering Committee

The IIHS completed a comprehensive study on centerline rumble strips (referenced earlier) so additional research on this type of rumble strip shouldn't be a priority. Evaluating other types of rumble strips on non-freeways (e.g., shoulder rumble strips, edgeline rumble strips, rumble strips on very narrow shoulders) has merit.

Response from White Paper authors

Problem Statement

Based on research conducted by individual states, the Federal Highway Administration estimates that shoulder rumble strips on freeways can reduce ROR crashes by 15 to 70 percent (<http://safety.fhwa.dot.gov/programs/rumble.htm>). However, less is known about the effectiveness of rumble strips on non-freeways. There are a number of rumble strip applications that may have the potential to improve roadside safety on non-freeways. These include:

Shoulder rumble strips: On roads with shoulders, rumble strips can be placed outside the edgeline. Research is needed to determine cost/benefit ratios for narrow shoulders. Although evidence does not suggest a negative effect of rumble strips on narrow shoulders, logic dictates that as the distance between the rumble strip and the edge of the paved shoulder decreases, the likelihood of recovery decreases as well.

Edgeline rumble strips: Another option for roads with narrow or nonexistent shoulders is to install rumble strips on the edgeline itself. There are three primary concerns regarding this application. First, drivers may try keep their distance from the rumble strips and as a result, be more likely to encroach into the lane to the left or cross the centerline. Second, research has not investigated the possibility that a driver who has come into contact with a rumble strip will make a steering overcorrection and encroach into the lane to the left or cross the centerline. Third, edgeline rumble strips must not degrade the quality of the edgeline delineation, though edgelines painted on rumble strips were found to have excellent visibility in a Michigan study cited by Morena (2003).

Midlane rumble strips: Neuman and his associates (2003) discuss the potential of midlane rumble strips to prevent ROR crashes. The authors note that midlane rumble strips may be most effective when shoulder rumble strips are not feasible. Because they are located in the center of the lane, midlane rumble strips may also be an effective countermeasure against centerline encroachments. However, negative effects of midlane rumble strips may include lack of public acceptance, risk to motorcyclists, and interference with snow removal. Furthermore, to avoid a constant annoyance during lane changes, use of midlane rumble strips will most likely be restricted to two-lane roads.

Centerline rumble strips: Although crashes in which vehicles cross over the centerline and strike opposing traffic are not classified as ROR crashes, the causes are often the same. Centerline encroachments have one of three results: a collision with oncoming traffic, a ROR event if the driver does not collide with oncoming traffic yet fails to make a steering correction, or a recovery into the correct travel lane. Centerline rumble strips may alert drivers who have encroached on the centerline and help them to recover safely. However, the potential negative effects of edgeline rumble strips may apply to centerline rumble strips as well (e.g., lane deviations to avoid rumble strips and degraded visibility of centerline delineation). Centerline rumble strips are of less concern for the proposed research because 1) the primary crash types for this treatment are head-on collisions and sideswipes rather than ROR, 2) the University of Kansas (in progress) and the Insurance Institute for Highway Safety (2003) have conducted recent studies of centerline rumble strips on two-lane rural highways, and 3) additional research is needed to investigate the value of highway-dividing median barriers as an alternative to centerline rumble strips. Nonetheless, centerline rumble strips have common attributes with other rumble strip treatments directly relevant to ROR and may be used concurrently with other types of rumble strips, in which case centerline rumble strips should be considered part of a larger system of countermeasures to prevent crashes.

The rumble strip applications discussed above may have the potential to reduce ROR crashes in a cost effective way. However, direct evidence of their effectiveness is incomplete. Furthermore, although many studies have found that ROR crashes are less frequent after rumble strips are installed, it is not known how rumble strips actually influence driver behavior (Campbell et al., 2003). This project proposes to investigate the effects of rumble strips for non-freeway applications, compare cost to implement versus safety improvement, and provide guidance on targeting installations to locations where they will have the most positive effect.

Method / Approach

Task 1: Identify alternatives and key factors. Review literature, current practices, design alternatives, and existing guidance regarding the use of rumble strips. Identify the key factors related to the use of rumble strips on non-freeways, including roadway, roadside, and vehicle characteristics. Include consideration of the requirements of non-motorized roadway users, including pedestrians, bicyclists, and ADA requirements. Develop a set of alternative treatments for the use of non-freeway rumble strips and the key factors, strengths, and weaknesses of each.

Task 2: Test track or other controlled evaluation of driver response and acceptability.

Systematically evaluate alternatives for rumble strip design and placement under controlled driving conditions. Compare alternatives in terms of driver reaction time, speed and accuracy of

recovery, using distracted and/or fatigued drivers and/or induced tracking errors. Collect data on problems and acceptability for various road user groups, including various categories of passenger vehicle, motorcycle, bicycle, and pedestrian. Investigate the changes in driver behavior that are associated with rumble strips through observation and discussion.

Task 3: Identify most promising treatments by condition. Based on the findings of Tasks 1 and 2, identify a set of most-promising rumble strip treatments. Organize recommendations by roadway type and characteristics.

Task 4: Field evaluation. Field-implement selected rumble strip treatments for formal comparison and evaluation. Comparisons should include a no-rumble-strip control condition as well as alternatives for rumble strip implementation (e.g., shoulder, edge line, centerline placements, RPM vs. milled/rolled, spacing, and dimensions). Site considerations should include geometry, design speed, ADT, crash history, shoulder and roadside characteristics. Treatment and control conditions must be comparable in terms of weather/seasonal effects. Measures of effectiveness should include the following:

- Driver performance: Both positive and negative effects of the treatment on driver performance should be measured. Measures should include shoulder encroachments, center line or lane line encroachments, and lane position. Since lane departures may be relatively infrequent, some automated system of data recording (e.g., sensors, video image processing) should be considered.
- Crashes and incidents: Records of crashes and incidents (from sources such as police reports, road assistance) should be compared for treatment and control conditions. The analysis should also consider “accident migration” effects (reduced crashes in the treatment area, but increased crashes in surrounding areas). The extent of the treatment area, the crash history of the roadway, and the duration of data collection should capture enough incidents to provide a meaningful comparison.
- Road user acceptance: Surveys, complaints, or other methods to determine the acceptability of the treatment to all classes of road users (including motorcyclists, bicyclists, and pedestrians).
- Maintenance issues and costs

Task 5: Estimate of safety outcomes, cost/benefit. Based on the findings of Task 4 and the literature of Task 1, estimate the probable safety effects (crashes, injuries, fatalities) of various rumble strip treatments for various conditions. Conduct cost-benefit analyses, including crash costs, installation, and maintenance.

Task 6: Guidelines and decision aids. Provide systematic guidance on how to select the most appropriate rumble strip treatment, warrants/recommendations for the use of rumble strips, and considerations for various road user groups.

Project Duration

A minimum of three years should be anticipated for this project. Tasks 1 – 3 would require a year and the field evaluation at least two years, assuming a before/after design. Because ROR crashes are rare events for any given stretch of highway, crash data may need to be collected over a longer period.

Payoff Potential

Rumble strips have established benefits for freeway applications. Because most ROR crashes occur on non-freeways, the potential exists for significant benefits from wider use on such roads. The proposed project would demonstrate and quantify the benefits associated with various rumble strip designs and roadway conditions and would provide designers and engineers with criteria and methods for implementing the most effective treatment.

ROR 2. Development of a System of Countermeasures to Reduce ROR Crashes on Curves

Comment from R&T Partnership Steering Committee

As the authors note, “The payoff potential of this study is largely dependent upon the assumption that unsafe driving behaviors are amenable to change.” Inasmuch as the chances of changing unsafe behaviors by a system of TCDs are not large, it seems that this specific project does not hold much promise for significantly reducing ROR crashes on curves now in service. Still a program of research into the safety of horizontal curves is in order. For curves now in service a research program along the suggested lines seems appropriate. It’s recommended, as stated earlier, that pavement widening on curves, shoulder paving, and guardrail installation be added to the measures considered (and that the title to be changed from “system of TCDs” to “system of countermeasures”). For curves not now in service the issues are entirely different. The problem should not be how to bend the drivers’ expectations to be in line with the curve on their paths but how to shape the curve so that the expectations of drivers do not need to be unduly bent.

Response from White Paper authors

On a per mile basis, curved sections of highway experience more ROR crashes than straight sections. Najm, Schimek, and Smith’s (2001) analysis of 1998 GES data includes a breakdown of factors associated with ROR crashes on curves. The authors report that about 28 percent of ROR crashes occur on curves. Roadway factors associated with ROR crashes on curves include: two-lane undivided roads (about 95 percent of crashes in which number of lanes was reported), non-freeways (90 percent), and a posted speed limit of 55 mph (33 percent of non-freeway crashes). Slightly more crashes occur during daytime than in the dark, and slightly more crashes occur under adverse and/or slippery conditions than dry and clear conditions, though these statistics do not reflect rates of exposure to these conditions. Although roadway and environmental factors often play a significant role in ROR crash likelihood, most crashes are to some extent the result of driver error. The driver circumstances most often associated with ROR crashes on curves include speeding (35 percent) and alcohol/drug use (18 percent).

Although numerous studies have evaluated methods to improve curve safety, the frequency of ROR crashes on curves indicates that current countermeasure systems are not having an ideal influence on driver behavior. “System” refers to the concern that all of the aspects of the roadway work together in a complementary fashion and result in safe and appropriate driver behavior. These system elements include all of the various signs and markings, roadway geometric features, lighting, and other aspects, both at the curve site and on the approach to it. A

limitation of previous research is that it often examined elements individually, whereas the driver is influenced by the entire system of features he or she encounters. The ability to reduce the likelihood of ROR crashes through improved curve design, shoulder paving and widening, or other physical aspects of the site will vary considerably, and there will be more opportunity for new facilities than for existing facilities. The research project should address all aspects of curve site as a system, including physical features as well as TCDs and lighting, and looking at how these factors interact to determine what the driver actually does.

There is a need for a comprehensive look at alternatives for a systematic approach to improving driver behavior on the approach to and negotiation of a curve. This may include treatments to improve curve awareness (e.g., fixed warning signs, active warning signs, and pavement markings), curve perception (e.g., RPMs, post-mounted delineators, and arrow panels), awareness of conditions (e.g., visibility warnings, slickness warnings, oncoming traffic warning), and speed choice (existing countermeasures and variations on existing countermeasures such as spacing delineators to give the illusion of increasing speed), and human factors solutions (e.g., variable speed warnings based on environmental conditions, speed-activated warning to speeders using radar or laser detection, or oncoming traffic warnings to motorists on blind curves).

NCHRP Project 3-61, “Communicating Changes in Horizontal Alignment,” which is currently being conducted by Michigan State University, addresses a number of these issues. The goal of this project is to develop a standard system of traffic control devices (TCDs) to better communicate information about upcoming curves to drivers. The scope of this project is limited to currently existing TCDs. This project is an important step in improving signing and delineation at curves and should provide a foundation for future advanced research.

The next step should be to build on the products of Project 3-61 by investigating innovative new technologies for curve communication and by expanding the focus to include roadway and roadside design factors, as well as non-TCD countermeasures such as lighting. Continuous fixed roadway lighting is associated with a reduction in nighttime crashes, but is usually too expensive for use on the rural roads where ROR crashes most often occur. Noncontinuous lighting at hazardous locations may be a more cost-effective solution, but a number of questions must first be addressed (e.g., Will noncontinuous lighting create glare and interfere with drivers’ darkness adaptation? Will noncontinuous lighting reduce the conspicuity of TCDs? Will the lighting poles be roadside hazards themselves?).

An ideal treatment for a problem curve site would accomplish three interrelated goals:

- Good driver perception of curve geometry while approaching and negotiating the curve
- Driver recognition and appreciation of the hazard
- Proper speed selection on approach and through the curve

These needs should be considered together. For example, improved delineation may make the path clear but can sometimes lead to *faster* speeds. Speed control measures may be ineffective if the driver does not appreciate the potential hazard at the site. The objective of the proposed research is to quantify the effectiveness of alternative treatments, singly and in combination, as they relate to the characteristics of the site. The goal is to provide the traffic engineer with a set

of options, with guidance in selecting treatments based on site characteristics and crash history. The emphasis of this project is on providing drivers with the information they need to choose safely negotiate curves rather than providing warnings and countermeasures to correct or protect errant vehicles.

Method / Approach

Task 1: Identify alternatives and key factors. Review literature, current practices, design alternatives, innovative prototypes, and existing guidance, regarding signage, delineation, and pavement markings for curves. Particular attention should be given to NCHRP Project 3-61. Using information from research and crash studies, conduct detailed task analyses to identify driver information needs and error potential on the approach to and negotiation of curves. These analyses should be used to generate a list of typical curve types and ROR scenarios to represent the range of important environmental and traffic conditions. Develop systems of alternative countermeasures for ROR crashes on curves and identify the key factors, strengths, and weaknesses of each. Map TCD devices and functions to the driver requirements in the task analyses.

Task 2: Evaluate countermeasures. Using laboratory, test track, or closed-road methods, evaluate the systems of countermeasures identified in Task 1 across a variety of representative roadway and environmental conditions. The objective of this research is to determine the effectiveness and appropriateness of each system of countermeasures. Specifically, the countermeasures must be visible, understandable, credible, and have a positive influence on behavior. Key measures may include speed selection/uniformity, recognition/tracking of path, and risk perception.

Task 3: Field implementation. Based on the results of Task 2, implement the most promising systems of countermeasures at select curves. The purpose of this implementation is to determine the real-world effects of the countermeasures. Countermeasures should be implemented at curves that represent a broad range of characteristics (e.g., speeds, sharpness, sight distances, number of lanes). Measures of success may include crash history and direct observation of motorist behaviors, including lane deviations, speed entering curve, and speed in the curve. Measures should also be recorded at matched control sites to account for trends not attributable to the countermeasures.

Task 4: Develop guidelines. Based on the results of Tasks 2 and 3, as well as existing guidance, develop/revise guidelines for the use of countermeasures to help drivers negotiate curves. Guidelines should address design and installation, cost, locations where they should or should not be used, and interaction with other countermeasures. The scope of the guidelines should bear in mind that a large body of guidance already exists on this topic and that the purpose of these guidelines is to provide new alternatives and to supplement and improve current best practices.

Project Duration

This entire project would require at least 36 months. Task 1 would require about four months. Task 2 may require six months to one year, depending upon the study methodology. Task 3 would require about eight months to install countermeasures and conduct a before-after evaluation of vehicle speeds and lane positions. If statistical comparison of crash data is a high

priority, Task 3 may require at least one additional year to collect a sufficient amount of data. Guidelines development would require an additional six months.

Payoff Potential

The majority of ROR crashes on curves are the result of preventable driver errors. The goal of this project is to develop systems of curve delineation that reduce the likelihood of ROR crashes on curves. The payoff potential of this study is largely dependent upon the assumption that unsafe driving behaviors are amenable to change. Even small changes in behavior are likely to result in a substantial reduction in ROR crashes on curves. Although the cost of treatments such as fixed roadway lighting may limit them to the most hazardous locations, treatments using relatively inexpensive devices may be sufficiently cost-effective for widespread use. The findings of this study will be most beneficial on existing roads where inexpensive alternatives to reengineering are needed to reduce the frequency and severity of ROR crashes at curves.

ROR 3. Optimizing the Net Benefits of Delineation

Comment from R&T Partnership Steering Committee

This proposed project is important. Its subject is the behavioral adaptation to various delineation devices and asks to what extent better delineation is converted into increased confidence, reduced alertness, higher speed etc. This project would be better classified as “fundamental research” since its object is to provide the now missing understanding of adaptation. Also, the results of the recently started study NCHRP Project 17-28 “Pavement Marking Materials and Markers: Safety Impact and Cost-Effectiveness” should feed into this research project. Also, NCHRP 5-17 project “Safety Evaluation of Permanent Raised Pavement Markers” mentioned earlier, should be considered. Finally, if lab studies are considered, it is critical that the lab measures used be validated surrogates of crashes (perhaps a fundamental research issue).

Response from White Paper authors

Problem Statement

When roadway and roadside delineation are improved, motorists are better able to perceive the proper path, track their vehicle’s position, and recognize driving demands and potential hazards. This should result in fewer ROR crashes and reduced injury. However, research on delineation has observed mixed results (Neuman et al., 2003). Findings have ranged from clear benefits to minimal effects to negative effects. For example, Kallberg (1993) found that on certain low design standard roads, the installation of raised reflector posts led to a significant *increase* in nighttime crashes.

One reason why the full benefits of improved delineation are not realized is that drivers may alter their driving behavior as a result of the “improvement.” In other words, if they continued to drive just as they had before the enhanced delineation, the treatment would lead to reduced crashes. But what actually happens is that behavior is altered in ways that give back part, or all, of the benefit. For example, when delineation is improved, speeds often increase (although in some studies, the delineation improvement has been confounded with road resurfacing, making interpretation difficult). Increased speed can influence safety in several ways. It can make path

tracking more difficult. It reduces the time that a given heading error will lead to an encroachment and it makes error recovery more difficult. Speed increases crash severity, should a crash occur. Increases in speed related to improved uproad path clarity can mean that the driver has less time to react to non-delineated road elements and hazards (“selective visual degradation”). Speed also influences where drivers direct their point of gaze and at greater speeds there is less peripheral vision sensitivity to near roadside cues.

In addition to the direct effects of speed, improved delineation might negatively influence driver behavior in other ways. The driver may see the road section as less ambiguous and of higher quality, reducing the perceived risk and sense of caution. The driver may devote less attention to tracking the vehicle’s position and path. There may be more willingness to engage in distracting activities that take the eyes off the road. Finally, particularly at night, numerous roadway and roadside (e.g., object markers) delineation elements sometimes can make the path confusing and lead to driver perceptual errors.

These concerns are examples of a general highway safety phenomenon termed “behavioral adaptation,” whereby roadway improvements do not result in the level of safety benefit that might be predicted, due to other induced changes in driver behavior. Improved delineation can certainly help reduce ROR crashes. However, we lack an adequate understanding of the conditions under which delineation alternatives will be effective, ineffective, or even counter-productive. We also do not understand behavioral adaptation to delineation enhancements well enough to know how to minimize its effects and maximize the benefits.

The purpose of the proposed research is to understand how delineation influences driver behavior, both negatively and positively, to result in some net safety benefit. The objective is to define the methods and conditions under which delineation will be most beneficial and to identify ways to minimize the negative effects. The focus of the research is on basic, traditional fixed markers and delineation, rather than more elaborate and high-cost technologies. While both day and night conditions should be considered, the issue is probably of greater concern at night.

Numerous research reports, guidelines, and standards documents that have addressed delineation, but this project is not intended to provide redundant research, syntheses, or meta analyses. Rather, this project will investigate the behavioral effects of current delineation and search for solutions to increase their systematic effectiveness. While most delineation studies have focused on crash history, visibility, and conspicuity, the proposed study will focus on the human factors that influence driver behavior. Another project with complementary goals is NCHRP Project 17-28, entitled “Pavement Marking Materials and Markers: Safety Impact and Cost-Effectiveness.” This objective of this project is to investigate the safety and cost-effectiveness of existing pavement markings and markers and develop guidelines for their use. This project was recently awarded and will be completed in 2007. A synergistic opportunity may be available between the proposed study and the NCHRP study.

Method / Approach

Task 1: Experimental studies of driver behavior. This task should use an appropriate mix of laboratory, driving simulator, and test track methods to develop an understanding of how drivers

react to various delineation configurations. Information should be acquired on such measures as the speeds that drivers adapt, the speeds they see as appropriate, glance locations, lane tracking, speed profile/braking, perceived risk/roadway demand, hazard recognition/perception-reaction time, willingness to engage in distracting activity, and the reasons underlying driver beliefs/attitudes about the road. The research should include a range of driver ages and capabilities and a range of roadway and geometric conditions. The set of experiments should provide a comprehensive description of how delineation and roadway factors influence the range of driver actions. Net safety benefits of alternative practices for key roadway/geometric conditions should be estimated.

Task 2: Development predictive model of delineation effects on driver behavior. Based on the findings of Task 1, develop a model that predicts how drivers will respond to a given treatment for a given application. The model should include driver attributes as well as delineation and roadway factors. The model should predict driver behavior and resultant effects on crash frequency and severity.

Task 3: Field comparison and evaluation of selected treatments. Field implements selected treatments to provide direct comparisons of alternatives in terms of behavioral effects and safety-related measures of effectiveness. The roadway situations and delineation treatments selected for field evaluation should be based on a need to identify optimal treatments, clarify questions remaining from the Task 1 experiments, and validate the Task 2 model.

Task 4: Guidelines for use of delineation treatments. Based on the findings and the model, develop guidance to aid traffic engineers in selecting delineation treatments that will maximize the net benefits for a given situation. The guidance should include recommendations for TCDs in addition to delineation, where that is seen as part of an effective system to generate the desired driver behavior. The guidance should focus on existing delineation and marking devices and techniques. However, if the research suggests innovative treatments that may be more effective than current practices, these should be included as possibilities or as recommendations for further research. The scope of the guidelines should bear in mind that a large body of guidance already exists on the topic of delineation. Guidance should focus on maximizing the benefits of delineation. If feasible, adapt the predictive model into a user-friendly decision tool that can be used by engineers to predict the effects of delineation enhancements on traffic behavior and safety outcomes.

Project Duration

The various sequential tasks of this project would require about three years. This is based on an estimate of one year for the experimental lab/simulator/test track work, six months for model development, one year for the field evaluations, and six months for finalizing the model, developing guidance, and designing a model-based decision tool.

Payoff Potential

Because this work addresses difficult, fundamental driver behavioral issues, there is some risk that the findings may not be definitive. But the fundamental nature of the work also means there is enormous potential for broad safety benefits and the opportunity to impact a great deal of practice.

ROR 4. Development and Application of a Roadside Inventory Database

Comment from R&T Partnership Steering Committee

The paper does not make it clear that an early step should be the determination of roadside research questions that need to be answered and cannot without this inventory, and the determination of other uses of the data for the collecting agency (e.g., use in maintenance or hardware inventory programs, use in tort cases, etc.). Current ongoing and proposed efforts (e.g., ARAN, FHWA digital highway measurement vehicle, F-SHRP) are not documented here. This is an important topic worth undertaking.

Response from White Paper authors

Problem Statement

In recent years, advances in GPS locating and computing technology have facilitated the development of GIS databases that can be used to maintain data about roadway geometry, traffic, maintenance information, crash history, and a variety of other information types. GIS enables highway databases to be viewed as interactive maps with data displayed by location. GPS technologies can be used to collect field data and map it to the GIS database. A thorough discussion of GPS/GIS interactivity issues can be found in *NCHRP Synthesis 301: Collecting, Processing, and Integrating GPS Data into GIS* (Czerniak, 2002).

The combination of GIS and GPS has opened new possibilities for roadside safety. For instance, a GIS database can be enhanced to include data on roadside features and safety countermeasures, including maintenance history. This roadside data can also be linked to ROR crash data from police reports. Police crash reporting procedures may also be improved to link ROR crash data more accurately with the locations where they occur. In fact, police may be able to use GPS to identify the exact location where a vehicle left the roadway and the exact location where it came to rest. Such information would greatly improve the understanding of vehicle dynamics before and during the ROR event, and would be an invaluable supplement to (and validating measure of) crash testing and crash simulation. Improved crash reporting combined with a detailed knowledge of roadside features may then aid in the identification and treatment of the most hazardous roadside locations. Campbell et al. (2003) consider a GIS database of roadway and roadside features to be a critical aspect of F-SHRP, especially to enable a large scale, long term instrumented-vehicle study of crash risk factors in naturalistic driving. Table 2.1 lists the potential uses of a GIS database for roadside safety. The table distinguishes between basic uses (possible with GIS database alone) and advanced uses (requiring additional enabling systems or technologies). There are other uses for GIS data, but this project exclusively addresses roadside safety.

The US Federal Highway Administration (FHWA) is currently testing a van that uses an array of sensors to create a three-dimensional digital highway map that includes data on roadway and roadside features (P. Mills, FHWA, personal communication, April, 2004). In addition to recording its location, the van will be able to scan pavement roughness for signs of wear, record lane width, presence of markings, and location of roadside hardware and traffic control devices.

All of this can be done while the van is traveling at speeds up to 60 mph with other vehicles present on the road. Although the system has not yet been field tested, it is designed to provide a GIS database and map that can be used to maintain information on roadside hardware. The system is even capable of digitizing three-dimensional roadway environments and transferring them into a driving simulator. FHWA and Pennsylvania Department of Transportation (PennDOT) plan to use the van to explore possible safety improvements at curves. Real highway segments will be digitized for study using FHWA's driving simulator at the Turner-Fairbank Highway Research Center.

A similar system is marketed by Roadware Corporation (<http://www.roadware.com>). ARAN (Automatic Road ANalyzer) is available in three models ranging in price from \$180,000 to \$1,000,000. The models range in size from a minivan to a full-size van to a larger cube van. The van can contain a maximum of 15 data collection subsystems. Data can be collected at highway speed, and include pavement roughness and rutting, pavement texture, grade, pavement condition, GPS location, location of roadway and roadside features, and video of the pavement, roadway, and roadside. Users can specify the number of subsystems they want to have. Data is coded to the exact location in a GIS and users can interact with the GIS to view roadway features and observe the condition of highway assets such as signs, roadside hardware, and pavement markings.

Table 2.5.1 Potential Uses of GIS Data to Improve Roadside Safety

Data Class	Example Elements	Potential Data Uses
BASIC USES		
Roadway Inventory	Number of lanes Lane width Lane markings/markers Speed limit Horizontal curves Vertical curves Pavement quality Sight distance	Roadway maintenance history Link to crash statistics Enhance detail of crash statistics Evaluate compliance with current guidance Identify locations needing improvement Aid in studies of countermeasure effectiveness
Roadside Inventory	Hardware type and location TCD type, location, visibility, and luminance Obstacle type and location Lighting type and location Shoulder width and materials Rumble strip type and location Slope/ditch angle/width Right of way width	Roadside maintenance history Link to crash statistics Enhance detail of crash statistics Evaluate compliance with current guidance Identify locations needing improvement Aid in studies of countermeasure effectiveness
ADVANCED USES		
Supplement crash statistics with Event Data Recorder (EDR) Information	Extreme deceleration Lateral motion Skidding Antilock brake deployment Airbag deployment Vehicle trajectory Location of control loss Location of first harmful event Location of subsequent harmful events Location where vehicle came to rest	Enhances understanding about crash causation Aids law enforcement in conducting crash reconstructions Vehicle crash metrics can be used to supplement crash testing and simulation Advanced EDRs may provide valuable crash surrogate data (i.e., close calls) Provides data to support insurance and tort liability claims
Use roadway/roadside database as foundation for in-vehicle ROR crash avoidance alerts, warnings, and countermeasures	Roadway/roadside database GPS-based in-vehicle navigation system	Curve and speed advisories Lane deviation warning system May be tied in with navigation system
Use roadway/roadside database as foundation for driving studies	Roadway/roadside database Vehicle instrumented with GPS as well as additional sensors and recorders	Provides researchers with detailed information about the highway environment in which subjects are driving Especially useful for long-term naturalistic driving studies

Another prospect made possible through the digitization of roadside features in a GIS database is the linkage of the roadside data with in-vehicle technologies. One potential use of this linkage is an in-vehicle GPS navigation system that provides a speed advisory or warning when approaching hazardous curves, as defined by crash history and/or roadway features.

Before these advantages can be realized, the roadside data must be collected and merged with a GIS. The purpose of this project is to develop a cost effective method to compile roadside information in a GIS database, linking this information to current databases and crash history, and improving highway design tools and best practices for roadside improvements. Ultimately, the addition of roadside data into GIS databases should allow engineers to gain a better understanding of factors that influence ROR crashes and how improvements can be made in the most cost effective manner. This project should also consider ITS applications of the roadside database including in-vehicle technologies.

Method / Approach

Task 1: Survey of DOT use of GPS/GIS and other technologies for roadside data. Conduct an exhaustive survey of state DOTs to assess how many use GPS/GIS to inventory roadside features. Compile a list of roadway and roadside features that are inventoried and the methods used to collect the data. Assess the extent to which these data aid users in identifying problem roadside locations and targeting roadside improvements. Determine what roadside data that is not currently compiled may provide additional benefit to engineers seeking to make roadside improvements. Also identify areas for improvement over current data collection, storage, and retrieval methods.

Task 2: Workshop on user needs and preferences. This workshop would bring together all parties with a stake in the development of a roadside database. This includes those who will participate in data collection and data management as well as those who may benefit from the use of the database, including government officials, highway engineers, safety researchers, law enforcement, and insurance industry representatives. The focus of the workshop is to allow stakeholders to have input in the design of the system so that it meets their needs. The potential uses listed in Table 2.1 may provide a starting point, but the ultimate users of the system should suggest additional possibilities and guide the focus and prioritization of resources.

Task 3: Technology review. Review potential technologies for roadside inventory, including systems currently in use. Consider technologies in terms of data collection, data transfer, data storage, compatibility, flexibility, security, and user interface.

Task 4: Develop data specifications and inventory methodology. Based on the results of Tasks 1 through 3, define specifications for technologies, data needs, and data collection methodology. One likely method will involve using a one-pass van to rapidly geocode roadside features. This method was the highest-rated ROR research topic in the recent Safety Research Agenda Planning Conference (Research and Technology Partnership, 2002). The one-pass van could be supplemented by direct observation to determine hazard type or to collect additional data. Additional data may be provided from engineering plans and maintenance records. Technologies should also be acquired as part of this task.

Task 5: Pilot test data collection procedures. In cooperation with selected state DOTs, a small sample of roadside sites should be inventoried and added to a GIS database to ensure that all systems are functional and compatible. The data should also be checked for compatibility and usefulness with roadside crash prediction models and roadside improvement cost/benefit tools, as well as vehicle-linked systems for warning, alert, and navigation.

Task 6: Collect roadside data. If Task 4 indicates that the data collection methodology is sound, thorough, and cost-effective, larger-scale data collection may begin. A plan should be developed to determine which agencies will collect data and what strategy will be used to select and prioritize sites for addition to the database.

Task 7: Integrate and standardize database. Ultimately, the roadside inventory data should be integrated with other roadway databases through a common GIS map and referencing system. Standard data elements and GIS systems should be used nationwide to allow maximum flexibility and compatibility of the data. Appendix A of *Strategic Plan for Improving Roadside Safety* (McGinnis, 2001) includes a detailed list of objectives and action items related to this task. The database should also be compatible with infrastructure- and vehicle-based intelligent technologies.

Project Duration

This project requires the cooperation and participation of numerous parties, as well as the acquisition and development of technologies, many of which may need to be built specifically for this project. As a result, a period of 4 – 5 years should be allowed for adequate collection and evaluation of data.

Payoff Potential

If successful, implementation of an improved roadside inventory method would allow more thorough analysis of crash causation and would aid decision-making by authorities regarding implementation of ROR countermeasures. Although a roadside GIS would provide many benefits as a stand-alone system, it may also be used as a platform for future research on in-vehicle navigation systems and alerts, naturalistic driving behavior, and detailed crash metrics based on EDR information.

2.6 Summary

The research projects discussed in this white paper were designed to fill critical knowledge gaps and to provide valuable insight into ROR crash problems and solutions. Based on the success of rumble strips on freeways, rumble strips are expected to provide substantial benefits on non-freeways. The project on this topic has a very high likelihood of establishing the effectiveness of various rumble strip applications on many different types of highways. The project to improve TCDs at curves also has the potential for substantial safety improvements, but success in this project requires developing TCDs that have a greater influence on behavior than currently used devices. Closely related to this project is the research goal of optimizing the net benefits of delineation. This project addresses high level issues of human perception and behavior, but an understanding of these fundamental driver issues may provide a foundation for future theory,

research, and safety countermeasures. All of the projects proposed in this white paper are independent of one another and take different approaches to improving highway safety. Although there are many more research needs than those addressed here, these four projects have significant potential to increase safety in a cost effective way.

2.7 Appendix A: Compiled Lists of Run-Off-Road Research Needs

This appendix provides lists of ROR research needs statements created by various working groups, committees, and researchers. These lists reflect the variety of strategies available to address roadside safety. Some of the lists emphasize narrowly focused current needs while others take a broad approach that emphasizes the need for a program of research to work toward long term safety improvements. Although the lists have been reformatted and some details have been removed for succinctness, the content of the lists have not been edited.

Strategic Plan for Improving Roadside Safety (McGinnis, 2001): This document presents a detailed plan to reduce the frequency of ROR crashes and mitigate their effects. The vision of the plan is “a highway system where people do not pay with their lives when vehicles inadvertently leave the road; but when they do, the vehicle and roadside work together to protect vehicle occupants and pedestrians.” The plan “contains 5 missions, 25 goals, 78 objectives, and 359 action items, 221 of which are research-oriented.” For simplicity, this appendix only extends to the “goal” level of detail.

- *Mission 1 Increase the awareness of roadside safety and support for it.*
 - A coalition of governmental, industrial, institutional and civic partners that will work toward the improvement of roadside safety
 - A heightened awareness of the importance of roadside safety by the public
 - Increased emphasis on roadside safety by partners and stakeholders and better communications between them
 - Sufficient financial resources
 - On-going dissemination programs
 - A roadside safety component in all DOT safety management systems
 - On-going process for updating the strategic plan
- *Mission 2 Build and maintain the information resources and analysis procedures to support improvement of roadside safety.*
 - Improved roadside and roadway databases
 - Sufficient roadside safety information resources on crashes, in service projects, research results, ...
 - State-of-the-art methodologies for analysis and simulations of crashes and crash tests
 - On-going programs to conduct safety analyses and identify hazardous roadside locations
- *Mission 3 Keep vehicles from leaving the roadway.*
 - Improved highway designs that reduce the probability of vehicles leaving the roadway
 - Improved traffic operating environment that reduces the occurrences of roadside encroachments
 - Sufficient maintenance of highways and vehicles to reduce the probability of loss of vehicle control
 - Improved vehicle-based systems that keep drivers on the road
 - Improved driver performance and behavior

- *Mission 4 Keep vehicles from overturning or striking objects on the roadside when they do leave the roadway.*
 - Improved roadway geometrics and roadside designs that reduce the probability of overturns
 - Improved vehicle designs that increase stability
 - Improved roadsides that reduce the number of collisions with hazardous objects
 - Improved driver performance in run-off-the-road situations
- *Mission 5 Minimize injuries and fatalities when overturns occur or objects are struck in the roadside.*
 - Optimum use of roadside safety features in relation to their selection, design, installation & maintenance
 - Improved roadside safety hardware
 - Improved vehicle compatibility and crashworthiness
 - Increased seat belt use and effectiveness and enhanced occupant protection systems
 - Improved emergency team responsiveness for highway crashes

Detailed Planning for Research on Making a Significant Improvement in Highway Safety. Study 2 – Safety (Campbell, Lepofsky, & Bittner, 2003): This report, which was prepared for F-SHRP, addresses future research needs in two high-priority areas: roadside safety and intersection safety. The report takes a holistic approach by creating a plan of codependent research studies. Research is proposed in three interrelated topic areas: research tools and methods, risk studies, and countermeasure evaluation. The list below includes project titles and objectives, but substantial additional detail is not reproduced here.

- **Topic 2-1: Research Tools and Methods**

- *Project 2-1.1: Legal and Privacy Issues in Recruiting Volunteer Drivers and Vehicles for Field Studies of Driving Safety*
Objective: The objective of this project is to develop recommended procedures to address privacy and legal issues inherent in a large-scale field study with volunteer drivers using their own vehicles equipped with extensive data recording capabilities.
- *Project 2-1.2: Development of Analysis Methods for Site-Based Risk Studies Using Recent Data*
Objective: The objective of this project is to further develop the hardware and software used for the site-based data collection approach. The goal is a semi-automated system that identifies the primary conflict situations and calculates the conflict severity incrementally as the vehicles move through the site. Continuous conflict, or traffic, events should be uniquely identified so they can be extracted as a unit for analysis. For example, the minimum value of the relevant crash margin measure could be extracted for vehicle pairs observed in a particular conflict situation, such as left-turn-across-path. The goal of this project is to enhance the performance of current systems so they can meet the needs of the site-based risk study.

- *Project 2-1.3: Development of Analysis Methods for Vehicle-Based Risk Studies Using Recent Data*
Objective: The objective of this project is to develop the analytic approach for the F-SHRP instrumented-vehicle field study and carry out a demonstration of the method using data from recent field studies for the road departure and intersection safety issues. Key aspects include the application of crash surrogate approaches (traffic conflicts, critical incidents, near-collisions), linking of roadway information based on GPS location, and the development of data storage and retrieval methods to implement these analytic approaches with the very large data sets produced by instrumented-vehicle field studies.
- *Project 2-1.4: Development of Comprehensive Roadway Information in a GIS Database*
Objective: Review the available sources of roadway data linked to a base map by GPS location in a geographic information system (GIS) and make recommendations to the instrumented vehicle design project (2-2.1) for each roadway data element.
- *Project 2-1.5: Application of OEM Electronic Data Recorders for Risk Studies*
Objective: The objective of this project is to explore the extension of this technology to support studies of collision risk. Important issues include determining the appropriate data and procedures for access and use of the information. The specific objective is to represent this application in current forums discussing the use and future of this technology.
- **Topic 2-2: Risk Studies**
 - *Project 2-2.1: Instrumented-Vehicle Risk Study—Phase I: Study Design*
Objective: This project will develop the design for a field study involving 4,000-5,000 instrumented vehicles operated for a period of 2-3 years. The data collection package must Future Strategic Highway Research Program 68 Safety Research Plan accommodate the needs of the road departure and intersection studies to follow. The fleet is to be split between 2-4 geographic areas to provide good coverage of both urban and rural areas. Data for the road departure and intersection studies will be separated and archived for analysis as part of the data processing.
 - *Project 2-2.2: Instrumented-Vehicle Risk Study—Phase II: Pilot Study*
Objective: The objective of this project is to demonstrate the data collection system for the instrumented-vehicle risk study.
 - *Project 2-2.3: Instrumented-Vehicle Risk Study—Phase III: Field Study*
Objective: The objective of Phase III is to carry out the instrumented-vehicle field study.
 - *Project 2-2.4: Instrumented-Vehicle Risk Study—Phase IV: Intersection Analysis and Countermeasure Implications*

Objective: The objective is to quantify the contribution of driver, roadway, vehicle, and environmental factors to the risk of specific intersection conflicts and assess the countermeasure implications of the findings.

- *Project 2-2.5: Instrumented-Vehicle Risk Study—Phase IV: Road Departure Analysis and Countermeasure Implications*

Objective: The objective of this project is to quantify the contribution of driver, roadway, vehicle, and environmental factors to lane-keeping performance and assess the countermeasure implications of the findings.

- *Project 2-2.6: Site-Based Risk Study—Phase I: Study Design and Pilot*

Objective: The objective of this project is to: (a) develop a road-side study design employing sets of SAVME, or analogous site-based systems, that will provide for direct and systematic comparison of selected roadway and operational design variables; and (b) carry out a demonstration of the study design.

- *Project 2-2.7: Site-Based Risk Study—Phase II: Field Study*

Objective: The objective of the present effort is to: (a) conduct a site-based study that will provide for direct and systematic comparison of selected roadway and operational design variables, and (b) demonstrate the relationship of surrogate measures to collision risk based on historical accident records.

- *Project 2-2.8: Site-Based Risk Study—Phase III: Analysis and Countermeasure Implications*

Objective: The objective of this project is to quantify the contribution of roadway characteristics and traffic operations to the risk of specific traffic events (conflicts, lane departure) and assess the countermeasure implications of the findings.

- **Topic 2-3: Countermeasure Evaluation**

- *Project 2-3.1: Identify Countermeasure Evaluation Topics*

Objective: The objective of this project is to revisit the identification of countermeasures for evaluation. While a tentative list of high priority countermeasures was developed by the Technical Panel and used in this research plan, it is appropriate to revisit this process with broader representation at the beginning of this topic area.

- *Project 2-3.2: Retrospective Countermeasure Evaluation Projects*

Objective: Conduct a rigorous evaluation to determine the benefits in reduced casualties, crashes, and costs of the subject countermeasure based on retrospective crash data using the best analytic approach.

Future Directions in Roadside Safety (Dearasaugh, Jr., 1998): This circular provides the results of a workshop intended to identify strategies to improve roadside safety. Workshop members included FHWA staff, state DOT officials, researchers, and hardware manufacturers. Using NCHRP Project 17-13 (*Strategic Plan for Improving Roadside Safety*) as a guide, workshop members considered research topics for inclusion in NCHRP Project 22-14

(Improvement of the Procedures for the Safety-Performance Evaluation of Roadside Features), which will be the basis for updating NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features.

Mission 1 - Increase the awareness of roadside safety and support for it.

- Develop communications and training techniques to improve the awareness and knowledge of roadside safety hardware installation and maintenance personnel, local law enforcement personnel responsible for accident reports, and key decision makers.
- Develop mechanisms to create a feedback loop between the research community and federal, state, local and private partners to enhance the exchange of information concerning roadside safety research results and implementation experience.
- Investigate ways to communicate research results and training techniques effectively to local and state practitioners, targeting issues and approaches suitable for local roads and county and city engineers.

Mission 2 - Build and maintain the information resources and analysis procedures.

- Develop improved methods of collecting real-world data necessary to enhance the design clear zone and side slopes, and to better design, install, and monitor roadside hardware.
- Research aimed at developing increased knowledge of: a.) the effect of modifications to the clear zone and side slopes on crash rates and severity; b.) the in-field crash performance of roadside hardware components, including the effects of installation and maintenance practices; and c.) general measures of the severity of roadside hardware impacts as affected by vehicle type, speed, and angles of impact.
- Research aimed at developing tools for state/local roadside improvement programs, such as data-driven procedures for roadside safety decisions as part of the Safety Management System.

Mission 3 - Keep vehicles from leaving the roadway:

- Develop techniques to encourage consistent designs that conform to driver expectancy.
- Investigate the use of safety audits in the roadway design process.
- Research the effectiveness of shoulder rumble strips, delineation of roadside hazards and fixed objects (poles, trees, etc.), and signing and lighting systems for all conditions, including severe weather.
- Develop and implement guidelines for low-cost maintenance improvements on low volume roads to reduce run-off-the-road crashes.
- Develop in-vehicle systems to provide safety information to the driver and/or assist in avoiding collisions with roadside objects.
- Develop technologies to enhance driver visibility during nighttime and adverse conditions (head lamp design, ultraviolet headlamps, etc.)
- Research driver monitoring systems and define driver behaviors and characteristics that contribute to loss of vehicle control.
- Develop and deploy speed enforcement strategies which promote safer driving behavior.

Mission 4 - Keep vehicles from overturning or striking objects on the roadside when they do leave the roadway.

- Improve understanding of interaction between vehicles and roadside geometrics to develop roadside terrain model and update guidelines for slopes, drainage, edge drop-offs, curbs/gutters, and other features.
- Develop improved benefit-cost analysis methodologies for the selection of roadside features.
- Evaluate performance of roadside safety features of side slopes and develop guidelines to minimize impacts. Revise warranting criteria to reflect new knowledge about roadside crashes. (e.g., median barrier warrants).
- Develop simulation programs based upon driver response to running off the road situations to generate information needed in driver training programs and evaluate the effectiveness of such training.

Mission 5 - Minimize injuries and fatalities when overturns occur or objects are struck in the roadside.

- Develop new methods for evaluating the risk of occupant harm in roadside hardware crashes. Assess the assumption of restrained occupants in full-scale crash tests.
- Improve crash testing procedures based on assessing many factors include the field relevance of current full-scale test impact conditions, site geometry for crash tests of guardrails, crash cushions and guardrail terminals, and the performance of a variety of vehicle types in roadside hardware crash tests. Examine possible linkages between vehicle compliance tests (FMVSS tests) and roadside safety hardware testing.
- Develop improved hardware or new hardware including generic guardrail terminals, guardrail terminals that perform acceptably in side impact collisions, and energy absorbing devices for trees and rigid poles. Use new and innovative materials in roadside hardware.
- Improve the maintenance of roadside safety hardware to assure that it will perform effectively when needed. Identify owner-agencies with innovative and effective methods of ensuring that roadside hardware is properly installed and maintained. Utilize maintenance equipment effectively to minimize the time and cost for safety hardware repair or replacement.

Safety Research Agenda Planning Conference: Summary and Proceedings (Research and Technology Partnership, 2002): The Research and Technology Partnership was created by the FHWA, AASHTO, and TRB. One of the major goals of the Partnership is to improve the research process. A breakout session of safety experts was convened to address improvements. One topic of particular focus was roadside safety. The following list contains the entire set of possible roadside safety research topics and knowledge gaps, with the issues identified as highest priority at the top.

- One pass van to inventory the roadside features – incorporate digitize the roads for vehicle/roadway interactions
- Methods for choosing ROR sites, corridors, treatment programs

- Rumble strips on narrow paved shoulders
- III Warning systems – field test of driver response
- Relationship of simulation and crash test results to real-world crash injuries
- Safer ditch design for rural two-lane roads
- Tree removal tradeoff research
- Vehicle/roadside interaction (Roll over, tripping effects, etc. by vehicle type)
- Edge line rumble strip effectiveness
- Methods for doing economic tradeoffs of treatment choice or trade-offs
- Tire-soil interactions in rollovers including soil modeling
- Develop a device and associated elements to put utility lines under ground
- Special curve warning markings (e.g., on-pavement markings)
- Positive guidance tools – set of tools/implementation manual
- Safety effects of grades and vertical curves
- Shoulder paving (with and without widening)
- Shoulder widening
- Role and cause of non-intersection “speed choice” (see F-SHARP)
- Effects of RPMs
- Road safety audits for ROR – assess an existing road and its potential to lead a driver off the road
- Slope flattening and widening effects
- Encroachment distance verification with real-world data
- Driver reactions on sideslopes (i.e., steer, brake or both)
- Refine severity indices for roadside
- Vegetation that reduces the severity of the crash
- Safety effectiveness of automated speed enforcement (with credible speed limits)
- “Object delineation” programs (e.g., marking trees and utility poles)
- Effect of 4-inch vs. 6-inch edge line
- Role of inattention, fatigue, driver error on ROR crashes (potential answers from F-SHARP)
- Effects/acceptability of mid-lane rumble strips
- Speed-reduction programs to reduce ROR crashes
- Resurfacing and remarking without other treatments (e.g., no alignment or roadside changes)
- Effects of variable speed limits
- ROR education program development and evaluation
- Optimum edge line installation and performance
- Barrier placement criteria (e.g., sideslope angle)
- Effect of pavement edge drop (lane and shoulder edge)
- Future congestion-speed effects on ROR crashes
- Effects of pavement edge wedge on shoulder drop-off crashes
- Field test/evaluation of new hardware designs
- Wooden guardrail posts in frozen soil
- Encroachment rates per mile by road class and design characteristics
- Flattening horizontal curves

- Vehicle angle and speed of impact by roadside design characteristics
- Barrier height after pavement overlay

Research Needs for Increasing Highway Safety Through Infrastructure Improvements (Harwood, 2002): This paper, which was presented to the Safety Research Agenda Planning Conference meeting in Irvine, CA, presents a set of research needs focused on “physical changes to the highway system including improvements to roadway geometric design features, traffic control features, roadside design features, and roadside hardware.” One section of needs addresses roadway improvements. The other section addresses roadside improvements. Only the roadside research needs are presented below. The original paper presents additional discussion of each research need statement.

- Determine the most effective strategies for reduce [*sic*] the likelihood that vehicle will encroach on the roadside.
- Improve highway agency data on cross-median collisions on divided highways and develop better median barrier warrants.
- Develop and test improved roadside hardware
- Develop better estimates of the safety effectiveness and cost-effectiveness of roadside improvements