Emerging Roadside Safety Issues

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Efforts to improve roadside safety have had a dramatic effect on the number of fatalities resulting from automobile accidents during the past 30 years. In 1966 the annual traffic fatality rate was 5.5 fatalities per 100 million vehicle miles traveled. In 1993, less than three decades later, the rate had dropped to 1.7 fatalities per 100 million vehicle miles traveled. This accomplishment has been achieved through a dedicated effort by every segment of the highway transportation industry, including the roadside design community.

The Federal Highway Administration, American Association of State and Highway Transportation Officials, Transportation Research Board, the states, and others have undertaken a variety of research activities to improve roadside safety. These activities include analyzing accident trends, formulating improved analysis procedures, developing new hardware, and promoting a sounder base of accident information. To further improve roadside safety all these efforts should be continued, but attention should also be devoted to a number of emerging issues, including better understanding of crash characteristics, accommodating a continually changing vehicle fleet, analyzing crash potential, selecting effective safety treatments, and making use of new technologies.

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Emerging Issues

Better Understanding of Crash Characteristics

Roadside safety research involves much more than the development of new roadside safety hardware. The effectiveness of the hardware designs, as well as the roadside itself, is dependent on understanding the characteristics of incidents in which vehicles leave the roadway and strike objects on the roadside. Recent analysis of accident data has indicated that nonimpact accident types, such as rollovers on steep side slopes, represent a major portion of all run-off-road accidents. This information raises questions about the appropriateness of current slope standards and suggests that greater emphasis needs to be placed on providing clear roadsides. The clearzone concept, although a basic tenet of highway design for many years, often cannot be used on state and local roadways because of right-of-way limitations. The result of these limitations is that collisions with fixed objects such as trees and utility poles continue to represent the largest group of fatalities involving fixed objects.

More detailed in-service evaluations of roadside safety hardware are also needed. It is important to understand the performance and failure mechanisms of a roadside element that has been hit to ascertain it functioned as expected. It is also necessary to assess whether such hardware functions properly under field conditions (e.g., with a buildup of snow or ice, after some post-installation settlement). Furthermore it is important to ensure that roadside safety hardware is correctly installed and maintained. It has been found, for example, that the misplacement of a bolt washer can degrade the crashworthiness of some barrier systems.

These issues involve more than designing roadside barriers and evaluating their performance in crash tests. A better understanding of crash characteristics will provide the basis for dealing with the whole range of possible harmful events that could take place when a vehicle leaves the roadway.

Accommodating a Changing Vehicle Fleet

Another emerging issue is the need for roadside safety features to accommodate a continually changing vehicle fleet. Better coordination is needed between the automotive design and manufacturing community and the roadside design community. Relatively little interchange has taken place between these groups because of the competitive nature of automobile design and possible violation of antitrust laws and litigation. The result has been that the roadside safety community has sometimes reacted to automotive changes long after the change has become widespread in the vehicle fleet. Typical roadside hardware crash-testing procedures call for the use of vehicles that are less than seven years old at the time of testing. However by the time the research is complete and the results are implemented in the field, the test vehicle may be 10 or more model-years old. For this reason roadside hardware may not effectively accommodate all elements of the vehicle fleet.

The breakaway cable terminal (BCT) provides a cautionary illustration. When the testing was originally done (1972 through 1980) using the guidelines in *NCHRP Report 153: Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances,* the small test vehicle was a 1020-kilogram passenger vehicle. The oil embargo of 1973 caused automobile manufacturers to start introducing smaller cars and by 1978, 820-kilogram vehicles like the Honda Civic and the Volkswagen Rabbit were common. By the mid-1980s researchers were beginning to observe problems when these smaller vehicles struck BCTs because their lower mass was insufficient to trigger the failure mechanisms needed to absorb crash energy. The result is that researchers have been trying for more than a decade to find an inexpensive retrofit to the BCT to rectify a problem that could have been avoided if testing had been done using newer vehicles in the 1970s.

Roadside safety hardware has a long service life, far longer than a typical vehicle. It is imperative that the roadside hardware community be able not only to keep pace with changes in the vehicle fleet, but to anticipate the performance of roadside hardware with these rapid changes. The Intermodal Surface Transportation Efficiency Act of 1991 has mandated that vehicle types other than the traditional passenger car be examined to see how well they perform with the current generation of roadside safety hardware. A current research focus is the light truck class of vehicles (estimated to represent 25 percent of the current U.S. vehicle fleet), which includes vans, minivans, pickup trucks, and four-wheel-drive vehicles that have become popular alternatives to the traditional passenger car. These vehicles have higher centers of gravity and different bumper configurations, body structures, and other features that influence the effectiveness of roadside safety hardware.

Analyzing Crash Potential

Another issue is the lack of quantifiable methods for predicting when combinations of roadway design and roadside features create hazardous situations. The encroachment-collision-severity model of off-road accidents has been available since the publication of *NCHRP Report 148: Roadside Safety Improvement Programs on Freeways.* Although this model is an intuitively valid analytical statement in the language of probability, the lack of probabilistic data to support the model has greatly hampered the utility of the method to roadside designers. The ROADSIDE program, developed as an adjunct to the AASHTO *Roadside Design Guide,* is based on the encroachment-collision-severity method, but it depends heavily on unquantifiable assumptions about the likely severity of collisions and the effect on encroachments of site geometry and operational conditions. Many agencies are unable to develop quantifiable input values for these types of programs. As a result, decisions about what roadside hardware to select, where it should be located, and how it should be replaced are often difficult to justify in objective, quantifiable terms. This lack of a quantifiable basis for decision making leaves agencies vulnerable to tort litigation and hinders their ability to focus scarce roadside safety resources on the most important problems. The quality of accident data has been a persistent problem in roadside safety research for many years, making it particularly difficult to develop the needed models for predicting highway safety. Collecting high-quality

> **Roadside Safety Workshop**
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> The Transportation Research Board's Roadside Safety Features Committee (A2A04) and National Cooperative Highway Research Program sponsored a workshop in August 1994 to discuss roadside safety and the research needed to explore new approaches and methods that could result in increased safety. The workshop, held in Woods Hole, Massachusetts, featured invited presentations by prominent researchers that provided workshop participants with a common background on major issues, recent and ongoing research efforts, and future issues and opportunities. After the presentations workshop participants met in four breakout groups to discuss (*a*) data and analysis needs, (*b*) selection and design of roadside safety treatments, (*c*) efficacy of simulation methods, and (*d*) assessment and development of roadside hardware.
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> The activities of the workshop are documented in *Transportation Research Circular 435: Roadside Safety Issues.* The Roadside Safety Features Committee is planning a follow-up meeting in summer 1995 to formulate a common vision of the roadside safety research agenda for the coming decade.
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data relevant to a specific roadside problem is prohibitively expensive. Relying on the accident data commonly gathered by police severely restricts the level of detail that can be examined—and is prone to errors and omissions. Technology may offer some improvement by allowing police officers to directly log accident information into portable computers, use global positioning systems to accurately locate crash sites, and record other pertinent information using a host of new data-acquisition hardware. The continued expansion and refinement of FHWA's Highway Safety Information System should help to make a relatively consistent set of accident and roadway data available to researchers and policy analysts. Whether sufficiently detailed accident data can ever be collected to examine the full realm of roadside safety questions in a robust statistical way remains in doubt. One fundamental problem is that decisions based on accident data are by definition made in reaction to the perception of past problems instead of in anticipation of future problems.

Selecting Effective Safety Treatments

The importance of properly selecting, locating, and installing roadside safety hardware continues to be an important area of research, development, and technology transfer. The 1989 AASHTO *Roadside Design Guide* and the 1977 AASHTO *Guide for Selecting, Locating, and Designing Traffic Barriers* are the preeminent guidelines for designing safe roadsides. Additional research continues to refine the criteria for selecting, locating, and installing hardware, but getting field practitioners to use up-to-date standards is a continuing problem. Hardware is frequently placed on the site in such a way that it could never perform correctly and even when properly located, it is often not installed correctly. For example, popular BCTs are sometimes placed just in front of steep untraversable slopes where, even if the terminal is activated correctly, the vehicle would be gated into an area in which it could roll over or strike a fixed object.

Research has developed the performance-level concept for the application of roadside safety hardware. Under this concept hardware is selected to accommodate the amount and type of traffic that is anticipated on a road. A high-volume, high-speed roadway would be expected to require barriers that had higher performance ratings. Low-volume rural roads would be accommodated with roadside safety hardware with lower performance ratings. Although this approach is intuitively attractive, it may not be easy to implement. Agencies may wish to simplify design and maintenance by using only one type of hardware, or changing traffic and land use conditions may suggest that a higher level of barrier be initially provided.

Making Effective Use of New Technologies

A number of new technologies have rapidly emerged during the past decade, creating a challenge to find effective uses for them and to establish means to promote their implementation. For example, simulation is a modern analytical technique that has been demonstrated as a new way to understand the expected performance of both vehicular and roadside safety hardware. Nonlinear finite element analysis allows a detailed analysis of impact reactions and the associated forces to help understand the severity of roadside collisions and allow designers to formulate more effective designs. Once a finite element model of a vehicle or roadside safety appurtenance (e.g., barrier, crash cushion, or small sign support) has been made, possible design changes can be examined quickly and with confidence. This allows designers to use full-scale crash testing efforts only for the most promising alternatives.

Another significant advantage of using finite-element simulations is the ability to examine the performance of new vehicle designs in impacts with roadside safety hardware. Simulation also allows researchers to explore impact situations that are difficult or impossible to test. For example, there is no method for performing nontracking side impacts with roadside features, so simulation can provide a way to explore this important scenario. In addition to untestable situations, simulation provides a way to parametrically search for the worst-case scenario. The standard crash test conditions in *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features,* like all testing specifications before it, assume that they explore the worst-case impact. However there may be other much more severe impact conditions that, because of the limitations on testing resources, are not explored in the "standard" tests. Simulation allows the researcher to explore these situations relatively quickly once a model has been developed.

Developing a finite-element model of a roadside hardware collision is not inexpensive: to develop a full model may cost $100,000 above the cost of the vehicle model. Once developed, however, a model can easily be changed, allowing the analyst to parametrically explore at little cost variations in the impact conditions or the design. Hundreds of collision scenarios can be examined using simulations during the barrier development or evaluation phase. Although there will always be a need for full-scale crash tests to unequivocally demonstrate the performance of hardware, a careful balance of analysis and testing could greatly improve roadside hardware designs.

The current generation of nonlinear finite element analysis tools can be used to address many roadside hardware collision events, but extensions and modifications will be required to investigate a wider range of roadside safety problems. Current finite element programs cannot be used to investigate situations such as tires rutting into soft soils, long impact events like rollovers, trajectories of vehicles after striking a barrier, and the effect of serious suspension damage. Addressing these types of problems is feasible, but will require research into improving the computer programs and analytical techniques used in simulating roadside events.

Other new technologies may also help improve roadside safety. These technologies include intelligent transportation system technologies that will keep vehicles on the road, new materials that will improve the performance of barriers, better vehicles and subsystem designs, and new procedures for incorporating safety considerations into the highway design process.

Need for Roadside Safety Research

The topics discussed here indicate the nature and scope of issues and problems that must be addressed by research if further improvements in roadside safety are to be made. Other research needs are reflected in the questions posed in Table 1. These questions reflect the overlap of issues and suggest that solutions to roadside safety problems will result from a variety of policy and procedural actions.

Roadside safety researchers have played a significant role in reducing fatalities and injuries in roadside collisions during recent decades. In the past many problems

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TABLE 1 Roadside Safety Research Issues

Issue	Research Questions
Rollover on Slopes	• What is the extent of the roadside slope rollover problem? • What mechanisms cause slope-related rollover? • What are the implications on slope standards?
Trees and Poles	• Are there reasonable strategies that can be used to decrease the number and severity of tree and utility pole collisions while balancing safety with the needs of private land owners, municipalities, and utility companies?
Better-Quality Accident Data	• What methods can be used to obtain higher-quality accident data? • What types of in-depth accident studies could be designed, funded, and implemented to address specific roadside safety problems?
Clearzone Concept	• How effective are clearzones? • Can clearzones be justified on a benefit-cost basis? • What alternatives should be used if it is not possible to satisfy clearzone standards?
Changing Vehicle Fleet	• What are the emerging trends in vehicle design and how will they affect the performance of the current generation of roadside safety hardware? • What features should new hardware have to ensure good performance with these new vehicles?
Criteria for Selecting and Locating Roadside Barriers	• What criteria should be used to select a barrier for a specific location and how should that barrier be located? • Are the recommendations in the 1977 AASHTO *Guide for Selecting, Locating, and Designing Traffic Barriers* and the 1989 AASHTO *Roadside Design Guide* adequate? • How should the multiple test levels in NCHRP Report 350 relate to the selection of roadside hardware for a particular site?
Training of Roadside Designers, Installers, and Maintainers	• What can be done to more effectively transfer knowledge about roadside hardware and proper design, installation, and maintenance practices to field practitioners?
Measures of Effectiveness for Roadside Design	• How can the safeness of a roadway be quantified to form the basis for policy and economic decisions? • What measures of effectiveness could be used and on what would the underlying models be based?
Better Encroachment Data	• Are there new ways to collect encroachment data so that models of encroachment could be developed as a function of roadway characteristics?
Quantifiable Severity Indices	• Can a systematic method for assigning severity indices be developed for use in the ROADSIDE program?
Enhanced Coordination with Automobile Manufacturers	• What are the barriers to better cooperation among automobile manufacturers, the roadside design community, Federal Highway Administration, and National Highway Traffic Safety Administration? • How can these barriers be overcome?
Performance of Vans, Pickup Trucks, and Sport Utility Vehicles	• How well do vehicles that have not typically been used in full-scale testing perform in collisions with typical roadside hardware?
Integrating Simulation into the Roadside Hardware Design Evaluation Process	• Can finite-element collision simulation and vehicle dynamics simulation be integrated into the design and evaluation process so that they are useful tools for improving hardware performance?
Extensions to Current Simulation Programs	• Can capabilities be added to the current generation of simulation tools to address issues such as traversing soft soil, long-duration impacts, and damaged suspension?
Nonstandard Impact Conditions	• Are the impact conditions recommended in *NCHRP Report 350* actual "worst case" conditions? • Are there other more demanding impact scenarios (e.g., side impact collisions and nontracking impacts) that should be addressed during the development of roadside hardware?
Arrest Versus Redirect Strategies	• In what situations is it better to redirect an errant vehicle instead of arresting it? • Can the difference in approaches be quantified in terms of severity? • What types of locations would be appropriate for each strategy?

Improved Methods for Increasing Wheel/Rail Adhesion in the Presence of Natural Contaminants

Light rail and commuter rail services experience schedule delays during various times of the year because of railhead contamination by moisture, ice, and leaves and other vegetation. These contaminants cause conditions that affect the ability of systems to safely maintain operating schedules. Sanding, the means most often used to improve adhesion under these conditions, is costly and has some undesirable side effects.

The Tranergy Corporation has been awarded a one-year, $150,000 contract (TCRP Project C-6, fiscal year 1994) to describe and evaluate current practices for the control of wheel/rail adhesion under contamination conditions and to identify new or modified alternatives to sanding that show promise for improving adhesion.

For further information, contact Christopher W. Jenks, TRB (telephone 202-334-3502).

Enhancement of Vehicle Window Glazing for Vandal Resistance and Durability

Transit agencies expend considerable resources in the procurement and maintenance of bus and rail vehicle passenger-side windows. Plastic and glass are the two predominant materials used, but both materials have become subject to vandal etching and damage from cleaning chemicals and brushes and harmful environmental conditions.

The University of Dayton Research Institute has been awarded an 18-month, $199,875 contract (TCRP Project C-4, fiscal year 1994) to compile information on current and emerging window glazing technologies with potential applicability to the transit industry and to develop guidelines to assist transit agencies in the preparation of procurement specifications related to transit vehicle passenger-side window glazing.

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High-Strength Concrete *continued from page 14*

despite the three layers of prestressing strands at 50-millimeter (1.97-inch) spacing. The beams were inspected after form removal and showed no signs of segregation or large air voids. Excessive heat of hydration was, however, generated by the U-girders because of the large cement content of the mix. This could be a problem for contractors in the production of high-strength concrete and may significantly affect the concrete's hardened properties. Future research is anticipated to develop methods for handling this excessive heat of hydration.

A rigorous quality control program will be implemented during construction of the Louetta Road Overpass to monitor the quality of the concrete placed. As construction proceeds, research will focus on monitoring the structural performance of the bridge and long-term properties of the high-strength concrete mix. The bridge will be extensively instrumented to measure concrete strains, internal concrete temperatures, girder deflections, and the shortening of bridge piers. The results will help to determine the feasibility of using high-strength concrete and the new U-sections for bridge girders and pinpoint problems that might occur in the long term. The durability of the structure will also be extensively monitored as part of the study. At a later date specific recommendations for structural design and suggestions for construction practices of high-strength concrete bridges will be developed.

Conclusion

High-strength concrete is a relatively new material and significant research must be performed to determine material properties and develop structural design procedures. Construction practices must be updated and improved quality control methods developed for its use. With such developments, the benefits of high-strength concrete for transportation structures—greater design flexibility, less maintenance through better durability, and cost savings—can be fully realized in the future.

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could be solved with the intuition and judgment developed by researchers during 20 years of crash testing and observing accidents in the field. Many of the problems that remain are difficult ones that have defied solution for many years. Maintaining the current level of safety in the face of increased travel demand, lighter vehicles, and strained public funding resources will require a strategic plan that coordinates the efforts of all agencies involved and maximizes the effectiveness of future research and development.

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2. *Guide for Selecting, Locating, and Designing Traffic Barriers.* American Association of State Highway and Transportation Officials, Washington, D.C., 1977.