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Strategic Directions on Roadway Departure Crashes

Supporting the Decade of Action

Summaries from a Workshop
July 29–August 2, 2012
Irvine, California

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TRANSPORTATION RESEARCH CIRCULAR E-C175

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Roadside Safety Design Committee
Transportation Research Board

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Foreword

The midyear meeting of the Transportation Research Board's Roadside Safety Design Committee was held in Irvine, California, in conjunction with the American Association of State Highway and Transportation Officials (AASHTO) Technical Committee on Roadside Safety from July 29 through August 2, 2012. The Committee met for approximately 3 days to discuss research needs regarding roadside departure crashes in support of the World Health Organization's (WHO) Decade of Action initiative. This e-circular contains authored summaries of the presentations and breakout discussions from the workshop.

WHO launched the Decade of Action (2011–2020) to reduce the number of serious injury and fatal crashes. In response to this call for action, many agencies are adopting a vision of Toward Zero Deaths and AASHTO has adopted the goal of reducing fatalities in half by 2030 (to less than 20,000 fatalities per year).

Roadway departure crashes are responsible for more than half of the fatalities on U.S. roads and are a major contributor to fatalities around the world. The TRB Roadside Safety Design Committee and the AASHTO Technical Committee on Roadside Safety are committed to contribute toward meeting and exceeding the AASHTO goals.

With the recent revision and publication of the AASHTO *Roadside Design Guide* and *Manual for the Assessment of Safety Hardware,* this is an appropriate time to look forward to identify goals and research needs that will lead to the next revision of these documents. This workshop focuses on the activities that are needed in the next 10 years to provide this direction.

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RESEARCH PROBLEM STATEMENTS

SESSION 1

Crash Data and Strategic Plans

Roadway Departure in the United States
Data-Driven Strategic Planning

FRANK JULIAN
Federal Highway Administration

Consistent with state Strategic Highway Safety Plans, FHWA developed a Roadway Departure Strategic Plan to guide our research, policy and guidance, and technical assistance based on opportunities identified through crash data. More than half of the fatal crashes on our highways are roadway departures (RwD). In 2008, FHWA standardized the criteria used to define RwD reporting. An RwD is defined as a nonintersection crash in which a vehicle crosses an edgeline, a centerline, or otherwise leaves the traveled way. The fatal crashes associated with these are reported using the Fatality Analysis Reporting System (FARS) to analyze whether the first event in a crash is an RwD, such as run-off road (ROR) or crossed centerline or median. In 2011, the three legs of safety (headquarters, Turner–Fairbank, and the Resource Center) began the development of an RwD Strategic Plan. During the strategic planning process, crashes were further analyzed based on the most harmful event (Figure 1), revealing that three-quarters of the RwD fatalities involve three primary crash types: overturns (31%), opposite direction crashes (24%), and roadside impacts with trees and shrubs (19%). Four secondary areas have also been identified which account for another 21% of RwD fatalities: posts or poles, other fixed objects, barriers, and roadside geometry.

The three predominant crash types are the primary emphasis areas in the new strategic plan (Figure 2). Based on further analysis of the overturn crashes, the focus will be rural areas, high-speed roadways, and curves. Opposite-direction crashes, in addition to the focus area of overturns, are overrepresented on undivided roads and under wet and icy conditions. Research

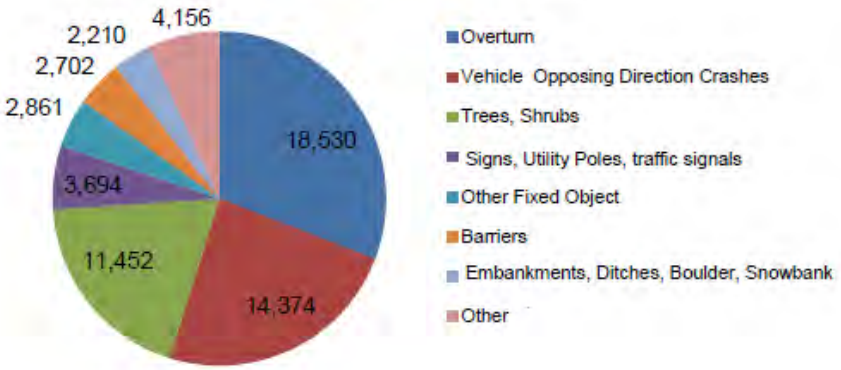
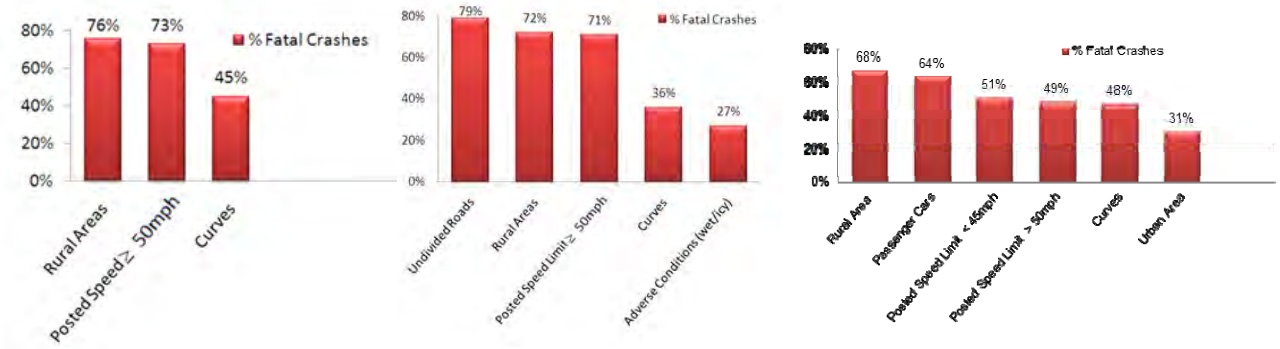


FIGURE 1 Roadway departure fatalities by most harmful event (FARS 2007–2009).



(a) **(b)** **(c)**

FIGURE 2 (*a*) Fatal overturn crashes; (*b*) fatal opposite-direction crashes; and (*c*) fatal tree crashes.

and evaluation will be critical as the currently available countermeasures to address this issue are limited. The prevalence of crashes with roadside vegetation (trees or shrubs) was found to be an issue on both high- and low-speed roads and under both rural and urban conditions. Curves accounted for nearly half of the fatal crashes involving trees.

The RwD team intends to further develop the strategic plan by exploring the crashes involving the three primary crash types in more detail. For example, we may analyze the sequence of events to shed light on the cause of the most harmful event. In other words, if the most harmful event in a crash was a rollover, and a significant number of these happened when a vehicle first struck a barrier or other device, it may help to focus our efforts on barrier-related overturns.

How Big a Problem Are Roadway Departure Crashes?
European Policies

MARCO ANGHILERI
Politecnico di Milano Italy

In this paper, statistics related to the European situation for roadside safety and departure crashes problem are reported. European Union (EU) countries are completely different in population, density of vehicles, road design, and traffic. The European Commission set the ambitious target of halving the number of road traffic fatalities by 2010 in its 2001 White Paper: European Transport Policy for 2010: Time to Decide. The European Road Safety Action Program of 2003 underlines the fact that this target is a "shared responsibility" and can thus only be achieved with the joint effort of all stakeholders

Figure 1 shows that much progress has been made with reducing the number of fatalities, but the number has fallen more slowly than had been envisioned. The number would have needed to fall by 6.7% per year on average to have halved by 2010, as shown by "uniform progress" in the figure. The average reduction between 2000 and 2007 was 3.6% per year. The number would need to fall by 20% in 2010 to reach the reduction target.

Almost 32,000 people were killed in road traffic accidents in the EU-19 countries in 2009, a reduction of more than one third (38%) since 2000. Almost 1,600 were killed in 2009 in the other five countries. Only in Romania was the number of fatalities higher in 2009 than in 2000.

Figure 2 shows the relative change in fatality numbers by country over the past decade.

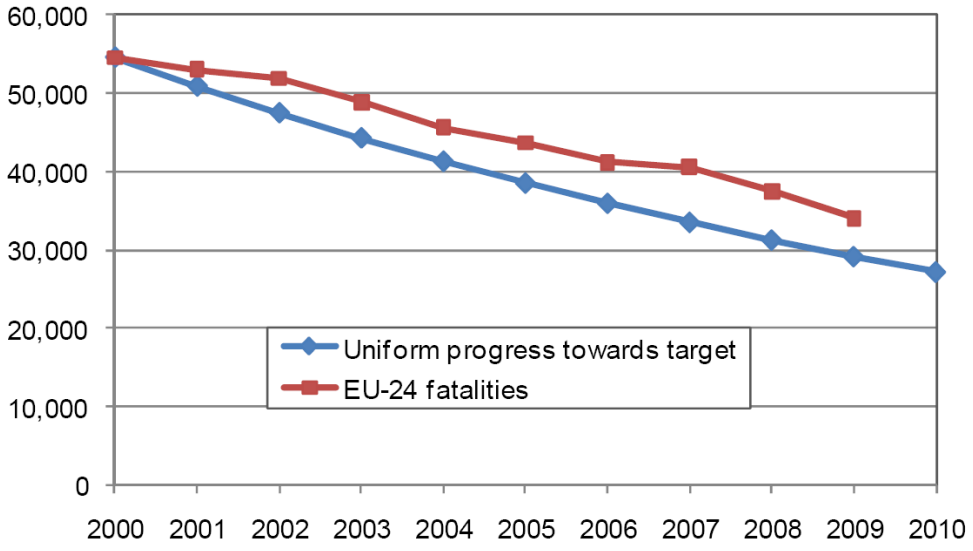


FIGURE 1 Progress made toward reducing fatalities.

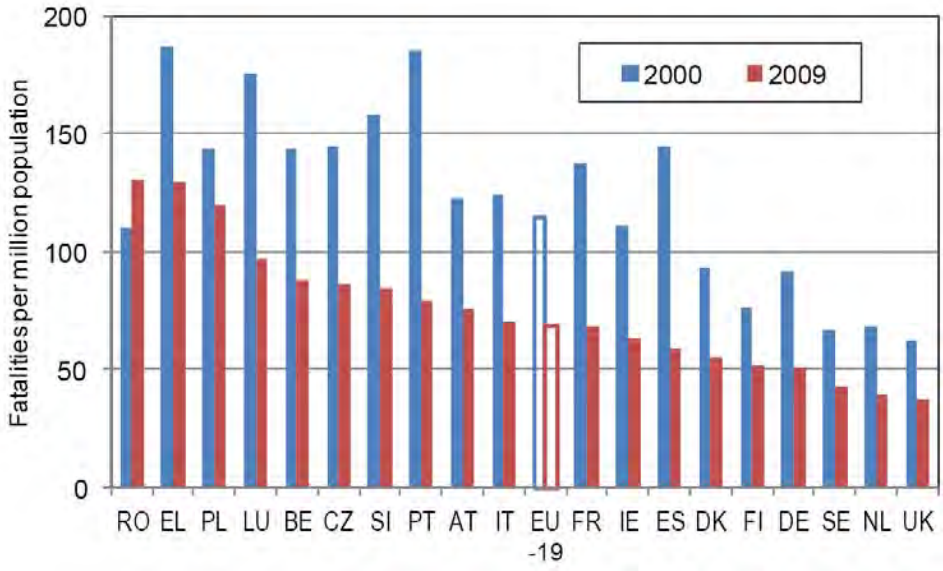


FIGURE 2 Relative change in fatalities by country over the past decade.

Considering the volume of traffic, population, and road design, the United Kingdom currently is to be considered the safest country in Europe.

Figure 3 shows the proportion of fatalities by type of road, with countries sorted by the proportion of rural roads. Overall, only 6% of road accident fatalities in 2009 died in accidents on motorways, and 56% died in accidents on nonmotorway rural roads.

Figure 4 shows the male and female distributions of fatalities in the EU-24 by road user type, and these differ considerably. Nearly two-third of female fatalities was car passengers (30%) or pedestrians (30%), while only 12% of male fatalities were car passengers and 17% pedestrians; 19% were motorcyclists.

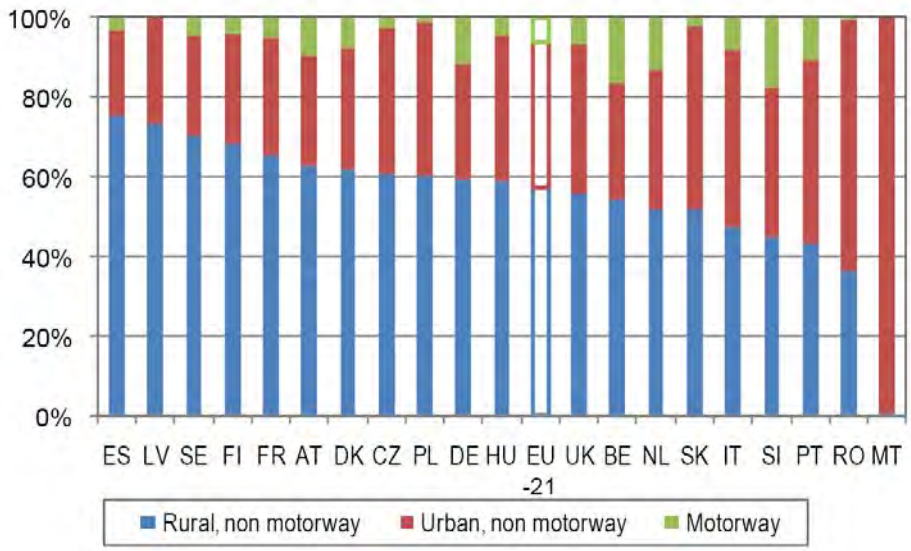
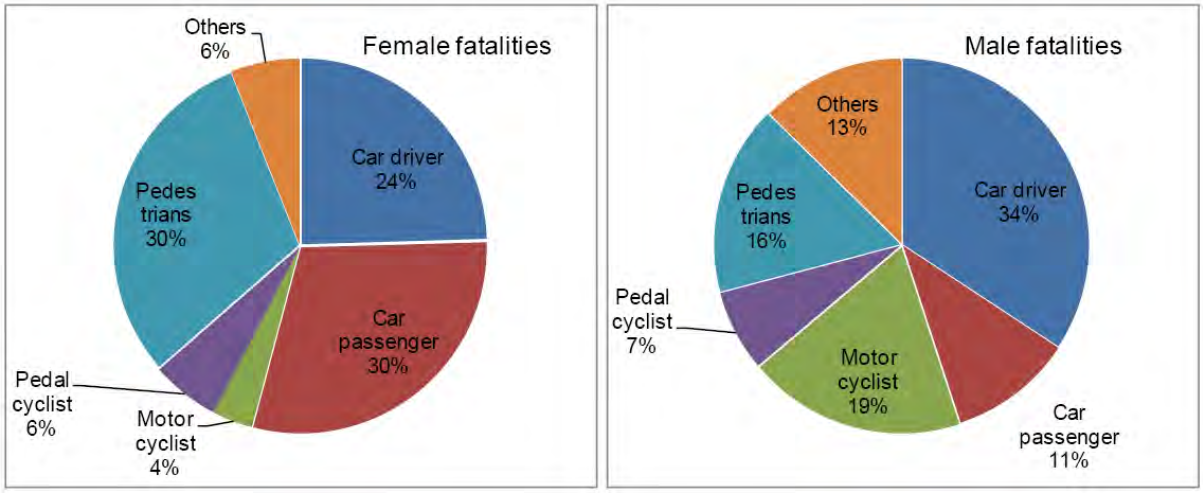


FIGURE 3 Proportion of fatalities by type of road.



(a) **(b)**

FIGURE 4 Distributions of fatalities in the EU-24 by road user type: (a) females and (b) males.

The following figures (Figures 5 through 7) show the proportion of fatalities by road user type on three types of road. This varies with type of road and is influenced by the modes of transport typically used on each type of road.

On motorways, where cars are the prevalent mode of transport, almost two-thirds of all fatalities were car occupants. There is more nonmotorized traffic on urban roads, however, almost half of fatalities on these roads were pedestrians or cyclists, and about one-quarter were car occupants. The number of fatalities for most groups of road user decreased appreciably between 2000 and 2009. In contrast, the number of motorcyclist fatalities scarcely changed over the decade.

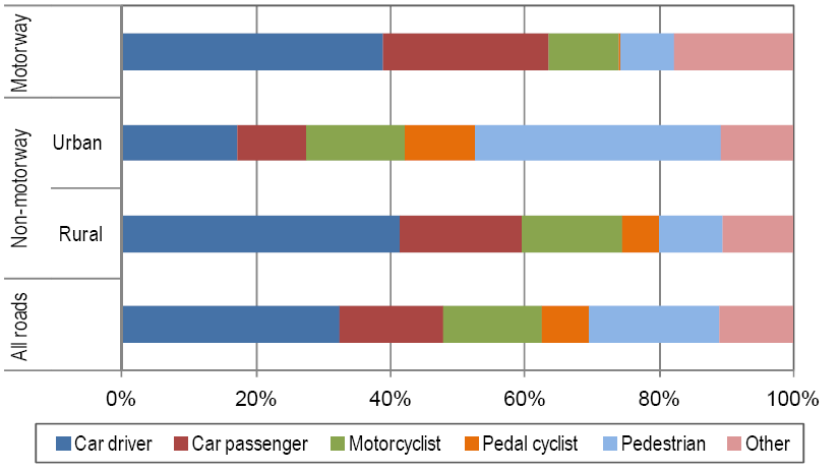


FIGURE 5 Fatalities by road user type and type of road.

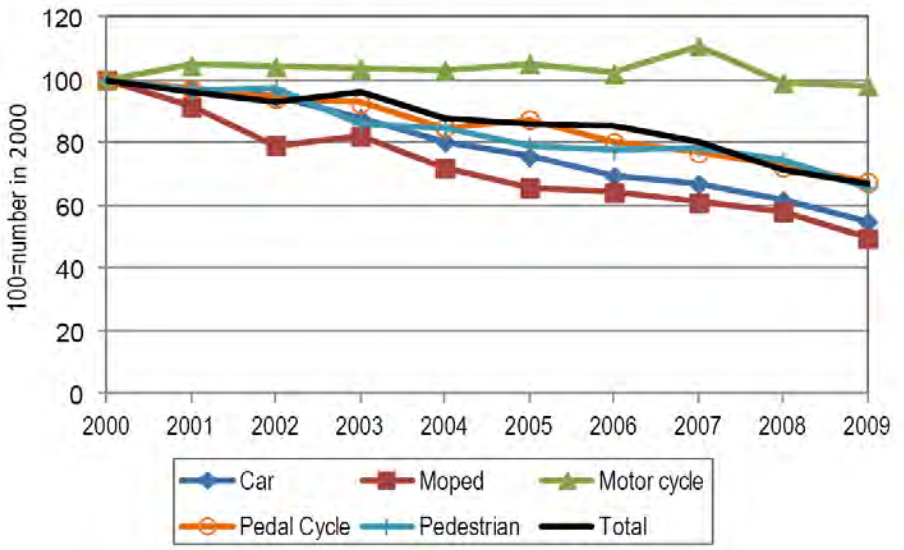


FIGURE 6 Fatalities by road user type, 2000–2009.

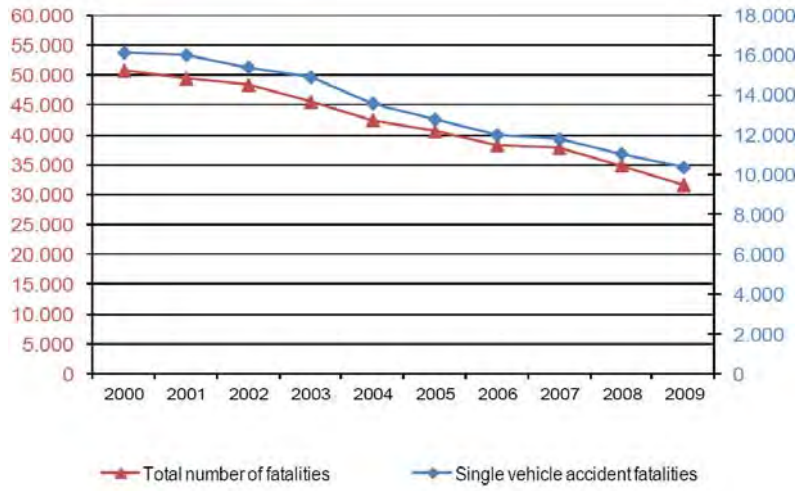


FIGURE 7 Total fatalities and single-vehicle fatalities, 2000–2009.

SINGLE-VEHICLE CRASHES AND DEPARTURES

A single-vehicle accident or single-vehicle collision is a type of road traffic accident in which only one vehicle and no other road user is involved. ROR collisions, collisions with fallen rocks or debris in the road, rollover crashes within the roadway, and collisions with animals are included in this category.

More than 134,000 persons were killed in single-vehicle accidents in 18 EU countries between 2000–2009. This number represents almost one-third of all traffic accident fatalities in those countries (32%). The number of people killed in single-vehicle accidents in 2009 (*1*) was 36% less than the respective number in 2000. The total number of fatalities also fell by 38% in the 18 EU countries over the same period

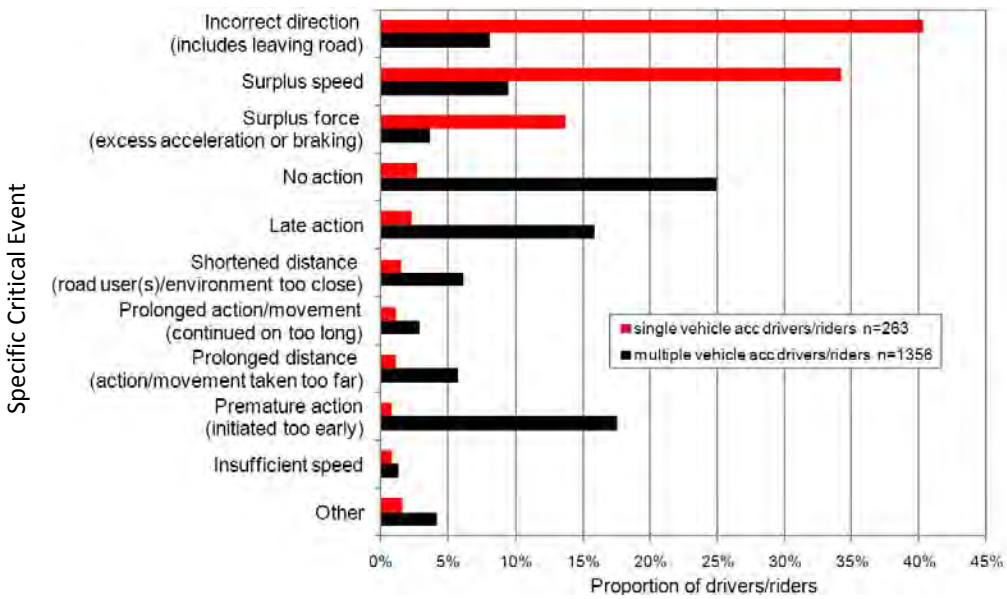


FIGURE 8 Specific critical events in single- and multiple-vehicle accidents.

The distributions are very different for all the most often recorded specific critical events (Figure 8). In single-vehicle accidents, incorrect direction and surplus speed are dominant, followed by surplus force (excess acceleration or braking). Surplus speed describes speed that is too high for the conditions or maneuver being carried out, or traveling above the speed limit. Incorrect direction refers to a maneuver being carried out in the wrong direction (for example, turning left instead of right) or leaving the road (not following the intended path of the road). Loss of control-type accidents can fall into any of these critical events depending on the specific situation. The timing events (no action, premature action, and late action) feature in high numbers for drivers or riders in multiple-vehicle accidents as they often refer to interactions between road users (for example, initiating movement at a junction too early) or taking no action in a required time frame in relation to another road user

Considering the total number of single-vehicle accidents numbers can be concluded that:

- 33% of single-vehicle accidents are outside urban areas;
- 64% of single-vehicle fatalities are outside urban areas;
- 10% of single-vehicle fatalities are on motorways;
- Single-vehicle accident fatalities are 47% of the total number of fatalities;
- Fatalities on single-vehicle accidents with departures are 40% (5,700 per year);
- Fatalities on multiple-vehicle accidents are with departures 8% (2,400); and
- In the EU about 8,100 fatalities per year involve departures.

EN1317 AND NATIONAL REGULATIONS

Situation on the road and how to protect vehicles is controlled by national regulations. While EN1317 is assessing the performance of road safety hardware, National Countries decide how to use hardware tested according to EN1317. The type of hardware to be installed in a given

location is left to competence of single member states. Some member states have recently developed rules, while some have had rules for a number of years, and others do not have any. The result is a discrepancy on the market and on the safety level of roads in different countries (e.g., United Kingdom compared to France, Italy, and Germany). Figure 9 shows the different containment levels used in some EU countries.

	Side Barrier	Central Barrier	Bridge Barrier
Austria	H2	H2	H3
Belgium	H2	H2	H4b
Denmark	H1	H2	H3
Finland	N2	N2	H2
France	N2	H1	N2
Germany	H2	H2	[illegible]
Ireland	N2	H2	H2
Italy	H2	H3	H4b
Holland	H2	H2	H2
Norway	N2	N2	H2
Spain	H1	H2	H3

FIGURE 9 Overview of containment levels used in EU countries.

Australian Crash Statistics
An Overview

ROD TROUTBECK
Queensland University of Technology and Troutbeck & Associates

There is no federal requirement to collect crash statistics in Australia. As a result, the states generally document where fatal crashes have occurred and some states have more detailed knowledge such as the hazard type. The data varies greatly.

The data for this paper was obtained from the VicRoads database, which is available to the public on their website. Victoria is a southern state in eastern Australia. It has a population of approximately 5.57 million (as of June 2012) and is approximately the same as Minnesota. The area of Victoria is 237,630 km^2 and again this is between the area of Minnesota and Michigan. The capitol of Victoria is Melbourne, which has a population of about 4 million.

This VicRoads data was used because it is comprehensive and current. Queensland data is several months behind in the reporting of crashes. This makes it difficult for the road authority to make rational safety decisions. The crash database is not managed by the state road authority, so less pressure can be applied to keep the data current.

GENERAL VIEW OF ROAD SAFETY IN AUSTRALIA

Victoria has typically been a leader in road safety in Australia. They have used community service announcements on television that have been the most graphic worldwide. Figure 1 shows the number of deaths per 100,000 people for the three states on the eastern seaboard in Australia between 2002 and 2011. This figure indicates that Victoria generally has a lower road crash fatality rate than the Australian average. Victoria does not have as many issues with areas with low-population densities as does either Queensland, Western Australia, and to a lesser extent New South Wales. In areas of lower population densities, generally in more flat and arid areas, the roads are straighter, narrower, and less well-maintained. They can be expected to have a poorer crash record if measured in deaths per 10 million vehicle kilometers.

Between July 1, 2007, and December 21, 2011, Victoria recorded 1,354 fatalities and 26,461 serious injuries on all roads. Nearly half (49%) of the fatal crashes were in Melbourne and about 8% were in towns, hamlets, and other nonrural locations. The remaining 576 fatal crashes (43%) occurred on rural roads.

Similar figures can be obtained for serious injuries. Approximately 70% of serious injury crashes occurred in Melbourne, about 12% were in towns, hamlets, and other nonrural locations. The remaining 5,380 serious injury crashes (18%) occurred on rural roads. Rural roads have a more significant problem with vehicles running off the road.

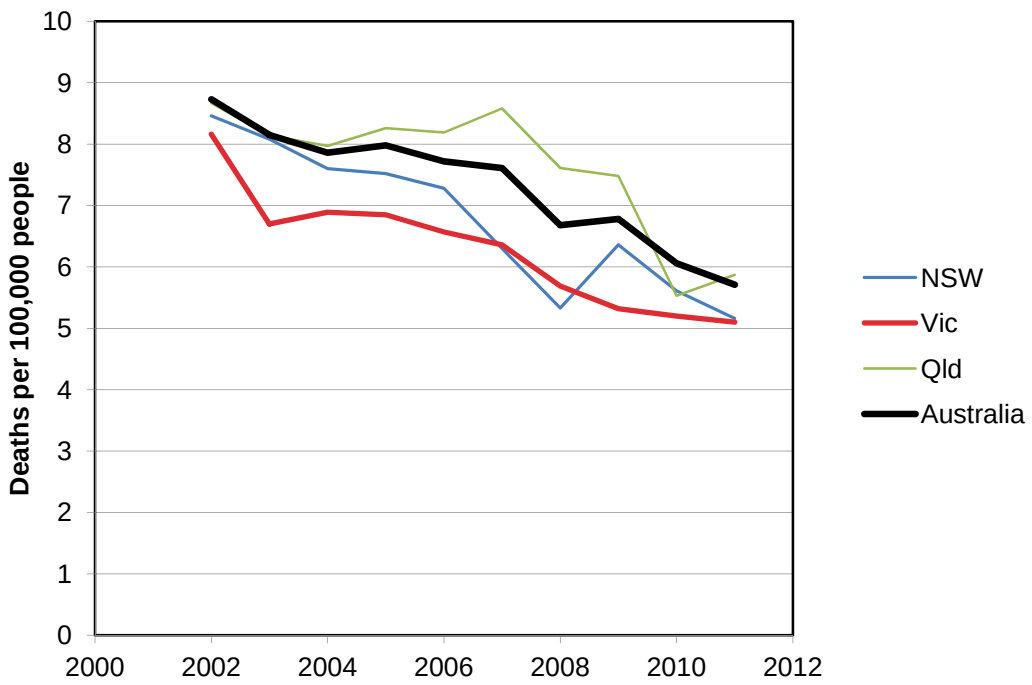


FIGURE 1 Crash rates (deaths per 100,000 population) in Victoria (Vic) and other states (NSW = New South Wales; Qld = Queensland).

When Do These Fatal and Serious Injuries Occur?

Figure 2 indicates that in the greater Melbourne area the crashes were similar for each month, while in the areas outside Melbourne there were fewer crashes in the colder months: June to September. The worst days for crashes are Saturday and Sunday with both recording about 18% of all fatal and serious injury crashes outside the greater Melbourne area.

Where Do Crashes in Rural Areas Occur?

About 18.2% of rural crashes occur at rural intersections. This includes 7.7% at cross intersections, 9.2% at T-intersections, and 1.3% at other intersection configurations. Obviously, the bulk of the crashes occur away from an intersection (the remaining 81.8%). About 85% occur on roads with speed limits between 80 and 100 km/h; these are the typical speed limits for Australian rural roads.

What Are Other Conditions When Rural Crashes Occur?

About 69% occur during the day, 25% at night, and about 6% at dawn or dusk. There is no clear trend here as most drivers travel in the day time. However, 83% occurred on paved roads and 79% in fine weather. It would appear that most crashes occur during relatively good conditions. It leads to the notion that the fatal four characteristics of fatal crashes are fatigue, excessive speed, seat belts not being used, and drivers under the influence of alcohol. These are often abbreviated to fatigue, speed, seat belts and alcohol.

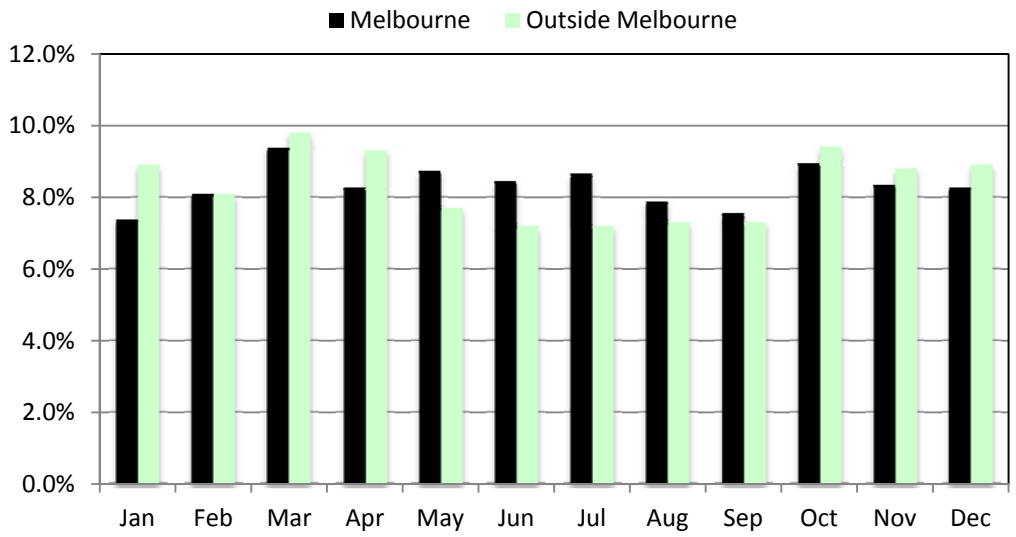


FIGURE 2 Crash frequency by month of the year.

Rural Road Crash Type

About 40% of crashes occurred on straight sections of road and about 25% were on curved sections of road. Given that curves occupy about 5% to 10% of the road network, we would expect curves are over represented by the crash rate. Overtaking crashes are about 10.3% of the rural crashes with intersection and other crash types being 13.5% and 11.3%, respectively.

Two or more vehicles collided in 28% of the fatal and serious injury crashes on rural roads. In 43% of crashes, vehicles collided with a fixed object and in 14% of crashes a vehicle overturned. In 9% of the fatal and serious injury crashes, the vehicle did not strike an object and of the remaining 6% the crash type was something else.

Considering only straight sections of road, in 54% of crashes the vehicle left the road to the left (across the verge) and in the remainder the vehicle went to the right across the lanes for oncoming traffic, if it was an undivided rural road, or across the median with the potential to collide with opposing vehicles.

For curves, the story is different; about 37% of drivers left the road on left-hand bend; these drivers would typically be expected to cross the lanes for opposing vehicles. This compares to 63% of fatal and serious injury crashes occurring on right-hand bend. This can be visualized using Figure 3.

Object Struck

The two most common objects struck were trees (54%) and embankments (11%). Crashes with other hazards are much less frequent, as shown in Table 1.

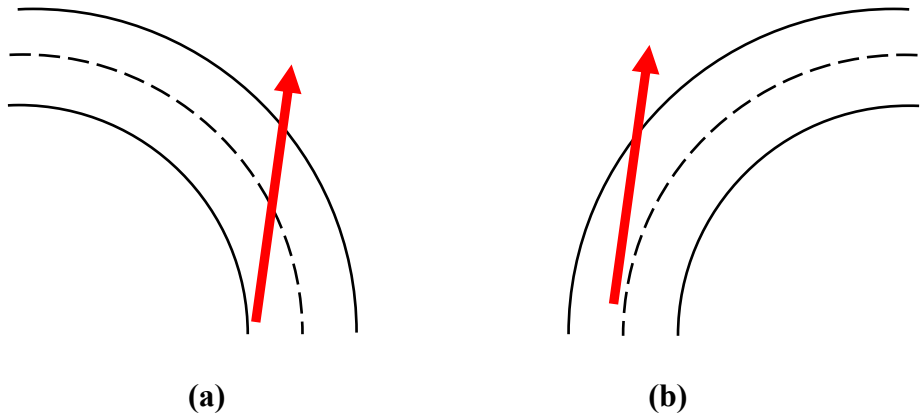


FIGURE 3 Different ROR fatal and serious injury crash rates for curves: (*a*) left hand bend (37%) and (*b*) right hand bend (63%).

TABLE 1 Proportion of Fatal and Serious Injury Crashes Colliding with Particular Fixed Objects

Fixed Object	Percentage of Crashes
Tree	54.1
Embankment	11.1
Fence or wall	8.4
Guardrail	5.7
Pole	3.8
Guidepost, traffic sign, etc.	4.0
Animal	5.4
Other fixed object	7.4

Vehicles Involved

The most common vehicles in fatal and serious injury crashes are cars and SUVs (66.5%). Motorcycles are involved in 26.1% of crashes and are significantly over represented. Trucks and buses are involved in 6% of crashes.

CONCLUSION

These statistics would be similar to those collected in other jurisdictions. Perhaps the most common element is the large proportion of fatal and serious injury crashes that involve trees. This is a concern especially as trees should not be removed and yet they are a significant road safety issue. Protecting isolated trees is more problematic than a number of trees together. Energy is managed better if vehicles are guided past the tree as a longitudinal barrier would do, but the longer longitudinal barriers will have higher impact rates. Designers around the world are looking for practical solutions for isolated trees. It is hoped that these statistics, when considered with others, will provide for better ways to improve roadside safety.

National Road Safety Council

SOAMES JOB
National Road Safety Council

Soames Job presented a paper, Strategic Plans: What Are Government Agencies Doing About Roadway Departure Crashes? The paper drew on examples from the Australian National Road Safety Strategy 2011–2020 and the United Nations Global Plan for the Decade of Action for Road Safety 2011–2020, as well as more recent measures and strategies adopted by the New South Wales (NSW) Centre for Road Safety, the lead government agency for NSW road safety, while Soames led that organization (2003–2011). The paper considered actions to improve roadside infrastructure, and to promote safer vehicles, safer road users, and education and enforcement measures to manage speeding, all of which can help address RwD crashes. The latter included the use of fixed speed cameras, mobile speed cameras, and point-to-point speed enforcement, all of which are employed in NSW along with strong mass media campaigns.

NSW has adopted a process of highway safety reviews, which involves a multidisciplinary team (psychologist, engineer, road designer, statistics expert, and police) reviewing the full length of key highways or major routes. The process includes consideration of every fatal crash location (last 5 years) with a focus on safe systems principles and roadsides rather than road surfaces. Evaluations show that these have been particularly successful. Packages of engineering treatments delivery based on these reviews have resulted in fatalities dropping by over 50% for surprisingly small expenditures (e.g., $35m for more than 500 km of road) yielding benefit–cost ratios of 12 or more, well above the normal black spot treatments employed in NSW.

California Strategic Highway Safety Plan and Roadway Departures

CRAIG COPELAN
Caltrans

California's Strategic Highway Safety Plan (SHSP) is a statewide, comprehensive, data-driven effort to reduce fatalities and serious injuries on public roads. Started in 2005, the SHSP is updated regularly to ensure continued progress in this coordinated effort to meet changing safety needs. Currently, more than 300 safety stakeholders from 80 public and private agencies and organizations work together to implement the plan under the direction of the SHSP executive leadership and a 13-member steering committee. The SHSP includes behavioral, infrastructure, and technology strategies addressing the 4Es of safety: engineering, enforcement, education, and emergency services.

The SHSP applies public and private resources in the areas where the greatest gains can be made to save lives, prevent injuries, and improve safety in the following challenge areas (CAs):

- CA 1: Reduce impaired driving related fatalities;
- CA 2: Reduce the occurrence and consequence of leaving the roadway and head-on collisions;
- CA 3: Ensure drivers are properly licensed;
- CA 4: Increase use of safety belts and child safety seats;
- CA 5: Improve driver decisions about rights-of-way and turning;
- CA 6: Reduce young driver fatalities;
- CA 7: Improve intersection and interchange safety for roadway users;
- CA 8: Make walking and street crossing safer;
- CA 9: Improve safety for older roadway users;
- CA 10: Reduce speeding and aggressive driving;
- CA 11: Improve commercial vehicle safety;
- CA 12: Improve motorcycle safety;
- CA 13: Improve bicycling safety;
- CA 14: Enhance work zone safety;
- CA 15: Improve post-crash survivability;
- CA 16: Improve safety data collection, access, and analysis; and
- CA 17: Reduce distracted driving.

One of the priorities within California's SHSP is to reduce the occurrence and consequence of leaving the roadway and head-on collisions. The department is currently working with support from the FHWA on a systemic safety improvement program to reduce RwD and head-on collisions where they occur. The planned actions include the deployment of a number of low-cost countermeasures over a 5-year time span that will put in place shoulder and centerline rumble strips, safety edge, friction course overlays, and roadside tree removal coupled with

programs of enhanced enforcement and public education. This systemic improvement program is to be included in the most recent update of the SHSP and is a good example of a comprehensive approach to improving traffic safety on California's highways.

The initial goal for the SHSP was to reduce California fatalities to less than 1 per 100 million vehicle miles traveled by 2010. Numbers for 2009 show that the overall goal was met a year ahead of schedule. Statistics for 2010 are not currently available, but preliminary figures indicate that total fatalities and the fatality rate have both continued to decline.

Kansas Strategic Highway Safety Plan

STEVEN BUCKLEY
Kansas Department of Transportation

In an effort to drive down fatalities, Kansas has developed an SHSP. An SHSP is defined as a coordinated (i.e., multi-agency and multidisciplined) and informed approach to reducing highway fatalities and serious injuries on all public roads. "Informed" means based on crash data and research results. And for Kansas public roads that mean 10,000 mi of state highways and an additional 130,000 mi of locally owned roads. This last item is a big challenge for a state with a population less than 3 million people.

Kansas is using the 4E approach, including engineering, education, enforcement, and emergency medical services. An executive safety council of almost 20 agencies has been formed to oversee development of the SHSP. Emphasis area teams and support teams have formed to develop implementation plans specific to a crash variable or support topic. These include RwD, intersections, occupant protection, impaired driving, teen drivers, data, local roads, and education. The mission, in short, is to drive how safety dollars are spent—both engineering [highway safety improvement program (HSIP)] and behavioral (NHTSA).

The overall goal is consistent with AASHTO's goal to cut fatalities and serious injuries in half by 2029. For Kansas that means reducing fatalities from a 5-year average of 417 between 2005–2009 and less than 208 fatalities by 2025–2029. Based on traffic projections, in order to reduce fatalities in half in 20 years, the fatality rate will need to reduce by 62%.

In Kansas, RwD represents over 50% of all fatalities. Some strategies being worked on that address RwD crashes include improved data, such as geocoding all non–state highway system crashes, intersection and horizontal curve inventories, and use of Safety Analyst. Others focus on the importance of seat belts such as changes to the current primary seat belt law that only has a $10 fine and does not apply to the backseat, and expansion of a very successful program that targets teens called SAFE (Seatbelts Are For Everyone). Engineering strategies specific to RwD either focus on preventing to crash to begin with or making it as forgiving as possible when it does happen.

Many strategies have already been implemented and are only reinforced by this plan, such as sign and marking retroreflectivity, 6-in. edge lines, shoulder rumble strips, and road safety assessments. Others are new and being implemented with varying degrees of success, such as centerline rumble strips, systemic removal of trees, headwalls, and culverts, Safety Edge, and a program focused on low-cost safety improvements at horizontal curves.

SESSION 2

Roadside Design Guide

Author Panels

Introduction to Roadside Safety
Chapter 1

MARK AYTON
Ontario Ministry of Transportation

Several minor changes were made to Chapter 1 in the *Roadside Design Guide* (RDG). These changes include the following:

- Updated the roadside crash statistics;
- Referenced the NCHRP Report 350 updated procedures prescribed by the *Manual for Assessing Safety Hardware* (MASH, 2009);
- Referenced the AASHTO–FHWA Joint Implementation Plan for Continued Use of Report 350 Accepted Hardware; and
- Referenced FHWA Acceptance Letter website and AASHTO Task Force 13 (TF-13) website.

Future changes to this Chapter will likely include the following:

- Combine Chapter 2 (Economic Evaluation) with Chapter 1;
- Expand information on the Roadside Safety Analysis Program (RSAP) based on the results of NCHRP Project 22-27;
- Include additional information on the *Highway Safety Manual* (HSM);
- Continued update (and expansion) of roadside crash statistics; and
- Include statistics and information on factors related to motorcycle crashes with longitudinal barriers based on results from NCHRP Project 22-26.

Economic Evaluation of Roadside Safety
Chapter 2

MARK AYTON
Ontario Ministry of Transportation

Several minor changes were made to Chapter 2 in the RDG. These changes included a reference to RSAP being updated under NCHRP Project 22-27; a reference to TRB website for status (and download) of RSAP; a reference to AASHTO HSM (2010) Chapter 7 for economic appraisal procedures, as well a new section on In-Service Performance Evaluation.

A majority of the future changes proposed for this chapter include information regarding reducing the potential for vehicles to leave the roadway. This includes additional discussion and guidance on how to keep vehicles on the roadway to further reduce roadside crashes; a reference to the *Manual on Uniform Traffic Control Devices* (MUTCD) for appropriate signing and delineation; expanded information on rumble strips; and new information pertaining to pavement friction and super-elevation.

Roadside Topography and Drainage Features
Chapter 3

Mark Ayton
Ontario Ministry of Transportation

The majority of the changes to Chapter 3 of the RDG dealt with the clear-zone concept. These changes included the following:

- Coordinating the clear-zone terminology with the AASHTO Policy on Geometric Design of Highways and Streets (e.g., the Green Book);
- Defining the clear-zone for auxiliary lanes;
- Expanded examples related to clear-zone evaluation; and
- Discussion of curbs omitted (moved to Chapter 5).

Future changes proposed for this chapter include a revised title and a reorganization of the sections based on the order a vehicle might encounter them when leaving the traveled way. Revised guidance and updated charts will be included from the following NCHRP projects:

- 15-30: Median and Median Intersection Design;
- 17-11(2): Clear Recovery Area;
- 17-55: Slope Traversability;
- 16-05: Cost Effective Roadside Ditch Treatments; and
- 22-21: Median Cross-Sections.

Sign, Signal, and Luminaire Supports, Utility Poles, Trees, and Similar Roadside Features

Chapter 4

TERI SOOS
Maryland Department of Transportation

Some changes incorporated into Chapter 4 in the 2011 RDG include mention of the new crash test required under MASH to evaluate potential for windshield penetration with the pickup truck; stronger language encouraging the use of breakaway supports in urban areas; a note that the MUTCD requires that all signs within the clear zone be breakaway with electrical disconnects if applicable; clarification that breakaway sign supports should be placed on 6:1 (H:V) or flatter slopes; and added strategies for reducing likelihood of crashes with utility poles and trees from NCHRP Report 500.

Future research needs for the next RDG update include: investigation of European-style collapsible poles; simulation of breakaway devices placed down fill slopes to establish if they perform as expected; establish the effect of soil plates or concrete footers in weak soil locations; establish if the maximum 4-in. stub height is realistic; determine how pendulum testing or other surrogates and be used with the MASH testing criteria; and establish more specific guidance on the placement of trees to strike a balance between roadside safety and context-sensitive design or livability ideals on projects.

Roadside Barriers
Chapter 5

ROD LACY
Kansas Department of Transportation

Changes to this chapter of the RDG include reference to the MASH document and associated implementation plan, reference to the AASHTO Task Force 13 Standardized Barrier Hardware and FHWA acceptance letter websites, revised discussion of guardrail placed behind curbing, reduced run-out lengths for barrier design, and a revised discussion of upgrading existing barrier systems. Revised rail height standards were also included for new construction TL-3 w-beam barriers placed on the National Highway System. This includes a 27.75-in. minimum top of rail height (26.5 in. on 3R projects) and a recommended 29 in. top of rail height with a 1-in. tolerance. New content added to the Chapter include the following:

- Addition of Midwest Guardrail System, other proprietary 31-in. barrier systems, and the T-39 Thrie Beam System;
- Discussion of the zone of intrusion (ZOI) concept;
- Discussion of guardrail posts embedded in rock or mow strips; and
- Brief discussion of motorcycle-to-barrier crashes.

Future research needs and additions that may be included in this chapter are as follows:

- Research to be conducted as part of NCHRP Project 12-90 developing risk-based guidelines for the protection of bridge piers;
- Improved barrier length of need values or procedures for approach barriers;
- Additional information with respect to ZOI and motorcycle-to-barrier crashes; and
- Additional higher test-level hardware including end terminals, barriers, and crash cushions.

Median Barriers
Chapter 6

JOE JONES
Missouri Department of Transportation

Changes to this chapter of the RDG include updated guardrail height requirements based on the 2010 FHWA memo, height tolerances for rigid and flexible median barriers, and the addition of information pertaining to high-tension cable barriers on 4:1 slopes. Additional areas of research include potential revision to the guidance on recommended placement of barrier in nonlevel medians as well as the provision of guidance for the placement of cable barriers in narrow medians.

Bridge Railings and Transitions
Chapter 7

PAUL FOSSIER
Louisiana Department of Transportation and Development

Changes to this chapter of the RDG include the following:

- Reference update to MASH 2009 and the current AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications;
- Updated discussion regarding placement location of hardware attachments such as signs, poles, and fences;
- Updated discussion on use of curbs with bridge rails;
- Addition of a section pertaining to considerations for urban and low-volume roads; and
- Omitted short-radius guardrail (moved to Chapter 5).

Ongoing research that will likely be included in future revisions to this chapter of the RDG include NCHRP Project 22-12(3) which is tasked with developing guidelines for the selection of TL-2 thru TL-5 bridge railing and NCHRP Project 12-90 which is tasked with developing guidelines for shielding bridge piers. New research needed to support further improvement include research to update the bridge rail loads, research on bridge rail types and connections to fiber-reinforced polymer (FRP) bridge decks, and the development of guidance for short bridge rail transitions due to interferences with obstructions (driveways, streets, etc.) at bridge ends.

End Treatments
Chapter 8

CHRIS POOLE
Iowa Department of Transportation

Larger changes to this chapter of the RDG include introduction of the work–energy principle, an updated list of currently used or marketed terminals and crash cushions, different classification schemes for terminals (cable barrier, w-beam and box beam), and crash cushions (reusable, sacrificial, low maintenance or self-restoring, and other) as well as reference to FHWA acceptance letters and AASHTO Task Force 13 standard drawings. Future data and research needed to improve this chapter include the following:

- Development of a consistent and objective method for classifying crash cushions;
- A large-scale in-service performance evaluation to determine the performance of older systems and benefits of energy-absorbing terminals; and
- Research and guidance on acceptable curb height and offset combinations near terminals and crash cushions.

Traffic Barriers, Traffic Control Devices, and Other Safety Features for Work Zones
Chapter 9

RORY MEZA
Texas Department of Transportation

Changes to this chapter of the RDG included the listing of additional portable barrier connections, a discussion of pinning barriers for reduced deflection, and the addition of steel barriers for work zones as well as some discussion on movable barriers. Additional research and data needs to support improvement of this chapter include how the clear-zone concept should be applied in work zones, an examination of existing guidance on the use of truck-mounted attenuators (TMAs), additional information on steel barriers and their crash performance, and transitions between safety features in work zones.

Roadside Safety in Urban or Restricted Environments
Chapter 10

KEVIN HERRITT
Caltrans

Changes to this chapter of the RDG were primarily updates based on research since the previous RDG publication including MASH and updated crash statistics. The major changes include a more specific description of the urban clear zone as being 4 ft minimum (6 ft desirable), and indication that obstacles should be kept away from intersections, driveways, and speed change lanes, and an emphasis that the 1.5-ft minimum lateral offset to obstructions is not considered a clear zone.

Erecting Mailboxes on Streets and Highways
Chapter 11

NICK ARTIMOVICH
Federal Highway Administration

Chapter 11 was revised to update the crash information for fatalities involving mailboxes and to address crash testing on heavy mailboxes that are designed to withstand vandalism or reduce theft. While these heavy mailboxes should be kept out of the clear zone on high-speed highways, some can be made crashworthy if properly connected to the post and the post is securely anchored to the ground. It also advocates the use of the safety edge paving technique to reduce the likelihood of drivers losing control should their vehicle drop a wheel into ruts in front of rural mailboxes caused by postal delivery vehicles.

To address future research needs a review of FARS data showed that the roughly 300 annual fatalities where impact with a mailbox is the first harmful event result in serious consequences due to subsequent rollover or impact with another fixed object on the roadside 90% of the time. FARS also indicates that there were only 40 fatal crashes where the mailbox impact was the most harmful event. The research that has already been done may be used to develop additional structural requirements for secure and vandal-proof mailboxes. A surrogate test program that may be used by mailbox manufacturers to assess their products has been considered but placing new requirements on private manufacturers is not likely to receive agency support.

Roadside Safety on Low-Volume Roads and Streets
Chapter 12

RORY MEZA
Texas Department of Transportation

Chapter 12 was a new chapter in the 2011 RDG that discusses roadside safety on low-volume roads. It includes strategies that focus on low-cost treatments such as signing and delineation and strategic application of clear zone and barrier use. The next update should include more information available from other state departments of transportation (DOTs) and from county associations.

SESSION 2

Roadside Design Guide

Breakout Summaries

Roadside Safety Design Committee Scope and Strategic Plan

ROGER BLIGH
Texas A&M Transportation Institute

Much of the discussion of the breakout group focused on the current scope of the committee and potential revisions to that scope. The current scope dates back to A2A04, Roadside Safety Features, and is shown below:

CURRENT SCOPE

The scope of the committee includes identification of research needs and dissemination of research related to the design, testing, selection, placement, and in-service performance of roadside safety features such as traffic barriers, crash cushions, structural supports for luminaries, signals, utilities, drainage structures, and other safety features located in the transportation system right-of-way (ROW).

The scope includes consideration of impact performance, degree of hazard, environmental factors, and cost-effectiveness that must be considered in the design and use of these features.

The primary objective is to aid in the development of roadside safety features that provide cost-effective safety to the traveling public.

After much discussion, the group developed the following proposed scope of the committee.

PROPOSED SCOPE

The scope of the committee includes identification of research needs and dissemination of research related to design countermeasures that will reduce the number or severity of roadway departure crashes.

The scope includes

- Understanding the nature and causes of roadway departures,
- Development of measures to reduce the potential of errant vehicles crashing if they do leave the roadway, and
- Development of safety hardware and features to reduce the severity of crashes that do occur

The committee aims to develop forgiving roadsides through countermeasures, safety hardware, and features that maximize the safety benefit to the traveling public.

NEXT STEPS

- Send out to committee members for vote.
- If revised scope passes, forward to Design Section for review.

Research Needs to Update AASHTO's *Roadside Design Guide* for 2016 and Beyond

DEAN SICKING
Midwest Roadside Safety Facility

MARK AYTON
Ontario Ministry of Transportation

Four research problem statements were identified in this breakout session; each is outlined below. [Note: Three committees are currently supporting In-Service Performance Evaluation of Median Barrier Applications on Divided Highway with the objective of developing guidelines for revising the RDG.]

1. Roadside Design Guidance at Intersections in Proximity to Bridges (Bob Bielenburg and Paul Fossier). Safety treatment for approach guardrails attached to a bridge.

Placement of a bridge in close proximity to an intersecting street or driveway can create difficult geometrics for placement of approach guardrails needed to shield motorists from the end of the bridge rail or the hazard under the bridge. The traditional method for treating these situations is to place a short-radius guardrail to turn the barrier down the driveway or intersecting street. Several state-funded studies have been undertaken by the TTI (TTI) and the Midwest Roadside Safety Facility. Unfortunately, none of these studies have been able to develop a short-radius barrier system that can meet NCHRP Report 350 or MASH impact performance criteria. In fact, no short-radius barrier system has been able to meet any safety performance criteria for use on high-speed roadways.

The primary objective of this study would be to develop safety treatment alternatives for use in areas where intersecting streets and driveways are placed near a bridge. These designs should be able to be installed when the intersection is placed within 40 ft of the end of the bride rail and should not extend more than 30 ft down the side street.

2. Performance-Based Implications of Tree Placement on Complete Street–Context Sensitive Solutions Projects (Chris Poole, Drew Boyce, and Christine Carrigan).

This research should develop safety guidelines for placement of new and removal of existing trees along urban and rural roadsides. The primary objective will be to develop the information needed to conduct a benefit–cost analysis of the use of trees in context-sensitive solutions and complete street projects. The guidelines will address a speed ranges, traffic volumes, roadway geometry, access density, population density, tree and shrub species, and roadside environment. The guidelines should also develop sufficient information to address the possibility of roadside barrier as an effective means to address tree crashes.

3. In-Service Performance for Median Barriers (AFB10) (Christine Carrigan and Joe Jones). AFB20 proposes to co-support the project, however, methods and objectives to achieve the development of guidelines were changed as follows:

- Conduct a literature review of ISPE studies for median barrier applications.
- Develop crash severity data for use in RSAPv3 from the collected literature for

each test level and type of barrier currently available.

- Gather additional data as needed to develop severity data.
- Incorporate severity data into RSAPv3 database.
- Conduct cost-effectiveness analysis to develop guidelines that consider barrier type, test level, placement and climate (frequency of snow and ice on pavement).
- Develop a minimum of one CMF for the use of median barrier type and test level

4. 20-7 for Objective Criteria for Crash Cushion Categories for Chapter 8. The objective of this study is to develop clearly defined classifications for crash cushions and guidance for determining traffic and geometric conditions under which each class of hardware should be considered.

Strategic Highway Safety Plans

How Can the TRB Roadside Safety Design Committee and the AASHTO Technical Committee on Roadside Safety Help States Meet Their Goals?

RON FALLER
Midwest Roadside Safety Facility

ROD LACY
Kansas Department of Transportation

This Breakout focused on what AFB20 and AASHTO's Technical Committee on Roadside Safety (TCRS) can do to assist states with their SHSPs. Some ideas were noted by individual participants to

- Encourage seat belt use in research and test reports.
- Encourage manufacturers to note positive benefits of seat belt use with roadside safety hardware.
- Provide improved methods (i.e., marketing) to deliver roadside safety message. This includes personalizing the message with actual facts, statistics, and photos and videos, etc. Should also support other organizations dealing with driver behavior, education, and training issues.
- Ask how do we keep drivers on road?
- Stress importance to share accident data between state DOTs and researchers.
- Standardize reporting format for existing and new data needs.
- Develop phone or tablet applications for teams to simplify crash investigations.
- Increase dialog with state fatal accident reconstruction teams to improve data sharing and knowledge with links DOT databases.
- Continue dialogue on and explore use of road safety assessments and audits in the United States.

Some issues from Kansas include the following:

- Majority of fixed-object crashes on off-state highway system;
- Difficulty in identifying locations of crash sites; and
- Importance noted to keep vehicles on road; benefits include:
  - Centerline–edge (C/E) rumble stripes,
  - Increased shoulder widths, and
  - A synthesis on use and benefits of delineation might be useful.

Some issues from California include the following:

- Would like to see more before–after accident studies of C/E improvements for use in promoting additional projects and

- Improved sharing of accident data to upgrade SHSP.

RECOMMENDED RESEARCH

1. Characteristics of Injury and Fatality of Run-Off-Road Crashes on Low Volume Roadways (#1 2011):
    - Strengthen and clarify title,
    - Review and rewrite, if needed, to garner more support,
    - Add EMS response time to data need,
    - Resubmit as high-priority project, and
    - Consider combining with Development of Low-Cost Safety Features for Low-Volume Roadways.
2. Crash Risk of Trees within Clear Zone:
    - Volunteers to rereview and rewrite as needed,
    - Resubmit full problem statement to NCHRP, and
    - Submit reduced Phase I literature review and synthesis study to acquire NCHRP 20-05 and 20-7 funds, including survey to acquire best practices and success stories.
3. In-Service Evaluation of End Terminals:
    - Consider revising as smaller Phase I effort and resubmit for NCHRP 20-7 funding and
    - Develop and demonstrate new simple, low-cost methods on limited scale in trial states.

SESSION 3

Primary Crash Types and Where They Happen

Overturn Crashes

ROGER BLIGH
Texas A&M Transportation Institute

Research was presented regarding single-vehicle ROR (SVROR) crashes with a focus on the time trend of this crash type, the percentage of these crashes that result in rollover, first and most harmful events in these crashes, as well as differences in crash severity for rollover versus nonrollover cases. The presented findings were part of NCHRP Project 16-05: Guidelines for Cost-Effective Safety Treatments of Roadside Ditches.

As shown in Figure 1 below, the percentage of SVROR fatal rollover crashes mirrors SVROR fatal crashes. Although there has been a downward trend in the past 5 years, this remains a significant problem that needs to be addressed with further research.

Figure 2 shows fatal rollover crashes as a percentage of SVROR fatal crashes. The percentage has been increasing over the last 20 years perhaps due to the makeup of the vehicle fleet. Rollover fatal crashes currently represent approximately 59% of total ROR fatal crashes.

Figures 3 and 4 show the five most prevalent first harmful and most harmful events in SVROR crashes based on data from more than 60,000 crashes. First Harmful Event (FHE) is defined as the first property damaging or injury producing event in the crash while the Most Harmful Event (MHE) is defined as the single impact that causes the greatest trauma and damage in the crash. Rollover was found to have the highest percentage of any first harmful event—even above trees. The percentage of SVROR fatal crashes with rollover as the most harmful event is 47%. This is almost double the percentage of fatal crashes with tree as the most harmful event.

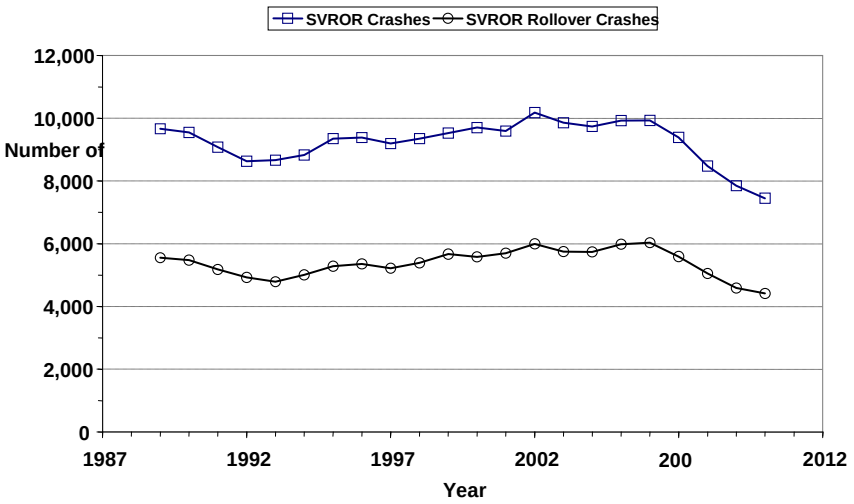


FIGURE 1 SVROR fatal crashes (FARS data, 1989–2010; passenger vehicle 45 to 75 mph).

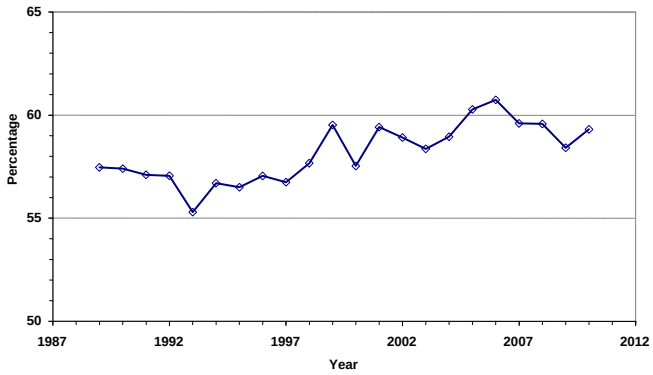


FIGURE 2 Percentage of SVROR fatal crashes that rolled over (FARS data, 1989–2010; passenger vehicle, 45 to 75 mph PSL).

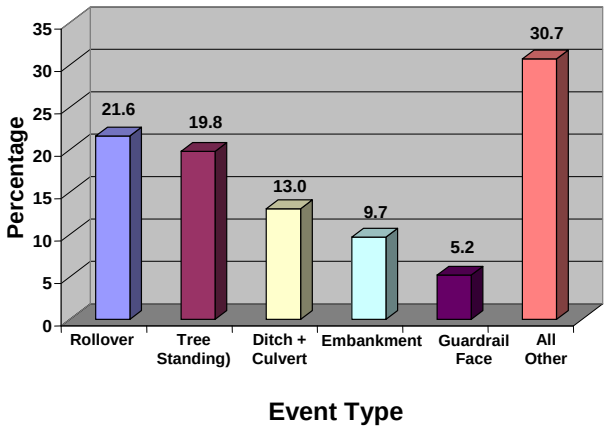


FIGURE 3 Top first harmful events (FARS data, 2004–2010, SVROR, passenger vehicle, 45 to 75 mph PSL, *n* = 62,759).

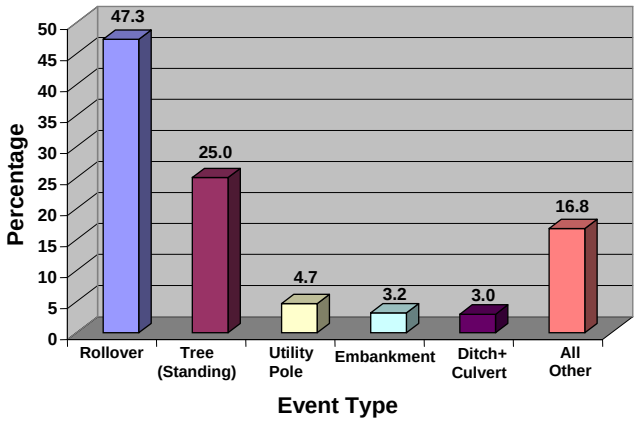


FIGURE 4 Top most harmful events (FARS data, 2004–2010, SVROR, passenger vehicle, 45 to 75 mph PSL, *n* = 62,759).

Using data from the FARS and the General Estimates System (GES) from 2004 thru 2009, the severity of rollover versus nonrollover ditch-initiated crashes were examined (see Table 1). The percentage of KAB rollover crashes (which represents fatal, incapacitating, and nonincapacitating injuries) is 2.8 times that of nonrollover lcrashes. The "C" designates possible injury crashes while "PDO" designates property damage-only crashes.

Rollover crashes were also examined as a function of highway type, posted speed limit, location with respect to the highway profile, horizontal alignment, and vertical grade. Findings from this investigation were as follows:

- The percentage of fatal rollover crashes on two-lane, two-way undivided highways dramatically eclipses all other highway types (62.9% of fatalities; 2004–2010).
- The percentage of rollover crashes on roadways with a posted speed limit of 55 mph is nearly three times that of any other posted speed limit. This is likely attributed to the distribution of posted speed on two-lane, two-way (2L2W) undivided highways more than being representative of a critical speed for rollover crashes.
- It can clearly be seen that the percentage of rollover crashes on 2L2W undivided highways with posted speed of 55 mph is more than three times that for any other combination of highway type and posted speed limit.
- 75% of fatal rollover crashes result from a tripped vehicle.
- The majority of rollover crashes (57%) initiate on the roadside. This is almost six times the percentage of median initiated rollovers.
- In terms of roadway alignment, more than 40% of rollover crashes occur along curved roadway segments and over 30% of rollover crashes occur along roadway segments with a vertical grade.
- In terms of vehicle type, passenger cars are underrepresented while utility vehicles are significantly overrepresented in terms of SVROR rollover risk (when accounting for exposure through the ratio of SVROR rollover crashes to SVROR crashes).

TABLE 1 Severity of Rollover Versus Nonrollover Ditch-Initiated Crashes

Severity	Rollover (%)	Nonrollover l(%)
KAB	39	14
C	19	11
PDO	42	75

NOTE: KAB = fatal, incapacitating, and nonincapacitating injuries; C = possible injury crashes; PDO = property damage only.

Risk of Fixed-Object Crashes in the United States

CLAY GABLER
Virginia Tech

BACKGROUND

Road departure collisions are one of the most dangerous types of crashes on U.S. highways. As shown in Figure 1, road departure crash fatalities peaked in 2006 at approximately 17,500 fatalities and have fortunately declined to approximately 13,500 fatalities in 2010. In 2010, road departures resulted in 41% of all fatalities.

The roadside is often not a friendly place for the errant motorist. Crash outcomes can include vehicle rollover and collisions with fixed unyielding objects such as trees. Other presentations at this meeting will discuss rollovers in road departure crashes. This paper will focus on road departure crashes with fixed objects.

OBJECTIVE

The objectives of this study are (*a*) to determine the characteristics of fixed-object crashes and (*b*) to determine the priorities for countermeasure development.

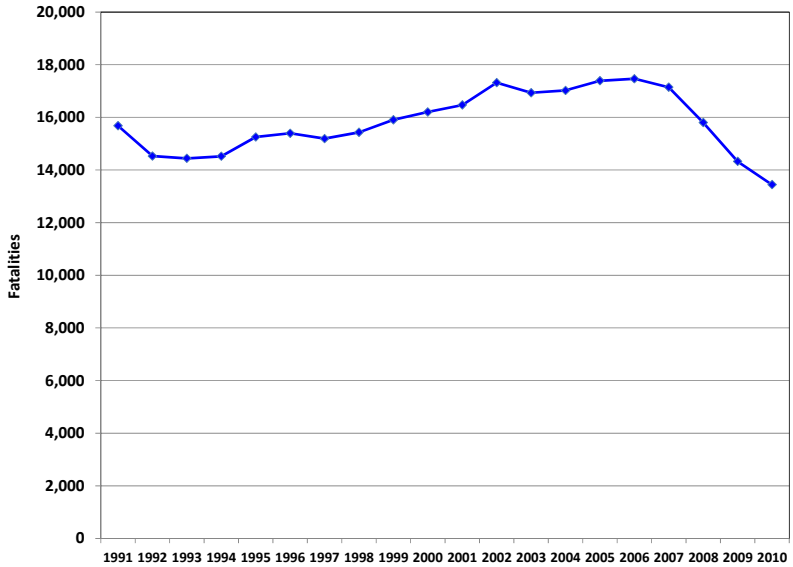


FIGURE 1 Fatalities in U.S. road departure crashes (FARS 1991–2010).

APPROACH

Our approach was to investigate this issue using the following national crash databases:

- FARS. This study will use the Fatality Automotive Reporting System 1991–2010 for fatality counts. FARS is a census of U.S. traffic fatalities that has been released each year since 1975.
- NASS–CDS. The National Automotive Sampling System–Crashworthiness Data Systems (1997–2008) was used to determine the in-depth characteristics of serious to fatal road departure crashes. NASS–CDS is a collection of approximately 5,000 in-depth crash investigations conducted by highly skilled crash investigation teams each year by NHTSA. NASS–CDS cases are weighted to allow national estimates of crash and injury risk. NASS–CDS provides an in-depth investigation and reconstruction of these crashes not available from FARS. FARS is based upon police accident reports which do not describe the crash in the high amount of detail needed to understand these complex crashes.
- NCHRP 17-22. The study used the NCHRP 17-22 set of specialized data elements to describe the unique characteristic road departures. The NCHRP 17-22 database is a collection of 890 road departures investigated as NASS–CDS cases and enhanced with supplemental collection of specialized data elements needed to represent and describe the unique characteristic road departures. The NCHRP 17-22 database provided supplemental data collection for NASS–CDS cases investigated in 1997–2001 and 2004.

Road departure cases were extracted from each of these databases. This study defined road departure crashes as single-vehicle crashes and excluded cases involving impacts with pedestrians, bikes, animals, fire, or explosion. The focus was on cases in which the most harmful event was a collision with a fixed object, e.g., a tree or guardrail. Guardrails included all forms of metal longitudinal barrier including w-beam guardrail and cable barrier.

Injury severity was defined using the Abbreviated Injury Scale (AIS) (Gennareli and Wodzin, 2005). AIS is a six-level medically based measure of injury severity based on threat to life. AIS 1is a minor injury, AIS 3 is a serious injury, and AIS 6 is an unsurvivable injury. NASS–CDS and, by extension, NCHRP 17-22 codes each occupant injury by this scale. For this study, we considered a seriously injured occupant to have suffered at least one injury ranging from AIS 3 (serious) to AIS 6 (unsurvivable).

RESULTS

Table 1 presents the distribution of fatalities in 2010 road departure crashes by vehicle type and most harmful event. Figure 2 presents the distribution of road departure fatalities in cars and light trucks in 2010. In 2010, over 5,000 motorists were fatally injured as a result of vehicle rollover. In cars and light trucks (pickups, SUVs, and vans), about half (44.7%) of all road departure fatalities occurred as a result of vehicle rollover. Tree impacts accounted for 3,505 fatalities in 2010, and comprised nearly one-third (28.8%) of passenger vehicle road departure fatalities. Pole impacts accounted for over 900 fatalities in 2010. Impacts with guardrails resulted in over 450 fatalities in 2010. Nearly half of the guardrail fatalities were motorcyclists.

Figure 3 presents the distribution of serious injury crashes in single-vehicle collisions.

When setting priorities for countermeasure development, serious injury crashes are widely accepted as a better more representative metric of safety needs than fatality counts. The injury analysis, in this case, mirrors the findings of the fatality analysis. Overturns and impacts with trees, poles, and guardrails together account for over three-fourths of all serious-to-fatal crashes. Together, collisions with the fixed objects of trees, utility poles, and guardrails resulted in half (50.1%) of all passenger vehicle occupant fatalities in road departures. In terms of priorities for fixed objects, the study that follows will focus on these three fixed objects as priorities for countermeasure development.

TABLE 1 Fatalities in Road Departure Crashes by Most Harmful Event (FARS, 2010)

Most Harmful Event	Total	Car + Light Truck	Motorcycle	Other Vehicle
Rollover	5,816	4,902	605	309
Tree	3,505	3,157	219	129
Utility pole	949	777	153	19
Embankment	379	284	72	23
Guardrail	455	227	206	22
Immersion	209	196	8	5
Ditch	247	163	70	14
Culvert	206	158	43	5
Fence	167	119	42	6
Bridge pier	127	117	3	7
Building	128	112	11	5
Wall	127	109	15	3
Concrete barrier	125	89	36	0
Sign or signal post	132	79	50	3
Other	871	479	321	71
Total	13,443	10,968	1,854	621

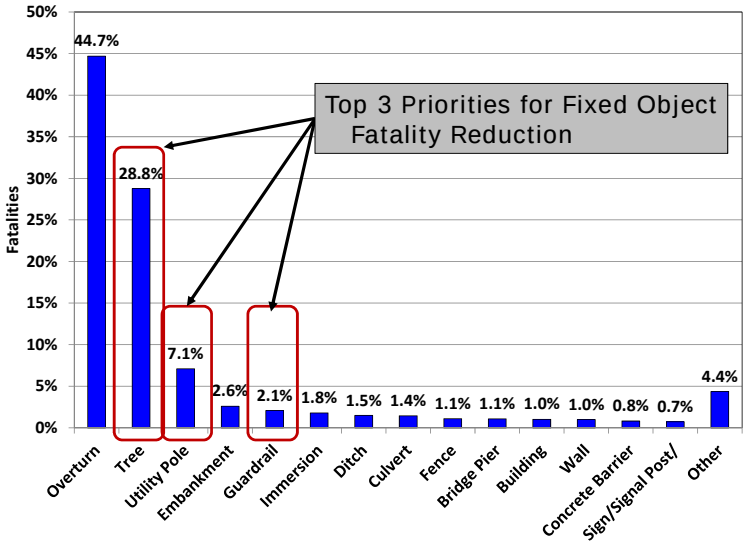


FIGURE 2 Fatalities in road departure crashes (FARS 2010; cars and light trucks).

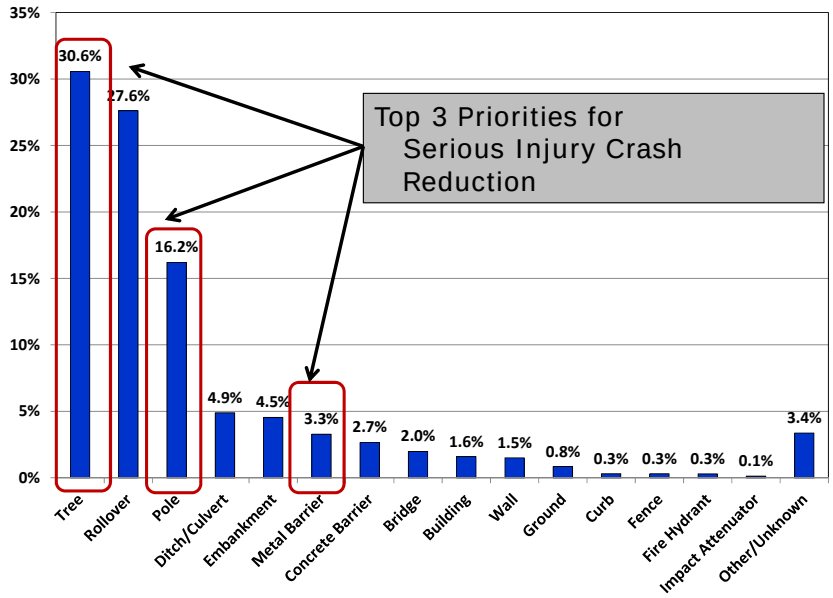


FIGURE 3 Serious to fatally injured occupants in road departure crashes (NASS 1997–2008; cars and light trucks).

Tree Impacts

Tree impacts result in 3,000 to 4,000 fatalities each year in the United States. NASS–CDS case 1999-11-133 illustrates one such case. In this case, an 18-year old driver was traveling down a two-lane undivided road, lost control of his 1999 Pontiac Grand Am, and slid sideways into a tree. As shown in Figure 4, the car suffered catastrophic collapse of the occupant compartment. Upon impact, the belted driver suffered multiple skull and brain injuries when his head rotated out the side window and struck the tree.

The case was investigated as part of NCHRP Project 17-22. Impact speed was estimated to be 46 mph with an impact angle of 90 degrees (a perpendicular impact to the driver door). As

FIGURE 4 1999 Pontiac Grand Am after side crash with tree (NASS–CDS 1999-11-133).

(a) (b)

FIGURE 5 1999 Pontiac Grand Am collision with 16-in. diameter tree: (*a*) tree located 10 ft from travel lane and (*b*) tree was rigid; no detectable damage. (NASS–CDS 1999-11-133)

shown in Figure 5, the tree was determined to have a diameter of 16 in., and was located only 10 ft from the travel lane. The tree was essentially rigid, and incurred little, if any, damage.

Serious injury crashes with trees occur at relatively low speeds. Based on analysis of tree crashes in NASS–CDS 1997–2008, Figure 6 shows that the median vehicle total delta-V was only 14.3 mph. Similarly, the median delta-V for serious injury crashes was only 22.4 mph. Ninety percent of all tree crashes occurred at delta-V below 25 mph and 90% of all serious injury tree crashes occurred at delta-V below 40 mph. Note that NASS–CDS does not record impact speed. However, in impacts with rigid objects, delta-V is an excellent surrogate for impact speed.

NCHRP 17-22 also investigated the location of the tree in these crashes. As shown in Figure 7, the trees in these events were very close to the travel lane. The median lateral offset of the tree was only 12.5 ft from the edge of the road. By comparison, the recommended extent of the clear zone for roadways is 30 ft from the edge of the travel lane. Despite this guideline, as shown in Figure 7, 85% to 90% of the struck trees were within 30 ft of the roadway edge or the clear zone.

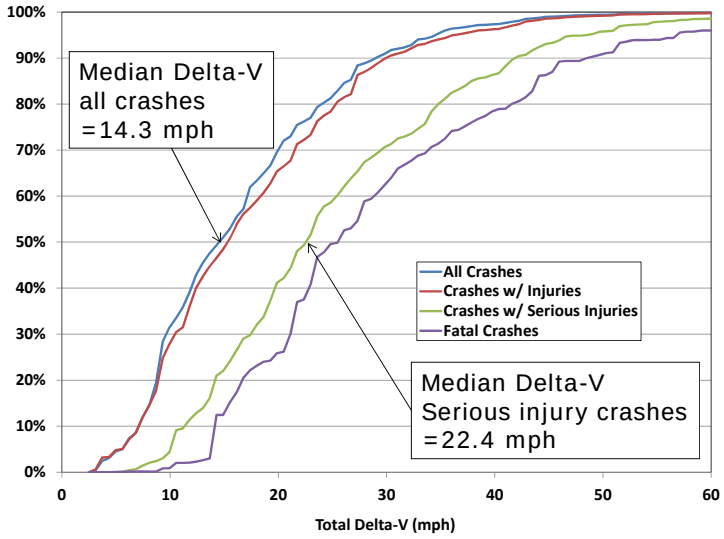


FIGURE 6 Distribution of total delta-V in tree crashes (NASS–CDS 1997–2008).

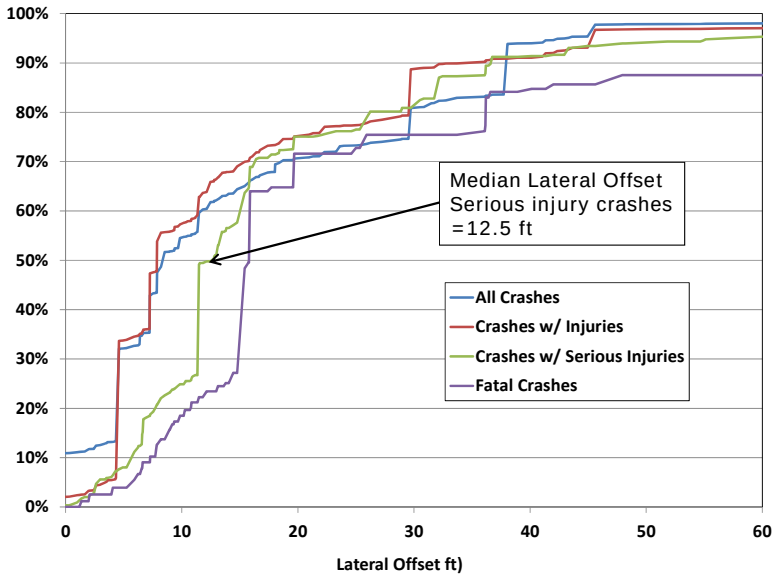


FIGURE 7 Lateral offset of trees in tree collisions (NCHRP 17-22).

Guardrail Impacts

Guardrail impacts result in an estimated 450 fatalities per year (Gabler and Gabauer, 2007). In 2010, over 200 car and light truck occupants were fatally injured in crashes in which the guardrail impact was the most harmful event. As shown in Figure 8, frontal impacts with guardrail account for about half of all occupants exposed to this crash mode as well as about half of all the fatalities. Frontal crashes are the crash mode tested in NCHRP 350 and MASH test procedures.

One of the most dangerous types of guardrails impacts is a side impact (Ray, 1999; Gabler and Gabauer, 2007; Stolle et al., 2011). Figure 8 shows that approximately 1 in 5 fatalities occur in side impact—an impact mode not tested in either the NCHRP 350 or MASH test procedure. Of particular concern are crashes in which a nontracking vehicle slides sideways into a guardrail end treatment (Johnson and Gabler, 2013). As shown in Figure 9, the resulting concentrated load on the side door structure can result in penetration of the guardrail directly into the passenger compartment and a high probability of serious occupant injury.

Analysis of NCHRP 17-22 in-depth crash investigations provided insight into how these side impacts occurred. As shown in Figure 10, nearly two-thirds of side impacts into guardrails occurred when the vehicle had lost control and impacted the barrier in a nontracking configuration. In 37% of the cases, the vehicle was in a lateral skid while rotating counter-clockwise while in 25% of the cases was in a lateral skid while spinning clockwise. In only about a third of the cases, the vehicle was tracking before side impacting the barrier. Many of the tracking cases occurred when the vehicle was negotiating a sharp curve or exit ramp and side-swiped the rail.

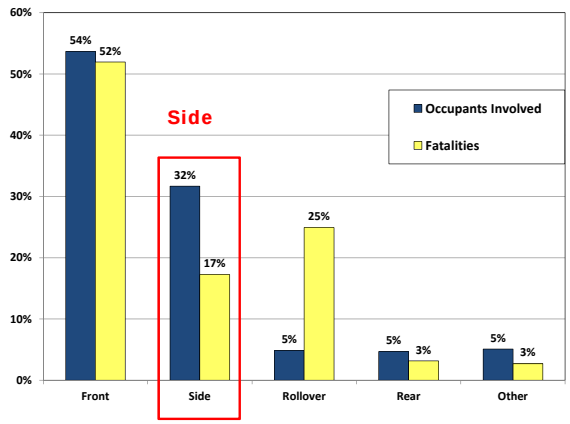


FIGURE 8 Distribution of fatalities in guardrail crashes by crash mode (FARS, GES 2005–2009).

FIGURE 9 Fatal nontracking side impact into a guardrail end terminal.

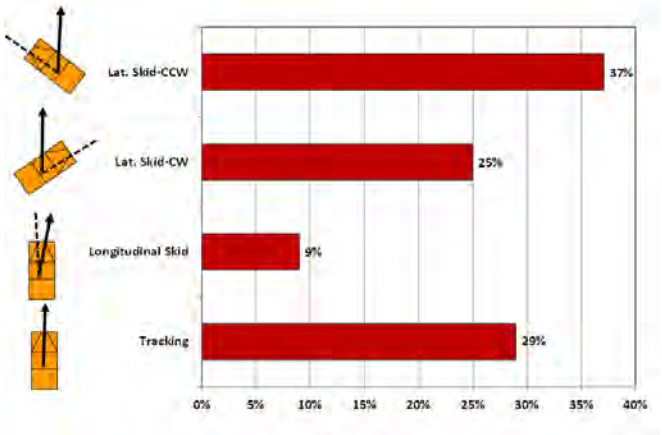


FIGURE 10 Precrash vehicle configuration prior to guardrail crashes (NCHRP 17-22).

Utility Pole Impacts

Vehicle impacts with utility poles are one of the most unforgiving types of crashes to which motorists are exposed. Each year in the United States, 900 to 1,000 motorists are fatally injured in collisions with utility poles. The rigid design of a utility pole, which allows the pole to survive the high winds of a storm, unfortunately makes the pole particularly unyielding in a traffic accident. Vehicles which undergo pole impacts suffer large, frequently devastating, deformation of the occupant compartment which too frequently leads to serious or fatal injuries.

Utility pole crashes have long been known to be a crash risk. *NCHRP Report 500: Volume 8: Utility Poles* (Lacy et al., 2004) reported on this problem and suggested a number of countermeasures including the following:

- Remove poles by placing utilities underground or decrease the number of poles,
- Relocate poles,
- Place traffic barriers,
- Replace with breakaway poles, and
- Install reflective markers.

Our research into utility pole crashes in New Jersey found that frequently utility poles were not moved when roads are widened (Gabler et al, 2007). Figure 11, taken on Route 22 in New Jersey, shows that utility poles are often just inches from the travel way. Little separates the errant motorist from a catastrophic collision with a rigid object.

Often pole relocation is problematic because of the expense of procuring additional ROW to move the poles. One potential solution is breakaway or energy-absorbing poles. Extensive research was conducted in this area, primarily at TTI, in the 1980s and early 1990s. Examples are the studies performed by Ivey and Morgan (1986) and Alberson and Ivey (1994). More recently, energy-absorbing collapsible poles have been proposed as a device to mitigate

FIGURE 11 Utility poles frequently are not moved when roads are widened (New Jersey SH-22).

utility pole impacts. To date, however, little progress has been made in the adoption of either breakaway or energy-absorbing poles. Issues include questions of pole durability, cost, and the lack of utility company acceptance.

CONCLUSIONS

This study has investigated the characteristics of fixed-object crashes in the United States with the goal of identifying the priorities for countermeasure development. Our analysis shows that impacts with trees, poles, and guardrails together account for half (50.1%) of all serious-to-fatal crashes. In terms of priorities for fixed objects, our study concludes that these three fixed objects—trees, utility poles, and guardrails—are priorities for countermeasure development. Our findings include the following:

- Tree impacts result in 3,000 to 4,000 fatalities per year. Trees are frequently unyielding in a collision, and can lead to catastrophic collapse of the vehicle structure. Even moderate impact speeds can lead to serious injuries. The median impact speed in serious injury crashes with trees was only 22 mph. Over 85% of struck trees were within the recommended 30 ft clear zone. The median tree lateral offset in serious injury crashes was only 12.5 ft from the travel lane.
- Guardrail impacts result in an estimated 450 fatalities each year in the United States. Half of these fatalities are motorcyclists. For car and light truck occupants, approximately, 20% of the fatalities occurred when a vehicle side impacted guardrail. This impact mode is not tested in either NCHRP 350 or MASH. Particularly dangerous are nontracking side impacts to guardrail end treatments. Research to develop a test procedure and countermeasures to mitigate nontracking side impacts to end terminals is needed.
- Utility pole impacts result in 900 to 1,000 fatalities per year in the United States. Although utility pole impacts have been long recognized as a severe traffic safety problem, the issue remains unresolved. NCHRP 500 recommended a suite of countermeasures which remain largely not implemented. Needed is research to develop new designs for economical breakaway or energy-absorbing utility poles.

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Characteristics of Opposite Direction Crashes in the United States

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Opposite direction crashes have the potential to be extremely severe because opposing vehicles often have high relative speeds. The objective of this study was to characterize opposite direction crashes in overall frequency as well as fatal and serious injury crash frequency. The results of this study can be used to guide future research and investment in infrastructure opposite direction countermeasures, such as centerline rumble strips. We used the 2010 National Automotive Sampling System (NASS) General Estimates System (GES), the 2010 Fatality Analysis Reporting System (FARS), and 2006-2010 NASS Crashworthiness Data System (CDS). We found that the most common opposite direction crash scenario was a driver departing over the center line or road edge to the left, which accounted for only 5% of nonjunction vehicle-to-vehicle crashes but 48% of fatal and 44% of serious injury crashes of the same type. Of these cross over to left crashes, 72% of fatal crashes occurred on rural undivided two-lane roads accounting for 1,618 fatal crashes in 2010. In cross over to left crashes on rural two-lane roads, the driver was going straight or negotiating a curve in 87% to 94% of crashes. The driver was overtaking another vehicle in only 6% of fatal and 2% of serious injury crashes. Crashes occurred on both curves and straight segments. Those that occurred on curves were to the outside of the curve more often than the inside of the curve. This research suggests that opposite direction countermeasures should focus on rural two-lane roads.

Roadway Departure Crashes Involving Large Trucks, Passenger Vehicles, and Motorcycles

DOUGLAS J. GABAUER
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Roadside safety devices such as longitudinal barriers, crash cushions, and breakaway sign support structures must be designed to handle impacts from a range of vehicle types. In order to design and appropriately crash test these devices, a good understanding of the characteristics of and the vehicles involved in real-world ROR crashes is necessary. The objectives of this research were to determine current ROR crash rates by vehicle type and the distribution of objects struck in these crashes. Single vehicle ROR crashes from FARS and NASS–GES (General Estimates System) was used in conjunction with vehicle miles traveled (VMT) data from FHWA. Data from 2010 was used to provide a current snapshot while data from 2004 through 2008 was used to provide some context for historical trends. Based on the available data, motorcycle crash rates were found to far exceed other vehicle types. In general, ROR crash rates were found to be generally stable with some decreasing trends observed in fatal single vehicle ROR crash rates. Overturns were the largest contributor to single vehicle ROR fatal crashes for light trucks and vans (LTVs) and large trucks while fixed-object crashes are a larger concern for passenger cars and motorcycles.

SESSION 3

Primary Crash Types and Where They Happen

Breakout Summaries

SESSION 3: PRIMARY CRASH TYPES AND
WHERE THEY HAPPEN: BREAKOUT SUMMARIES

Overturn Crashes

ROGER BLIGH
Texas A&M Transportation Institute

ROLLOVERS ON CURVES RANK

Steve Kan and Raph Grzebieta

A disproportionally high percentage of rollover crashes occur on curved roadway sections. Investigation of effectiveness high-friction surface treatment and other countermeasures is needed to determine their effectiveness in mitigating the rollover problem on curves.

INTERACTION OF VEHICLES WITH EXPOSED FOUNDATION ELEMENTS OF ROADSIDE SAFETY STRUCTURES

Dane Hansen and Roger Bligh

Erosion and improper grading often result in foundation elements of roadside safety structures (e.g., mow strip, post footers, end treatment anchor tubes, sign support foundations) being exposed. The interaction of vehicles with these exposed foundation elements may be a trip mechanism in rollover crashes

EFFECT OF ROADSIDE ELEMENTS ON DRIVER RESPONSE

Mitchell O'Laughlin

This research is intended to determine if driver response is influenced by different roadside design elements (steep slopes, etc.) and the perceived risk of running off the road. This may be suited to a human factors study with driver simulators.

ROLLOVER MECHANISMS ASSOCIATED WITH BARRIER IMPACTS

Will Longstreet and Raph Grzebieta

A significant percentage of barrier impacts (42%) have rollover as the most harmful event. Research is needed to understand types of barriers involved in rollover crashes, trip mechanisms associated with these crashes, and to develop improved barrier configurations. Consider barrier types, shape of concrete barriers, height of beam guardrail systems, sensitivity to angle of impact, etc.

This was combined with a previous research problem statement entitled: Injury and Fatality Causation during Rigid Barrier Impacts. The title of the problem statement was changed to Rollover Causation During Barrier Impacts. The modified objective is to identify the causes of

rollover barrier crashes. The identification of rollover mechanisms will allow for optimal selection and design of barriers to both contain errant vehicles and minimize rollovers and associated occupant injuries.

The research plan for this project will include detailed review of rollover crashes and rollover crash data. Research is needed to understand types of barriers involved in rollover crashes, trip mechanisms associated with these crashes, and to develop improved barrier configurations that mitigate rollovers. The research will focus on rollover crash data for roadside and median barriers of various types and shapes, height of beam guardrail systems, sensitivity to angle of impact, etc. This information will be used to develop improved barrier designs that enhance occupant safety in barrier impacts.

DETERMINING CAUSES OF VEHICLE ROLLOVER CRASHES

Mario Mongiardini and Nauman Sheihk

This problem statement was developed by the Roadside Safety Design Computational Mechanics subcommittee [AFB20(1)]. The objective of this project is to determine causation factors of rollover crashes, such as encroachment angle and speed, terrain features, vehicle types, types of objects impacted. This project should enhance understanding of the key causation factors of rollover crashes using finite element simulation analysis and limited crash testing.

SESSION 3: PRIMARY CRASH TYPES AND
WHERE THEY HAPPEN: BREAKOUT SUMMARIES

Fixed-Object Crashes

CLAY GABLER
Virginia Tech

OBJECTIVE

The goal of the Breakout Session E was to develop research statements on fixed-object crashes as potential NCHRP research projects.

APPROACH

An estimated 30 attendees of the Roadside Safety Design Committee's (AFB20) Summer meeting participated in this breakout session. The group first reviewed the distribution of fatalities in single-vehicle crashes. The group decided to focus on (1) trees, (2) utility poles, (3) embankments, ditches, or culverts, and (4) guardrails as priority areas. Following are summaries of our discussions in this area from which two research topics, also discussed below, were proposed.

Trees

The breakout group had a lively discussion about the problem of tree impacts and ways to mitigate the problem. Currently in the United States, tree impacts result in 4,000 to 5,000 fatalities each year.

It was noted that this a problem for which we know the solution: removal of trees that pose a threat. However, several challenges to implementing tree remediation were noted:

1. There is often intense public resistance to cutting trees. In addition, the landscape architects who are planning these plantings do not appreciate the risk that small trees may pose as they grow into larger trees.
2. Many tree impacts happen when a vehicle leaves the road in a heavily traveled rural area. There is often insufficient ROW on heavily treed rural roads to fix the problem. And given the funds, the question becomes where to start in a state with thousands of miles of rural road. How does one prioritize the remediation areas?
3. It was pointed out that the tree problem varies by urban, suburban, and rural environment. There may not be a one-size-fits-all solution. Suburban areas are complex environments with trees, buildings, pedestrians, and transit. Trees are not the only objects in the clear zone.
4. It was suggested that in some cases some landscape design choices might actually improve tree crash safety. Some shrubs planted near trees may actually help to slow an errant vehicle, reducing injury risk. There is a need to educate landscape architects.
5. Needed is a synthesis of best practices for balancing aesthetics with safety. The group felt that it would be useful to invite groups like Scenic America to one of Roadside Safety Design

Committee meetings to discuss balancing aesthetics with safety.

It was pointed out that solving the tree problem could benefit from better coordination between the automakers and the highway community. Cars could be designed for better performance in narrow object crashes, e.g., trees and poles, both in front and side impact. The recent enhancement to Federal Motor Vehicle Safety Standard (FMVSS) 214: Side Impact Protection (FMVSS214), which requires pole side impact testing of all passenger vehicles, may help to mitigate the tree problem in the future. Needed is an evaluation of how the injury outcomes from tree crashes will change as these systems are deployed in the fleet.

One member of the breakout group noted that mowing practices can remediate trees by cutting saplings before they grow too large. This state regularly mows from ROW line to ROW line. However, as a cost-saving measure, this state has gone from yearly mowing to every 4 years. Consequently, small saplings can no longer be cut with the mower, and requires that the state deal with the issues associated with cutting down bigger trees, a much more expensive proposition. The question is whether infrequent mowing to save costs is actually false economy. Needed is an examination of model policies or a statement of best practices for mowing to prevent the growth of trees in clear zones.

During this discussion, one member commented that utility companies are very aggressive about cutting or pruning trees to keep their power lines clear. In some cases this helps the DOTs who have much more trouble removing trees near the roadway.

One member of the group asked if there are any formal studies of the effectiveness of the clear zone? Are any of the studies by Zeeger applicable? What percent of injuries and fatal accidents would be reduced if a clear zone is established along a highway corridor? What are the priorities for tree removal? Are motorists hitting trees because clear zones are not being hit, or because they are hitting trees adjacent to a clear zone?

Guardrail Impacts

The breakout group next discussed the problem of nontracking side impacts into guardrail and ways to mitigate the problem. Currently in the United States, guardrail impacts result in about 450 fatalities each year. About 20% of the car impacts are side impacts. Most of these side impacts occur when the vehicle is nontracking and slides into the guardrail end.

It was noted that there is much previous research in this area including FHWA research during development of modified eccentric loader terminal (MELT), Don Ivey's TRB paper in 2010, and Malcolm Ray's research in the 1990s on side impact into roadside hardware. There may also be some papers on side impact that will be submitted to the 92nd Annual Meeting of the Transportation Research Board in 2013.

Several members of the group commented that the draft version of MASH contained a draft side-impact test procedure. The ET-Plus end terminal, in fact, was tested to the draft side-impact procedures for MASH. However, the side-impact procedure was dropped from final MASH. There was uncertainty in the group as to why the procedure was dropped. Many felt that the draft side-impact procedure should be revisited in a follow-up research project in this area.

The group wondered if there was any information on which guardrails end types might be involved in fatal or serious injury side impacts. There is, unfortunately, little data on this. The question was whether fatalities are the result of states not adopting new guardrail design or guardrail end designs. Some states have a replace-in-kind policy. Many felt that this type of policy was an

obstacle to adopting improved end-terminal designs.

It was noted that, in order to make further progress in reducing guardrail fatalities, the side-impact problem needs to be addressed. Many felt that a much broader emphasis should be placed on side impact. It was estimated that 50% of all fixed-object fatalities (trees, poles, guardrails) are in side impact. One suggestion was that current end-terminal designs should be tested with the draft MASH side-impact procedure. The expectation was that many of them would pass. This would be an excellent subtask in a research statement on this subject.

Utility Poles

The breakout group next discussed the problem of impacts with utility poles and ways to mitigate the problem. Currently in the United States, utility pole impacts result in nearly 1,000 fatalities each year. Utility poles are designed as rigid structures and are unforgiving in crashes. The following comments were offered during the session by individual participants:

- Utilities will only remediate poles if there are sufficient lawsuits.
- Poles are on DOT easement. DOTs should be able to enforce pole placement.
- What is effectiveness of delineators on poles?
- There is a lot of great research on reducing number of utility pole impacts. HSM provides a method for predicting crash reduction from utility pole remediation.
- Are there newer technologies to bury utilities? Robotic trenching and Global Positioning System-based technologies are in place.
- There is a need to investigate new breakaway pole designs or collapsible pole designs from Europe.

RESEARCH TOPICS

Two research topics were proposed:

1. Strategies to reduce tree and utility pole crash risk.
   - Problem: In the United States each year, there are more than 4,000 to 5,000 fatalities from tree impacts and nearly 1,000 fatalities from utility pole impacts.
   - Objective: Develop methods and, in the case of poles, new technologies for use by the states to reduce the risk of fatality and serious injury in tree and utility pole crashes. One specific objective was to develop strategies to help the states implement remediation techniques that have been developed in previous research projects.
2. Development of methods to mitigate side impact problem in nontracking impacts.
   - Problem: Side impact into devices such as guardrail end terminals is a particular hazardous crash mode for which roadside hardware is not currently tested under MASH.
   - Objective: Develop and evaluate countermeasures and test procedures that will lead to a reduction in fatality and injury crash risk in nontracking side impacts with roadside hardware, including longitudinal barriers, end terminals, sign posts, luminaries, and utility poles.

SESSION 3: PRIMARY CRASH TYPES AND
WHERE THEY HAPPEN: BREAKOUT SUMMARIES

Head-On Crashes

KRISTOFER D. KUSANO
Virginia Tech

NARRATIVE OVERVIEW OF SESSION

Our breakout session started with a discussion on head-on countermeasures that state DOTs are currently implementing and new countermeasures that could potentially be applied to mitigate head-on crashes. The group identified a list of the following countermeasures:

4. Centerline rumble strips,
5. Raised markers or thermoplastics,
6. Delineators,
7. Wire rope barriers,
8. Additional opposing lane separation (narrow median), and
9. Other barrier types (e.g., concrete).

There was some discussion on how various states applied traditional head-on countermeasures and some of the challenges they faced. We heard from experiences in California, Kansas, and Texas, as well as Australia. We discussed issues such as using centerline rumble strips on curves and straight segments, wire rope on curves in Australia, possibly using delineators to separate opposing lanes on curves, challenges in implementing centerline rumble strips, and noise and human factors studies for rumble strips.

We then took that discussion and defined two problem statements. The outlines of these problem statements are below.

PROBLEM STATEMENT OUTLINES

1. Relationship of average daily traffic and head-on crashes on two-way undivided rural roads.
   - Problem: Countermeasures, e.g., centerline rumble strips, are infrastructure investments that have been proven to reduce both total crashes and serious injury crashes (NCHRP Report 641). It is probable, however, that certain types of roads will have more risk for head-on crashes than others and should be prioritized for head-on countermeasures.
   - Past work: Sicking et al. (2009) performed a study entitled Guidelines for Implementation of Cable Median Barriers. This study developed a relationship between ADT and encroachment frequency and head-on crash frequency for median-divided highways. Encroachment rates across the median were linearly related to ADT and crash frequency showed a second order relation to ADT. This study was only performed for

divided highways and is not applicable to two-way undivided roads.

– Objective: Determine the relationship between ADT and the frequency of head-on crashes on two-way undivided roads. This project will also investigate the influence of other factors (e.g., horizontal curves or speed limits) that affect crash frequency.

– Outcome: The outcome of this study would help develop policy on the implementation of cross-over countermeasures (e.g., centerline rumble strips, thermoplastics, delineators, and barriers).

– Volunteers to develop problem statement: Steven Buckley and Richard Butler.

2. The evaluation of countermeasures for reducing head-on crashes on undivided highways.

– Problem: There are many countermeasures for head-on crashes with limited guidance on when they are appropriate. Examples are centerline rumble strips, additional separation of opposing travel lanes, delineators, and barriers. The progression of countermeasures that should be applied in particular applications (i.e., rumble strips to additional separation to barriers) is not well documented.

– Objective: Determine the performance of countermeasures in reducing head-on crashes. For example, what is the overall safety benefit of increasing separation between opposing lanes and reducing either lane width or shoulders?

– Outcome: This project would use a retrospective analysis of head-on countermeasures already installed on roads. The project should also investigate the impact of these treatments on other road uses (e.g., bicycles, motorcycles) and if there are differences between the performance of countermeasures on tangent and curved roads.

– Volunteers to develop problem statement: Dick Albin, Craig Copelan, and Jeff Shewmaker.

SESSION 3: PRIMARY CRASH TYPES AND
WHERE THEY HAPPEN: BREAKOUT SUMMARIES

Addressing the Range of Vehicle Types

DOUGLAS J. GABAUER
Bucknell University

The purpose of this breakout session was to develop proposed research topics related to how the range of vehicle types in the fleet are addressed in roadside safety design. Discussion topics primarily included roadside safety hardware testing procedures involving motorcycles, issues related to motor coaches, and nontracking impacts with roadside hardware. A total of six possible research topics were developed and prioritized for further consideration. These topics are listed in the table below along with the ranking details and associated notes. The ranking procedure consisted of each attendee anonymously ranking all six of the proposed topics from highest to lowest priority. A weighting scheme was used to compute the score which assigned six points for each time a proposed project was ranked highest priority, five points for a second place rank, four points for a third priority rank, and so forth.

Rank	Proposed Title	Notes	Score
1	Roadside Encroachment Census by Vehicle Type for Crash Testing Procedure Review	Current encroachment data has been collected only for passenger cars; all other encroachment rates for other vehicle types have been extrapolated. Additional data is required for large vehicles (motor coaches, single-unit trucks, combination trucks, etc.). Must be a census of all encroachments.	70
2	Off-Tracking–Side-Impact Vehicle Test Procedure Development	A large portion of roadside hardware impacts are nontracking yet this mode is not currently included in the testing procedures.	53
3	Interaction of Roadside Safety Countermeasures with Different Vehicle Types	Identification of safety countermeasures that have a positive benefit for a given vehicle type but pose a risk to another vehicle type. Examples include rumble strips that may pose a risk to motorcyclists and high-performance barriers that are impacted by smaller passenger cars.	49
4	Warrant Criteria for High-Performance–Level Median and Roadside Barriers	Currently being developed by another committee [Geometric Design Committee (AFB10)]?	45
5	Motorcycle-to-Barrier Crash Test Procedures	Development of U.S.-equivalent roadside crash test procedures for motorcycle vehicle segment.	39
6	Roadside Safety Considerations for Motorcoaches	What are the characteristics and causes of these crashes? How does the body of the vehicle impact the redirection performance? Should test procedures be developed and if so, how should occupant risk be handled? Develop potential recommendations for appropriate barrier test levels for these vehicles.	38

SESSION 4

Data and Assessment Techniques

TRB's SHRP 2 Naturalistic Driving Study and Roadway Information Databases

OMAR SMADI
Iowa State University

Omar Smadi from Iowa State University and principal investigator for SHRP 2 Roadway Information database project presented an update on the SHRP 2 naturalistic driving field study (NDS) and complementary roadway information project. The intent of the study is to determine what risks are inherent in the relationship of a driver's performance to the roadway design and to traffic conditions. Charles Fay, SHRP 2 staff, was present as well to answer questions and to solicit input in guiding SHRP 2 in the production of reduced datasets that are more useful for the committee's high-priority issues.

The NDS will provide objective scientific information about what happens when people crash, when they experience a near crash, and when they drive without incident. These data will be linkable to a database of roadway characteristics as well as driving environment information (e.g., traffic, weather, work zones). Together these databases will be a one-of-a-kind resource for surface transportation researchers and professionals to utilize for decades to come.

The *Highway Safety Manual* and the Roadside Safety Analysis Program

MALCOLM RAY
RoadSafe LLC

The RSAP has been distributed with the AASHTO *Roadside Design Guide* since the 2002 edition. Benefit–cost analysis has been an increasingly important tool in roadside design since the late 1970s when it was introduced as part of the 1977 AASHTO *Barrier Guide*. The encroachment conditional probability method first presented in the *Barrier Guide* has been modified and refined resulting in roadside design benefit–cost programs like Roadside, Benefit–Cost Analysis Program (BCAP), and finally RSAP. RSAP is currently being updated again and the new version, RSAP 3.0.0, is expected to be complete and available for use at the end of 2012.

HSM is a much more recent addition to the highway and roadside safety tool box that relies on several decades of crash data analysis research and statistical modeling. The first edition of HSM was released in 2011and states are being encouraged to use it as a tool in making highway safety decisions. HSM is not a benefit–cost model for the selection of a preferred alternative per se but it does predict the reduction in the number and severity of crashes resulting from implementing a variety of potential solutions using crash modification factors (CMFs) and safety performance functions (SPFs). While HSM contains a rich variety of CMFs, some of them address roadside safety issues like the installation of guardrails and median barriers.

Since both RSAP and HSM provide predictions about the effectiveness of roadside design alternatives, one might ask which tool should I use? RSAP allows for the very detailed examination of a specific site that allows designers to answer question such as how long should the guardrail be in order to shield a bridge pier at this location? HSM is a corridor-level tool that allows designers to ask questions such as how many crashes might be avoided if rumble strips are installed on a particular route. RSAP is a microlevel design tool whereas the HSM is a macrolevel design tool. One would have difficulty using HSM to, for example, determine if a 100-ft or 200-ft length of need is required to shield a particular hazard. Similarly, using RSAP to estimate the reduction in crashes on a long section of road would require a great deal of modeling effort and input data to say nothing of the long analysis time. The two tools, therefore, have complimentary but different uses.

Unfortunately, early comparisons between RSAP and HSM results show that the two approaches at present do not necessarily produce consistent results. Some CMFs for roadside hazards in HSM result in counter-intuitive results and some are defined in such a way that they are difficult to apply to typical roadside design situations. NCHRP has recently initiated a project aimed at improving HSM predictions for ROR crashes which will result in new SPFs for ROR crashes. It is hoped that the improved HSM results will compare more closely with the RSAP results. In fact, one of the project goals is to coordinate both models so comparisons between them are more direct and more meaningful.

Both techniques, RSAP and the HSM, are crash-data driven techniques that ultimately rely on field observations. In fact, some of the most important improvements to RSAP in the most recent version involve eliminating subjective methods and replacing them with methods based on observable data. Both tools will continue to evolve and will provide improved methods for making roadside safety decisions.

Crash Testing and Finite Element Simulations

MARIO MONGIARDINI
Midwest Roadside Safety Facility

In the past decade, numerical simulations have been extensively used to support researchers in assessing the safety performance of roadside safety hardware. In particular, nonlinear dynamic finite element (FE) simulations have been successfully used to determine the critical impact point (CIP) for full-scale crash testing a variety of roadside safety systems. This presentation showed two examples of how supportive FE simulations can be for identifying the most critical scenario before full-scale crash testing roadside safety hardware. In both cases, the tested hardware consisted of a midwest guardrail system (MGS) with nonproprietary end-anchor system. Simulations were used to determine the farthest downstream initial impact location that could guarantee the redirection of a 5,000-lb (2,270-kg) pickup truck, or the end of the length of need, and the CIP that could maximize a potential instability of a 2,425-lb (1,100-kg) small passenger car for impacts in proximity to the downstream anchorage. For both cases, the initial impact speed and angle were 62 mph (100 km\h) and 25 degrees, respectively. The simulated pick-up truck trajectory and guardrail deformation matched with what measured from the corresponding full-scale crash test. Although the simulated trajectory of the small passenger car did not completely reproduce the actual vehicle kinematics observed in the full-scale crash test, FE simulations clearly provided indications that severe vehicle snag on the anchor cable may have occurred for that selected initial impact location. The two presented cases indicated that FE simulations definitively represent a valuable tool to determine the worst potential conditions for full-scale crash testing roadside safety hardware (Figures 1 and 2).

FIGURE 1 Simulations were used to determine the farthest downstream initial impact location that could guarantee the redirection of a 5,000-lb (2,270-kg) pickup truck.

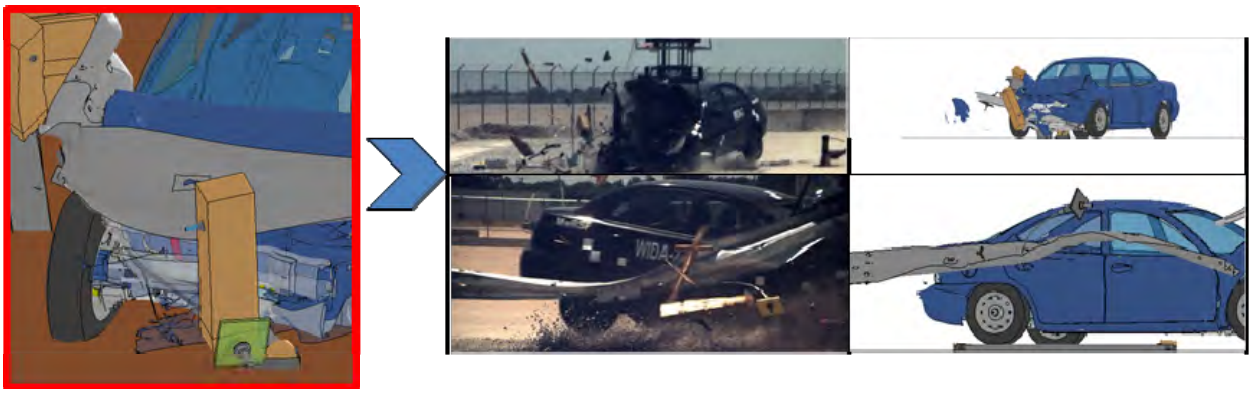

FIGURE 2 Simulations were used to determine the CIP that could maximize a potential instability of a 2,425-lb (1,100-kg) small passenger car for impacts in proximity to the downstream anchorage.

SESSION 4

Data and Assessment Techniques

Breakout Summaries

The *Highway Safety Manual* and the Roadside Safety Analysis Program

MALCOLM RAY
RoadSafe LLC

The group discussed research needs and priorities related to the HSM implementation and the soon-to-be-released RSAP version 3. Currently there are NCHRP projects underway involving both RSAPv3 and the HSM: NCHRP 17-54 and NCHRP 22-27. Project NCHRP 22-27 is nearly complete and RSAPv3 is nearly complete whereas NCHRP 17-54 is still in the beginning stages. Project 17-54 will be carefully reexamining how the HSM incorporates roadside design issues and in particular, run-off-road crashes.

Since project NCHRP 22-27 is nearly complete, most of the discussion centered on research and implementation needs arising out of the completion of the new program. During the rewriting of RSAP the research team found several areas where the underlying data is in need of reexamination. The three primary areas where more work is needed are as follows:

- Vehicle encroachment characteristics for multiple vehicle types. All the previous roadside safety benefit–cost programs (i.e., Roadside, BCAP, RSAP) have made an implicit assumption that all types of vehicles encroach at the same rate and have the same types of encroachment trajectories. This seems to be a very questionable assumption. While the older programs assumed straight paths, RSAPv3 uses actual trajectories collected in NCHRP 17-22 but all of these trajectories are from passenger-vehicle crashes. In addition, a quick assessment of the limited data available suggests that trucks encroach onto the roadside at a much lower rate than passenger vehicles. The purpose of this project would be to collect encroachment and trajectory data for nonpassenger vehicles like single-unit trucks, tractor-trailer trucks, and motorcycles.
- Update of geometric adjustment factors for RSAPv3. The horizontal and vertical curve adjustment factors used in RSAPv3 were inherited from those used in Roadside and those adjustments were based on a now very old and very small study by Wright. While the HSM has similar CMFs based on much newer and larger dataset, the HSM CMFs are not directionally dependent, which is necessary in RSAP. This project would use the databases used in the HSM to rederive the horizontal and vertical curve adjustment factors in a way that can be integrated into RSAPv3.
- Development of vehicle crash cost adjustment factors for RSAPv3. Just as Roadside, BCAP, and prior versions of RSAP assumed that all vehicles encroached in the same ways, these older programs also assumed that all vehicles resulted in similar crash costs. The commonly used crash cost values, however, are based on data that overwhelmingly represents passenger vehicles. In NCHRP 22-27 the RSAPv3 development team introduced an adjustment for crash costs based on vehicle types and used tentative values based on the literature. For example, studies performed for the FHWA indicated that in general ROR truck crashes have crash costs that are about 3.5 times greater than passenger vehicle crash costs. There is a need to more carefully examine the variation of crash costs by vehicle type in order to be able to use the best values in the RSAPv3:

In addition to the above research needs, the group discussed how to more effectively disseminate RSAPv3 and bring it to agencies and field practitioners who can most effectively benefit from it. The group developed the following two problem statements aimed at training and implementation of RSAPv3:

1. **Programming and web support for RSAPv3.** The purpose of this project would be to provide some short-term programming and web support for RSAPv3. This would allow any minor errors to be resolved or the addition of some features. It would also allow for developing and connecting the online resources to the AASHTO RDG website. Such online resources would include the user, engineer, and programmer manuals, the software itself, the help files, example problems, and a frequently asked questions page.
2. **Training and implementation of RSAPv3.** In the past, there has been some RSAP training made available as part of the National Highway Institute's Roadside Design Course. An on-site, sit-down course, however, is probably not the best way to deliver training in computer software. An alternative would be to develop online training materials that would allow new users to train themselves on their own schedule. This would avoid the problem of getting the right users to a sit-down training session and it also allows users to return time after time to the online resources as they have new questions or as they undertake more complicated problems. Online training would also have the benefit of spreading the software technologies out to the personnel who actually need to use it.

Last, the group also discussed the fact that these types of topics (i.e., benefit–cost analyses and crash prediction modeling for roadside safety) are often over shadowed by crash testing, FE simulation, and roadside hardware development issues. The group discussed the possibility of having a new Roadside Safety Design (AFB20) subcommittee that was focused on crash data prediction and benefit–cost analysis. This would help keep problem statement such as those discussed above at the forefront of AFB20 discussions and would also be helpful in working with several other TRB committees that have explicit crash data collection and analysis subcommittees.

Crash Testing and Finite Element Simulations

BOB BIELENBERG
Midwest Roadside Safety Facility

The objective of Breakout Group I was to identify research needs that would improve crash testing and provide information and data for future potential updates to the current MASH testing requirements and to identify research that would advance capabilities and confidence in computer simulation of roadside safety hardware. The research identified in the areas of simulation and crash testing would then be used to develop research problem statements to improve safety of the motoring public through advanced simulation and testing.

The breakout group began with a brief discussion of the advantages and shortcomings of crash testing and computer simulation as they relate to roadside hardware. Crash testing provides the primary method for determining hardware performance. Current crash testing standards for roadside hardware are defined in MASH. While MASH provides a good platform for hardware evaluation, it does possess certain shortcomings or limitations. These would include a limited number of available impact scenarios (speed, angle, orientation, vehicle type, etc.); the need for better correlation between real-world impacts and testing parameters; relatively high cost; limited data available from test instrumentation; and a significant degree of variability between similar tests.

Computer simulation of roadside hardware has a similar list of advantages and shortcomings. The advantages of computer simulation are the ability to conduct an infinite number of impact scenarios, to collect data not available in crash tests, and it is the only method available for evaluating performance of untested hardware. However, the implementation of computer simulation to evaluation roadside hardware has been limited due to the inability to model critical phenomena (metal fracture, suspension and tire failures, etc.) and the fact that the model accuracy is dependent of ability of modeler to anticipate and incorporate critical failure modes.

With this in mind, the group set out to identify the most pressing research needs in crash testing and computer simulation. Many research needs were identified and discussed. These needs included the following:

1. Nontracking impacts,
2. Evaluation methods for determining the effect of attachments on the performance of the barrier,
3. Occupant risk for restrained occupant,
4. Round robin simulation comparisons,
5. Procedures for evaluation of roadside safety hardware and determination of what types of modifications can be predicted through simulation, and
6. Updated limits for verification and validation (V&V).

In the end, a total of four research needs were prioritized and selected for development as future research problem statements. They are as follows:

1. Determine the parameters needed to define nontracking impact test conditions.
   a. Review previous research with respect to side impacts on narrow hazards.
      - Determine most severe nontracking impacts on specific barrier types: reconstruct fatal and severe nontracking impacts to identify critical impact conditions.

   b. Occupant risk criteria for side impacts:
      - Differentiate from Intersection Capacity Analysis Package (NCAP)-type evaluation.

   c. Future research following determination of nontracking impact parameters from accident data would be the use of computer simulation and crash testing to evaluate and validate the critical impact conditions identified in the first phase.
   d. Volunteers: Erik Emerson and Bob Bielenberg.
2. Evaluate roadside hardware modifications:
   a. Objective: provide guidelines and criteria for evaluation methods to determine the effect of modifications on the safety performance of the barrier by engineering analysis, simulation, component testing, and full-scale crash testing.
   b. Provide a defined path for evaluation modifications to designers and FHWA.
   c. Volunteers: Mike Dreznes and Garret Dyke.
3. Develop procedures for the evaluation of roadside safety hardware through simulation.
   a. Objective: determine what types of roadside hardware modifications can be predicted through simulation and develop best practices for simulation of critical phenomena.
   b. Develop procedures for ILCs and round-robin simulation comparisons to improve harmonization and build confidence.
   c. European community is investigating simulation procedures for vehicle modeling and other items.
   d. Volunteers: Mario Mongiardini and Marco Anghileri.
4. Develop updated limits for V&V.
   a. Current V&V parameters are based on round-robin testing of oblique crash tests of concrete barriers.
   b. Are these valid for terminals, crash cushions, or other systems?
   c. Need to develop improved parameters for other simulated impacts.
   d. Add to existing proposal: synthesis of procedures used in verification and validation of crash simulation models.

Cable Median Barrier Testing

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TABLE 1 Single Median Barrier Placed at 0- to 4-ft Offset from Single Break Point

Test No.	Test Designation No.	Vehicle Type	Impact Conditions		Ditch Width (ft)	Barrier Position	Barrier Location	Primary Evaluation Factors
			Speed (mph)	Angle (deg)				
1	3-11(+)	2270P	62	25	≥30	Front Slope	4 ft from Front SBP	Vehicle containment, override prevention, & W.W.
2	3-10(+)	1100C	62	25	≥30	Front Slope	4 ft from Front SBP	Vehicle stability & A-pillar integrity
3(*)	3-10(+)	1100C	62	25	Narrow (22 ft wide)	Back Slope	4 ft from Back SBP	Vehicle containment, ORA/OIV, & underride prevention
4a 4b	3-10(+) 3-10(+)	1100C 1100C	62 62	25 25	46 30	Back Slope Back Slope	4 ft from Back SBP 4 ft from Back SBP	Increased vehicle orientation at impact & override
5	TBD	1500A	62	25	Note 1	Note 1	Note 1	Vehicle penetration & A-pillar integrity
6	3-11	2270P	62	25	NA	Level Terrain	NA	Vehicle containment & W.W.
7	3-10	1100C	62	25	NA	Level Terrain	NA	Vehicle stability & A-pillar integrity
8(*)	3-11(+)	2270P	62	25	30	Back Slope	2 ft from Back SBP	Override & increased vehicle orientation at impact
9(*)	TBD	1500A	62	25	Narrow (22 ft wide)	Back Slope	4 ft from Back SBP	Vehicle containment, ORA/OIV, & underride prevention

NOTE: SBP = single break point; W.W. = working width; ORA = occupant ridedown acceleration; OIV = occupant impact velocity; TBD = to be determined; NA = not applicable. Note 1: Testing laboratory should determine critical barrier position from 0 to 4 ft on front slope of ditch or on level terrain to maximize propensity for front end of 1500A vehicle to penetrate between adjacent vertical cables. Critical factors may include vertical cable spacing, location and type of cable release mechanisms, and vehicle projectile motion.
*Corresponding test for Single Median Barrier Placed Anywhere in Ditch can be considered an equivalent substitute.
+Specific test designation to be assigned.

Research Problem Statements

Following are the NCHRP Research Problem statements developed during the breakout sessions of the meeting and submitted to the AASHTO Technical Committee on Roadside Safety on August 20, 2012. The five topics are listed in priority order.

Management of Roadside Trees

Statistics show that from 2007 through 2009 there were more than 11,400 fatalities that resulted from crashes into trees (FARS, NHTSA). These crashes accounted for half of the fixed-object fatalities and nearly 20% of all roadway departure fatalities. To reduce the number of people killed on the nation's highways, it is critical that guidelines be developed that consider the risk posed by these objects so that this risk can be managed appropriately. In areas where trees are present along the roadside, a process is needed to determine the level of risk to the motorist. When considering the placement of new trees a similar process should be considered. To that end a better understanding of highway characteristics that experience a higher proportion of motor–vehicle tree crashes needs to be developed. Based on this information guidelines can be developed to ensure decisions are made with a full understanding of the risk to the motorist.

It is not the intent of this project to prove that inclusion of trees is the right thing or wrong thing to do. There is a need for guidance for decision makers to use in analyzing the risk associated with placement of roadside trees and the maintenance of existing trees. Research is needed to learn how roadside trees can be introduced and maintained without compromising safety.

LITERATURE SEARCH SUMMARY

In 1979, the Michigan DOT and FHWA sponsored the development of *Guidelines for Removing Hazardous Trees from Highway Rights-of-Way: A Management Manual* (*1*). From this study, the researchers found that trees were involved in 12% of all crash fatalities. In Michigan, more than half of all tree–vehicle crashes resulted in death or serious injury.

FHWA funded the preparation of a handbook for aiding maintenance workers with the safe accommodation and treatment of vegetation along highways and roadways, *Vegetation Control for Safety: A Guide for Street and Highway Maintenance Personnel* (*2*). The guide depicted simple photographic examples of various tree and vegetation problems encountered along road systems, including small saplings that eventually become large trees or trees planted too close to road and within the clear zone. In addition, several schematics were prepared to explain proper cutting practices as well as safety concerns associated with the inappropriate tree cutting and removal, including excessive stub heights and presence on roadside slopes.

In 1991, Ray et al. determined that trees and utility poles were the most frequently struck roadside fixed objects in side-impact events, resulting in the highest risk of injury and greatest loss to society (*3*). When considering most harmful event, nearly 50% of all side-impact fatal crashes involved trees.

In 2001, McGinnis published a Strategic Plan for Improving Roadside Safety in order to assist with planning of future research activities as well as to lead to new approaches to actual safety improvements (*4*).One current safety need pertained to trees located adjacent to roadways. After identifying several critical issues, McGinnis offered a dozen action items for making safety improvements regarding trees placed near roadways, which include (*a*) identify and remove hazardous trees on or off the ROW; (*b*) establish a policy—if a tree is hit, remove it; and (*c*) educate the public about the hazards of trees close to the roadway.

California Polytechnic State University researchers published a Phase I study on the Safety of Trees with Narrow Clear Zones on Urban Highways in late 2002 (*5*). This effort included a substantial literature review as well as the Phase II planning for a follow-up research study aimed at determining statistical relationships between collision experience and presence of trees with narrow clear zones on curbed urban highways. The authors found conflicting standards in use for determining clearance for trees in medians of urban highways. However, it was noted that severe crash consequences result when trees are placed near high-speed rural roadways and caution placement of large trees close to any roadways, especially with medium to high speeds. In 2003, Sullivan published the Phase II results which found median trees on urban and suburban conventional highways to be associated with a higher rate of accidents (*6*). Significantly higher accident rates were found for highway sections with median trees and 30- to 35-mph posted speeds, as well as for highways located near commercial or high-density development.

In 2003, NCHRP Report 500: Volume 3 addressed motor-vehicle collisions with hazardous trees with the goal to either eliminate tree crashes or reduce the harm that results from these collisions (*7*). Two main emphasis areas were covered: prevent trees from growing in hazardous locations and eliminate the hazardous condition or reduce the severity of the crash. Several strategies were proposed to address these objectives, including

1. Develop, revise, and implement planting guidelines to prevent placing trees in hazardous locations;
2. Develop mowing and vegetation control guidelines;
3. Develop guidelines for tree removal in hazardous locations;
4. Develop guidelines for shielding hazardous trees with barriers;
5. Modify clear zone in vicinity of trees; and
6. Delineate trees in hazardous locations.

In 2006, Mok et al. published the results from an accident study aimed at evaluating crash reductions on Texas roads resulting from landscape improvements (*8*). Out of 61 landscape improvement projects, 10 were selected for use in evaluating before-and-after crash data. For this effort, the researchers reported a reduction in tree collisions of more than 70% after landscape treatments were implemented. However, it was unclear as to what treatments were added or removed for this particular site as well as for the others, and it was noted that clear zone rules and planting setback rules were also updated in compliance with Texas DOT standards. As such, the results from this study were inconclusive as to whether the planting of trees in the clear zone results in a reduction in vehicle–tree collisions.

In 2007, researchers at the Georgia Institute of Technology conducted an investigation of roadside crashes in nine Atlanta urban arterial roadways (*9*). This research focused on the determination on whether collisions with utility poles and trees were more common at intersections and midblock locations. From the study, more than 23% of all off-road or on-shoulder vehicle crashes occurred into utility poles or trees. Also, the area within 25 ft of intersections encounters a disproportionate number of roadside collisions and should receive greater attention when regulating the placement of utility poles and trees within the ROW. Thus, it was noted that no utility be placed within 25 ft of an intersection. Further, if this guidance is violated, a minimum setback of 10 ft from the edge of the traveled way should be applied.

In 2008, *NCHRP Report 612: Safe and Aesthetic Design of Urban Roadside Treatments* was completed by Dixon et al. for use in updating Chapter 10 of AASHTO's RDG (*10*). This study

was somewhat limited in the availability of guidelines, supporting data, and tools related to the safety design of roadside features for urban and suburban highways. Several strategies were proposed for addressing the placement of trees and landscaping features near roads, including the restriction of planting trees that become large in hazardous locations, the elimination of hazardous tree conditions through removal or shielding, and a decrease in the severity of vehicle–tree crashes through speed reduction. Unfortunately, no quantification of the benefits for implementing the various treatment options was provided.

In 2008, University of Wisconsin researchers studied urban and rural ROR crashes into trees, fences, and poles on Wisconsin Interstate and state highways from 2000 through 2006 to examine clear zone policy and crash severity (*11*). From this investigation, it was discovered that 77% of all vehicle–tree impacts occurred on rural state highways. In addition, the mean and median lateral offset for struck trees was 37.4 and 32 ft, respectively. The 80th and 95th percentile lateral offsets were 47.5 and 77.5 ft, respectively. For design speeds of 60 mph and considering all ranges of annual ADT (AADT), trees were struck at an average distance of 38 ft, while the average lateral distance was 50 ft for design speeds between 65 and 70 mph.

In 2009, Briglia et al. continued the in-service performance evaluation of landscape treatments on state highways in the Seattle area using changes in analysis and methodology (*12*). The before-and-after analysis results were again considered. From this study, it was noted that the installation of landscaped medians did not degrade safety and may result in an overall decrease in accidents, such as in curb, median, or tree accidents. However, the number of accidents may be expected to increase as a result of placing fixed objects near roadways.

Later, Clemson researchers investigated crashes in South Carolina in order to evaluate the adequacy of current clear zones along state roadways as well as to access the risks of leaving the roadways and striking hazards (*13*). Nearly 50% of tree-related crashes occur on secondary roads. Also, 72% of tree-related crashes occur on curved sections. From this effort, the researchers concluded that a fixed-object crash was 42 times more likely if the minimum clear zone was not met. In addition the research team noted that tree removal and vegetation clearing can provide many positive benefits, including a decrease in tree-related fatal and injury crashes, improved traffic sign visibility, improved sight distance around curves, reduced risk of falling trees on roads during inclement weather, and reestablishment of roadside drainage along roadside.

In 2010, Pledge of Passive Safety UK noted that 180 people were killed and 796 people were seriously injured in single-vehicle accidents with trees on British roads in 2008 (*14*). Further, approximately 1 in 13 single-vehicle road deaths in Great Britain involved trees in 2008. The safety organization proposed several strategies to reduce roadside risks, including the mapping and identification of trees exceeding 250 mm, recording accidents with trees, utilizing preventive tree removal to maintain 4.5-m minimum clear zones on carriageways, cutting of boundary hedges to prevent them from becoming rows of trees, shielding of hazardous trees, reduction in speed limits, and tree removal with compensatory planting away from carriageway.

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RESEARCH OBJECTIVE

The relationship between acceptable tree location and design elements, such as roadway geometry (e.g., horizontal and vertical alignment), roadside environment, speed, traffic volume, and frequency of access points is not well understood.

This research will develop safety guidelines for the maintenance of existing roadside trees and proper placement of new trees. These guidelines will address a variety of speed ranges, traffic volumes, roadway geometry, and access density. These guidelines will also address the possibility of roadside barrier as an effective means to reduce tree crash severity.

In order to achieve the research objective, the following tasks are anticipated.

Phase I

Task 1: Literature Review

Conduct a literature search for completed and ongoing studies pertaining to the establishment of recommended lateral clear zones, guidelines, and policies related to roadside safety treatments, collisions with trees and other landscape or roadside elements. NCHRP project 17-54 are currently

ongoing. This project may develop CMFs for trees or clear zones and should be reviewed.

Task 2: Identify Existing Data and Additional Data Needs

It is anticipated that the literature review will provide a good deal of information associated with the acceptable location and maintenance of existing roadside trees, particularly in rural areas. Understanding the risks associated with the planting of new trees, particularly in urban areas, may require new analysis of data. Outline a work plan which includes identified data sources or the need for collecting new data to formulate the guidelines.

Task 3: Prepare Interim Report of Findings and a Work Plan to Complete Phase II

Submit it to the panel for review. Meet with the project panel to discuss the findings and proposed work plan.

Phase II

Task 4: Collect Additional Data

Based on the information obtained under Task 2 collect additional data needed to formulate the guidelines.

Task 5: Prepare Draft Guidelines as an Appendix to the Final Report

A key component of this document is to identify conditions where roadside trees can present less risk. At this time, it is anticipated the guidelines may include the density of trees, offset to trees, roadway geometrics (i.e., access density, horizontal curves and vertical grade) and traffic characteristics (i.e., traffic volume, speed).

Task 6: Solicit Feedback

Solicit feedback on the proposed guidelines from other professionals, organizations, or agencies. The concerns of the reviewers would be captured and, in conjunction with the panel, decisions made about modification to the guidelines.

Task 7: Develop Any Additional CFMs That Were Not Included in NCHRP Project 17-54

These CFMs would be specific to this research and would be added to the HSM.

Task 8: Prepare a Final Report That Fully Documents the Research Effort and Incorporates the Guidelines as an Appendix

The final report should document the assumptions made, the limitations of the analyses and findings, provide recommendations for implementation of the guidelines, opportunities to make them more robust, and cite needs for future research.

ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

- Recommended funding: $300,000.
- Research period: 3 years.

URGENCY, PAYOFF POTENTIAL, AND IMPLEMENTATION

This research will produce guidelines for the safe placement of new roadside trees and reduced risk of maintaining existing roadside trees. Use of the guidelines will improve safety. These guidelines will facilitate decisions resulting in money saved in project development resources and lives saved on our roadsides.

The AASHTO Technical Committee on Roadside Safety in conjunction with TRB Roadside Safety Design Committee (AFB20) has identified this as a high priority. The information developed as part of this study would provide specific guidance to be included in the next updated of the AASHTO RDG. Additionally, the information developed will be used to develop CMFs to be used by the HSM to help assess the risk associated with trees in the ROW.

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Development of Methods to Evaluate Side Impacts with Roadside Safety Features

Side impacts of vehicles into roadside hardware are a growing public safety problem. In particular, side impacts with guardrail account for 22% of fatalities in passenger vehicle–guardrail crashes (Gabler and Gabauer, 2007). The occupant of a car that side impacts a guardrail has a 30% higher probability of being fatally injured than the occupant of a car involved in a frontal impact into a guardrail. Many roadside safety features (e.g., guardrail end treatments, crash cushions, and luminary poles) are designed to break away under the loads which are typical of a frontal impact. However, side impacts by nontracking vehicles may not have enough force to engage the breakaway mechanisms of these features. Because the side of a vehicle, unlike the front, has so little structure to protect an occupant, these impacts can be especially dangerous.

To date, however, the side impact problem remains largely unaddressed. NCHRP Report 350 provided side-impact test and evaluation procedures for information purposes only, but made no recommendations for side-crash performance of roadside hardware. More recently, the appendix for side impact test and evaluation procedures was not included in the MASH crash test procedures. The few available side-impact tests of roadside hardware in the literature are now over 20 years old and were performed on a previous generation of roadside hardware with a previous generation of vehicles. Little is known about how Report 350– or MASH-compliant hardware performs in nontracking side crashes.

After the side impact research in the 1990s, it was concluded that it was not technologically feasible to design most roadside safety features to satisfy side-impact evaluation criteria. This conclusion, however, was based upon the crash testing of 1980s-era vehicles manufactured before recent advances in dynamic side-impact protection required by NHTSA. In particular, the new NHTSA side-impact pole test has led to more robust side structures and side curtains, and potentially improved energy sharing between the vehicle and roadside objects during a crash. For example, Alberson et al. (2006) showed the feasibility of reducing injury risk in nontracking side-impact crashes by making relatively low-cost modifications to existing guardrail end terminals.

The objective of this research program will be to develop methods to evaluate and reduce the risk of serious and fatal injury in nontracking side impacts with roadside safety devices, establish crash test procedures based upon the developed methods, and determine the effectiveness of current-generation roadside hardware with respect to side-impact collisions.

LITERATURE SEARCH SUMMARY

Research has been conducted at both FHWA and NHTSA on the issue of side impact into fixed narrow objects.

FHWA sponsored an extensive research program in the late 1980s and early 1990s to investigate nontracking side impacts into roadside safety features (Ray et al., 1991, 1992). The program conducted 30 side-impact crash tests of cars sliding into various narrow roadside features at 30 mph. A follow-up program developed recommended procedures for conducting nontracking crash tests including impact conditions, test vehicle, test article orientation, injury criteria, and

evaluation criteria. Stolle et al. (2011) proposed nontracking impact conditions which should be evaluated for a possible side impact test.

In 2007, NHTSA instituted an upgrade to the FMVSS 214 side-impact rule with specific implications for nontracking impacts to roadside features. The new rule requires that all passenger vehicles be subjected to a nontracking side impact with a rigid pole in addition to the previous vehicle-to-vehicle side impact test. This new rule should encourage automakers to both strengthen the side structure and make side door airbags and side curtains standard equipment on all new vehicles. The strengthening of vehicle side structures holds great promise for designing roadside hardware to accommodate side impact crashes.

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7. Stolle, C. S., J. Bohlken, K. A. Lechtenberg, and D. L. Sicking. Recommendations for Impact Conditions Used in Side-Impact and Nontracking Testing. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.

ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

- Recommended funding: $500,000.
- Research period: 36 months.

URGENCY, PAYOFF POTENTIAL, AND IMPLEMENTATION

The protection of motorists in side crashes is an urgent issue. Fatal side crashes into guardrail terminals now comprise nearly one-quarter of fatalities in vehicle–guardrail impacts, yet roadside hardware is rarely tested in this crash mode. There is an urgent need to develop roadside safety hardware that will not place motorists in a side impact at unacceptable levels of risk. This research project will take the crucial first step of developing a crash test procedure which can evaluate the safety of roadside hardware for nontracking vehicles involved in a side crash. In the long term, the benefit of this research project will be to establish the technical foundation for an update of MASH

crash test procedures and the development of roadside hardware which reduces the potential for injuries and fatalities in side crashes.

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Evaluation of Opposite Direction Crashes and Appropriate Countermeasures

From 2007 through 2009 there were more than 14, 000 fatalities that resulted from opposite direction crashes. (FARS, NHTSA). Nearly 80% of these crashes occurred on undivided roadways. Countermeasures such as rumble strips or stripes, delineators, and barriers have proven to reduce both total crashes and serious injury crashes (NCHRP Report 641); however there is limited guidance on their specific performance. Improved guidance is needed on when and what type of countermeasure is appropriate, and what roadway factors (ADT, horizontal curves, speed limits, access control, etc.) may lead to higher opposite direction crash frequency rates. Additionally, guidance on progression of countermeasures (i.e., rumble strips or stripes to additional separation to addition of barriers) and how these countermeasures could be applied on a systemic basis to proactively address opposite direction crashes is not well documented in AASHTO guidance.

LITERATURE SEARCH SUMMARY

Volume 4 of *NCHRP Report 500*: *Guidance on Implementing AASHTO's Strategic Highway Safety Plan* suggests countermeasures for head-on collisions. The two goals suggested in Report 500 are to (*a*) keep vehicles from encroaching into opposite lanes and (*b*) minimize the likelihood of crashing into an oncoming vehicle. To achieve the first goal the report suggests centerline rumble strips, profiled thermoplastic centerline markings, widening cross sections, and providing shared center-turn lanes on undivided roads. The second goal can be accomplished by providing alternating passing lanes and installing median barrier on divided roads. At the time of writing in 2003, all of these suggested countermeasures were tried but not proven at preventing head-on crashes with the exception of providing wider cross sections, which was considered experimental.

NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips was published in 2009. This study found that centerline rumble strips were effective in reducing both the number of total and incapacitating injury or fatality crashes using a before-and-after empirical Bayes analysis. Although almost all states had written policy on application of shoulder rumble strips that prevent ROR crashes (46 out of 50), very few had a similar written policy for centerline rumble strips. A more recent study in 2009 by Finley et al. polled state policy on centerline rumble application found a similar result.

In 2009, Sicking et al. performed a study that developed a relationship between ADT and cross-median encroachment and crash rate. This study found that on controlled access highways that median encroachment rate was linearly related to ADT and crash frequency had a second order relationship to ADT. There is no such study that has been performed that would be applicable to undivided roadways, where opposite direction crashes occur most frequently. The proposed research will develop a better understanding of how roadway factors, such as ADT, horizontal curvature, lane and shoulder widths, etc., affect opposite direction crashes on a large range of road functional classes.

Although many opposite-direction crash countermeasures have been studied individually, a

full synthesis of the state of the practice in a wide range of opposite direction countermeasures does not exist. Median barriers for divided roads and centerline rumble strips for undivided roads have been the most studied countermeasures, but other countermeasures, such as reallocating lane width to create a small buffer median between opposing lanes, may be appropriate in some applications. The proposed research will provide guidance on the application of effective countermeasures. A comprehensive guide on opposite direction countermeasures combined with a better understanding of what roadway factors increase opposite direction crash risk would aid policymakers to invest cost-effectively in countermeasures to reduce crashes on their road systems.

RESEARCH OBJECTIVE

The objective of this research is to first understand the roadway factors that influence opposite direction crashes and their frequency, such as ADT, horizontal curves, speed limits, access control, etc. After determining the locations where opposite direction crashes are likely to occur, the study will quantify the safety performance of countermeasures in place individually and when used together, such as rumble strips or stripes, providing separation between opposing lanes, addition of a barrier, etc., if there are differences between performance of countermeasures on tangent and curved roads, the extent that barrier placement in narrow medians may increase collisions, and if the countermeasures impact other road users (such as bicyclists and motorcyclists) as well as adjacent property owners (i.e., noise from rumble strips or stripes).

ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

- Recommended funding: $350,000.
- Research period: 24 months.

URGENCY, PAYOFF POTENTIAL, AND IMPLEMENTATION

The AASHTO Technical Committee on Roadside Safety in conjunction with TRB Roadside Safety Design Committee (AFB20) has identified the need for design guidance on Reducing the Potential for Vehicles to Leave the Travel Way. The information developed as part of this study would provide specific guidance to be included in the next updated of the AASHTO RDG and would assist agencies in selecting and prioritizing opposite direction crash countermeasures as part of their safety programs. The information can also be used by the HSM to refine information on recommended countermeasures and the expected substantive safety associated with each type of application. It is expected that this research will also provide guidance to respond to a National Transportation Safety Board (NTSB) recommendation (H-06-13) in which NTSB requested AASHTO work with the FHWA to establish evaluative criteria for determining when to install median barriers on high-volume, high-speed roadways, regardless of access type.

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Roadside Design for Conflicts in Proximity to Bridge Ends and Intersecting Roadways

A general problem that occurs at many existing highway bridge locations throughout the United States is where the required length of need for guardrail that is required at bridge ends cannot be installed due to conflicts within the existing ROW limits. The conflicts may consist of an existing intersecting private driveway, state or local roadway intersection, or other objects that do not allow the placement of the required guardrail length of need. It is not unusual at some existing bridge sites to have 10 ft or less between the end of the bridge and the conflict.

The traditional methods for treating these situations have included using a short-radius guardrail system that relocates the barrier around the conflict, using a shorter guardrail section that does not meet the required length of need, using a crash attenuator, relocation of the conflict or leaving the end of bridge barrier unprotected. Since most typical Test Level 3 (TL-3) tangent or flared guardrail-end treatment systems are normally around 37 to 50 ft in length, there is typically a problem with fitting the end treatment systems and guardrail transitions to the bridge rail at these restricted sites. Additionally, no current short-radius guardrail system has been able to meet NCHRP Report 350 or MASH TL-3 safety performance criteria for high-speed roadways. In many cases the private or public entity is unwilling to relocate the driveway, intersecting roadway or other conflict and the state DOT is left with dealing with a safety problem.

Typically these traditional solutions are not very practical for the sites and prevent the bridge end and any other hazards around the bridge from being properly protected by a longitudinal barrier. In many cases the state DOTs will require that a design exception be acquired to install anything less than the required length of need with the proper guardrail end treatment. State DOTs that use these traditional solutions are also exposed to greater risk to the public being injured in accidents as these sites and future risk to additional litigation from the accidents.

This problem has been a need for more than 20 years and was one of the issues specifically called out in the August 18, 1998, AASHTO–FHWA Agreement on Implementing NCHRP Report 350 (See note 18 in the referenced memo attachment at http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/policy_memo/memo0898/).

LITERATURE SEARCH SUMMARY

Several completed studies or current studies have been or are currently being conducted by Midwest Roadside Safety Facility and Texas Transportation Institute (TTI) on various short guardrail systems or attenuator systems. These include

- Evaluation of Existing T-intersection Guardrail Systems for Equivalency with NCHRP Report 350 TL-2 Conditions, TTI, August 2010.
- Short-Radius Thrie Beam Treatment for Intersecting Streets and Drives, final report, TTI, November 1994.
- Phase I, II, III, and IV: Development of a Short Radius Guardrail for Intersecting Roadways, Midwest Roadside Safety Facility, 2000–2008.

- Short Radius MASH TL-3 Guardrail Treatment, TTI, Texas Department of Transportation, ongoing project.
- New Conceptual Development of an Impact Attenuation System for Intersecting Roadways, Midwest Roadside Safety Facility, University of Nebraska, Nebraska Department of Roads, ongoing project.
- Review of Best Practices for Barrier Protection of Bridge Ends Due to ROW Conflicts, Roadside Safety Pooled Fund, TTI, ongoing project.

The previous research with short-radius type systems has either been unable to meet the TL-3 safety criteria or have proven unable to meet the space requirements for many of the intersecting roadway sites. Thus, no effective method for treating these sites is currently available for high-speed facilities.

RESEARCH OBJECTIVE

The primary objective of the research would be to develop safety treatment alternatives for documentation in future update of the AASHTO RDG to be used where intersecting driveways, streets, local roads, or other conflicts are placed near a bridge end. The designs should be able to be installed where the intersection or conflict is placed within a short distance from the bridge end. If required the design may also be installed in a short distance down the side intersection conflict.

ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

- Recommended funding: $750,000.
- Research period: 3 years (36 months).

URGENCY, PAYOFF POTENTIAL, AND IMPLEMENTATION

The resulting research efforts would give state DOTs a safety treatment that could be used at these sites with conflicts near bridge ends. The resulting effort can also be implemented as a guideline to be used in the AASHTO RDG to give engineers a design tool to be used for projects. The primary payoff is better information that can be used to properly protect bridge ends and thus create a safer environment for the public at these sites and reduce liability issues for state DOTs.

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Rollover Causation with Roadside and Median Barrier Impacts

Analysis of crash data from the FARS indicates that 42% of barrier impacts have rollover as the most harmful event. Research is needed to understand types of barriers involved in rollover crashes, trip mechanisms associated with these crashes, and to develop improved barrier configurations that mitigate rollovers. The research should consider barrier types, shape of concrete barriers, height of beam guardrail systems, and sensitivity to angle of impact, speed, vehicle type, etc.

The research plan for this project will include detailed review of rollover crashes and rollover crash data. The research will focus on rollover crashes for roadside and median barriers of various types, shapes, and geometry. This information will be used to develop improved barrier designs that enhance occupant safety in barrier impacts.

The design and implementation of a roadside or median barrier is primarily focused on the redirective capacity of the barrier while considering various traffic volumes, vehicle speeds, and vehicle types. Roadside and median barrier installations are chosen based on state barrier warrants for the type of roadway, anticipated impact loads, the recommended test level, and the level of effort and expense in maintaining the barrier. Current roadside and median barrier selection processes are limited because they seldom consider the factors that cause rollovers and associated serious injury and fatal crashes. For example, many studies have linked events such as rollover, occupant ejection and contact with the barrier, and secondary collisions in barrier crashes. Unfortunately, these studies have only offered recognition of the potentially fatal event, and efforts to quantify the frequency and extent of these types of serious injury and fatal events together with the type of roadside or median barrier system have yet to be undertaken.

An improved barrier design would factor in the various causes of rollovers in roadside and median barrier impacts offering enhanced safety to vehicle occupants for a broad range of vehicle types. However, no quantitative analysis has been performed that identifies the specific causes and trip mechanisms during collisions with roadside barrier that result in a rollover. Thus, a need exists to identify these causes to facilitate the design of improved barrier systems and better selection guidance for roadside and median barrier designs that optimize safety on all levels.

LITERATURE SEARCH SUMMARY

The causes of a severe injury or fatality in barrier impacts can be classified into four categories: (1) the primary impact between the vehicle and the barrier; (2) secondary collisions with vehicles or objects other than the barrier system; (3) occupant ejection and contact with the barrier; and (4) vehicle rollover.

Previous research regarding rollover and secondary impacts has demonstrated that these events occur with some frequency during barrier crashes and can lead to serious injury. A study by Mak and Sicking (1990) regarding vehicle rollover found that rollover was a major cause of severe injury and fatalities. It also noted that the shape of concrete barrier affected the frequency of rollover accidents. It was shown that 8.5 percent of safety shape barrier accidents result in rollover, and that safety shape median barriers are associated with rollover events at twice the rate of other

median barriers. The increased rollover potential with these barrier shapes becomes critical because rollover accidents double the risk of incapacitating and fatal injuries.

However, no study to date has identified rollover causation with data for flexible and semi-rigid barriers detailing the geometry and other properties of the barrier impacted. This type of analysis would yield real insight into which barrier designs are successfully redirecting errant vehicles and providing optimum levels of safety for the occupants of those vehicles and provide data for developing improved barrier designs that reduce rollover probability.

REFERENCE

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RESEARCH OBJECTIVE

The objective is to identify the causes of rollovers in conjunction with barrier crashes. The identification of rollover mechanisms will allow for optimal selection and design of barriers to both contain errant vehicles and minimize rollovers and associated occupant injuries.

The research plan for this project will consist of an extensive review of crash reports from multiple states and national databases. The research will focus on crash data that includes a rollover in conjunction with a barrier impact.

Analyses will be conducted to determine the rollover causation mechanisms for different barrier types, shapes, and geometries. This information will be used to develop improved barrier designs that enhance occupant safety in barrier impacts.

ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

- Recommended funding: $600,000.
- Research period: 30 months.

URGENCY, PAYOFF POTENTIAL, AND IMPLEMENTATION

Roadside and median barriers are routinely placed to enhance safety by shielding motorists from various terrain and fixed-object hazards. What we know about their impact performance is based largely on laboratory crash test results. An analysis of crash data to determine the causes of rollovers in barrier impacts is needed. This analysis will aid in the development of improved barrier designs that enhance occupant safety and provide a broader range of stable vehicle containment. Implementation of these improved barrier systems at appropriate locations will mitigate rollover crashes and reduce the frequency of barrier crashes resulting in serious injury and fatality. The improved barrier designs can ultimately be implemented through guidance in the AASHTO RDG and the AASHTO–ARTBA–AGC Task Force 13 Guide to Barrier Hardware.

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