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# Roadside Safety Issues Revisited

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# ROADSIDE SAFETY ISSUES REVISITED

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# INTRODUCTION

This *Transportation Research Circular* summarizes the activities of a Transportation Research Board Committee on Roadside Safety Features (A2A04) Workshop, held at the Arnold and Mabel Beckman Center of the National Academies of Sciences and Engineering in Irvine, California, July 31–August 2, 1995. The workshop was supported by the National Cooperative Highway Research Program, the American Association of State Highway and Transportation Officials, and the Federal Highway Administration. It was organized to bring together transportation professionals to discuss the current status of roadside safety research and explore new approaches and methods that could produce safety benefits in the coming decade.

Many efforts are under way by FHWA, TRB, AASHTO, the states, and others to address issues related to roadside safety. These include efforts to analyze accident trends, formulate improved analysis procedures, develop better hardware, and promote a firmer understanding of the applicability of roadside improvements. There is a fundamental need to coordinate these efforts on the basis of a common vision of the most critical requirements and expected products. Issues related to the extent and design of the existing infrastructure, agency resources, new national policies, changing vehicle designs, emergence of innovative materials and technologies, and other factors must be considered in evaluating and prioritizing research needs in roadside safety.

The activities of this workshop were planned to build on the accomplishments of the 1994 TRB Committee A2A04 Workshop, which was conducted at the J. Erik Jonsson Center of the National Academy of Sciences in Woods Hole, Massachusetts. *Transportation Research Circular 435: Roadside Safety Issues* documents the accomplishments of that meeting.

In a related development, a new National Cooperative Highway Research Program Project, Number 17-13, "Strategic Plan for Improving Roadside Safety," is under way. This important initiative meshes with the mission of TRB Committee A2A04, and the results of the 1994 and 1995 workshops will provide valuable input to this strategic planning activity.

This Circular contains 12 invited papers, summarizes the findings of five breakout groups, and presents edited and combined versions of the research problem statements generated in those breakout group meetings. The rankings of these research problem statements by the participants of the Irvine workshop are provided.

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# IMPLICATIONS OF INCREASED LIGHT TRUCK USAGE ON ROADSIDE SAFETY

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## INTRODUCTION

Prior to the 1990s the basic design vehicles for most of the widely used roadside safety hardware were a small and a large passenger car. As recommended in NCHRP Report 230 *(1)*, standard test vehicles were a subcompact 820 kg car and a 2,040 kg full-size sedan. A limited number of barriers were designed to accommodate large trucks and busses.

Since 1980, sales of light trucks has been on a steady and rather dramatic increase. As shown in Figure 1, the market share of light trucks in relation to total passenger vehicle sales, both domestic and import, has increased from approximately 20% in 1980 to almost 40 percent in 1994. Light trucks are defined herein in terms of eight subclasses:

- Passenger vans (minivans);
- Large vans [1/2 ton (450 kg) and 3/4 ton (680 kg) vans];
- Small pickups (such as the Chevrolet S-10);
- Large pickups [1/2 ton (450 kg)];
- Large pickups [3/4 ton (680 kg)];
- Small sport/utility vehicles (such as a Geo Tracker);
- Mid-size sport/utility vehicles (such as a Ford Explorer); and
- Large sport/utility vehicles (such as a Chevrolet Suburban).

Of the 5,700,000+ light trucks sold in 1994, approximately 40% were large pickups (primarily 1/2-ton (450 kg)). Passenger vans were the next highest in sales, with about 23%, followed by small and mid-size sport/utility vehicles at about 20%. The balance of sales were roughly equally divided among the remaining subclasses.

In recognition of the increasing size of the light truck population, the U.S. Congress enacted legislation within the Intermodal Surface Transportation Efficiency Act of 1991 which requires that the Secretary of Transportation shall

> issue a final rule regarding the implementation of revised guidelines and standards for acceptable roadside barriers and other safety appurtenances, including longitudinal barriers, end terminals, and crash cushions. Such revised standards shall accommodate vans, mini-vans, pickup trucks, and 4-wheel drive vehicles and shall be applicable to the refurbishment and replacement of existing roadside barriers and safety appurtenances as well as to the installation of new roadside barriers and safety appurtenances. (Section 1073, Public Law 102-240, 12/18/91)

This ISTEA requirement creates the need to: (1) determine if vans, mini-vans, pick-up trucks, and 4-wheel drive vehicles (hereafter referred to as light trucks) have impact behaviors different from the previously tested passenger vehicles, and (2) assess the adequacy of current design guidelines and standards for roadside barriers, safety appurtenances, and geometric features. Roadside features include permanent and temporary traffic barriers, crash cushions, terminals, truck-mounted attenuators, breakaway supports, cross-sectional elements, and terrain.

NCHRP Report 350 *(2)* published in 1993, superseded NCHRP Report 230 and contains recommended procedures for the safety performance evaluation of highway features. Among other things, Report 350 recommends that the 3/4-ton (680 kg) pickup be used as one of the basic design/test vehicles. This was done in recognition of the increased use of light trucks as passenger vehicles and in response to the 1991 ISTEA requirements. The degree to which the 3/4-ton (680 kg) pickup typifies the light truck fleet, or is a good surrogate for the fleet, has yet to be determined. The Federal Highway Administration (FHWA) adopted Report 350 through rule making as the procedures by which safety features are to be qualified for use on federal-aid highway projects.

There has only been limited research on the safety performance of light trucks for several reasons. One reason is that until recently, crash testing for roadside features only required the use of passenger cars. Another reason is the relatively recent emergence of many types of light trucks for use primarily as passenger vehicles. A final reason is that only in the last few years has accident data become available to permit the study of vehicles in this class.

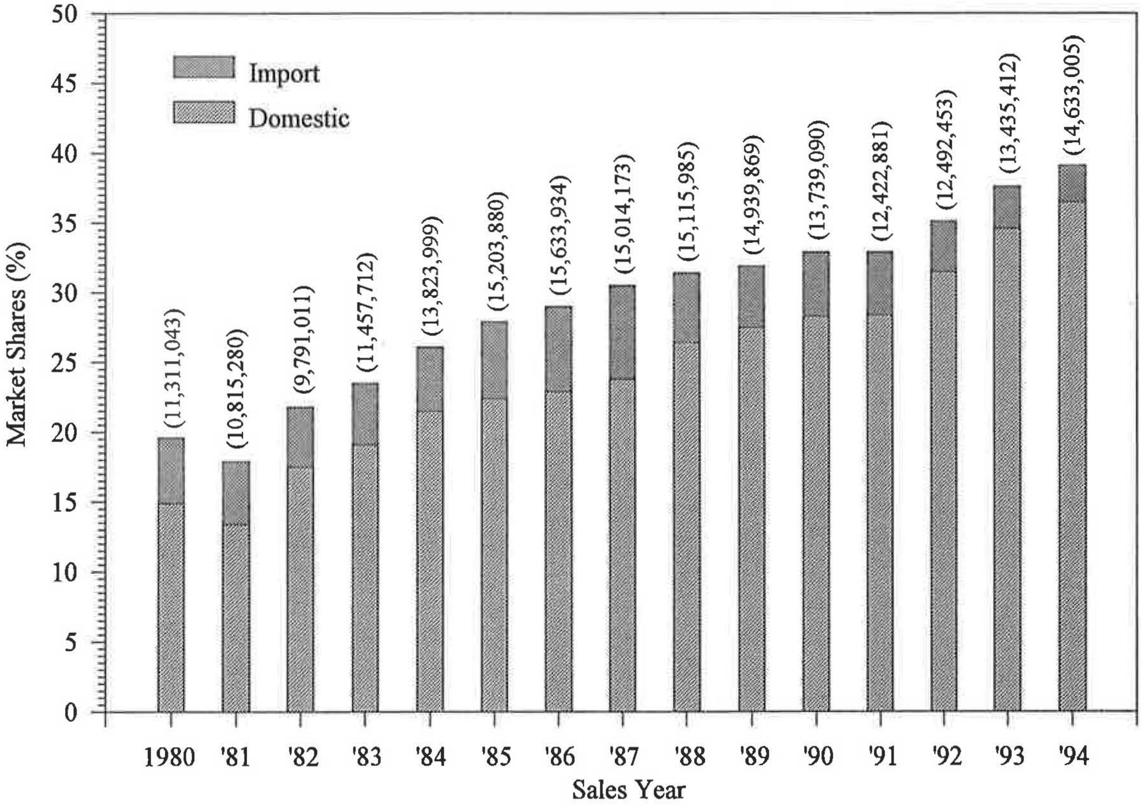

FIGURE 1 Market shares of light trucks, domestic and imported, of total passenger vehicle sales (total passenger vehicle units sold given in parentheses).

To address these concerns, NCHRP Project 22-11 was initiated. Objective of this project are to: (1) evaluate current information on the safety performance of roadside features for each subclass of light trucks, (2) assess the significance of gaps in safety performance information, and (3) recommend priorities for future research, testing, and development needed to ensure that roadside features accommodate light trucks.

Also, although not specifically stated in the objective, the Project Statement states that "In NCHRP Report 350, a 2000 kg pick-up truck is designated as the standard 2000P test vehicle. It has been proposed as the surrogate for all light trucks. It is desired that this project be structured to aid in determining if the 2000P test vehicle is an appropriate or sufficient surrogate for evaluating the safety performance of roadside features with light trucks." Project 22-11 is being conducted by the Texas Transportation Institute. It began June 1994 and is scheduled for completion in June 1996.

This paper presents preliminary findings from this study. Specifically, information is presented on a) projected trends in light truck sales and design, b) light truck properties thought to have an influence on the impact performance of safety features, c) crash test experience with light trucks impacting roadside safety features, and d) field performance of safety features as determined from accident studies. Possible implications of increased light truck usage on roadside safety are offered. It is noted that various accident data bases will also be examined in Project 22-11 for information relative to safety feature performance for light trucks. Information from this phase of the study is not currently available.

The interested reader can find complete details, including sources of un-referenced information, of data summarized in this paper in references 7, 8, and 9.

## PROJECTED TRENDS IN LIGHT TRUCK SALES AND DESIGN CHARACTERISTICS

The sales of light trucks, i.e., vans, mini-vans, pickup trucks, and 4-wheel drive vehicles, have been one of the few bright spots for the U.S. automotive industry in recent years. According to the Ward's Automotive Reports, the sales of light trucks in 1963 numbered approximately 1 million vehicles and accounted for 13.9 percent of total new vehicle purchases. The percentage

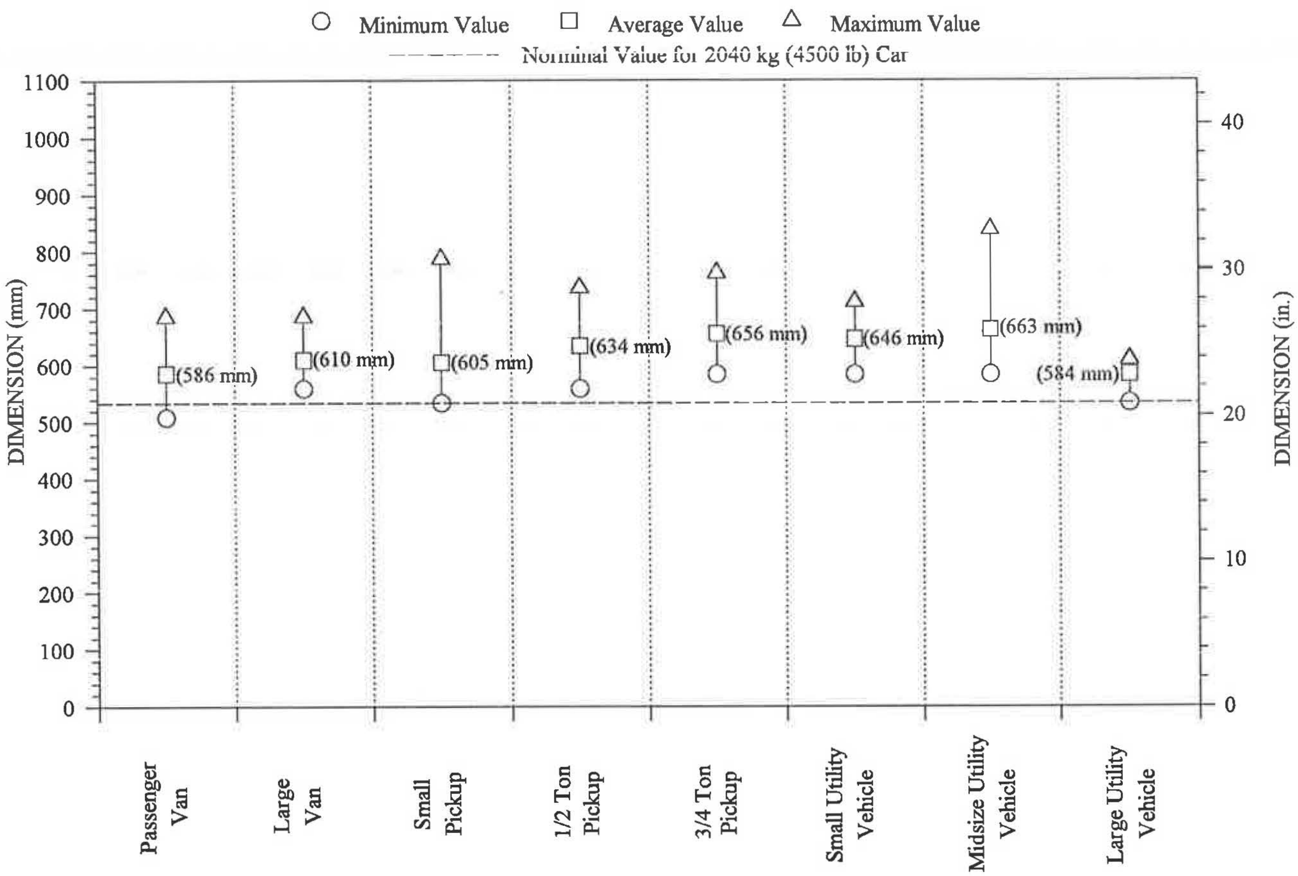

FIGURE 2 Bumper height (top of bumper), 1989–1995 models.

increased to 21.1 percent in 1981 and to a record 38.3 percent and 5.3 million units in 1993. Light trucks are no longer used principally by farmers and construction workers, but are becoming increasingly popular with families for use as passenger vehicles.

Due to the intensely competitive nature of the automobile industry and the unpredictable nature of factors that influence vehicle design, it is extremely difficult to project or predict even short term trends in the vehicle fleet. However, these uncertainties notwithstanding, the automotive industry is predicting continued increases in the market share of light trucks in new vehicle purchases. Perhaps the best source for projected trends in automotive design and marketing is a report entitled "Delphi VII - Forecast and Analysis of the North American Automotive Industry," published in February 1994 *(3)*. It was conducted by the Office for the Study of Automotive Transportation, University of Michigan, Transportation Research Institute, Ann Arbor, Michigan. It was the seventh report in a series of delphi surveys of high-level automotive industry leaders.

Key projections from the Delphi VII report are as follows:

1. Development cycles for new vehicular platforms are projected to continue to decrease, from 48 months now to 36 months in 2003. This means that the highway community will probably have to deal with new design vehicles more frequently.

2. Sales of cars and light trucks are projected to continue to increase at a modest rate, and the ratio of light truck to total passenger vehicle sales is projected to continue to increase slightly up to 2003. The study projects sales of light trucks to reach approximately 38% of total passenger vehicle sales by 2003. However, as shown in Figure 1, these projections are suspect since 1994 sales indicate approximately 40% of total passenger vehicle sales were light trucks, and the trend over the past few years points to an even greater percentage.

3. With regard to passenger car sales by segment (size/model), modest growth is projected for the upper/specialty segment.

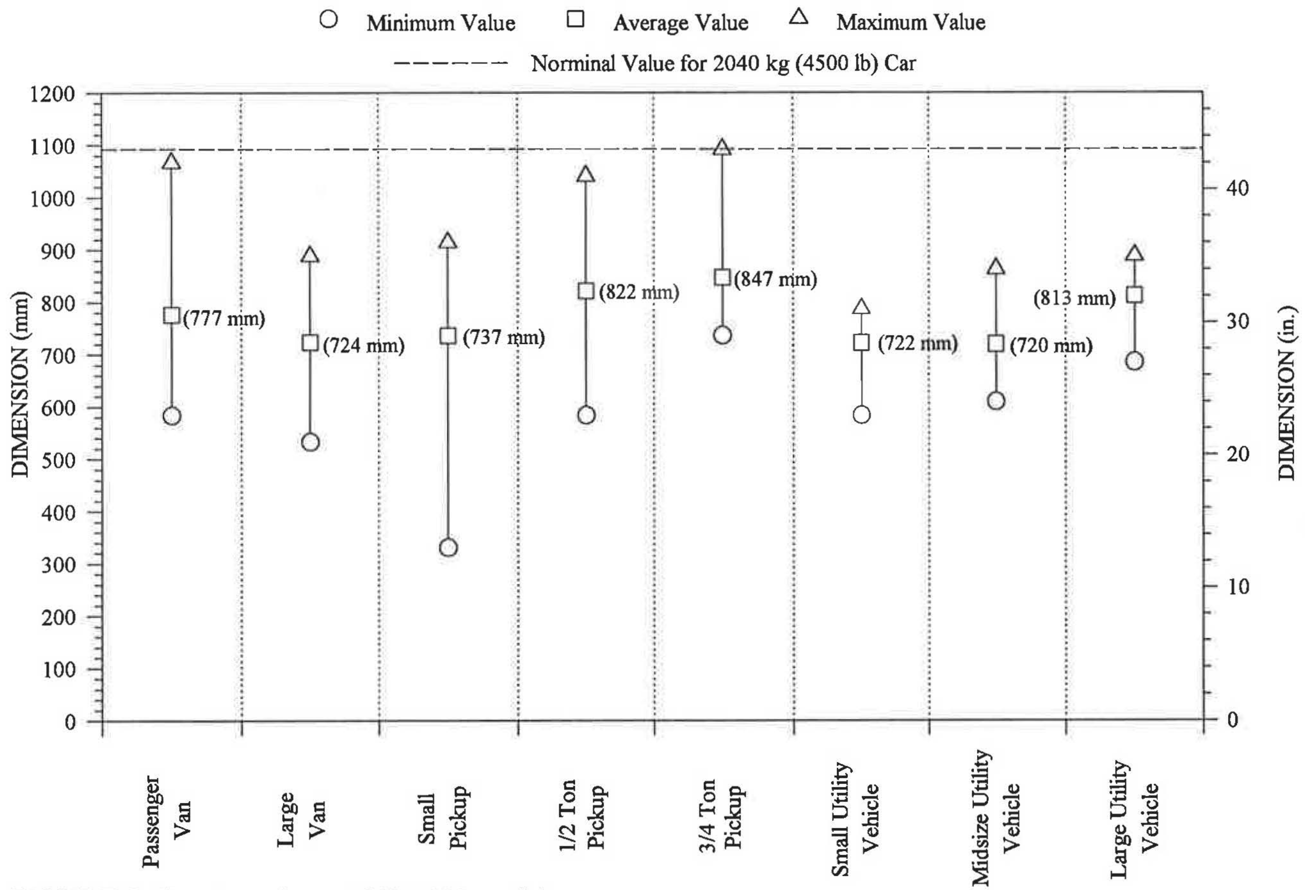

FIGURE 3 Front overhang, 1989–1995 models.

4. With regard to light-truck sales by segment (size/model), no major changes are predicted in the light truck market overall segmentation.

5. By the year 2003, it is predicted that almost all light trucks will have driver's side airbags and 50% will have passenger side airbags. If this happens, adjustments in occupant risk criteria used is assessing crash test results may be warranted, i.e., higher occupant impact velocities and ridedown accelerations may be acceptable.

6. Car and light truck weight is projected to decrease by 7% to 8% by 2003.

7. There will be little change in frame designs for cars and light trucks by 2003.

8. Cars and most mini-vans will continue to have integral body/frame or uni-body construction, while the remainder of light truck subclasses will continue to have separate body/frame construction.

Others in the automotive industry are also predicting continued increases in the market share of light trucks in new vehicle purchases. As stated in a recent newspaper article by Edward W. Hagenlocker, Executive Vice President of Ford Motor Company, "There's no reason we can't see trucks go above 40 percent of total vehicle sales by the year 2002....Fifty percent is a ways out there, but not unattainable."

## LIGHT TRUCK PROPERTIES

As part of Project 22-11, a large data base of light truck sales information and dimensional and inertial properties has been assembled. These data have been derived from various sources, including:

1. Gasoline Truck Index, Diesel Truck Index, and Import Truck Index - These documents provide the following parameters: front overhang, overall length, overall height, overall width, wheel base, curb weight on front tires, curb weight on rear tires, tire and rim size, and track width.

2. Automotive News, Wards Automotive yearbooks, and Oak Ridge National Laboratory series on "Light-

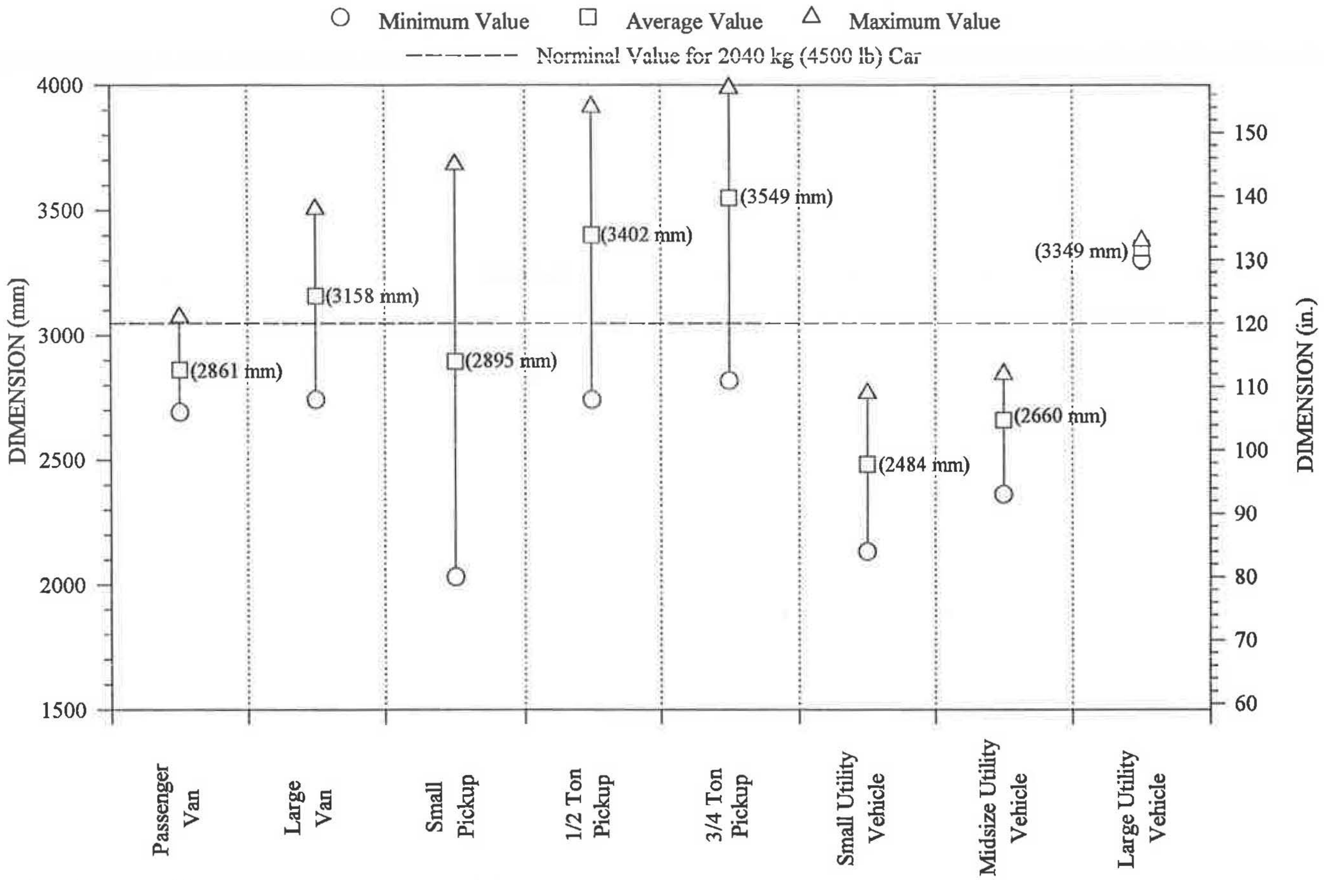

FIGURE 4 Wheel base, 1989–1995 models.

Duty Vehicle MPG and Market Shares Report" - These publications have provided sales data.

3. National Highway Traffic Safety Administration's (NHTSA) Light Vehicle Inertial Parameter Data Base — This is the most comprehensive source for c.g. height and moments of inertia data. It contains measured vehicular inertial parameters for 356 tests performed with NHTSA's Inertial Parameter Measurement Device (IPMD). This data was recently reported in a Society of Automotive Engineers (SAE) paper *(4)*.

4. Other sources for inertial properties — Another report by NHTSA *(5)* contains Inertial properties, including c.g. height and roll and yaw moments of inertia, for 51 vehicles, including 21 passenger cars, 13 pickup trucks, 10 utility vehicles, and 7 vans. An SAE Technical Paper *(6)* presents measured inertial properties of sport utility vehicles, pickup trucks, and vans and describes analytical estimation techniques for moments of inertia applicable to light trucks. Several rollover studies have also reported some inertial properties for light trucks. A paper titled "Engineering Parameters Related to Rollover Frequency," by Jones presents data for 11 models of pickups and 16 models of utility vehicles. Others include "Vehicle Dynamics and Rollover Propensity Research" by Garrott et al., and "An Evaluation of Static Rollover Propensity Measures," by Chrstos. Center-of-gravity heights for a Chrysler mini-van, a full-sized Ford pickup truck, and a GM sport/utility vehicle were published in a University of Michigan report entitled "Center of Gravity Height: A Round-Robin Measurement Program" by Walker et al. In addition, many test agencies have reported c.g. height and, in a few instances moments of inertia, for various light trucks which were used as test vehicles in full-scale crash tests or in computer simulation studies. It should be noted that much of these data are for vehicles produced prior to 1990.

5. Parking lot surveys - Significant parking lot and dealers' lot data have been gathered, primarily dimensional properties such as overall length, overall length, wheelbase, front overhang, bumper height, etc. Software program "VINAssist," version 1.06LE, was used

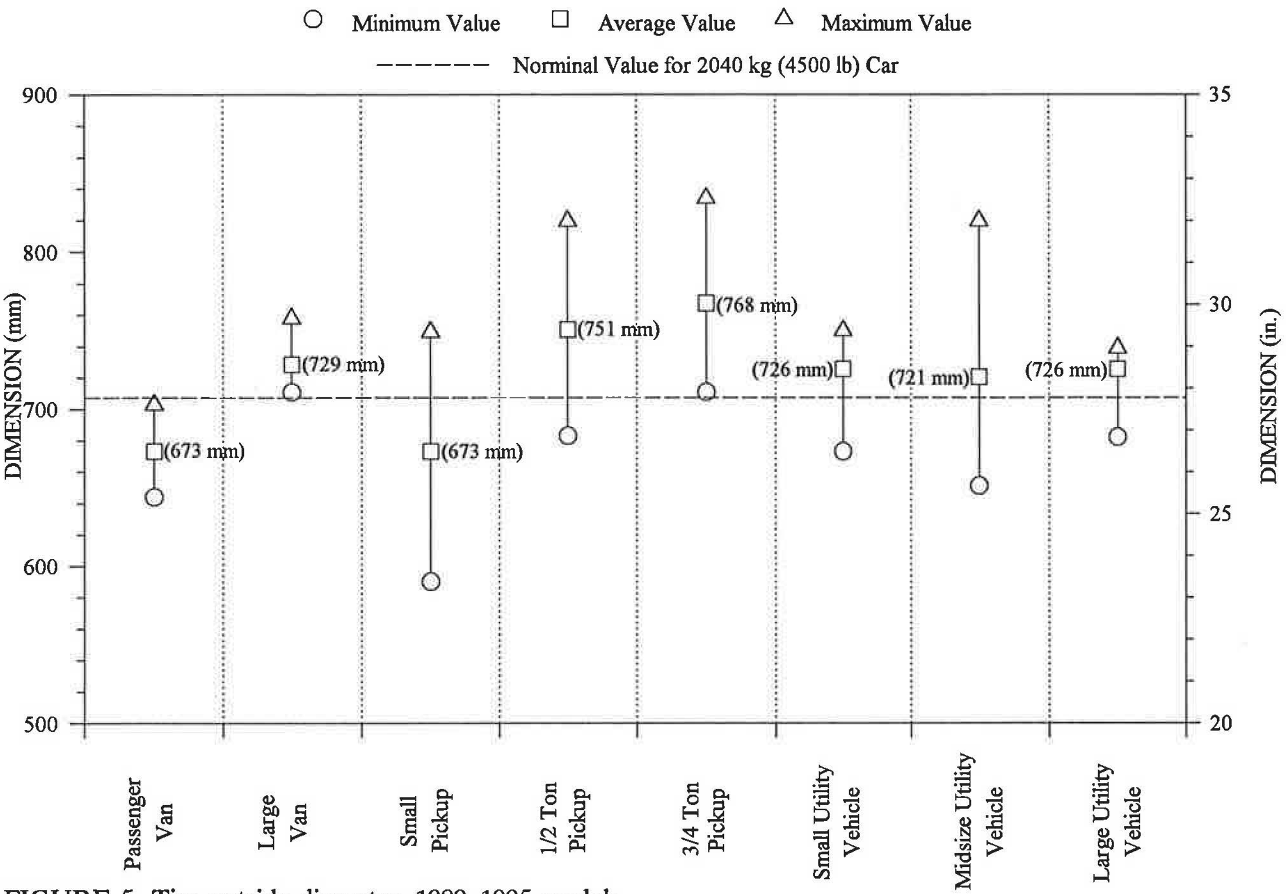

FIGURE 5 Tire outside diameter, 1989–1995 models.

to identify specifics of each vehicle surveyed (model year, type of cab (if applicable), 2 or 4 door, type of engine (diesel or gasoline), 2 or 4 wheel drive, etc.).

Shown in Figures 2 through 8 are dimensional and inertial data for light trucks for model years 1990 through 1994. Figures 2 through 5 contain bumper height, front overhang, wheel base, and un-deflected tire diameter for 1989-95 model years. These data were acquired via parking lot surveys, and included 4-wheel drive vehicles. Vehicles with special "jacked-up" suspension systems were omitted. As previously stated, with the exception of bumper height, data on the same parameters have also been collected from published sources and were correlated with parking lot data.

Shown in Figures 6 through 8 are selected inertial data for light trucks, including curb weight, c.g. location above ground, and c.g. location aft of the front axle.

Based on initial and preliminary examination of these data, one may conclude that the 3/4-ton (680 kg) pickup truck is reasonably representative of the light truck population. In terms of some of the more sensitive parameters such as bumper height, front overhang, mass, and c.g. location above ground, there are some subclasses with parametric values that are believed to be more critical than those of the 3/4-ton (680 kg) pickup and some with values less critical. By more critical is meant that an impact will be more demanding on a safety feature, i.e., more difficult for the impact performance of the features to meet recommended criteria, all other parameters being equal. For example, it is conjectured that demands on a longitudinal barrier will generally increase as the bumper height increases, as the front overhang decreases, as the c.g. height increases, as the tire diameter increases, etc.

Nominal values of the parameters for the 2,040 kg full-size car previously used as a design vehicle are also shown on the figures. It can be seen that the light truck parameters are typically more critical than those of the 2,040 kg car, i.e., for the 2,040 kg car bumper heights are lower, front overhang in larger, and c.g. height is lower.

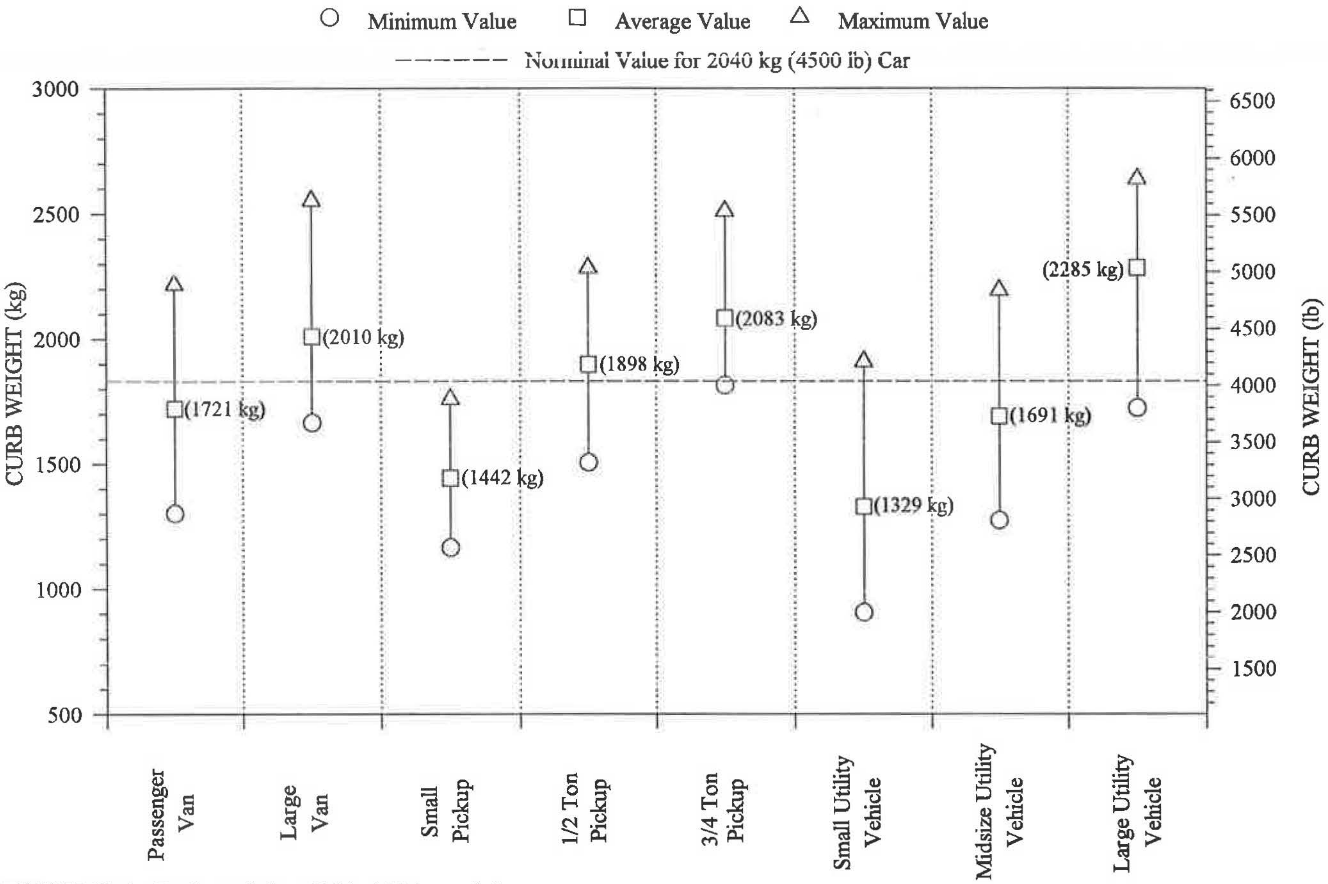

FIGURE 6 Curb weight, 1990–1994 models.

## CRASH TEST EXPERIENCE WITH LIGHT TRUCKS

Most of the crash testing with light trucks conducted to date has involved either a 1/2-ton (450 kg) or 3/4-ton (680 kg) pickup truck. Only a very limited amount of testing has been conducted with light truck vehicles such as sport/utility vehicles and vans, respectively.

A vast majority of crash tests with pickup trucks have involved a full-size pickup ballasted to 2,450 kg. Since some of these tests involved a 1/2-ton (450 kg) vehicle, and since the impact conditions typically used in conjunction with the 2,450 kg test vehicle have a smaller impact angle and result in a significantly lower impact severity than those required by test level 3 of Report 350, it is difficult to make conclusive assessments regarding the ability of some of these systems to meet Report 350 criteria. However, in general, these tests do provide considerable insight into the safety performance of current hardware with pickup trucks from which some general observations can be made.

Generally speaking, it appears that most of the common rigid barriers and bridge rails such as the New Jersey safety shape, F-shape, vertical wall, and constant-slope barrier perform satisfactorily with pickup trucks when tested to PL-2 of the AASHTO Guide Specification or TL-3 of NCHRP Report 350. In addition to several pickup truck tests, two tests of a CMB were successfully conducted with a Ford Bronco. However, the results of these tests must be qualified by the model year of the test vehicle (1966) and the impact angles (7 and 15 deg). Clearly, further investigation of these barriers for other light truck vehicles, particularly full-size vans and sport/utility vehicles, is warranted. These vehicles may have greater c.g. heights than the pickup trucks, which increases the propensity for rollover.

The most critical area of concern appears to be the performance of widely used flexible guardrail systems. The short front overhang and increased c.g. and bumper heights of the light truck class significantly increase the

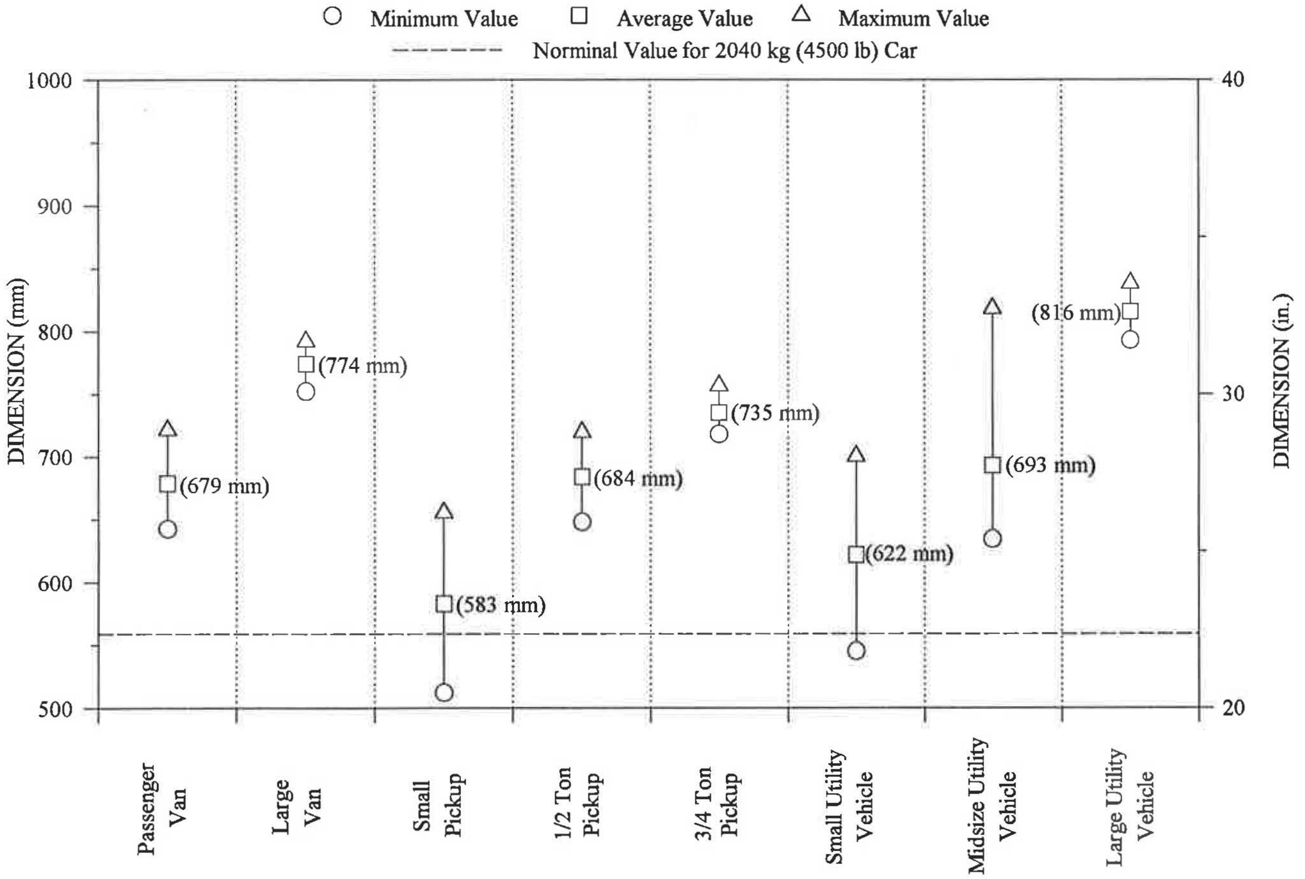

FIGURE 7 C. G. location above ground.

potential for vaulting and rollover during impacts with these systems. Results of recently conducted tests indicate that the performance of the commonly used G4 strong-post W-beam guardrail systems appears marginal when evaluated under NCHRP Report 350 Test Level 3 conditions. During a test of a G4(2W) guardrail system, the front wheel assembly of the vehicle became detached and the vehicle achieved a maximum roll angle of 39 degrees before being redirected. A similar test with a G4(1S) steel post guardrail system under the same nominal impact conditions resulted in a rollover. In another series of tests conducted on the G4(1S), an increasing propensity for rollover with an increase in c.g. height was demonstrated. In these tests, a small 1/2-ton (450 kg) pickup was redirected in a very stable manner, while a full-size 1/2-ton (450 kg) pickup achieved a roll angle of 35 deg, and a 3/4-ton (680 kg) van rolled over.

In other tests, a G2 weak post W-beam guardrail was found to be deficient as a TL-3 barrier, but was found to have satisfactory performance when evaluated as a TL-2 barrier. A G1 cable guardrail system was found to exhibit good impact performance when impacted by a 2000P vehicle under test level 3 conditions.

Most surprising of all, evaluation of the standard G9 three beam system for TL-3 of Report 350 resulted in a failure. Upon impact the 2000P vehicle was redirected but large pitch and roll rates were induced, resulting in a violent rollover. It had been surmised that the G9 system could be the solution to the W-beam problem.

Tests of guardrail-to-bridge rail transitions have been successful in containing and redirecting 3/4-ton (680 kg) pickup trucks. However, during tests of transitions to rigid barriers, a high occurrence of floorpan deformation has been observed that was not evident in previous testing with large passenger sedans. This floorpan deformation has occurred in instances when no evidence of wheel snagging on the end of the parapet was reported. This may be attributed to the reduced front overhang dimension of the pickup truck resulting in more vehicle-barrier interaction, or it may

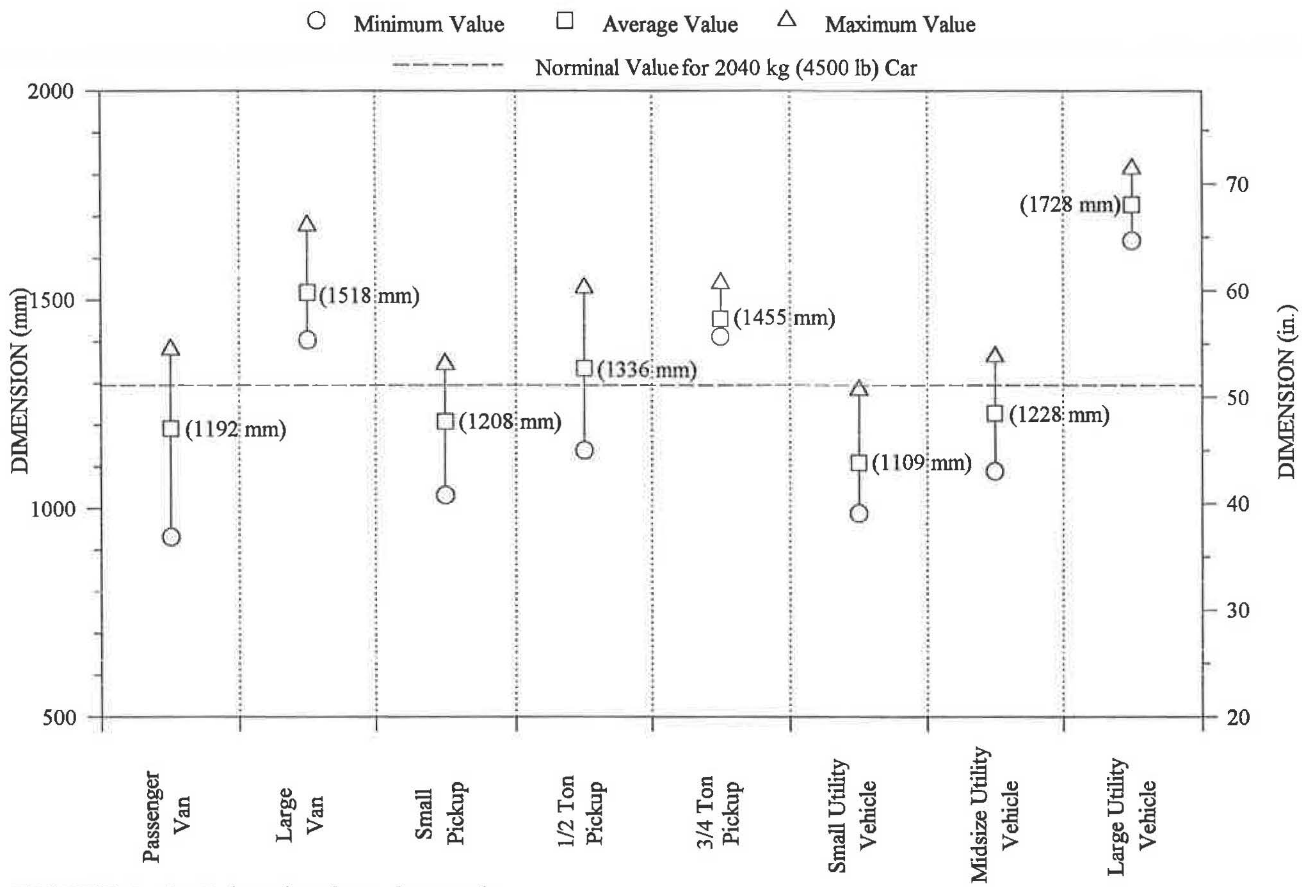

FIGURE 8 C. G. location from front axle.

be due to some other inherent characteristic of these vehicles.

Results of tests on crash cushions and energy-attenuating devices appear to indicate a strong potential for good impact performance. The React 350 crash cushion developed by Roadway Safety Services (RSS), Inc., has been fully qualified according to Report 350 requirements. The Fitch Inertial Barrier System, marketed by RSS, and the Energite Inertial Barrier System, marketed by Energy Absorption Systems (EAS), Inc., have also been qualified for Report 350 requirements. Work was underway at the time of this writing to qualify the ADIEM crash cushion.

At the time of this writing, the Modified Eccentric Loading Terminal (MELT), the ET-2000, and the Slotted Rail Terminal (SRT) were being evaluated in accordance with Report 350 requirements. Details of these test programs were not available for this paper.

Some concern exists regarding the potential for vehicular override or overturn during end-on impacts with some common end treatments due to the geometrics of the light truck class of vehicles and the potential for the accumulation of debris in front of the impacting vehicle. A test with an eccentric loader terminal (ELT) was judged as marginally passing when a 1/2-ton (450 kg) pickup ballasted to 2,450 kg and impacting at a speed of 51 mph achieved a roll angle of 43 degrees. Concern also exists in regard to the potential for vehicular vaulting and overturn during impacts into the side of the terminal at the beginning of length of need.

Testing of roadside geometric features with light trucks has been very limited. In two full-scale embankment traversal tests, a 1/2-ton (450 kg) pickup truck and 3/4-ton (680 kg) van successfully negotiated a 3:1 side-slope with an embankment height of 15 ft. In a similar test with a small passenger car, the vehicle slid down the embankment and rolled over when the tires plowed into the ground. This would appear to indicate that, in terms of roadside encroachments, a small passenger car is more critical than a high c.g. van. However, the rollover of the small car was not a function of the geometry of the side-slope as it was the conditions of the soil. The van, on the other hand, experienced a 23 deg roll angle before stabilizing, and would likely be more sensitive to the actual geometry of the side-slope. Clearly, much more study is required before any conclusions in this regard can be substantiated.

Testing of temporary barriers with light trucks has been very limited. A standard New Jersey concrete safety-shaped barrier connected to a bridge deck with 1 1/4 in. steel pins was successfully tested for TL-3. Although the barrier was neither completely rigid nor free standing, the results of this test are encouraging. However, further testing is needed to more fully define the capabilities of a precast CMB in containing light trucks.

The low-profile portable concrete barrier was developed and tested according to TL-2. This barrier is 508 mm in height and has a negative slope on the traffic face. It is of particular interest to note that almost immediately after impact, the bumper of the pickup truck overrode the top of the barrier, yet the vehicle was still smoothly redirected. This may be at least partially attributed to the negative slope on the face of the barrier.

The TRITON water-filled barrier, developed by EAS, has also passed TL-2 requirements. In addition, suitable end treatments and transitions have also been developed for use with this barrier system and successfully tested to TL-2.

A test of temporary concrete safety-shaped half barrier was not successful. To accommodate space restrictions at some work sites, the Iowa Department of Transportation evaluated the concept of using a half-barrier, which is similar in cross section to a safety-shaped bridge rail, as an alternative to a full-width concrete median barrier. When impacted by a 2,450 kg pickup truck at 60 mph and 20 deg, the barrier segments began to rotate, and the vehicle vaulted the installation.

## FIELD EXPERIENCE

A review of literature on field performance data did not result in much useful information for the purpose of Project 22-11, which is to determine the effects of light trucks on the impact performance of various roadside features. There is considerable information in the literature on the accident experience of light trucks, but not specific to crashes involving roadside features. The literature indicates that light trucks are over-represented in fatal crashes and have significantly higher rollover rates than passenger cars. Side-slopes and ditches are identified as the primary tripping mechanism in rollover crashes. The severity of accidents involving light trucks is similar to that of passenger cars overall and for a number of roadside features studied. There are numerous studies to evaluate the impact performance of specific roadside features, but the accident data were not categorized by vehicle type and the findings are thus of little use for the present study.

Further studies of light truck involvement with safety features are being pursued in Project 22-11 through analysis of various accident data bases. These data bases include

- Fatal Accident Reporting System (FARS),
- National Accident Sampling System (NASS) - General Estimate System (GES),
- NASS — Crashworthy Data System (CDS),
- Highway Safety Information System (HSIS), and
- NASS Longitudinal Barrier Special Study (LBSS).

## FINDINGS AND IMPLICATIONS

1. Light truck sales have continued to climb over the past 20 years. In 1994 light truck sales were approximately 40% of all passenger vehicle sales. The large pickups (1/2-ton (450 kg) and 3/4-ton (680 kg)) have the largest market share of all the light truck subclasses. Attention must be given to the light truck fleet in the design of roadside safety features.

2. In general, light trucks create greater demands on roadside features than did the heretofore 2,040 kg passenger car design vehicle, all other factors being the same. This is due to higher bumper heights, shorter front overhangs, stiffer crush properties, and higher c.g. locations, among other things.

3. Based on findings to date, the 2000P test vehicle (3/4-ton (680 kg) pickup) appears to be reasonably representative of the larger light truck subclasses (large vans, mid-size and large utility vehicles) with regard to key parameters that influence impact performance.

4. The standard W-beam guardrail systems, which are widely used in the USA, and the standard thrie-beam guardrail system, whose use is fairly widespread and increasing, are marginal at best when subjected to the "basic" Test Level-3 requirements of NCHRP Report 350. In this test the 2000P vehicle impacts the barrier at 100 km/h at an impact angle of 25 degrees. Implications of these results could be enormous.

5. Impact performance of the 2000P vehicle with rigid barriers such as the New Jersey concrete safety shape barrier or the single slope concrete barrier appears to be acceptable.

6. Impact performance of inertial crash cushions are acceptable for Report 350 TL-3 requirements.

7. Test and evaluation of widely used guardrail end treatments such and the MELT and the ET-2000, and the newer slotted rail terminal (SRT) were underway at the time of this writing, and results were not available for inclusion in the paper.

8. Light trucks are more prone to overturn on embankments, ditches, and other roadside geometric features than are cars. Guardrail warrants for embankments and side-slopes may have to be reevaluated.

## RECOMMENDATIONS FOR FURTHER RESEARCH

1. Test 3-11 of Report 350 should be conducted with the standard W-beam guardrail system using a representative vehicle from the "large van" and the "large utility" subclass. Note that test 3-11 with the 2000P vehicle with the G4(1S) system has been conducted. Also, similar tests have been conducted with the 1/2-ton (450 kg) pickup with the G4(1S). The purpose of these tests would be to compare performance of the "heavier" light truck subclasses for the "strength" test of Report 350. Test 3-11 would never be conducted with any of the "lighter" light truck subclasses (since it is a strength test), and therefore test 3-11 should not be the basis on which to compare light truck performance. The G4(1S) system is recommended since 1) it is known to have poor performance for the large pickup subclass for test 3-11, and 2) it is the most widely used guardrail system in the USA. These tests would provide valuable insight and data from which the efficacy and relevance of the 2000P vehicle could be evaluated, at least for test 3-11.

2. Test 3-10 of Report 350 should be conducted with the G4(1S) system with a representative vehicle from each of the seven light truck subclasses. The purpose of these tests would be 1) to provide data from which to evaluate and compare the performance of the "heavier" light trucks at impact angles of 20 and 25 degrees, and 2) to evaluate and compare the performance of a representative vehicle from each of the light truck subclasses for the "severity" test of Report 350.

Summarizing, it is anticipated that results from parts a) and b) would be used for several purposes, as follows.

First, results of part a) would aid in determining the efficacy of the 2000P vehicle as a representative/ suitable vehicle from the "heavier" light truck subclasses for the strength tests of Report 350 (tests 1-11, 2-11, 3-11, 4-11, 5-11, and 6-11). It is possible, for example, that a 3/4-ton (680 kg) Suburban vehicle would accomplish the desired goal of testing the strength capabilities of a barrier, without the instability now seen in the 2000P vehicle. Based on instrumented wall tests, the Suburban is known to produce greater loads on a barrier than the pickup, all other factors being the same. Replacing the 2000P vehicle with another vehicle would require/imply acceptance of the premise that a 25 deg/100 km/h impact is such a rarity that longitudinal barriers should not be expected to keep all light trucks upright for such conditions.

Second, results of parts a) and b) may point to the desire/need to abandon test 3-11 altogether as it is now defined if tests in part "a" are failures and tests with the same vehicles in part b) are successes, and if the highway safety community agrees that it should no longer require longitudinal barriers to be designed for test 3-11 conditions. These tests may point to the desire/need to change test 3-11 to a higher speed and lower impact angle, or to the same speed but a 20 degree impact angle, etc.

Third, results of part b) would allow for the direct comparison of the performance of a representative vehicle from each light truck subclass for a widely used safety feature for the "severity" test. Results of part b) may also point to the need for an additional "severity" test involving a vehicle from one of the light truck subclasses. For example, whereas the 820C vehicle's performance with the G4(1S) system is satisfactory, the same may not be true for one or more vehicles from the light truck subclasses.

3. Depending on results and conclusions drawn from parts a) and b), other tests that may be considered include; 1) tests to evaluate alternate impact conditions for test 3-11, e.g., a higher speed and a lower impact angle - tests would be conducted with the G4(1S) system, 2) tests of the concrete safety shaped barrier with vehicles from selected light truck subclasses (FHWA is planning to conduct test 3-11 on the concrete safety shaped barrier in the near future), or 3) tests of other longitudinal barriers (cable barrier for example) with vehicles from selected light truck subclasses.

4. Tests to determine inertia properties, and limited suspension properties, of a representative vehicle from each of the seven light truck subclasses should be conducted. These data are needed for future computer simulation studies.

5. Additional vehicular finite element models should be developed for use with DYNA 3D to better simulate the full range of light truck subclasses. At a minimum, a model of a representative passenger van and a mid-size utility vehicle are needed. These models could be calibrated/validated with previously recommended crash tests (see item b).

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# SAFETY APPURTENANCE DESIGN AND VEHICLE CHARACTERISTICS

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## INTRODUCTION

Energy Absorption Systems, Inc., (EASI) has been designing, testing and manufacturing highway safety appurtenances for over 25 years. The purpose of this discussion is to present some of the observed vehicle characteristics that can directly influence crash test results, especially as they relate to the recent adoption of NCHRP Report 350 testing guidelines versus the previous NCHRP Report 230 guidelines. This 20-minute presentation was originally given at the April 12, 1995, SAE session in Washington, D.C., titled "Roadside Hardware Design Issues and Vehicle Interactions." Specific areas that will be reviewed include

1. Front bumper reinforcement differences between various types of 3/4-ton pickups.
2. Front suspension differences between various types of 3/4-ton pickups.
3. Center-of-gravity location differences between various types of 3/4-ton pickups.
4. Frontal crush differences between 4500S and 2000P vehicles.
5. Bumper height differences between various vehicles.
6. Hood retention characteristics of light-weight vehicles.

NCHRP Report 350 is a comprehensive set of updated procedures for crash testing highway safety appurtenances. Report 350 differs from Report 230 in that it specifies the use of 3/4-ton pickup trucks as the standard passenger vehicle in place of the 4500-lb passenger car. This reflects the fact that almost one-quarter of the passenger vehicles on U.S. roads are in the "light truck" category. "This change was made recognizing the differences in wheel bases, bumper heights, body stiffness and structure, front overhang, and other vehicular design factors."*(1)*

EASI has conducted numerous crash tests using 3/4-ton pickups impacting various types of highway safety hardware at Test Level 3 conditions (100 km/h). The first three topics detailed below are the result of a comparative evaluation of various types of 3/4-ton pickups.

## FRONT BUMPER REINFORCEMENT

The first noteworthy variation between different types of 3/4-ton pickups is the difference in front bumper

FIGURE 1 1990 Ford F250 front bumper reinforcement.

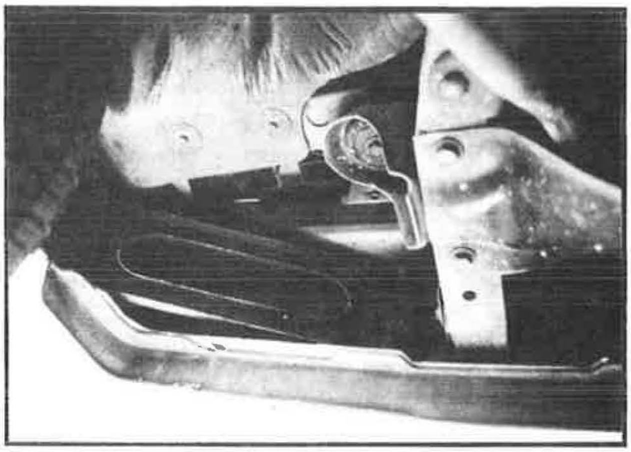


FIGURE 2 1990 Ford F250 front bumper reinforcement.

FIGURE 3 1989 Chevrolet 2500 front bumper reinforcement.

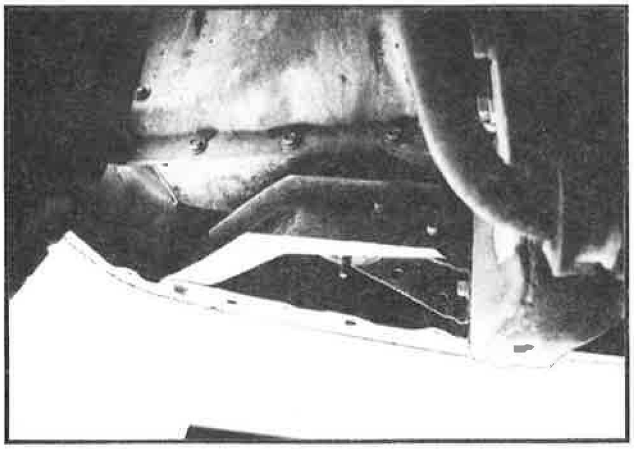


FIGURE 4 1989 Chevrolet 2500 front bumper reinforcement.

reinforcement, depicted in Figures 1, 2, 3, and 4. In this example, a comparison is made between the Ford F250 and the Chevrolet 2500. Both types of front bumpers are equipped with reinforcing braces. The Chevrolet 2500's lateral brace ties into the side of the truck frame. The Ford's reinforcing braces tie back into the bumper itself. The Chevrolet design is inherently stronger due to the triangulation of the bumper, bracket, and truck frame. The Chevrolet's bumper appears to offer more protection for the front wheel of the vehicle. Vehicles with better lateral bracing of the front bumper experience less front wheel snagging during offset and angled impacts.

FIGURE 5 1990 Ford F250 front suspension.

FIGURE 6 1990 Ford F250 front suspension.

## FRONT SUSPENSION

The second variation between different types of 3/4-ton pickups is the differences in front wheel suspensions,

FIGURE 7 1989 Chevrolet 2500 front suspension.

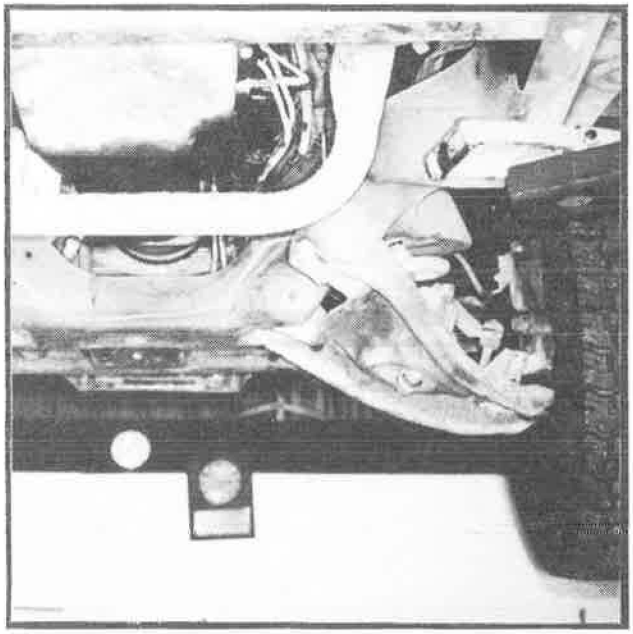


FIGURE 8 1989 Chevrolet 2500 front suspension.

depicted in Figures 5, 6, 7, and 8. In this example, a comparison is made between "I-beam" and "Wish-bone" suspensions. Experience has shown that when the "I-beam" suspension's vertical strut fails during severe front-angled impacts, upward loading can be imparted into the truck through the still-connected "I-beam," creating a potential upward loading condition. When the "Wish-bone" suspension fails, it typically fails in a horizontal plane, which reduces the likelihood of upward loading on the truck. These failure modes are presented graphically in Figures 9, 10, 11, and 12. Thus, during severe lateral or angular nose impacts that cause suspension failure, pickups with "I-beam" suspensions may experience a higher tendency to climb or ramp than the pickups equipped with "Wish-bone" suspensions.

## CENTER-OF-GRAVITY LOCATION

The third variation between different types of 3/4-ton pickups is the general location of the center of gravity (CG) above the ground and from the front of the vehicle. The actual CG location varies from vehicle to vehicle depending on model, wheel diameter, gas tank fill level, etc. In this example, a comparison is made between the Ford F250 and the Chevrolet 2500*(2)*. Typically, Ford F250s have CG locations that average up to 6.4 cm (2.5 in) higher than the Chevrolet 2500s. The Ford F250s also have CGs that are located up to 17 cm (6.7 in) closer to the front bumper than the Chevrolet 2500s. This information is shown graphically in Figure 13.

A vehicle's CG location affects how it interacts with highway safety hardware. Vehicles with higher CGs have a greater tendency to ramp over some highway appurtenances, especially during frontal impacts. Also, if vehicle rolling is induced during the impact, higher CG vehicles have a greater tendency to roll over.

Vehicles that have CGs located closer to the front have a greater tendency to counter rotate instead of being smoothly redirected during lateral impacts into longitudinal barrier, see Figures 14 and 15. The logic behind this is depicted graphically in the free-body diagram shown in Figure 16. As the CG location moves rearward, the "redirection moment arm" increases which increases the likelihood of smooth redirection. Thus, vehicles with CGs located further back on the vehicle have a higher chance of being smoothly redirected.

## FRONTAL CRUSH DIFFERENCES BETWEEN 4500S AND 2000P VEHICLES

As stated earlier, NCHRP Report 350 differs from Report 230 in that it specifies the use of 3/4-ton pickup trucks (2000P) as the standard passenger vehicle in place of the 4500-lb passenger car (4500S). In the past, highway safety hardware designers could rely on the front end crush of the 4500S car to safely dissipate

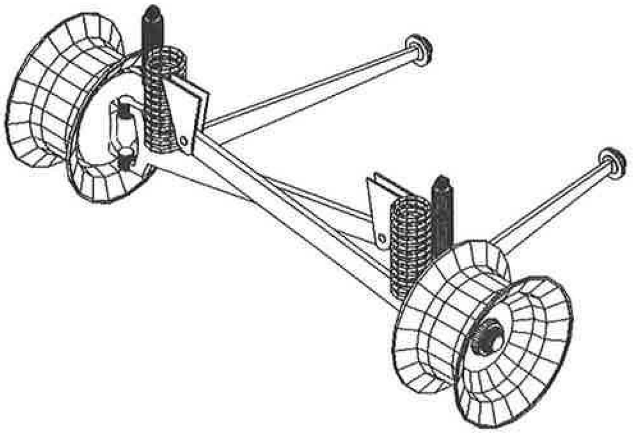


FIGURE 9 Ford F250 dual I-beam suspension.

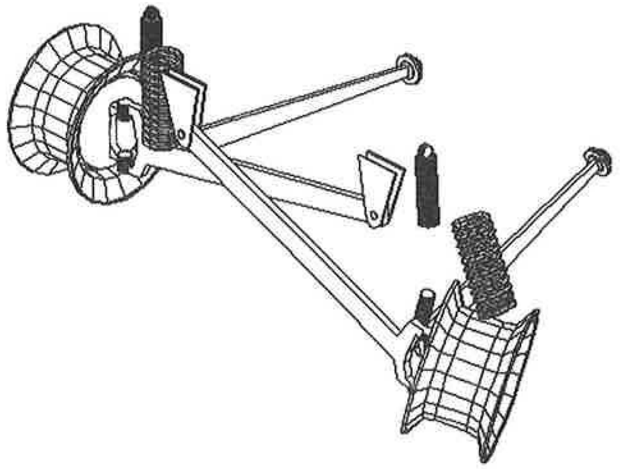


FIGURE 10 Ford F250 dual I-beam suspension failure.

approximately 5% of the vehicle's kinetic energy. Using the crush of the 4500S vehicle plus the stroke of the attenuator, a designer could design the shortest practical system to meet the occupant risk criteria recommended by NCHRP 230. The front ends of 2000P vehicles are much stiffer and do not have as much overhang as the 4500S cars. Thus, they do not have the ability to safely absorb as much kinetic energy. Consequently, to meet the new NCHRP 350 standards, attenuators will need to be made longer or collapse more efficiently to dissipate the extra energy not safely absorbed by the crush of the 2000P vehicle. The variations in the front end crush between the 4500S and the 2000P vehicles can be seen in Figures 17 and 18.

## BUMPER HEIGHT DIFFERENCES BETWEEN VARIOUS VEHICLES

Figures 19 and 20 represent a picture study of typical vehicles placed immediately in front of typical highway appurtenances. The depicted vehicles include a 1988 Ford Festiva, a 1990 Ford F250 pickup, a 1994 Dodge Intrepid, and a 1991 Dodge Stealth. The highway appurtenance shown in Figure 19 is a cut away of a typical 320 kg (700 lb) inertial barrel showing the proper fill height for the sand. The highway appurtenance shown in Figure 20 is a typical guardrail end terminal.

The conclusion that can be drawn from Figures 19 and 20 is that highway appurtenance designers must

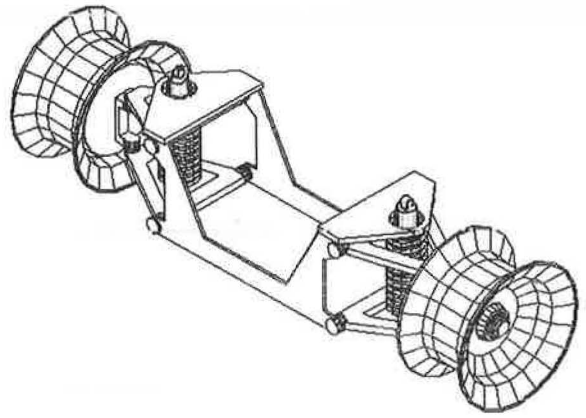


FIGURE 11 1989 Chevrolet 2500 suspension.

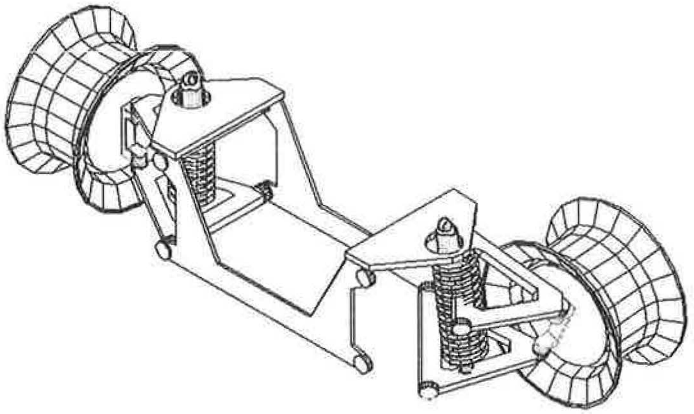


FIGURE 12 1989 Chevrolet 2500 suspension failure.

optimize their designs to accommodate a wide range of front bumper heights as well as vehicle shapes. The height of the front bumpers, measured to the center, ranges from 41.9 cm (16.5 in) for the Intrepid to 65.4 cm (25.75 in) for the Ford F250. Vehicles with low bumper heights combined with the currently popular aerodynamic wedge shape have a greater tendency to "nose dive" under some devices. "Nose-diving" can lead to possible windshield penetration and, because the safety device's energy dissipation capabilities are not efficiently utilized, the vehicle may impact the hazard at a higher-than-normal rate of speed. Vehicles designed to have high ground clearance combined with high front bumpers have a greater tendency to ramp. A ramping vehicle will not be decelerated efficiently by highway appurtenances, which can result in possible high-speed impacts into the hazard. Vehicle trajectory can also be a problem.

## HOOD RETENTION CHARACTERISTICS OF LIGHT-WEIGHT VEHICLES

NCHRP Report 350 includes a set of safety criteria to evaluate the relative performance of highway safety hardware. The three primary evaluation criteria include 1) structural adequacy, 2) occupant risk, and 3) post impact response. A subset to the occupant risk criteria is listed as follows:

> "Detached elements, fragments or other debris from the test article, or *vehicular* damage should

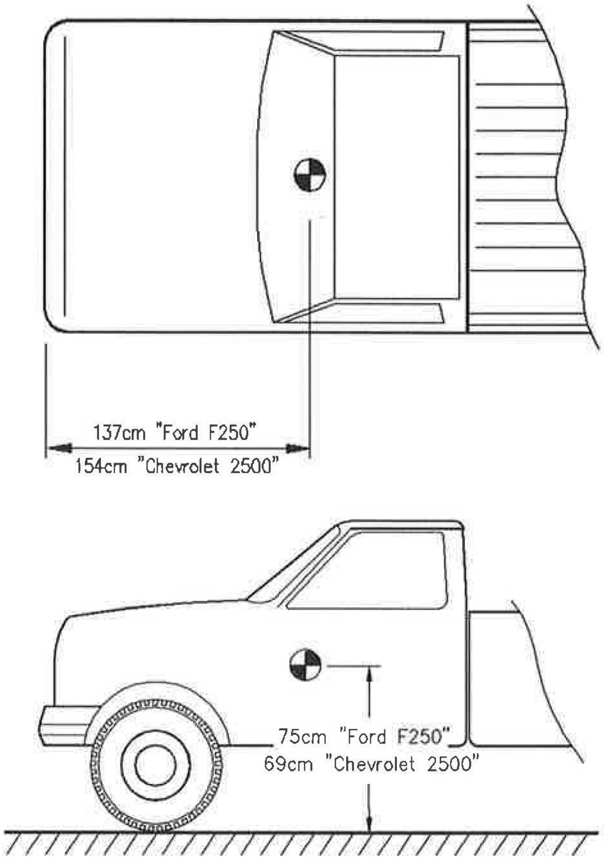


FIGURE 13 Ford F250 versus Chevrolet 2500 center of gravity location.

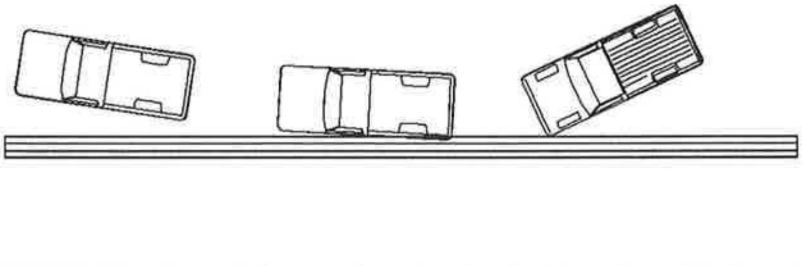


FIGURE 14 Lateral impact into longitudinal barrier with "smooth redirection."

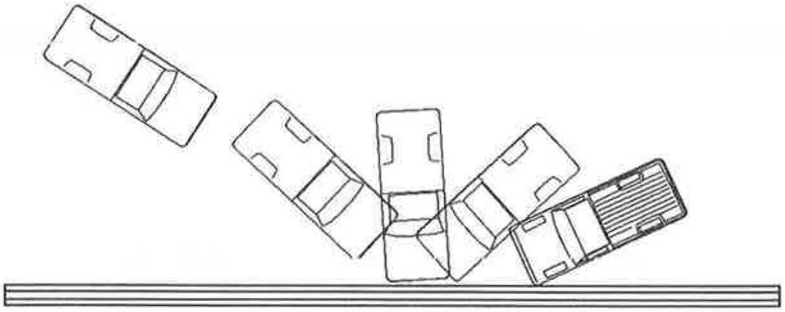


FIGURE 15 Lateral impact into longitudinal barrier with "counter rotation."

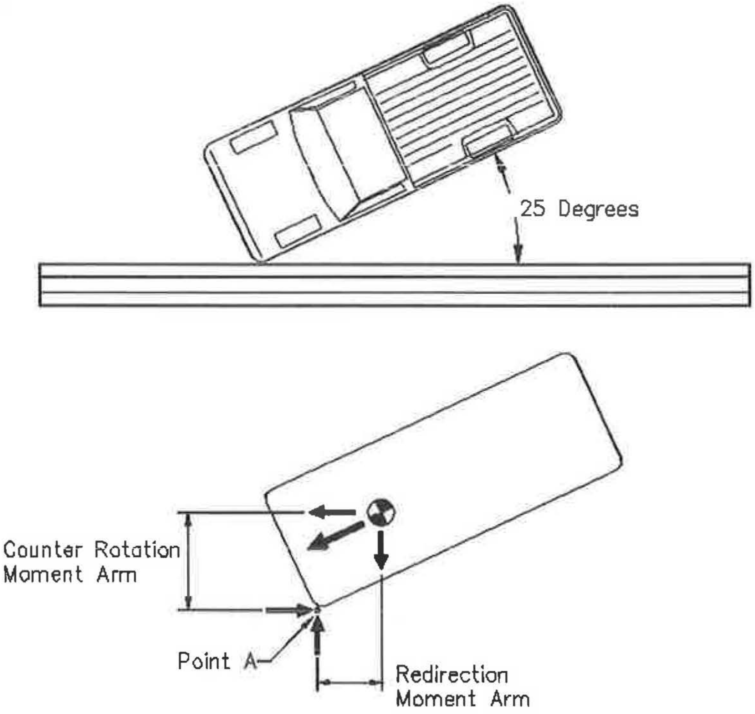


FIGURE 16 Lateral impact into longitudinal barrier with free-body diagram.

> not block the driver's vision or otherwise cause the driver to lose control of the vehicle."

Figure 21 depicts the after test results of a subcompact vehicle impacting an inertial barrel array at 100 kph (60 mph). Note that the vehicle's hood is missing. Experience has shown that some vehicles, especially low-cost, light-weight, subcompacts have hood latches and hinge mechanisms that are not structurally adequate enough to keep the hood attached during certain types of relatively safe, low g impacts. This characteristic is not so much a flaw of highway safety hardware, but instead, is an undesirable characteristic of the impacting vehicle. This is a problem that needs to be addressed by the automotive design engineers.

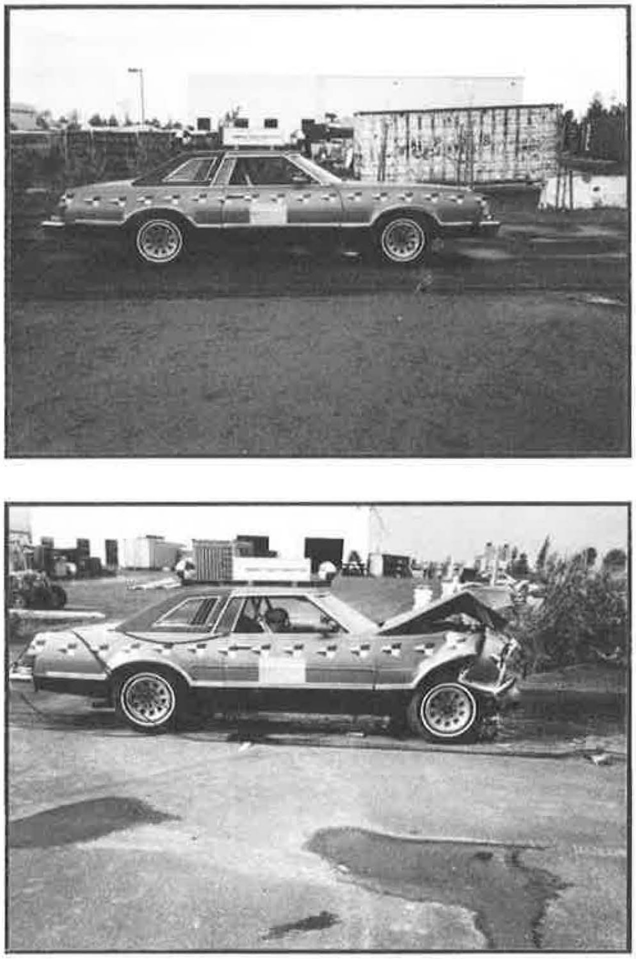


FIGURE 17 Before and after front end crush of a 4500S vehicle.

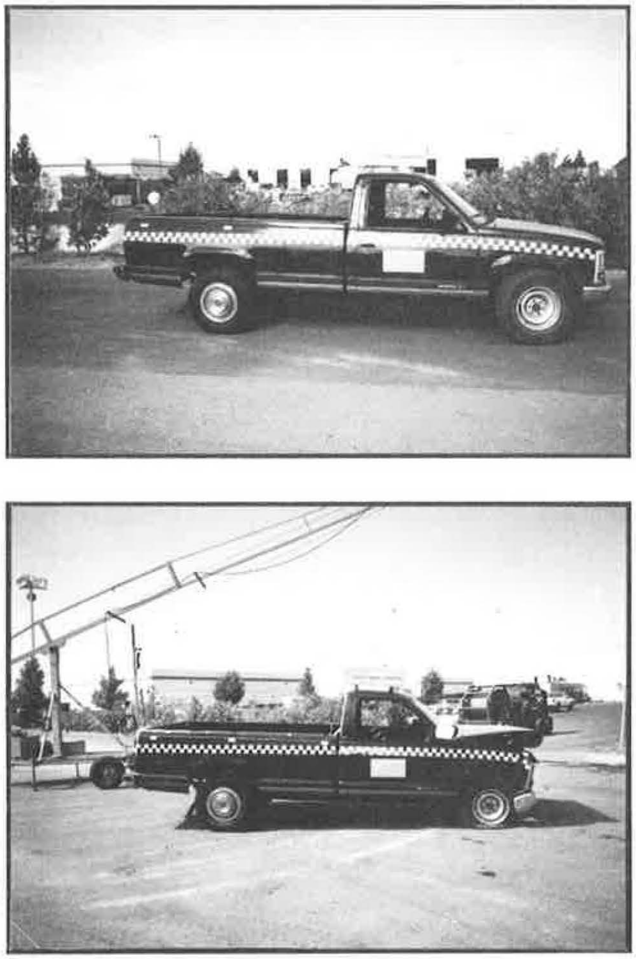
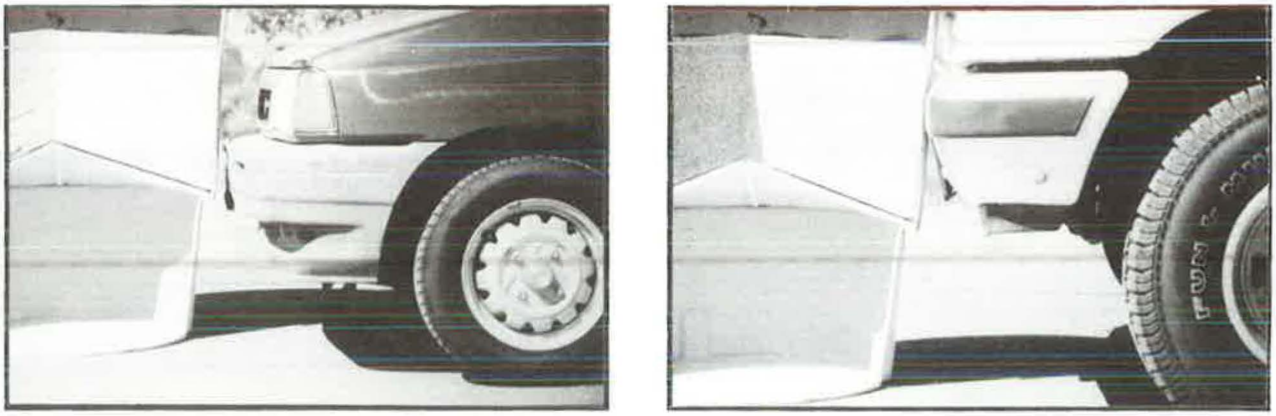


FIGURE 18 Before and after front end crush of a 2000P vehicle.

## CONCLUSIONS

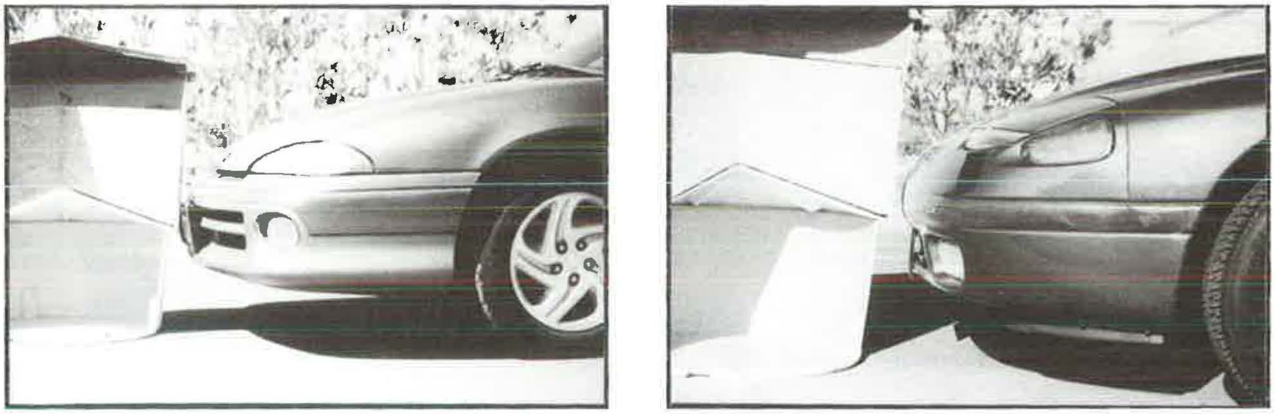
This presentation has reviewed just a few of the vehicle characteristics that can directly influence the overall outcome of impacts into highway safety appurtenances. Energy Absorption believes that new highway safety appurtenance designs need to keep pace with the changes in the nation's vehicle fleet. When the motoring public chooses to buy vehicles that range from light-weight subcompacts to 3/4-ton pickups, any new highway appurtenance designs need to safely accommodate these vehicles. At some point, however, the appurtenance designer may ask himself, "When am I measuring a characteristic of my highway safety device and when am I measuring a design flaw in the impacting vehicle?"

Automobile designers have continued to make tremendous strides toward designing forgiving vehicles as evidenced by padded interiors, steering wheel impact protection, head restraints, seat belts, air bags, side door impact protection, etc. Perhaps it's time to educate the automobile designer on the substantial time, effort, and expense that's gone into the design of the nation's "forgiving" highways. Highway appurtenance designers, researchers, and government officials have access to valuable information dealing with various types of vehicle interaction with highway appurtenances that needs to be shared with automobile designers. A forum, perhaps through NHTSA, SAE or TRB, needs to be established to allow for the exchange of this information, with the ultimate goal being the design of a forgiving highway that works well with a future fleet of forgiving vehicles.



1988 Ford Festiva

1990 Ford F250



1994 Dodge Intrepid

1991 Dodge Stealth

FIGURE 19 Variation in vehicle bumper heights.

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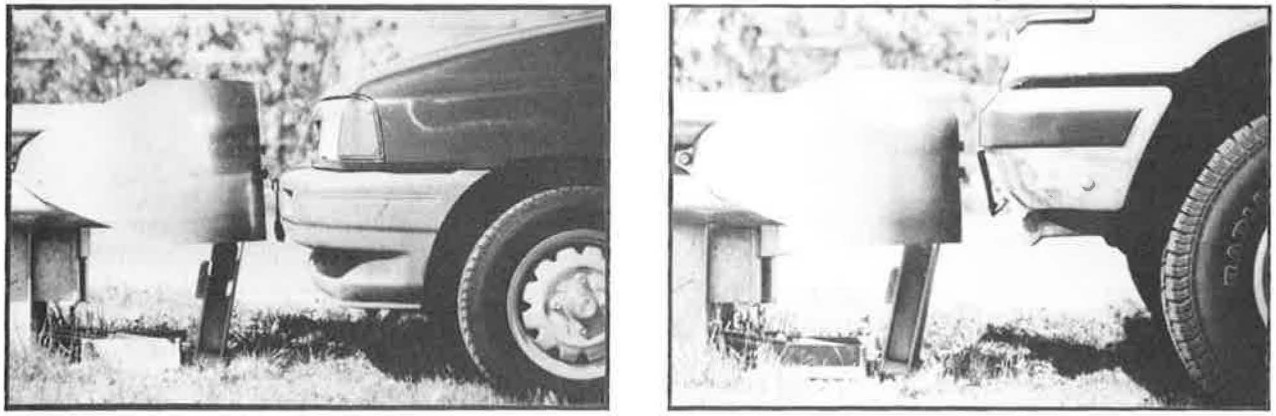
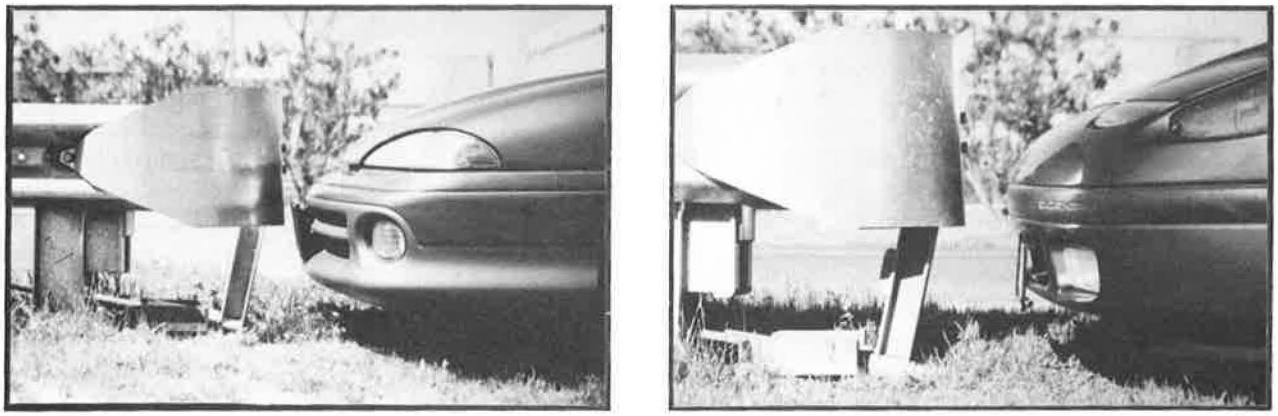


1988 Ford Festiva

1990 Ford F250



1994 Dodge Intrepid

1991 Dodge Stealth

FIGURE 20 Variation in vehicle bumper heights.

FIGURE 21 1988 Ford Festiva with missing hood after impact into inertial barrel array.

# PARTNERSHIP FOR A NEW GENERATION OF VEHICLES

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## ABSTRACT

On September 29, 1993, President Clinton, Vice President Gore, and the Chief Executive Officers of Chrysler, Ford, and General Motors announced the formation of a historic, new partnership aimed at strengthening U.S. competitiveness while protecting the environment by developing technologies for a new generation of vehicles. Tabbed the "Partnership for a New Generation of Vehicles" (PNGV), the program's long-term objectives include developing a range of technologies to yield automobiles with a threefold improvement in fuel efficiency and reduced emissions. This is to be achieved without compromising other features such as performance, safety, and utility. This also requires developing and introducing manufacturing technologies and practices that will reduce the time and cost associated with designing and mass producing this new vehicle *(1)*. Within the Department of Transportation, NHTSA is the focal point for the PNGV program support. Toward this support, the agency's role is to ensure that the PNGV developed vehicles will meet existing and anticipated safety standards and that the overall crash and other safety attributes are not compromised by their light weight and the use of new advanced materials used in production of the vehicles. This paper is written to provide a general overview of the PNGV program and to outline the activities that NHTSA has planned in support of its role in the program.

## INTRODUCTION

On September 29, 1993, President Clinton, Vice President Gore, and the Chief Executive Officers of Chrysler, Ford, and General Motors announced the formation of a historic, new partnership aimed at strengthening U.S. competitiveness while protecting the environment by developing technologies for a new generation of vehicles. Tabbed the "Partnership for a New Generation of Vehicles" (PNGV), the program's long-term objectives include developing a range of technologies to yield automobiles with a threefold improvement in fuel efficiency and reduced emissions. This is to be achieved without compromising other features such as performance, safety, and utility. This also requires developing and introducing manufacturing technologies and practices that will reduce the time and cost associated with designing and mass producing this new vehicle.

To address the aforementioned objectives, the Federal Government and the United States Council for Automotive Research (USCAR), which represents Chrysler, Ford, and General Motors, have initiated activities to address the following three interrelated goals:

- Goal 1: Significantly improve national competitiveness in manufacturing.
- Goal 2: Implement commercially viable innovation from ongoing research on conventional vehicles.
- Goal 3: Develop a vehicle to achieve up to three times the fuel efficiency of today's comparable vehicle (i.e., the 1994 Chrysler Concorde, Ford Taurus, and Chevrolet Lumina).

### Goal 1

The goal is to improve productivity of the U.S. manufacturing base by significantly upgrading U.S. manufacturing technology, including the adoption of agile and flexible manufacturing and including the reduction of cost and lead times while reducing the environmental impact and/or improving quality.

Manufacturing technologies are critically important to assuring competitiveness in today's market place, as well as assuring the ability to produce the new generation of vehicles. The focal areas of research and development for achieving Goal 1 include improving the design and development processes to reduce lead times and achieve cost reductions; developing new manufacturing and vehicle assembly systems that will increase productivity; and assuring the ability to integrate and validate combined technologies.

Research and development may include the following specific technologies: flexible/agile tooling and equipment that will reduce costs and model change-over time; more sophisticated computer simulation systems for testing complex research designs as they apply to issues such as tire rolling resistance, braking characteristics, etc; design and analytical methods to determine strength characteristics of composite structures; and others.

Development and deployment of these new technologies will increase the competitiveness of U.S. manufacturing industries in general, and will strengthen the U.S. automobile industry in particular. Research also is required to assure the manufacturability of the advanced technologies necessary to address Goal 3.

### Goal 2

The goal is to pursue advances in vehicles that can lead to improvements in the fuel efficiency and emissions of standard vehicle designs, while maintaining safety performance. Research will focus on technologies that reduce the demand for energy from the engine and drive train. Throughout the research program, the industry commits to apply those commercially viable technologies resulting from this research that would be expected to increase significantly vehicle fuel efficiency and improve emissions.

In order to maximize fuel efficiency and minimize emissions, the combustion process must be analyzed with sufficient accuracy so as to predict energy release and pollutant formation. Furthermore, improved diagnostics are required to assure that the desired processes are actually occurring during operation. Other key factors toward addressing Goal 2 include the design and fabrication of components that can operate in increasingly more severe operating environments than with current engines (e.g., higher temperatures, higher cylinder pressures, higher loads and stresses, lower oil viscosity, and more chemically reactive fuels). Engines running at higher temperatures and pressures will result in increased wear on piston rings, cylinder liners, valves, valve stems, fuel injectors, cams, bearings, and other components. Therefore, improved methods for analyzing friction, wear, and lubrication in materials, components, and engine systems are needed.

Research is also needed on vehicle technologies that reduce the demand for energy from the engine and drive train. Toward this need, work is needed on improved aerodynamics and reduced rolling resistance. Such research contributes to Goal 2 in the near term and to Goal 3 in the longer term.

### Goal 3

The goal is to achieve fuel efficiency improvement of up to three times the average Concorde/Taurus/Lumina with equivalent customer purchase price of today's comparable sedans, adjusted for economics. This is to be achieved while costing no more to own and drive than today's automobiles (adjusted for economics) and while meeting customers' needs for quality, performance, and utility.

In developing a vehicle which achieves up to three times the fuel efficiency of today's comparable vehicles, the PNGV partners have determined a number of specific assumptions/requirements toward this venture. The first is an assumption regarding the use of an efficiency metric of miles per equivalent gallon of gasoline. If an alternative source of energy is used, the goal will be miles per BTU equivalent of a gallon of gasoline (or 114,132 BTUs). The second is a requirement that the vehicles will be designed to Tier II emissions at the default levels of 0.125 HC, 1.7 CO, and 0.2 Nox at 100,000 miles while complying with other Clean Air Act requirements. The third is a requirement that the vehicles meet present and future Federal motor vehicle safety standards, while also meeting equivalent in-use safety performance. The fourth is a requirement that recyclability be achieved for at least 80 percent of the vehicle materials, up from the seventy-five percent industry average today. The final requirement is that the vehicle concept be available in six years and a Production Prototype be available in approximately ten years.

The PNGV partners also have defined what is meant by a comparable family design vehicle. First, the function of the vehicle is to carry up to six passengers with a comfort level equivalent to the Chrysler Concorde, the Ford Taurus, and the Chevrolet Lumina cars with the fuel efficiency of up to three times the average 1994 Concorde/Taurus/Lumina 26.6 mpg (unadjusted combined metro highway based on Federal Test Procedure), or 26.6 miles per 114,132 BTUS. (Three times this efficiency is 80 miles per 114,132 BTUs.) Secondly, the vehicle must have an acceleration of 0-100 kmph (0-60 mph) in 12 seconds at its curb weight with 300 lbs of passenger and a full fuel tank. Thirdly, the luggage capacity must be at least 475 liters (16.8 cubic feet) and its load carrying capacity must be equivalent with the Concorde/Taurus/Lumina (six passengers, full fuel tank, and 200 lbs of luggage). The fourth is that the vehicle must have an operating metro-highway range of 610 kilometers (380 miles) on the 1994 Federal Drive Cycle. The fifth is that the vehicle provides the equivalent performance in all aspects including acceleration, cruising speeds, gradeability, and driveability at sea level and at altitude; provide equivalent performance in ride, handling, an noise, vibration, and harshness control; provide the customer certain features and options including climate control and entertainment packages; and provide an equivalent total cost of ownership (adjusted for economics). The sixth is that the vehicle have a useful life of 160,000 km (100,000 miles) at a minimum, and comparable if not improved service intervals and refueling times. Finally, the vehicle is to be easily homologated for export and sale in major world markets.

Major advances must be made in several technologies on order to achieve an 80 mpg vehicle. A three pronged approach is required to shift the energy balance in favor of improved fuel economy. These include converting energy more efficiently, implementing regenerative braking to recapture energy, and reducing the energy demand for the vehicle. An examination of the design space for these approaches identifies three technical targets to improve the fuel efficiency: improve the fuel efficiency of the primary fuel converter, reduce the mass of the vehicle, and implement efficient regenerative braking.

The design space has both theoretical and practical limits. On the basis of practically achievable thermal efficiencies with various heat engines, three times the fuel economy may not be reached by engine improvements alone. The thermal efficiency needed ranges from 40 to 55 percent, which is about twice that of today's engines. Even with advanced fuel cells, which do have the higher potential efficiencies than the heat engines, other vehicle improvements are likely to be needed.

Analyses show that an efficient regenerative braking system must be implemented to recover energy store or reuse energy currently lost when using brakes, even with improved engines and lighter vehicles. This reduces the amount of energy which must be converted from fuel, normally the most inefficient step of the energy cycle.

Also, even with improved power converters and regenerative braking, reductions in vehicle mass on the order of 20 to 40 percent from today's baseline vehicles are required. These levels of mass reduction are beyond the simple refinement of today's steel frame, steel body construction, and will involve the introduction of entirely new classes of structural materials to the automobile.

Finally, several other advances must be made, though these contribute less to the overall system goal. These advances include reduced aerodynamic drag, reduced tire rolling resistance, and more efficient mechanical and electrical components.

In summary, in order to reach Goal 3, research and development is needed in the technology areas leading to vehicle and propulsion system improvements. These technologies include advanced lightweight materials and structures, energy efficient conversion systems (e.g., advanced internal combustion engines and fuel cells), energy storage devices (e.g., advanced batteries, flywheels, and ultracapacitors), more efficient electrical systems, and waste heat recovery.

## NHTSA INVOLVEMENT

Within the Department of Transportation, NHTSA is focal point for the PNGV program support. Toward this, the agency's role is to ensure that the PNGV developed vehicles will meet existing and anticipated safety standards and that the overall crash and other safety attributes are not compromised by their light weight and the use of new advanced materials used in production of the vehicles.

The most recent projections indicate that a 40 percent reduction of the vehicle mass will be required to meet the fuel economy requirements of the PNGV program. This reduction, coupled with the potential use of materials other than the conventional steels used in automobile construction today and with the possible use of entirely unique power trains, requires that careful attention be given in determining the overall crash safety of the vehicles. Beyond the testing required by the Federal motor vehicle safety standards, the safety analysis must include evaluating the performance of the vehicles in crash modes that are representative of the real world accident environment. When considering the PNGV vehicles interactions with the existing fleet, the mass reduction requires extra attention be given to crash energy absorption characteristics of the vehicle structure and to the performance of the occupant restraint systems. Furthermore, the potential of developing vehicles with mass distributions that vary significantly from today's vehicles may require careful scrutiny regarding how these vehicles will behave in their interactions with roadside safety hardware such as guard rails, breakaway luminaire supports, etc.

Toward meeting the aforementioned stated objectives, research will be initiated to develop advanced computer models and acquire the computing capacity necessary to evaluate the crashworthiness characteristics of alternate vehicle designs and of the new lightweight materials. Detailed finite element models will be developed for each of the PNGV baseline vehicles and for vehicles representing the fleet (e.g., subcompact, compact, mid-sized, and full-sized cars, small and large pickup trucks, and a minivan). This activity involves the tear down of the PNGV baseline vehicles and selected fleet vehicles for scanning the vehicles to develop geometric data to be used in prescribing the finite element mesh, and for measuring the inertial and other physical properties of the vehicles. Crash testing will be conducted to validate the models as well as provide for audits of simulations undertaken in support of the fleet analysis. Design concepts will be explored and evaluated for the various power trains under consideration for the PNGV vehicles. This includes exploring the use of advanced structural materials such as composites and aluminum. It is anticipated that research into improved material models will be required in the computer software to accommodate these studies. Finally, a system model will be developed for identifying optimal characteristics for the PNGV vehicles.

The approach to be used in the system model will be similar to that found in Reference 2. In particular, the approach to crashworthiness optimization may be stated formally as the following non-linear problem:

$$\text{Minimize Inj}\ (\underline{x},u) = \sum p_i\, s_i\, (\underline{x},u) \qquad [1]$$

subject to

$$Wgt\ (x) \leq Wgt_{max}$$
$$Cost\ (\ x,\ w(x)\ ) \leq Cost_{max}$$
$$x_{min} \leq x \leq x_{max}$$

where

$x$ — Vector of Design Variables

$u$ — Belt Usage Rate

Inj $(x,u)$ — Total Injuries

$Wgt(x)$ — Incremental weight associated with design 'x'

Cost — Incremental cost associated with x and $Wgt(x)$

$Wgt_{max}$ — Upper Constraint on incremental weight

$Cost_{max}$ — Upper Constraint on incremental cost

$p_i$ — Probability of Event i

$s_i$ — Injuries resulting from occurrence of Event i

The objective expressed in Equation 1 is to determine that vector of design variables which minimizes total injuries or some measure of societal cost of total injuries *(3)*. The simulations will attempt to minimize normalized harm, defined as total harm in dollars normalized by the harm associated with an AIS 6 injury level. Total harm is computed by summing the harm incurred in each of accident encounters i weighted by $p_i$, the annual expected probability of event i.

The incremental weight penalty associated with any proposed design modifications w(x) is limited to the upper constraint $Wgt_{max}$. Similarly, the incremental cost of the proposed design modifications is limited to an upper constraint of $Cost_{max}$. The incremental cost in this context includes both the additional cost of design modifications and an estimate of the cost of material substitution to reduce weight. To ensure that design modifications lie within realistic ranges, the design variable vector is constrained by lower and upper limits on each design modification. The annual expected probability of a crash event i, sometimes referred to in the literature as exposure, is computed based on historical accident data. For the model, a crash event i is completely characterized by prescribing the crash speed, the impacting vehicle weight, the occupant seating location, the occupant height, the occupant gender, and the occupant restraint type.

NHTSA also will provide for peer reviews of the conceptual designs developed by the PNGV program, and will initiate the creation of a comprehensive knowledge base for conducting analyses of the impact of the new vehicles on the U.S. economy, transportation system, and motor vehicle industry. For the various propulsion and vehicle design options, the need for new materials and components will be evaluated. On the basis of these needs, the resulting impacts will be assessed. These will include the cost and availability of materials (including the need for imports), manufacturing capacity, new facilities and tooling, capital requirements, impact on service and repair industries, impact on labor, impact on the fuels industry (including capital, distribution, and environmental concerns), and balance of trade considerations.

## ACKNOWLEDGMENT

The information presented for the general overview of the PNGV program was extracted directly or paraphrased from that provided by the United States Department of Commerce's "Partnership for a New Generation of Vehicles Program Plan" (Reference 1).

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# ROADSIDE SAFETY: AREAS OF FUTURE FOCUS

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## ROADSIDE SAFETY: AREAS OF FUTURE FOCUS

Within the past ten years, this country and the world has undergone an unprecedented change. As Toffler described in his 1970 book *Future Shock*, life and information exchange is accelerating. We are firmly within his "third wave". Because of this rapid and accelerating change, it is proper and necessary for the TRB A2A04 Committee to attempt to visualize the nebulous future and then define a course of action. It is an honor to be asked to share my views and suggestions.

## VIEW OF THE PAST

Before gazing into the crystal ball, it may be appropriate to briefly recall the relatively short history of roadside safety. Although several groups were working in the area of crash testing of bridge rails and guardrails in the early 1950s, many attribute "Day-One" to Ken Stonex when he reasoned that highway safety should be patterned after industrial safety in which workers are assumed to be non-perfect humans who may commit an unintentional error. His 30-ft wide "forgiving roadside" was recognized by AASHTO and the U.S. Congress in the late 1960s and was incorporated into the Interstate Highway System. the reduction in the rate of single vehicle ran-off-the-road fatal accidents has clearly shown the efficacy of this powerful concept. The basic concepts of the "forgiving roadside" and "clear zone" have not changed and should remain the underlying principles for roadside safety.

In 1966 the annual traffic fatality rate was 5.5 fatalities per 100 million vehicle miles traveled (100 VMT) but had declined to 2.1 per 100 VMT by 1990. If the 1990 fatality rate had been the same as the 5.5 rate in 1966, the 1990 traffic fatalities would be 118,000 rather than 44,529. This improvement has been achieved through the dedicated effort of every segment of the highway community, including the roadside design group.

As shown in Table 1*(1)*, single vehicle crashes, which are most affected by roadside design technology, are analyzed by roadway function and rural/urban setting. Roadside safety upgrading is beneficial at locations where an improvement can achieve a significant reduction in single vehicle accidents. Where the urban and rural interstate have low rates for single vehicle crashes based on 100 VMT, the rates based on highway length (i.e., 100 miles) are the highest. This table suggests that further improvement to the interstate may be needed such as premium barriers, flatter embankment slopes and increased clear zone widths.

## PLAN FOR THE FUTURE

This TRB committee has achieved outstanding success in the past thirty years due to a number of factors including being in an active research area, having an active membership and producing timely and important results. This task is far from being accomplished; and it is most important to make plans for the future. As suggested by Ray, Carney and Opiela *(2)*, there are at least sixteen research issues worthy of attention. It is my recommendation that the A2A04 Committee should concentrate its effort in four primary areas.

### Focus on Major Problems

In Table 2, Viner *(3)* has identified overturns, trees and utility poles as the top three most harmful events or roadside features involved in ran-off-the-road fatalities. A reduction of even a modest ten percent from the 9364 fatalities from the three events translates into a $1 billion savings in annual societal cost (using a nominal $1 million per fatality).

Effectively addressing the three events may require an approach that deviates from the committee's "hardware development/crash test" mode to a mode that involves more roadside design applications, benefit-cost analyses and development of model roadside design for various types of highways and streets. Some thoughts on the three events are discussed in the following paragraphs.

#### *Overturns*

There is a need to further define the various mechanisms that cause vehicle overturns and the biomechanics of occupants resulting in injuries and fatalities. The effects of curbs, embankment slopes, soft and/or non-uniform terrain, fixed objects and other

TABLE 1 1992 FATAL ACCIDENT REPORTING SYSTEM: SUMMARY OF SINGLE VEHICLE CRASH DATA (*1*)

| ROADWAY FUNCTION | VMT (million) | MILEAGE | SINGLE VEHICLE FATAL CRASHES | SINGLE VEHICLE CRASHES/ 100m VMT | SINGLE VEHICLE CRASHES/ 100 miles |
|---|---|---|---|---|---|
| **RURAL** | | | | | |
| INTERSTATE | 204,960 | 33,027 | 1,237 | .60 | 3.75 |
| PRIMARY ARTERIAL | 196,153 | 94,798 | 1,020 | .52 | 1.08 |
| MINOR ARTERIAL | 146,723 | 137,637 | 1,414 | .96 | 1.03 |
| MAJOR COLLECTOR | 184,326 | 434,175 | 2,779 | 1.50 | .64 |
| MINOR COLLECTOR | 49,945 | 284,706 | 870 | 1.74 | .31 |
| LOCAL | 98,986 | 2,132,212 | 2,175 | 2.20 | .10 |
| **URBAN** | | | | | |
| INTERSTATE | 302,091 | 12,466 | 699 | .23 | 5.60 |
| OTHER FREEWAY OR EXPRESSWAY | 137,959 | 8,465 | 463 | .33 | 5.47 |
| PRIMARY ARTERIAL | 344,195 | 52,165 | 1,004 | .29 | 1.92 |
| MINOR ARTERIAL | 260,507 | 80,368 | 776 | .30 | .97 |
| COLLECTOR | 115,631 | 82,652 | 372 | .32 | .45 |
| LOCAL | 198,352 | 549,039 | 1,018 | .51 | .19 |
| | 2,239,828 | 3,901,715 | 14,019 | .63 | .36 |

features should be quantified. Computer models such as HVOSM may require further enhancement to more adequately simulate tire behavior and non-ideal tire/soil interaction. Potential solutions may include recommendations for wider paved shoulders, more gentle embankment slopes, and slopes with a specified degree of smoothness and compaction. Further analyses of current accident data bases and enhancement of accident investigation programs may be warranted to refine rollover severity in terms of the number of rolls, vehicle passenger compartment deformation, speed of vehicle prior to roll, etc. For crash test assessment, there is a need to know whether a quarter roll of a vehicle after impact with a test device should be basis for failure. It is noted that the vehicle rollover event is also a concern of NHTSA and having a NHTSA staff member on the committee will be beneficial.

### *Trees*

The roadside safety community has been timid and cowed by environmentalists into a near complete "hands-off" policy with regard to trees located within the clear zone. While an "Atilla the Hun with Chain Saw" approach is not advocated for solving the tree problem, there are many missed opportunities in which a tree or a group of trees can be and should be removed without significant adverse effect to the environment. Most importantly, a case should be made that in the future trees should not be planted in the clear zone.

Several suggestions with regard to addressing the tree problem would include the following tasks:

1. Assist in the establishment of a special task force within TRB to concentrate on trees as traffic hazards. Membership would include representatives from A2A04 and A2A05 (Landscape and Environmental Design), ITE, county engineers, urban planners, etc. Specific goals of the task force would be to develop model roadside design standards for highways and streets that consider landscape features, mailboxes, bus stop shelters/benches, signal and luminaire poles, etc. Models would be devised based on operating speed and volume of traffic. It is anticipated that the model development would follow extensively funded research

### TABLE 2 HARMFUL EVENTS IN RAN-OFF-ROAD FATALITIES

| Harmful Event | First Harmful Event | Most Harmful Event | Change MHE-FHE | MHE as % of FHE |
|---|---|---|---|---|
| Tree | 2,870 | 3,246 | 376 | 113 |
| Overturn | 2,492 | 4,820 | 2328 | 193 |
| Utility pole | 1,235 | 1,298 | 63 | 105 |
| Embankment | 1,187 | 601 | -586 | 51 |
| Guardrail | 1,101 | 456 | -645 | 41 |
| Ditch | 750 | 302 | -448 | 40 |
| Other | 565 | 613 | 48 | 108 |
| Culvert | 537 | 281 | -256 | 52 |
| Curb | 506 | 117 | -389 | 23 |
| Other fixed object | 461 | 219 | -242 | 48 |
| Other post | 457 | 237 | -220 | 52 |
| Fence | 421 | 156 | -265 | 37 |
| Sign post | 295 | 99 | -196 | 34 |
| Bridge pier | 211 | 255 | 44 | 121 |
| Concrete traffic barrier | 211 | 83 | -128 | 39 |
| Bridge rail | 194 | 118 | -76 | 61 |
| Luminaire support | 148 | 146 | -2 | 99 |
| Wall | 143 | 127 | -16 | 89 |
| Boulder | 133 | 76 | -57 | 57 |
| Bridge end | 122 | 95 | -27 | 78 |
| Building | 101 | 143 | 42 | 142 |
| Immersion | 98 | 354 | 256 | 361 |
| Shrubbery | 66 | 13 | -53 | 20 |
| Other noncollision | 53 | 40 | -13 | 75 |
| Other traffic rail | 33 | 16 | -17 | 48 |
| Fire hydrant | 28 | 9 | -19 | 32 |
| Impact attenuator | 7 | 3 | -4 | 43 |
| Overhead sign post | 6 | 11 | 5 | 183 |
| Unknown | 4 | 272 | 268 | 6800 |
| Fire/explosion | 0 | 292 | 229 | - |
| Totals | 14,435 | 14,435 | 0 | 100 |

and study programs and ideally would be endorsed/adopted by AASHTO, ITE and others.

2. Based on benefit/cost analytical procedures, develop simplified methods that can be used by subprofessional personnel to identify trees critical to traffic safety. Recognizing that 74 percent of the nation's highways are administered by other than federal and state agencies, it should be assumed that tree decisions will be made by individuals with minimum technical skills with regard to roadside safety.

3. Develop typical standards for shielding trees that cannot be removed for political or other reasons. Such standards would reflect traffic operating speed and volume, offset distance, etc.

There are certainly other potential solutions to the tree hazard problem and these may be developed by research studies and/or brainstorming sessions within the special task force.

### *Utility Poles*

Utility poles are unique items in the right-of-way (ROW) as they are usually owned by other than the transportation agency and are allowed to be placed in the ROW by agreement or franchise. In many cases, the pole owners have wide latitude where the poles are placed and have little incentive to relocate an existing

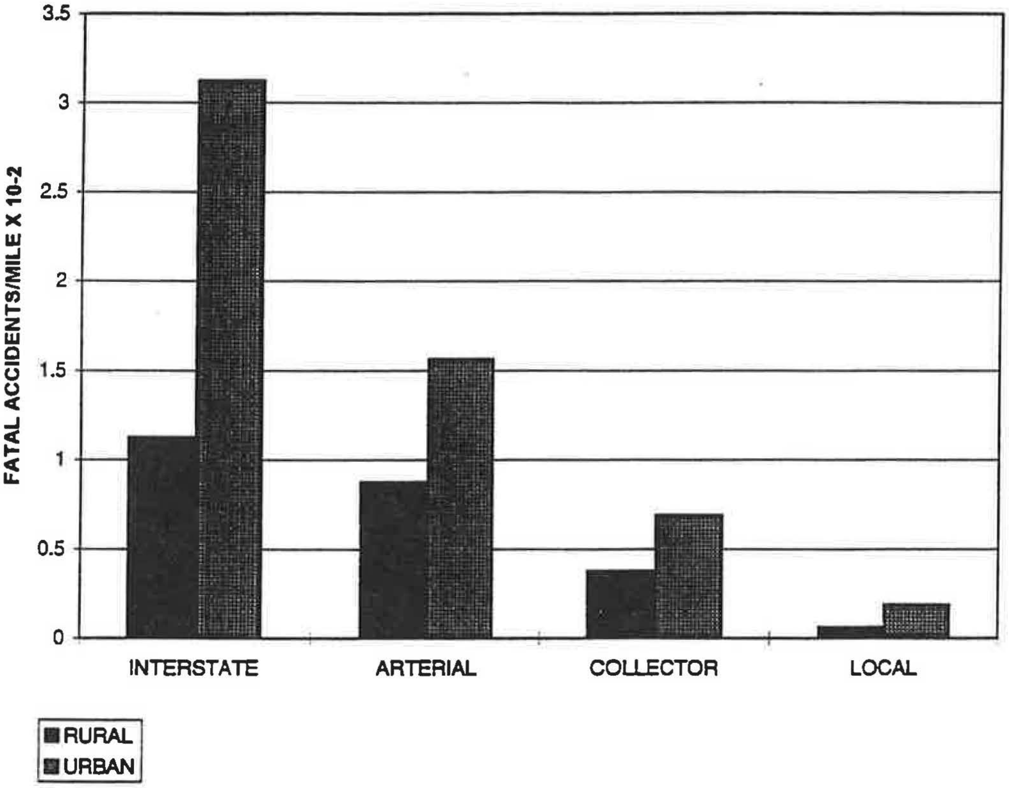

FIGURE 1 Comparison of rural and urban single vehicle ran-off-road fatal accident rates (*4*).

pole. Current National Electric Code considers a utility pole located as near as 18 inches from a curb face as acceptable, regardless of traffic characteristics. Evidently the utility industry considers the non-forgiving, cluttered roadside solely a highway agency concern.

Since 1975, FHWA has funded extensive research to develop methods to convert timber utility poles into fail-safe, breakaway devices with some success. However, it is evident that the breakaway design will not be a total solution; it will be necessary for the highway and utility agencies to employ complementary techniques such as burying service lines and/or relocating poles further away from the traveled way.

To focus on the utility pole problem, the A2A04 committee should push for the formation of a special task force with representation from TRB Committee A2A04 and A2A07, from AASHTO, FHWA, ITE, and National Electric Code committee. Examples of goals for the task force would include:

1. Development of pole placement procedures as related to highway geometrics, cross section and traffic characteristics.
2. Development of model roadside design cross-sections for various classification of highways and streets.
3. Development of model franchise/easement agreements that will insure preferred placement of new poles.
4. Investigate pole/foundation design that minimizes need for guys and stub poles.

Admittedly the three problems of vehicle overturns, trees and utility poles may presently be outside the main stream of the committee's technology and interest, but nevertheless the three problems should be addressed vigorously. Otherwise the roadside safety community will be like the befuddled drunk who searches for his keys under the street light even though he knows he dropped them somewhere else. Vehicle overturn, trees and utility pole problems are presently in the dark.

### Focus on Urban Highways and Streets

To date most roadside applications have been directed to rural highways with high-speed, high-volume traffic with less attention given to urban highways and streets. Yet a significant number of single vehicle ran-off-the-road fatal accidents occur in urban areas as shown in Figure 1 *(4)*. The urban highway roadside has probably been avoided because it poses a more difficult set of problems, namely more clutter, more environmentally sensitive features and a more constricted right-of-way. It is time that the urban roadside problem is tackled.

A strategy that the committee could employ would be based on a long term solution. As a first step, a series of roadside design models should be developed for inclusion in AASHTO and ITE documents that would provide guidance for new construction. Second, a new array of crash-safe features peculiar to the urban area should be developed; items that come to mind include fire hydrants, newspaper boxes, signal poles, mail boxes, and luminaire supports. Attention should be given to curb design including driveway and wheelchair access. And finally, safety upgrading should be applied to existing streets where it is cost-beneficial. Certainly when streets are rehabilitated, techniques to select roadside features to be upgraded should be available.

### Refined Benefit-Cost Analysis

Safety upgrading of roadsides has been limited to finite allocated funds. Only in recent years with development of benefit-cost analysis models has the potential of roadside safety expenditures been more clearly defined. Unfortunately, effectiveness of roadside safety has been a well kept secret to the detriment of both research and implementation funding. Based on crude measures of accident reduction and sometimes understated benefits, roadside safety upgrading has been shown to be a very attractive investment for highway agencies. As shown in Table 3 benefit-cost ratios for highway safety improvements for period 1974-1991 range from 1.5 to 12.1*(5)*. These numbers are impressive and should be broadcast to the public.

It is recommended that such B/C models as FHWA Roadside 5 be further developed and refined, in particular accident prediction modules and severity indices. With improved and more extensively validated B/C models and with similar injury and fatal costs used by other organizations, it will facilitate the comparison of returns on investment in roadside safety with say air traffic safety or environmental cleanup. Importantly, the committee must be less timid in publicizing to the general public and funding agencies the attractive returns from roadside safety upgrading investment.

A second area of use of improved B/C models will be to develop/revise guardrail and median barrier warrant curves. Standard guardrail layouts should be examined including typical offset and flare rates. Longitudinal traffic barriers are performing much better than previously thought, although layout and sloping terrain are not always addressed satisfactorily*(6)*.

Innovative techniques to further refine and validate the B/C models should be examined, in particular the encroachment prediction module. For instance, breakaway luminaire supports located within the clear zone of a high traffic volume highway can be monitored for knockdowns. Generally, the breakaway pole is knocked down in every impact, so every impact is known and there is little likelihood for error in estimating non-reported accidents. In San Antonio, poles are routinely struck on a section of Interstate 410, and data such as these should be useful in validating the assumed vehicle encroachment rates. Also, frequency of vehicles running down and being trapped at the bottom of selected steep embankments could be another source of comparative data. There are probably a number of other useful techniques that should be explored.

### Improved Roadside Feature Application

For the past ten years, several members of the committee have had the opportunity to critically examine safety features involved in vehicle collisions. It has been disappointing to find that all too often the safety features were not properly laid out and/or installed; on many occasions it has been concluded that these deviations led to performance failures and unnecessary injury and fatal accidents. The most glaring deficiency has been longitudinal barrier systems that did not adequately shield the identified hazard, mostly being too short. Another example is the approach guardrail to a bridge that while doing its job in shielding the bridge rail end failed to shield the embankment length of need hazard. Breakaway cable terminals (BCTs) have been improperly installed without the necessary 4-ft offset and parabolic curve in W-beam; both factors were determined to be essential to performance in numerous developmental crash tests but were too quickly "adjusted" to adapt to local conditions. Even one of the more recent safety devices, the ET-2000 guardrail terminal, is being installed immediately behind a 6-in. barrier curb, certainly a condition not evaluated in crash tests. These are just a few examples. These deviations exist on the Interstate System and in most states although they are more common on other highways.

Obviously if the highway safety features are not properly installed and maintained, they will not accomplish their intended purpose. It seems rather absurd that researchers are "tweaking" advanced technology features for peak performance with complex, multi-degree of freedom simulation models while the installers are completely defeating the device with careless or uninformed methods. This is a serious problem!

TABLE 3 HIGHWAY SAFETY IMPROVEMENTS WITH THE HIGHEST BENEFIT-COST RATIOS, 1975–1991 (*5*)

| Rank | Improvement Description | Benefit-Cost Ratio |
|---|---|---|
| 1 | Illumination | 12.1 |
| 2 | Upgrade Median Barrier | 8.0 |
| 3 | Traffic Signs | 7.3 |
| 4 | New Median Barrier | 4.9 |
| 5 | Upgrade Guardrail | 4.6 |
| 6 | Remove Obstacles | 4.5 |
| 7 | Upgrade Bridge Rail | 4.3 |
| 8 | Upgrade Traffic Signals | 3.2 |
| 9 | Impact Attenuators | 3.2 |
| 10 | Improve Sight Distance | 2.8 |
| 11 | Improve Minor Structure | 2.7 |
| 12 | Groove Pavement for Skid | 2.6 |
| 13 | Median for Traffic Separation | 2.2 |
| 14 | New Railroad Crossing Gates | 2.1 |
| 15 | Turning Lanes and Channelization | 2.0 |
| 16 | Upgrade RR Crossing Flashing Lights | 2.0 |
| 17 | Flatten Side Slopes | 1.7 |
| 18 | New RR Crossing Flashing Lights | 1.6 |
| 19 | New RR Crossing Lights & Gates | 1.5 |
| 20 | Guardrail End Treatment | 1.5 |

Source: FHWA, Highway Evaluation Safety System

There are several areas that researchers need to address. First a better job must be done in developing simple, forgiving features that are less sensitive to installation variation and maintenance needs. For example, the concrete safety shape exhibits a wide range of dynamic performance while requiring a minimum of routine and damage repair maintenance. On the other hand, the height of the 12-in. W-beam guardrail must be maintained within a narrow range of height tolerance to prevent either vaulting or submarining of impacting vehicles. Conservatively, it should be assumed that safety features will receive minimum maintenance

TABLE 4 U.S. HIGHWAY MILEAGE CLASSIFIED BY ADMINISTRATIVE RESPONSIBILITY (FHWA 1992a, DOC 1993) *(7)*

| Administrators | No. of Agencies | Miles (%) |
|---|---|---|
| Federal agency | 5 | 182,411 ( 5) |
| State agency | 51 | 800,589 (21) |
| County agency | 3,043 | 1,726,629 (44) |
| Town and township | 16,666 | 483,631 (12) |
| Municipal | 19,296 | 526,232 (13) |
| Other local | - | 182,244 ( 5) |
| Toll highway authority | - | 4,692 (<1) |
| Total | 39,061 | 3,901,715 |

and/or adjustments after installation and that the features must function under unusual but expected environmental conditions.

Second, it should be assumed that safety features will be installed by individuals who are non-engineers, who are not familiar with roadside design principles and who may deal with safety features on an infrequent basis. As shown in Table 4 *(7)*, only 26 percent of U.S. highways are administered by federal or state agencies; the remaining 74 percent are counties, towns, cities and others which may lack technical expertise in roadside safety. Accordingly the technical documents and instruction manuals must be simplified. For instance, the 1989 AASHTO Roadside Design Guide is probably too complex for most county and city transportation departments. Current TRB documentation seems to be more attuned for communication among researchers but apparently ineffective in instructing the local users on where and how to properly install the devices. FHWA has devoted considerable effort to "technology transfer"; however, judging by the number of faulty installations, one could certainly conclude that more effort by all is needed.

There are of course other worthy areas of roadside safety which need to be addressed; however, it is important that the committee's effort be concentrated on those items with greatest potential payout. The four areas presented in this paper are believed to meet this criterion.

In closing, a perspective is given on three unrelated topics. First, with regard to the IVHS program, the committee should not be dazzled by futuristic plans that could divert our attention and limited resources away from more mundane rollover, tree and pole problems. The reduction in rollover, tree and utility pole fatal accidents is where roadside safety will pay off and where our focus should be.

The committee should continue as it has in the past to keep the relative importance of various research tools in proper perspective, particularly the relative roles of full-scale vehicle crash tests versus computer simulations. Most researchers who have conducted full-scale crash tests are not satisfied with the sometimes crude tests, using old vehicles and imprecisely controlled and recorded conditions; economics is generally attributed as the limiting factor. On the other hand, with exploding computer capabilities and development of more sophisticated simulation programs, many see the more universal use of this tool as the wave of the future. Maybe. However, the efficacy of the simulation program continues to be limited by realism of the input data (i.e., garbage in, garbage out) which becomes even a more challenging task as the simulation programs become more complex.

Finally, with the growing presence of airbags in the vehicle fleet, several researchers have mentioned the possibility of relaxing the occupant risk factors that assume unrestrained occupants. This may not be a good idea for two reasons. The airbag provides little if any side protection for redirectional impacts with longitudinal barriers. Second, time duration that an airbag is effective (i.e., fully deployed) is between 40 and 120 ms. For a crash cushion or energy absorbing terminal, the airbag restraint would not provide any protection for events that generally range beyond 120 ms. Moreover, maintaining the vehicle upright after a breakaway support test may be the limiting factor and not the occupant risk factor.

One might ask if roadside safety technology development has reached or is reaching a point of diminishing returns? The answer is an emphatic *no*. With over 14,000 ROR fatalities each year, there is a great opportunity for improvement. The overriding goal should be to reduce this number.

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# FUTURE OF REAL WORLD ROADSIDE SAFETY DATA

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For roadway design engineers and evaluators interested in the effectiveness of roadside safety treatments, the path to results seems to remain continually perilous. This is related to several factors. The cycle of design and testing, implementation, and evaluation takes a number of years, and this is complicated by seemingly constant changes in the vehicle fleet. Data collection is normally done by police agencies, which normally means variables pertaining to speed and angle of impact into various roadside safety features are missing; thus, crash test and real world comparisons are difficult.

There are a number of research goals related to roadside safety hardware:

- *Determine whether a new design can pass a "practical worst case" scenario* — This is normally done with crash testing in a very limited matrix of test conditions. As an example, for many years the standard strength test for a guardrail face was striking the rail with a 4,500 pound passenger car at 60 miles per hour and 25 degrees. The testing requirements are now more rigorous with the publishing of NCHRP Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features."*(1)* Nonetheless, the current test matrix is not designed (and cannot for cost reasons be designed) to collect information on the wide range of impact conditions occurring in the real world.
- *Determine which roadside features to treat* — This is normally a State transportation department function and usually pertains to a site-specific examination. Typically there is the need to predict the frequency or rate of impacts with fixed objects and the resulting severity, as well as to estimate the injury severity savings associated with a treatment.
- *Determine whether what has been designed using crash tests and simulation works in the real world* — This requires real world severity-based evaluations and, ideally, a developed linkage between crash tests and simulation results and occupant injury when actual ran-off-road events occur. This implies the need for data from crash tests, simulations of crashes, encroachment studies, police or special team crash reports, and roadside inventories.

This paper is an attempt to examine the questions of whether we have adequate data to meet these goals, and if not, what can be done to produce better data. The following text uses crash data and related files to scope the overall roadside safety problem.

## CURRENT KNOWLEDGE CONCERNING ROADSIDE OBJECT IMPACTS

Let us first turn to the current status of roadside-object knowledge. That is, what do we know based on current research that will help us determine where emphasis should be placed in future roadside research, evaluation, and implementation activities.

The most recent and most pertinent research related to roadside object crashes was reported by Viner *(2)* at the 1994 A2AO4 summer meeting. In his analysis, Viner used data from the 1985 NASS/CSS files to determine the number and severity of both overturn accidents and accidents involving impacts with roadside objects. He then used comprehensive crash cost figures from Miller *(3)* to derive a total cost of roadside crashes, a cost associated with each object, and the estimated percent of total societal loss for each object. His results are shown in Table 1. Viner then conducts additional analyses concerning categorization of overturns with respect to whether they involved fixed objects or were simply related to the roadside (sideslope) design, an analysis of guardrail ends versus length of need to determine the nature of the economic loss, and provides some discussion of emerging trends that may affect these economic losses in the future — changes in the vehicle fleet, including increased availability of airbags and anti-lock brakes, and vehicle styling.

Under the assumption that one would like to guide the roadside research and implementation program by the economic loss being sustained (which appears to be a valid assumption), it is clear that the Viner estimates provide a great deal of guidance. His analyses indicate a clear need to concentrate research and implementation programs in the reduction of overturn crashes. This would relate both to the redesign of fixed objects such that they would not cause rollover, and also to the need for a more careful look at the design of sideslopes, ditches, and embankments.

With "tree" being the next leading cause of economic harm, it would appear that additional research needs to look at questions of clear zones on both curve

TABLE 1 CRASH LOSSES BY MOST HARMFUL EVENT (MHE) FOR MHEs LARGELY ASSOCIATED WITH ROADSIDE OCCURRENCES — 1985 (OVERTURNS LIMITED TO THOSE THAT OCCURRED ON ROADSIDE) *(2)*

| Most Harmful Event | Fatalities | Injuries | PDO Vehicles | Total $Millions | Percent of Loss |
|---|---|---|---|---|---|
| Overturn | 4,820 | 134,000 | 32,000 | 17,886 | 27.5% |
| Tree | 3,497 | 88,000 | 26,000 | 12,485 | 19.3% |
| Utility pole | 1,522 | 110,000 | 33,000 | 8,769 | 13.6% |
| Embankment | 668 | 95,000 | 18,000 | 6,004 | 9.3% |
| Guardrail | 600 | 21,000 | 17,000 | 2,435 | 3.9% |
| Other traffic rail | 18 | N/A | N/A | 43 | |
| Ditch | 353 | 23,000 | 16,000 | 1,932 | 3.0% |
| Other fixed object | 279 | 20,000 | 25,000 | 1,632 | 2.7% |
| Fire hydrant | 12 | N/A | N/A | 29 | |
| Impact attenuator | 7 | N/A | N/A | 17 | |
| Mail box | N/A | 2,000 | 7,000 | 104 | |
| Other post | 277 | 13,000 | 19,000 | 1,295 | 2.5% |
| Traffic signal pole | N/A | 5,000 | 3,000 | 235 | |
| Overhead sign post | 15 | N/A | N/A | 36 | |
| Other noncollision | 121 | 5,000 | 18,000 | 551 | 2.4% |
| Immersion | 394 | N/A | N/A | 946 | |
| Culvert | 302 | 17,000 | 4,000 | 1,514 | 2.3% |
| Bridge rail | 151 | 15,000 | 11,000 | 1,071 | 2.1% |
| Bridge end | 115 | N/A | N/A | 276 | |
| Luminaire support | 115 | N/A | N/A | 427 | 2.1% |
| Nonbreakaway | N/A | 14,000 | 3,000 | 649 | |
| Breakaway | N/A | 5,000 | 5,000 | 239 | |
| Curb | 193 | 13,000 | 24,000 | 1,078 | 1.7% |
| Bridge pier | 296 | 4,000 | 3,000 | 900 | 1.4% |
| Building | 174 | 10,000 | 4,000 | 884 | 1.4% |
| Concrete barrier | 100 | N/A | N/A | 240 | 1.3% |
| Concrete median | N/A | 7,000 | 4,000 | 329 | |
| Concrete non-med. | N/A | 3,000 | 5,000 | 147 | |
| Median barrier | N/A | 3,000 | 2,000 | 141 | |
| Fence | 192 | 8,000 | 16,000 | 856 | 1.3% |
| Wall | 159 | 7,000 | 7,000 | 716 | 1.1% |
| Signpost | 123 | N/A | N/A | 295 | 0.8% |
| Large sign | N/A | 3,000 | 1,000 | 140 | |
| Small sign | N/A | 1,000 | 5,000 | 55 | |
| Shrubbery | 15 | 16,000 | 12,000 | 324 | 0.5% |
| Total | 14,571 | 642,000 | 320,000 | $64,578 | 100% |

and tangent sections in both rural and urban areas. Viner also points out that "guardrail" is the highest ranked safety hardware device in terms of economic loss, and further notes that guardrail ends appear to be overrepresented. In short, Viner's analysis of the data is indeed quite helpful in helping to decide where emphasis should be placed in future roadside safety programs. While the authors do not feel that a great amount of information can be added to what was done in the Viner paper, we have taken the liberty to examine a limited number of additional tables of fixed object collisions using data from the Highway Safety Information System (HSIS). These runs were conducted simply to provide additional information concerning what is being struck, how often it is being struck, and under what conditions the striking is occurring. Table 2 on the following page presents the numbers of fixed object impacts for each of six HSIS states. The data shown in this table cover the years of 1985-1989, giving us five years of data in each state.

The data in this table are not as directly related to "loss due to the object" as the data in the earlier Viner paper. That paper included only single vehicle crashes in which the most-harmful-event was the object impact. These data are more directed toward the total size of the problem in that they contain both single vehicle crashes and some number of multivehicle crashes where a vehicle might rebound from the initial crash into a

TABLE 2 LISTING OF FIXED-OBJECT TYPES STRUCK IN CRASHES FROM HSIS STATE ACCIDENT FILES

| | STATE | | | | | | |
|---|---|---|---|---|---|---|---|
| TYPE OF OBJECT STRUCK | IL | ME | MI | MN | UT | NC | TOTALS |
| Embankment/Ditch/Stream/Rock Outcrop | 5,389 | 14,608 | 15,740 | 12,316 | *4,258 | 73,064 | 127,269 |
| Snow Bank | 352 | | | | *288 | | |
| Tree (or Shrub) | 6506 | 13,380 | 7,262 | 8,592 | *2.309 | 34,625 | 72,674 |
| Guardrail or Guardpost | 12,281 | 3,912 | 16,657 | 3,571 | 2,978 | 7,874 | 47,273 |
| Guardrail End | - | - | - | - | *116 | 1,872 | 1,988 |
| Concrete Barrier/Median Barrier | 1,703 | 1,366 | 11,443 | 3,887 | *1,629 | 2,416 | 22,444 |
| Bridge or Bridge Guardrail | 2,929 | - | - | - | - | - | 2,929 |
| Bridge Rail or Deck | - | - | 902 | - | - | 5,587 | 6,489 |
| Bridge Pier or Abutment | 247 | 1,924 | 888 | 4,952 | | - | 8,011 |
| Bridge. Culvert or Other HW Structures | - | - | - | - | 1.297<br>- | - | 1,297 |
| Culvert/Headwall | 109 | 446 | 679 | 823 | - | 7,472 | 9,529 |
| Underpass Structure | 625 | - | - | - | | 1,182 | 1,807 |
| Utility Pole | 7,194 | 9,231 | - | 5,321 | 4.474 | 26,036 | 52,256 |
| Light Pole or Standard | 4,502 | 871 | - | 4,302 | - | 2,571 | 12,246 |
| Street Light or Utility Pole | - | - | 10,554 | - | - | - | 10,554 |
| Signal or Signal Pole | 5,206 | 255 | - | 2,429 | - | - | 7,890 |
| Highway or Railroad Signal | - | - | 478 | - | - | - | 478 |
| RR Crossing Signal or Device | 252 | 122 | - | 292 | - | - | 666 |
| Other Pole/post or support | - | 1,133 | - | 1,937 | - | - | 3,070 |
| Sign Structure or Post | 7,362 | 1,541 | 12,599 | 8,718 | 2,313 | 8,826 | 41,359 |
| Advertising Sign | 442 | - | - | - | - | 1,470 | 1,912 |
| Delineator Post | 885 | | | - | 2,225 | - | 3,110 |
| Fence (or Fencing)/Median Fence | 4,482 | 1,053 | 3,126 | 2,863 | 5,259 | 10,254 | 27,037 |
| Mailbox or Posts | 1,349 | 1,580 | 4,450 | 2,077 | *570 | 6,116 | 16,142 |
| Safety Island/Curb/Channelizing Island/Traffic Island | 603 | | 4,072 | | 2.531 | 7,806 | 15,012 |
| Construction Barricades, Equipment, etc. | 885 | 317 | | 1,630 | | 353 | 3.185 |
| Crash Cushion or Impact Attenuator | 228 | 196 | | 304 | *68 | 129 | 925 |
| Building or Wall | 1,402 | 1,318 | 1,677 | 2,057 | *2.355 | - | 8,809 |
| Hydrant/Parking Meter | 1,026 | 578 | - | 1,169 | - | - | 2,773 |
| Machinery | 84 | - | | - | - | - | 84 |
| Overhead Fixed Object | - | - | 859 | - | | | 859 |
| Other (Fixed) Object | 14,106 | 4,565 | 14,887 | 3,918 | *2,151 | | 39,627 |

Illinois, Maine, Michigan, Minnesota, Utah Accident Data = 1985-1989 (5 years) except *denotes those not including 1985 data

fixed object, or might hit one fixed object and then rebound into a more- or less-severe fixed object. In general, these figures represent an indication of the first object struck as recorded on the crash form.

The total column provides some overall information related to the frequency of impacts. (We note that these impacts are not weighted by any type of severity as Viner was able to do in his analysis, nor is there any control for exposure to impact — the degree of presence of a given object beside the roadway.) The table is somewhat difficult to read in that there are differences in definitions for the same type of object across the states. For example, if one observes the fourth category down related to bridge structures, one sees a number of different categories used in the different states. In like fashion, utility poles are captured alone in five of the

TABLE 3 FIXED-OBJECT CRASHES BY URBAN AND RURAL LOCATIONS FOR NORTH CAROLINA AND ILLINOIS

| TYPE OF OBJECT STRUCK | NORTH CAROLINA | | ILLINOIS | |
|---|---|---|---|---|
| | Rural | Urban | Rural | Urban |
| Embankment/Ditch | 24,559 (94.6) | 1,365 (5.4) | 2,665 (69.0) | 1,200 (31.0) |
| Tree (or Shrub) | 9,792 (82.3) | 2,102 (17.7) | 1,370 (40.6) | 2,001 (59.4) |
| Guardrail or Guardpost | 2,326 (62.3) | 1,410 (37.7) | 2,285 (34.8) | 4,291 (65.2) |
| Guardrail End | 6,291 (63.8) | 357 (36.2) | | |
| Concrete Barrier/Median Barrier | 413 (35.9) | 736 (64.1) | 63 (5.2) | 1,154 (94.8) |
| Bridge or Bridge Guardrail | | | 573 (51.8) | 534 (48.1) |
| Bridge Rail or Deck | 1,339 (75.0) | 447 (25.0) | | |
| Bridge Pier or Abutment | 92 (40.0) | 138 (60.0) | 52 (55.3) | 42 (44.7) |
| Culvert/Headwall /Catch Basin | 2,595 (87.8) | 362 (12.2) | 21 (80.8) | 5 (19.2) |
| Underpass Structure | 55 (23.5) | 179 (76.5) | 99 (18.4) | 439 (81.6) |
| Utility Pole | 3,185 (37.4) | 5,350 (62.6) | 1,061 (31.5) | 2,307 (68.5) |
| Light Pole or Standard | 367 (25.9) | 1,051 (74.1) | 134 (5.5) | 2,295 (94.5) |
| Traffic Signal or Signal Pole | | | 120 (5.4) | 2,102 (94.6) |
| Railroad Signal | | | 30 (10.3) | 262 (89.7) |
| Sign Structure or Post | 238 (59.9) | 1,593 (40.1) | 1,325 (38.7) | 2,098 (61.3) |
| Advertising Sign | 283 (48.7) | 268 (51.3) | 41 (20.6) | 158 (79.4) |
| Delineator Post | | | 367 (73.8) | 130 (26.2) |
| Fence (or Fencing)/Median Fence | 2,273 (74.9) | 757 (25.1) | 1,169 (51.2) | 1,116 (48.8) |
| Mailbox or Posts | 1,786 (85.5) | 304 (14.5) | 374 (58.7) | 263 (41.3) |
| Curb/Traffic Island | 520 (16.7) | 2,586 (83.3) | 145 (7.9) | 1,684 (92.1) |
| Construction Barricades, Equipment, etc. | 147 (47.6) | 162 (52.4) | 269 (27.0) | 727 (73.0) |
| Crash Cushion or Impact Attenuator | 16 (38.1) | 26 (61.9) | 29 (18.2) | 130 (81.8) |
| Building or Wall | | | 135 (18.1) | 612 (81.9) |
| Machinery | | | 143 (30.8) | 321 (69.2) |
| Other (Fixed) Object | 5,732 (58.0) | 4,138 (42.0) | 2,723 (26.2) | 7,685 (73.8) |
| TOTAL | 58,490 (71.5) | 23.331 (28.5) | 15,193 (32.5) | 31,556 (67.5) |

states, but are captured in the same category with street lights in Michigan. Even with these difficulties, some information concerning the relative size of the impact problem can be gained from the table.

What is immediately obvious is that impacts involving the general category of embankments, ditch banks and other roadside elements (which would clearly include sideslope-related collisions) are the leading category in terms of overall frequency. As in the Viner paper, the second leading category is "trees."

The table also indicates that guardrail, guardposts and median barriers are, as would be expected, another major category of impacted objects. Remember that these are the safety hardware that Viner noted as having the highest economic loss percentage. Other longitudinal barriers such as bridge rail or bridge guardrail do not appear to have near the impact frequency. However, it is noted that structures such as culverts and bridge piers or abutments do experience fairly major numbers of impacts over the five year period.

Turning now to point objects, the table indicates that utility poles, light poles, and other poles beside the roadway are another major problem in terms of frequency of impact. Sign structures and sign posts are also high in terms of number of impacts, but might be assumed to be less severe than the category related to utility poles and luminaires. Moving on down the table, other objects which indicate fairly high numbers of impacts include fences, mailboxes or mailbox posts, and a combined category related to traffic islands and curbs.

Finally, it is of interest to note that there are very few crash cushion/impact attenuator impacts across the five years of data — only 925 as captured in five of the six states. This small number most likely reflects both the small number of these safety devices that are in place across the six states, and, perhaps to some extent, the fact that some of the vehicles which strike them drive away without reporting the crash to police

In addition to this overall table, we also produced a series of additional tables using data from Illinois and North Carolina to provide a limited amount of additional information on conditions pertaining to the impacts. The states were chosen because they represent both a more rural state (North Carolina) and a more urban state (Illinois). In these tables, object struck was again defined using any impact and was not restricted to single vehicle cases, nor was an attempt made to try to more specifically relate a given vehicle to a given object struck. These tables were run using 1990-1992 data from the two states, the most recent years of complete data from both states in the HSIS system.

Table 3 indicates the categorization of fixed objects by urban and rural location within the two states. As can be seen from the last "Total" row, the two states are indeed quite different.

While 71.5% of the North Carolina objects are struck in rural areas, 67.5% of the Illinois objects are struck in urban areas. Given these differences, which reflect where roadway mileage (and objects) are located and where crashes occur, one is not surprised to find that the patterns for individual objects sometimes reflect the overall urban/rural breakdowns within each state. What is of some interest are the cases where an object has a significantly higher proportion of strikes within either the urban or rural category than the state "average" would suggest. Here, for example, the category of roadside embankment/ditch is overrepresented in rural areas in each state, suggesting relatively high impact speeds. In similar fashion, impacts with trees, culvert/catch basins, and mailboxes are somewhat overrepresented in rural areas in both states.

On the other hand, median barriers, underpass structures, utility poles (in North Carolina), light poles, traffic signal poles (in Illinois), curbs/traffic islands, and impact attenuators appear to be overrepresented in urban impacts. This would imply lower impact speeds for most of these objects, although the speed limit data presented below modify this conclusion for median barriers and crash cushions.

Table 4 provides additional information on speeds in fixed object impacts, using the speed limit variable in the more rural North Carolina data. While police reports cannot provide accurate estimates of impact speed, speed limit at least provides some general information on the approximate impact speeds. Since the primary interest is in the distribution of impacts by speed limit for each object, the percentages of total impacts (rather than frequencies) are shown in each cell. The majority of objects (56%) are struck in locations where the speed limit is 50-55 mph. Over 20% are struck on roadways with speed limits are 35 mph or less, or urban areas. With respect to specific objects, and consistent with the North Carolina urban/rural findings above, bridge piers/abutments, underpass structures, utility and luminaire poles, and traffic islands are more likely to be in areas with lower speed limits. This perhaps implies lower impact speeds for these objects.

Also supporting the earlier findings, ditch banks, trees, guardrail ends and faces, bridge rails, catch basins/culverts, and construction barriers have a high proportion of their crashes in locations with speed limits of 50 mph or greater, implying higher impact speeds. In addition, median barriers and crash cushions, which were noted above as experiencing more urban crashes, are shown to more likely be struck on higher speed roads. Here, over 50% of the crash cushion impacts and more than 60% of the median barrier impacts are in locations with speed limits above 50 mph. This supports the earlier hypothesis that these objects are on the higher speed urban roadways, and would be impacted at higher, rather than lower, speeds.

To examine the issue of curvature and grade as related to fixed object impacts, Table 5 provides North Carolina information on object struck classified by curvature and some measure of grade as provided by the investigating police officer. Note that this was not done by linking crashes with a curvature/grade file, but is simply an indication as provided by the officer as to whether he feels that crash occurred on a curve or a tangent section. Thus, in all likelihood, minor curves may be classified as tangents. While "level" is as specified, the term "other" includes grades, sags, and crests. Again, only the (row) percentage of crashes falling within each category are presented in the table.

As can be seen from the bottom row of the table, approximately 65% of all objects struck are on tangents, while 35% are on curves. Of some interest are the cells in the table which are greatly different from the overall percentages at the bottom of the column. For example, it appears that ditch banks, trees, and fence posts are more likely to be struck on curves, in comparison to other objects. In contrast, underpass structures, luminaire supports, traffic islands, construction barricades, crash cushions, and, to a more limited extent, guardrails and sign supports are more likely to be struck on tangent sections. These findings are somewhat difficult to interpret, since what is not known, of course, is the distribution of curves and tangents, or the distributions of objects on curves versus tangents. For example, luminaire supports would be more likely found

## TABLE 4 PERCENT OF FIXED OBJECT CRASHES WITHIN SPEED LIMIT CATEGORIES — NORTH CAROLINA DATA

| | SPEED LIMIT | | | | | |
|---|---|---|---|---|---|---|
| TYPE OF OBJECT STRUCK | Not Stated | < =35 mph | 40-45 mph | 50-55 mph | > 55 mph | Total |
| Ditch Bank | 0.35 | 6.06 | 14.20 | 77.05 | 2.33 | 25,969 |
| Tree | 0.63 | 17.14 | 16.04 | 61.50 | 4.69 | 11,914 |
| Guardrail Face | 0.88 | 8.10 | 10.02 | 59.67 | 21.31 | 3,740 |
| Guardrail End | 1.52 | 9.03 | 10.04 | 55.07 | 24.34 | 986 |
| Median/Shoulder Barrier | 1.21 | 19.98 | 17.02 | 58.64 | 3.12 | 1,151 |
| Bridge Rail End or Face | 1.23 | 14.77 | 13.70 | 59.50 | 10.79 | 1,788 |
| Bridge Pier or Abutment | 0.87 | 25.22 | 20.87 | 39.13 | 13.91 | 230 |
| Catch Basin/Culvert | 0.24 | 10.63 | 19.51 | 66.37 | 3.24 | 2,962 |
| Underpass Structure | 0.85 | 61.54 | 8.97 | 18.80 | 9.83 | 234 |
| Utility Pole | 1.32 | 55.35 | 19.85 | 23.42 | 0.07 | 8,550 |
| Luminaire Pole | 5.43 | 51.73 | 19.24 | 20.08 | 3.52 | 1,419 |
| Sign Structure or Post | 0.58 | 27.15 | 22.75 | 45.08 | 4.45 | 3,982 |
| Advertising Sign | 1.81 | 36.17 | 24.05 | 35.80 | 2.17 | 553 |
| Fence or Fence Post | 1.32 | 24.93 | 17.38 | 53.97 | 2.41 | 3,033 |
| Mailbox | 0.62 | 15.60 | 24.59 | 59.19 | 0.00 | 2,090 |
| Traffic Island | 1.32 | 54.99 | 29.21 | 12.64 | 1.83 | 3,108 |
| Construction Barrier | 1.29 | 11.33 | 11.97 | 69.58 | 5.83 | 309 |
| Crash Cushion | 2.38 | 28.57 | 14.29 | 45.24 | 9.52 | 42 |
| Other (Fixed) Object | 2.81 | 33.43 | 16.81 | 41.72 | 5.23 | 9,889 |
| TOTAL | 860<br>(1.05) | 17,911<br>(21.86) | 13,824<br>(16,87) | 45,858<br>(55.96) | 3,496<br>(4.27) | 81,949 |

in urban areas with fewer curves. In like fashion, traffic islands are more likely to be at intersection (tangent) locations.

Thus, more detailed inventory data are needed to truly define the differential risk of object impact on curves and tangents. However, the figures in the table do provide at least some insight into where the various objects are being struck, given the current distributions of objects and curves in a rural state.

Also of interest in the ongoing discussions of the specifics of impact is the question of the distance of the impact from the edge of the roadway. Very few states capture any such information in their accident reporting/investigating procedures. However, North Carolina does have a police-reported variable titled "Distance to object struck." Unfortunately, rather than a simple estimate of distance, the variable is categorized, with the first category being "in road," and the second being "0-10 ft." For general information, Table 6 provides a summary of this distance-related data for all objects combined in urban and rural areas. The percentages shown are row percentages, indicating the urban/rural breakdown. Again, it is noted that this is an *estimate* provided by the officer, rather than a measured distance.

What is of initial interest here are the overall figures for distance as shown in the final total column. Here, summing the objects on both sides of the roadway, approximately 46% of the objects struck are within 10 ft of the roadway. Approximately 43% of the objects struck in rural areas are within the same distance. An additional 32% of the total objects struck are estimated as being between 11 and 30 feet from the edge, and approximately 8% of the objects struck are estimated to be at distances greater than 30 feet.

With respect to the distributions of distance within urban/rural category, those objects struck in urban areas are more likely to be closer to the roadway, as would be expected based on encroachment speeds and on "normal" placement of objects. While 59% of the urban

## TABLE 5 FIXED OBJECT CRASHES BY POLICE-REPORTED CURVATURE AND GRADE CATEGORIES — NORTH CAROLINA DATA

| | CURVATURE/GRADE CATEGORY | | | | |
|---|---|---|---|---|---|
| TYPE OF OBJECT STRUCK | Straight, level | Straight, other | Curve, level | Curve, other | Total |
| Ditch Bank | 39.43 | 16.03 | 24.26 | 20.27 | 25,927 |
| Tree | 37.44 | 16.72 | 23.01 | 22.83 | 11,888 |
| Guardrail Face | 47.56 | 25.94 | 8.72 | 17.78 | 3,728 |
| Guardrail End | 50.56 | 23.65 | 8.87 | 16.92 | 981 |
| Median/Shoulder Barrier | 52.09 | 23.73 | 8.81 | 15.36 | 1,146 |
| Bridge Rail End or Face | 52.22 | 21.59 | 10.79 | 15.40 | 1,779 |
| Bridge Pier or Abutment | 51.30 | 22.17 | 16.52 | 10.00 | 230 |
| Catch Basin/Culvert | 39.84 | 21.14 | 20.49 | 18.53 | 2,957 |
| Underpass Structure | 51.50 | 32.19 | 8.15 | 8.15 | 233 |
| Utility Pole | 51.51 | 21.03 | 15.51 | 11.95 | 8,529 |
| Luminaire Pole | 67.45 | 21.73 | 4.60 | 6.23 | 1,419 |
| Sign Structure or Post | 55.72 | 20.34 | 12.11 | 11.83 | 3,972 |
| Advertising Sign | 50.64 | 21.96 | 15.79 | 11.62 | 551 |
| Fence or Fence Post | 39.29 | 17.83 | 20.53 | 22.35 | 3,029 |
| Mailbox | 43.10 | 19.51 | 21.00 | 16.40 | 2,090 |
| Traffic Island | 61.25 | 23.18 | 7.90 | 7.67 | 3,102 |
| Construction Barrier | 55.19 | 26.30 | 12.34 | 6.17 | 308 |
| Crash Cushion | 45.24 | 30.95 | 11.90 | 11.90 | 42 |
| Other (Fixed) Object | 54.20 | 21.00 | 12.78 | 12.01 | 9,856 |
| TOTAL | 37,244<br>(45.55) | 15,611<br>(19.09) | 14,958<br>(18.30) | 13,944<br>(17.06) | 81,757 |

## TABLE 6 DISTANCE FROM ROADWAY THAT FIXED OBJECT IS STRUCK, BY URBAN/RURAL CATEGORIES — NORTH CAROLINA DATA

| DISTANCE TO OBJECT | LOCATION | | Total |
|---|---|---|---|
| | Urban | Rural | |
| None or Not Stated | 2,629<br>(64.44) | 1,451<br>(35.56) | 4,080<br>(4.99) |
| In Road | 2,268<br>(46.46) | 2,614<br>(53.54) | 4,882<br>(5.97) |
| 0-10 ft Right of Road | 9,729<br>(40.20) | 14,473<br>(59.80) | 24,202<br>(29.58) |
| 0-10 ft Left of Road | 3,669<br>(26.56) | 10,143<br>(73.44) | 13,821<br>(16.88) |
| 11-30 ft Right of Road | 2,050<br>(13.68) | 12,930<br>(86.32) | 14,980<br>(18.31) |
| 11-30 ft Left of Road | 1,151<br>(10.18) | 10,156<br>(89.82) | 11,307<br>(13.82) |
| >30 ft Right of Road | 721<br>(20.47) | 2,801<br>(79.53) | 35,22<br>(4.30) |
| >30 ft Left of Road | 561<br>(19.40) | 2331<br>(80.60) | 2892<br>(3.53) |
| TOTAL | 22,778<br>(28.59) | 56,899<br>(71.41) | 79,677 |

objects struck are within 10 feet of the roadway, only 43% of the rural objects are. In contrast, while 41% of the rural objects struck are estimated to be between 11 and 30 feet, only 14% of the urban objects are in this range.

In summary, the above data provide some indication of the nature of fixed object impacts. The data in this compilation are limited to only two states, Illinois and North Carolina, with the majority of the tabular information being from the more rural North Carolina database. While not provided in this paper, databases from six other HSIS states could be examined to provide similar or additional data if specific questions of interest can be identified.

Finally, of a more philosophical nature, one question raised by Viner's work and the above tables concerns the basis on which the decision of program direction should be made. In short, should we base fixed object research and implementation programs on frequency of crash (as in these tables), impact severity, a combination of frequency and severity (as in the Viner work), or some other basis? While we do not profess to have the answer to this question, it would appear that one should consider not only the loss being incurred, but also the cost of making an improvement to a given object or roadside design, and the probability of success one can expect from the expenditures. For example, although both the Viner analysis and our analysis indicates the roadside design (e.g., sideslopes, embankments and ditches) to be the leading "cause" of harm, the questions remaining concern whether the design can be feasibly changed, and what the related estimated costs and potential benefits would be. In like manner, can "trees" be successfully removed from the roadway? Or could we devise a relatively inexpensive but effective utility pole treatment that might be implemented rapidly to affect a sizable portion of the lower-rated utility pole harm? In short, it appears to these authors that some form of economic analysis needs to be considered which factors in the *probability of success*, both in terms of crash loss reduction per treatment and the chances of the treatment being implemented in the real world. This is certainly not to say that we should not consider clear zone, sideslope and ditch design as high priorities, but that we might be better served by extending our analysis at least one more step in determining program direction.

## STATUS OF ROADSIDE RESEARCH DATA

Having now conducted a limited exploration of the current problem in the sense of what roadside objects are being struck, let us now return to the overall question concerning whether we have adequate data to conduct the necessary research to identify the problems and find the solutions that are needed.

### Site Identification and Examination

As noted in the introduction, the first type of research needed is aimed at determining whether a specific site should be improved and the benefits of a particular treatment. This site-specific research requires the development of a model which would predict how often an impact will occur with a given fixed object, and how severe the resulting impact is likely to be. This prediction effort can be done in at least two different ways — through the use of an encroachment type model or through the use of a detailed accident-based model.

The encroachment type model has been referenced in a number of studies including an early study by Glennon *(4)*. These models predict impact with an object of specific dimensions and specific distance from edge of pavement by estimating the number of vehicles that would encroach from the road at a given angle and to a given distance from the edge of the pavement. The use of this model requires good data on the rate of encroachments per passing vehicle, the distribution of angles at which the vehicles leave the roadway during the encroachment event, and the distribution of the distances that the vehicles travel.

To develop an accident-based model whose goal is to predict the probability of impact with a specific class of object, detailed data would be required. The model would be "section based," predicting the number of impacts per object per passing vehicle. The data required would include information on fixed-object crashes by object type, traffic volumes, and information on how many objects there are beside the roadway to be struck (i.e., a roadside inventory file).

There are clearly existing gaps in the available data for both these models. Available encroachment data is often based on older studies, primarily Hutchinson and Kennedy *(5)*. These data were collected on multilane roads during snow season, and at least one of the authors has questioned the suitability of using the data in very detailed, deterministic models. It also appears that current attempts to develop encroachment data through a number of different studies have been less than totally successful. In short, there is a continuing need to collect better encroachment data. With respect to the data needed in the accident model, while most accident reports include a list of generic types of fixed objects which could be used in the modelling exercise, and while the number of passing vehicles can be estimated from available AADT data, we know of only one state (Michigan) that has any kind of roadside

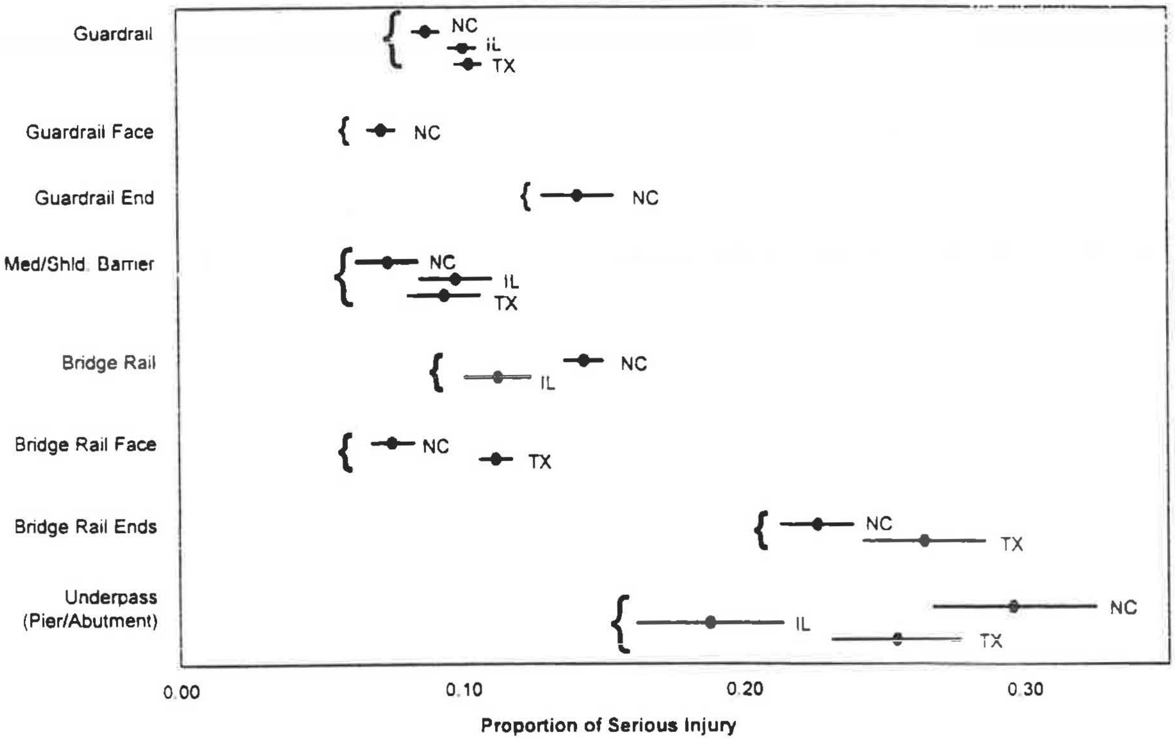

**FIGURE 1** Proportions and 95 percent confidence intervals for barrier-type objects (North Carolina, Illinois, and Texas data) *(6)*.

inventory that would allow one to develop a measure of exposure to the objects. Here, for example, one would need to know the beginning and ending milepoints for longitudinal barriers in order to produce a model that predicted impacts into the barrier per million passing vehicles. In short, roadside inventory data are sorely needed in this effort and currently exist in only a limited fashion.

The second set of data needed to produce the final output from both the encroachment and accident models is related to the severity of an impact given a fixed object has been struck. Here, detailed "severity indices" are needed for a wide variety of objects. Indeed, for the encroachment model to predict as it should, these severity indices need to be further categorized by encroaching vehicle speed, angle and vehicle type.

With respect to such severity index research, a recent paper by Council and Stewart *(6)* is now under review by FHWA and will be converted into a TRB paper. The study used data from Illinois and North Carolina, where the specific injury to the driver could be fairly accurately specified as having resulted from the impact with the object being studied. This was done through the use of the most harmful/first harmful event in North Carolina, and through a sequence of events in the Illinois data. While more detailed indices for specific vehicle types, speed limits, road classification and roadway locations are presented in the paper, the "average" severity indices from these two states and from earlier research by Mak et al. *(7)* using Texas data are included in the three figures that follow.

The continuing problems noted in this recent research include the need for more detailed descriptions of certain fixed objects (e.g., whether a "guardrail" is a w-beam, blockout or non-blockout, etc.), more complete indication of unreported crashes which will affect the severity-based indices, and the need to modify the indices based on changes in the vehicle fleet.

In short, there are continuing data needs for both the encroachment-based model and the accident-based model, and for more complete severity indices required by both models.

## In-Service Evaluations of Hardware

In-service evaluations of hardware have been promulgated by the last two guidelines for crash testing, NCHRP *Reports 230 (8)* and *350 (1)*. To perform such studies requires quality evaluations of operational and crash severity for specific pieces of hardware (e.g., breakaway cable terminal (BCT) versus turn-down end

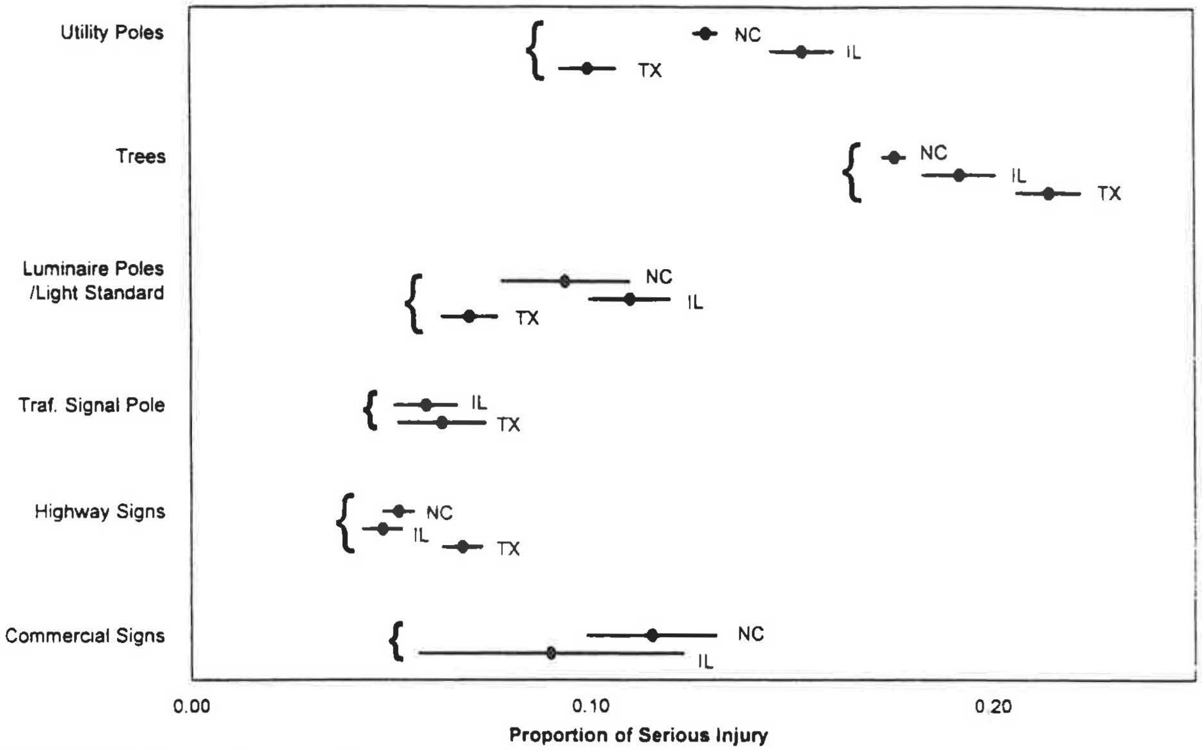

FIGURE 2 Proportions and 95 percent confidence intervals for point-type objects (North Carolina, Illinois, and Texas data) *(6)*.

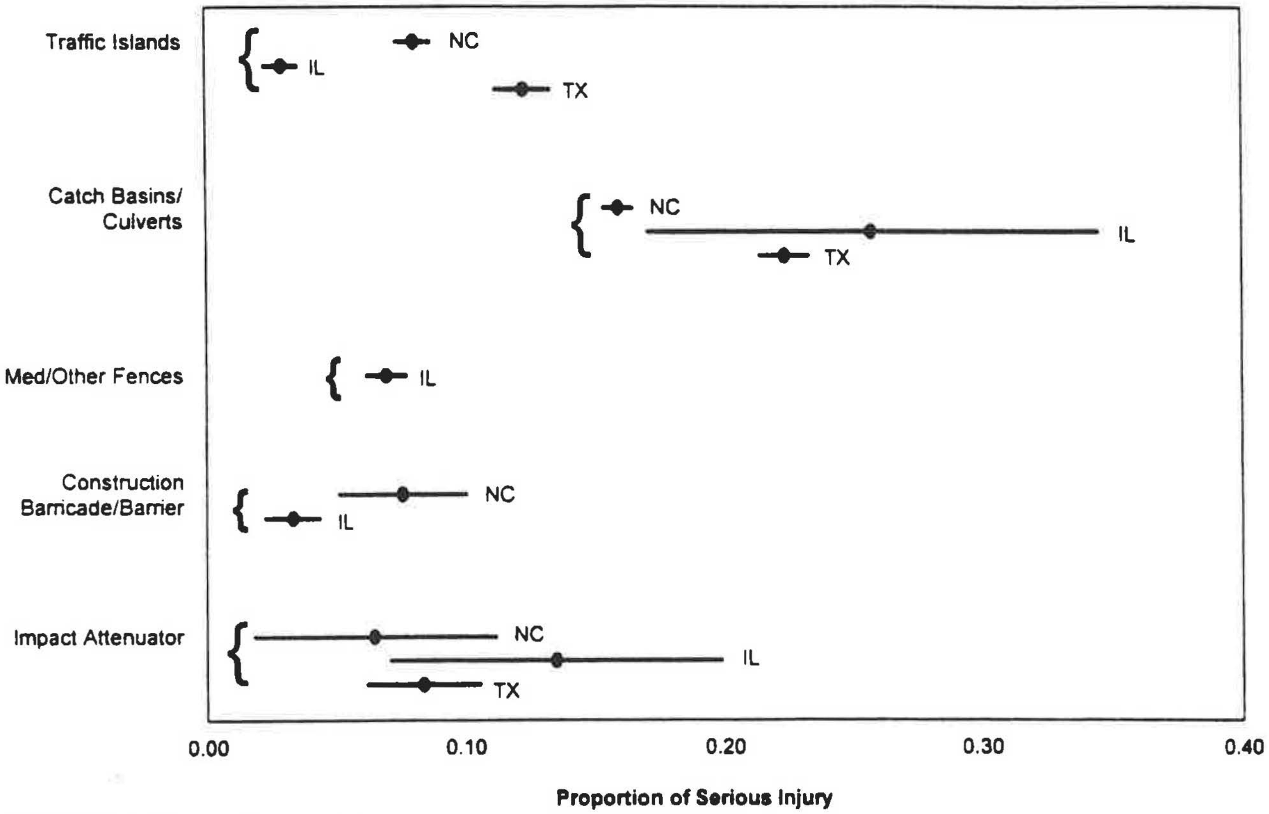

FIGURE 3 Proportions and 95 percent confidence intervals for other objects (North Carolina, Illinois, and Texas data) *(6)*.

treatments). The normal sequence of evaluation would be determination of the function of the device, development of preliminary designs, the conduct of laboratory and crash tests, redesign and retesting if necessary, installation of feature and in-service evaluation, declaration of operational status if warranted, and then further observation of the device to determine if there are other problems. The problem is that few in-service evaluations of quality have been done. Some that can be named include the State of Connecticut's evaluation of the Connecticut Impact Attenuation System (CIAS), where a series of studies was performed *(9)(10)(11)(12)(13)*; barrier system studies using maintenance personnel in New York State *(14)*; and end treatment studies in Kentucky *(15)*.

The BCT is a device that has received a good bit of scrutiny over the years. This is probably the most widely used end treatment in existence, but a design which has all too often resulted in improper installation because of the necessity of a 4-foot parabolic flare. Many BCT's have been installed with a 1-foot parabolic flare and others with no flare whatsoever. Poor performance of these non-standard designs has been noted when evaluations have been performed (15). The field of roadside safety knowledge would be potentially farther advanced if more in-service evaluations were routinely done and reported in the literature.

As with any kind of evaluation, there are factors that must carefully be considered with in-service performance. Since comparisons between treatments are generally relative, and since some hardware, if designed properly, leads to vehicle "driveaways," the evaluation method must assure that the same threshold of reporting is taking place. Put another way, are the same levels of property-damage-only (PDO) crashes being captured (or are the same levels of crash energy being captured)? Matching on PDO crash levels is generally not a problem, as many police reporting agencies adopt $500 as a threshold value, but this should be verified. The "driveaways," or unreported crashes, present another problem, in that ascertaining the actuality of these events is relatively difficult. Actuated cameras have been used to record vehicles striking crash cushions, a device that can certainly lead to driveaways. For barrier impacts, maintenance personnel have been utilized to record scrapes or gouges on barriers, and one Southwest Research Institute (SwRI) study *(16)* actually instrumented a section of guardrail to record impacts. One problem with the latter approach was that intended encroachments (e.g., pulling onto the shoulder to allow a following vehicle to pass) were difficult to interpret.

Before any new piece of hardware is put into service, laboratory and crash tests are usually performed to assess whether the device is acceptable from a human tolerance standpoint. The problem here is twofold: (1) the devices are struck in a variety of ways in the real world that cannot currently be cost-effectively crash tested, and (2) the linkage between measured crash test forces to the vehicle and ultimate occupant injury has yet to be effectively defined. (It is also not clear that modern simulation developments are reducing this gap). A related problem is that much crash testing takes place with older vehicles that are more affordable, but which may have decidedly different characteristics than the current fleet. An example is the ever increasing frequency of air-bag-equipped vehicles on the road.

Thus, in-service evaluations are not without problems. The cycle of design, testing, and implementation may be lengthy (perhaps 5-10 years), and during this time vehicle fleet characteristics may tend to change. It is difficult for the roadway designer to keep up with the system — the target appears always to be moving.

## FUTURE DATA PROSPECTS

So where is the field heading in regard to future data collection. This will be discussed from the aspects of data file possibilities and innovative means of collecting and analyzing data.

### Data Files

There are various data files that can be used to study the roadside safety problem. In regard to crash data, the HSIS offers a capable set of police files that come from states with good roadside data. Missing ingredients include better information about impact conditions (primarily speed and angle data) and more detail about specific hardware (e.g., type of guardrail struck, rail height, post spacing, standard design or not). It is not clear that other federal files, an example being the General Estimates System (a refinement of the earlier NASS PSU data), would be of any more value than working with the HSIS data, except for a better estimate of national frequency of these kinds of crashes.

The Longitudinal Barrier Special Study (LBSS) files were created to collect just the kind of hardware specificity mentioned above but tended to be biased toward the more severe crashes. These data were collected from 1982-1986 but are still quite valuable from a clinical standpoint. Hunter, Stewart and Council *(17)* recently performed a comparative analysis of barrier and end treatment types using the LBSS file.

Unreported crashes pose yet another problem to be dealt with in roadside safety studies. (For discussion purposes, unreported should be assumed to mean crashes above some minimum reporting threshold.) The problem is that unreported (presumably PDO-type) crashes tend to inflate the proportion of serious and fatal and other injuries, and thus inflate severity indices based on these severe injuries. Another question is whether various fixed objects are underreported to differing degrees. For example, it is presumed that breakaway support and other attenuating devices have more propensity for driveaway events than collisions with barriers and other non-breakaway designs (see Mak and Mason, 1980 *(18)*.

It appears that the best source of data for unreported crashes is maintenance data of the type used in previous studies (Galati, 1970 *(19)*; Carlson, Allison, and Bryden, 1977 *(14)*), where maintenance personnel regularly monitored impacts with objects. Assuming that a maintenance organization exists which regularly monitors their roadside objects, and that a computerized record system tracks the damage and repairs to such objects, then one should be able to extract usable information on a per object basis. A key to such a data collection effort is establishing some value of damage severity or repair amount which can be used as a threshold value above which crashes should be reported by the police. Not all cases of minor damage would fit the description of unreported in a state with a property damage value of $500 or more. A clearly defined and justified threshold is needed to define the impact which should be countable in an analysis of unreported crashes.

The maintenance-based analysis should be conducted in a state (or states) whose police data can be used in the development of severity indices. This means data with a relatively low reporting threshold, with a large variety of fixed objects, and with the ability to link injury directly to a given object.

Another type of data file pertinent to roadside safety analysis is roadside inventory information, or a record of what actually exists on the roadside. To produce such a file is a laborious process that sometimes is simplified through sampling. Once obtained, the inventory data must be linked with crash data.

Files based on encroachment data are also difficult to obtain but represent another way to examine the problem. TTI has been active for many years with developing these encroachment models. A current NCHRP cost effectiveness study (Project 22-9) is being completed based on an improved encroachment probability model.

## Innovative Means of Collecting and Analyzing Data

Innovative can mean many things. This section will start with comments about working with recent hi-tech developments and then move to a brief discussion concerning the use of traditional police reporting systems in innovative ways

*Hi-Tech Innovations* — A recent FHWA study by Bellomo-Mcgee and the UNC Highway Safety Research Center *(20)* provided information about new and emerging technologies for improving accident data collection. The document is extensive and covers techniques that include use of portable computers, location systems such as Loran-C and GPS/GPI, cellular phones, black box recorders for vehicles, and other automated incident detection systems. While innovative, the technology is so costly in general that widespread use will be difficult to obtain. However, two techniques appear promising. GPS/GPI systems are not prohibitively expensive and are gaining rapid acceptance and use in transportation settings. There is promise for use of such technology in improving the location of reported crashes. Such improved locations would be helpful in studies of roadside safety devices, providing that an inventory is in place. In addition, laptops, notebooks, and pen-based computers can be used by police to collect data electronically at the scene of a crash. Software can be used to create special forms for entry, such as a barrier special study form. Pop-up menus can also be used to prompt the investigator to obtain pertinent data for crashes of interest, such as guardrail type, rail height, post spacing, end treatment, etc. in a barrier study.

*Improved Detail on Police Forms* — An improvement that would be quite valuable is the more widespread use of detailed sequence of events protocols by crash investigators. Most state data files are not sophisticated enough to enable an analyst to precisely link a crash injury with a specific fixed object, especially if there are multiple impacts taking place. Most states only have an "accident type" which indicates the first harmful event. North Carolina is like some states in having a "first harmful event" and "most harmful event" recorded. This is helpful but not as good as the event sequence used in Illinois, where 3 or 4 events may be recorded (e.g., vehicle ran off road and struck small sign, then struck a guardrail, and then overturned). Such a sequence allows the analyst to screen out unwanted occurrences. For example, the analyst could accept only cases in which the first and only impact was with a guardrail. Then the analyst would be reasonably confident that any resulting driver or other occupant injury would be related to the guardrail.

Improved detail can also be obtained through better designed crash reporting forms or supplemental forms. For example, if several states were participating in a study of barriers, it might be possible to redesign the basic state form to include specific lines of questioning if a vehicle struck a barrier, such as barrier type, barrier height, distance from edge of pavement, etc. Of course this additional detail would much more likely be gained through use of a supplemental form to be filled out in the event of a barrier crash. As noted above, special prompting is also available through the use of portable computers for crash reporting, where menus can appear to lead one through a series of questions for certain kinds of crashes.

*Roadside Inventory* — As mentioned earlier, collecting roadside inventory information is labor intensive. One way of gathering this data is through use of photologs, videologs or videodiscs. Such a project is currently being conducted as part of the HSIS project at FHWA. Staff are viewing a videolog from Minnesota and then coding/entering information concerning various features on a computer keypad, with the milepost information being automatically extracted from the videodisk system. Such a system could be used to build a file of various kinds of barriers or other fixed objects. The ARVAN vehicle, an automatic recording vehicle connected to GPS/GPI systems, is currently used to collect videolog and pavement information. Conceivably a distance-measuring beam could be focused to the side as the vehicle travels along the roadway so that distance to objects could be obtained as well.

A second possible source of roadside inventory data are computerized state maintenance files. Unfortunately, the maintenance files that the authors are familiar with are usually based on "maintenance sections," with counts for various objects within the section. For example, a section might be one mile in length, and the file would contain counts (but not locations) of the number of feet of guardrail, the number of breakaway signs, the number of catch basins, etc. Since these objects are not tied to a location, it would be difficult to link a specific crash to a specific object. However, these data may be useful in severity related studies since they provide a more detailed description of the object than is found on the accident form and, with some thought and planning, might be useful in accident-based modelling efforts.

*Clinical Examination of Police Reports* — Police data are not as complete as special supplemental data, but a good bit of clinical information can be obtained from these reports. Highway Safety Research Center staff once used hard copies of barrier crashes in North Carolina to aid Southwest Research Institute in a study concerned with vehicle redirection after a barrier crash *(21)*. A possible study using HSIS data could involve the clinical examination of over 900 impact attenuator crash reports from six different states.

## Factors Affecting Current and Future Research

In his paper for this committee last year, Viner (2) noted three factors which may affect both the frequency and severity of roadside object impacts in the future. These include the increased proportion of light trucks and vans in the vehicle fleet, the effects of airbags and anti-lock brakes on the severity and type of hardware impacts, and the effects of aerodynamic front-end styling.

Little can be added to what was noted in the Viner paper concerning the effects of light trucks and vans. As noted there, a TRB paper recently published using North Carolina and Michigan state data and FARS and GES national data examined this issue *(22)*. The overall results indicated that there was no significant difference in the risk of serious and fatal injury between car and pickup drivers when examined for all objects struck or by specific object type. Of interest was the fact that although pickups experienced more rollovers in almost all types of object impacts, the proportion of serious and fatal (A+K) injury for pickups was lower in rollover crashes when compared to rollover crashes for passenger cars. This probably is related to the higher amount of energy required to overturn a passenger car. In essence, the higher rollover risk coupled with the lower rollover injury rates for pickups resulted in the finding of no significant difference between the driver injury for the pickup and the passenger car groups.

However, there was an indication of difference in fatal accidents when the FARS data were compared to exposure based on GES and vehicle registration data. It was concluded that the increase in pickup fatality rate could very well have resulted from the increased risk of ejection in pickups.

The final conclusion drawn was that even though there appears to be a higher risk of fatalities for pickup drivers in impacts with roadside safety hardware, redesign of the hardware may not be the most effective way to solve the problem. Instead, programs aimed at either improving basic vehicle stability or increasing the use of occupant restraints may be more cost effective means. However, given the difficulty that we are now experiencing in increasing use of seat belts among pickup drivers, and the question of whether the automobile industry can indeed improve the basic stability of the vehicle, this issue should not be disregarded by the roadside safety community. In fact, it is the subject of a current NCHRP study.

With respect to the issue related to anti-lock brakes, where reduction in skidding and yawing under hard braking may indeed affect "if" and "where" rollovers occur, there is little additional data that can be added to that developed in the Viner paper. The same is true with the question of whether or not the wedge-shaped profiles of new cars, which are now becoming an increasingly large segment of new car sales, will result in increased problems with cable guardrails and guardrail end systems such as the BCT. While Viner concluded that it will be impractical to answer these kinds of

TABLE 7 SEVERITY INDICES FOR PASSENGER CARS/STATION WAGONS EQUIPPED WITH AIRBAGS — NORTH CAROLINA DATA

| Fixed Object | Airbag SI | 95% C.I. | N | Non-AB SI | 95% C.I. | N | % Decrease |
|---|---|---|---|---|---|---|---|
| Guardrails (Ends and faces) | 0.023 | (.000,.058) | 87 | 0.088 | (.083, .093) | 12,131 | 73.9% |
| Trees | 0.113 | (.077,.149) | 292 | 0.176 | (.173,.179) | 62,772 | 35.8% |
| Utility Poles | 0.075 | (.036,.114) | 173 | 0.129 | (.126, .132) | 44,894 | 41.9% |

questions through accident research, we note that it might be worthwhile to at least explore the possibility of developing additional information on these issues. For example, HSIS contains vehicle identification number (VIN) files for the states of North Carolina, Illinois, Utah and Michigan. While none of these states have cable guardrails as a standard roadside safety device, it may be possible to explore the question of whether they do use the BCT end treatment. More specifically, approximately 90% of all guardrail end systems in North Carolina are BCT's, and the North Carolina accident report form separates end impacts from guardrail face impacts. If one could get listings from automobile manufacturers of the vehicles that have this wedge-shaped front profile, and if the sample of these vehicles has now become large enough, it may be possible to extract a subsample of these crashes and examine vehicle damage, rollover, and driver injury in either a clinical study of accident reports or through tabular statistical analysis.

Viner also noted that the conversion of the car, light truck, and van fleet to airbags is now well underway, and that this should result in injury reductions in roadside impacts. Preliminary information on such effects was developed in the soon to be published paper by Council and Stewart (6). In this paper, airbag-equipped vehicles (which were all involved in accidents in the post-1986 era) were identified by decoding VIN's in the North Carolina file. They were then compared to non-airbag vehicles in crashes during the same time period. An attempt was made to develop severity indices for a large number of fixed objects. As would be expected, airbag-related sample sizes for most of the objects were so small that meaningful indices could not be developed.

However, as shown in Table 7, there were somewhat sizable samples of airbag-related fixed object impacts for guardrails, trees, and utility poles. Fortunately, this provides at least some preliminary information on both a barrier-type object and on two point objects. The severity indices are defined as the proportion of serious and fatal driver injury in the impacts.

First, as expected, the airbag-related proportion of severe and fatal injury, which is shown in the third column of the table, is consistently lower than the corresponding non-airbag proportion shown in the sixth column of the table. Figure 4 provides the same information graphically. Since there is no apparent reason to assume that the guardrails, trees, or utility poles struck by airbag cars would be necessarily different from those struck by non-airbag cars, the difference seen is, in all likelihood, related to protective effects of the airbags themselves.

The final column of Table 7 presents the percent decrease in the proportion of serious and driver injury shown by the airbag cars. As is seen, the severity index for guardrails shows the greatest decrease, with the airbag index being approximately 74 percent lower than the corresponding non-airbag index. The percent decrease for the two classes of point objects — trees and utility poles — is less than for the guardrails. However, the airbag severity indices are still 36 and 42 percent less than the corresponding indices for the non-airbag vehicles. Unfortunately, the reason for the difference in the decreases between guardrails and trees and utility poles cannot be determined from the data. For example, it would be of interest to determine what the decrease would be for guardrail ends versus faces, and for guardrails, trees, and utility poles in urban versus rural areas where speed limits, and thus crash speeds, would be expected to be different. The size of the data samples does not allow us to look at these factors with confidence.

What is clear is that there is indeed a difference in the proportion of those drivers who are seriously injured in the airbag cars versus those in the non-airbag cars. Clearly, severity indices developed for the future fleet of vehicles will be lower than the current values shown in either this current work or any other past research. The question that still remains unanswered

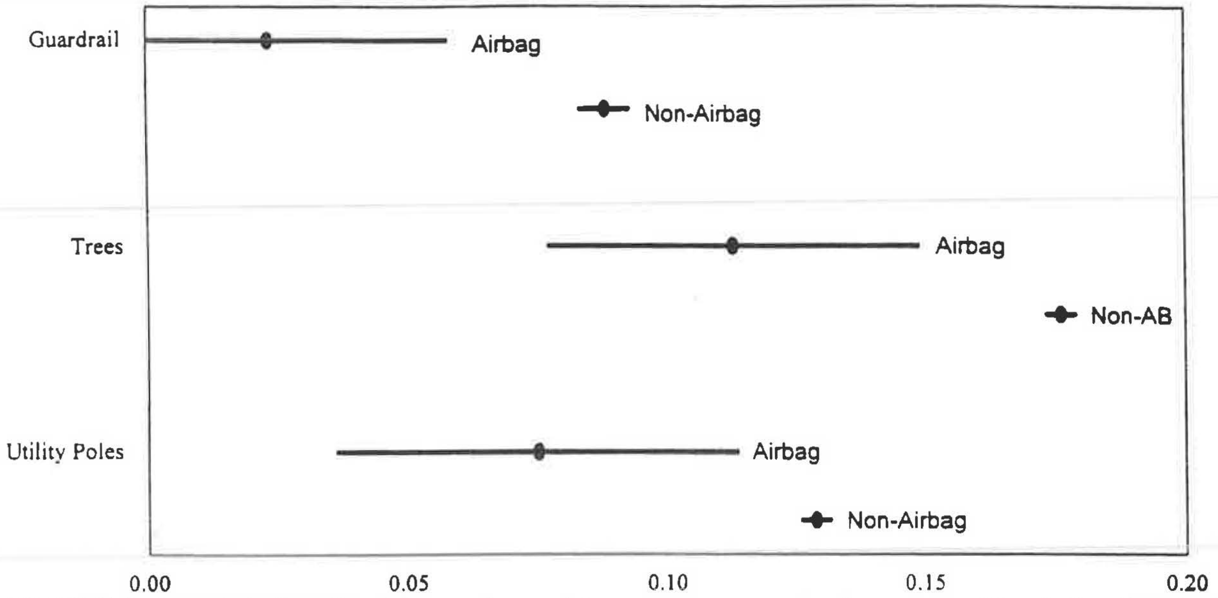

FIGURE 4 Severity indices for airbag and non-airbag passenger cars/station wagons (North Carolina data).

is whether or not the shift to airbags will lead to consistent decreases across all objects or, as these data indicate, lead to differential effects between classes of objects.

## Furthering Knowledge

*Current NCHRP Projects* — The NCHRP has at least the following projects ongoing or planned in regard to roadside safety, which are pertinent to the issues addressed in this paper:

- Project 17-11 — Recovery-Area Distance for Highway Roadsides;
- Project 17-12 — Improved Safety Information to Support Highway Design;
- Project 22-9 — Improved Procedures for Cost-Effectiveness Analysis of Roadside Safety Features;
- Project 22-11 — Evaluation of Roadside Features to Accommodate Vans, Minivans, Pickup Trucks, and 4-Wheel Drive Vehicles;
- Synthesis Project 20-5 — Highway Guardrail and Median Barrier Crashworthiness;
- Project 22-12 — Guidelines for the Selection, Installation and Maintenance of Highway Safety Features;
- Project 17-13 — Strategic Plan for Improving Roadside Safety;
- Project 17-14 — Effect of Median Width and Slope on the Frequency and Severity of Cross-Median Accidents on Rural Roadways; and
- Project 22-13 — Performance of Roadside Barriers.

The last in the list is a new project that can consider many of the thoughts offered in this paper. There will be an opportunity to plan for and collect a variety of data pertaining to longitudinal barrier and end treatments. There will be an emphasis on barrier condition prior to the crash and performance during the crash. Data will be collected and analyzed on some 1,500-2,000 crashes.

*Need for More In-Service Evaluations* — In a paper prepared for the A2A04 Committee's 1994 summer meeting *(23)*, Hayes Ross offered the following:

> Both [NCHRP] Reports 230 and 350 pointed out that field evaluation was the final and perhaps most important step in the evaluation of a feature. Both reports provided guidelines by which a feature could be field evaluated. However, to a large extent, field evaluation remains the weak link in the assessment of a feature's performance and suitability for use.

There evidently needs to be a better way to get these evaluations planned and implemented. Perhaps FHWA should take a stronger hand in emphasizing their importance. Perhaps NCHRP pooled fund studies are an outlet by which more could actually be performed, where various states who have features of interest and good records systems would participate. An excellent candidate feature is the single slope concrete median barrier, which is believed to have improved impact performance, especially for small vehicles, when compared to the New Jersey shape. The barrier is gaining increasing acceptance in the U.S.

## SUMMARY

With the ever changing fleet and its ever changing safety features, there continues to be the need for studies of the performance of roadside safety features. Real world ran-off-road-crashes occur in many ways, some of which are far removed from the practical worst case scenario embodied in crash tests. What are the effects of more vehicles with air bags and antilock braking systems? What will happen when side air bags become more prominent? What about a proliferation of electric vehicles?

Researchers need to be innovative in using data or data collection techniques not used extensively in the past, such as maintenance data or maintenance personnel to define roadside inventories, encroachments and/or crashes, to help fill gaps. New data will also need to be collected and should be coordinated with existing databases to maximize efficient use of resources. An example would be collecting roadside inventory data in HSIS states and then matching to their crash files. However, before any data are collected, the roadside safety field needs to decide what basic questions are most deserving of answers. For example, what hardware is most important, and what do we know least about? What is deserving of priority treatment?

In summary, there are clear gaps in our existing knowledge of roadside safety measures, and there are gaps in the databases used to build this knowledge. However, with properly targeted funding and creative thought about both new data and use of existing data, the gaps in our knowledge can be filled.

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# INTERACTIVE HIGHWAY SAFETY DESIGN MODEL (IHSDM): DESIGNING HIGHWAYS WITH SAFETY IN MIND

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The Federal Highway Administration (FHWA) has designated Highway Safety Design Practices and Criteria as a high-priority research and development area. The objective of this program is to develop an integrated design process that systematically considers safety in developing and evaluating cost-effective highway design alternatives. Conceptually, the idea behind this research program is to develop a system that can be used to evaluate the safety of alternative highway designs in a Computer-Aided Design (CAD) environment. This evaluation would include an examination of the entire roadway design including both the roadway alignment and cross-section and the roadside design (sideslopes, ditches, guardrails, utility poles, etc.). Work in this area has been underway for several years and this initial objective has grown from a rough concept into a well-defined research program that is aimed at developing a fully functional system called the Interactive Highway Safety Design Model (IHSDM).

This paper will provide a status report on the IHSDM research program and present the current vision of how a fully-functional IHSDM can improve the consideration of safety in the design process.

## BACKGROUND

The goal of the IHSDM research program is to develop a systematic approach that will allow the highway designer to explicitly consider the safety implications of design decisions. In the past, "safe" design has meant satisfying a set of minimum design criteria. There has been no effective way for a designer to compare the safety of various alternatives or to optimize the safety of a particular design. Failure to explicitly address safety issues during the design process can result in inconsistent or inappropriate design decisions that manifest themselves in the form of "accident black spots" once the project is constructed. Limited funds and staff time must then be spent trying to remedy problems through the safety improvement program.

In the early planning stages for the IHSDM it was recognized that achieving the goal of explicit consideration of safety would require that the IHSDM operate from within the design process and not as a separate outside activity. Operating within the design process required the adoption of several basic principles to be followed in the development of IHSDM:

- IHSDM must be applicable for both new construction and reconstruction projects. While the general design principles are similar for both types of projects they also differ in some important respects. New construction projects are initiated by planning for transportation access and traffic growth. Reconstruction projects are generally initiated because of capacity problems or to preserve the structural integrity of the roadway. Reconstruction projects are typically constrained by the available right-of-way and/or funding availability.
- IHSDM must facilitate decision-making from the planning through the final design stages. While the highway design process varies considerably among the 50 states, it can be generally divided into two phases: (1) preliminary design often associated with the preparation of environmental impact statements (EIS); and (2) detailed design associated with the preparation of plans, specifications, and estimates (PS&E). At the preliminary design stage only limited information on the alignment, design speed, ADT, traffic mix, and crosssection, and intersections is available. In developing the detailed design final decisions on the alignment, crosssection, intersection and median layout, roadside hardware, signing and markings, etc. are made. The IHSDM will be primarily focused on the detailed design stage, however parts of the model must also be appropriate for the preliminary design stage when important safety-related decisions are made.
- IHSDM must be a computer-based system that can be integrated into the CAD environment. With the advances in computer technology, the designer now has the ability to view, analyze, and change designs electronically. Clearly, if IHSDM is to be an integrated part of the design process then it must operate in this environment. The IHSDM is envisioned as a series of modules that could be integrated into and accessed from the commercially-available CAD packages that are now being used by State Departments of Transportation and

their consultants. The designer would be able to work in an interactive process to evaluate a potential design and correct problems that are identified by IHSDM.

The FHWA plans to conduct the research and development necessary to develop the IHSDM modules and demonstrate their application. Full implementation would occur as these modules are integrated into the CAD packages by the software vendors. The FHWA plans to enter into cooperative agreements with all interested vendors in 1995. These cooperative agreements will provide for sharing of information between the FHWA and the vendors during the research process to facilitate implementation.

- IHSDM must integrate safety research into a form usable by the designer. Considerable research has been conducted into the relationships between geometric design elements and highway safety. However, much of this research was not conducted with the designer in mind and cannot be directly used by highway designers to make decisions. IHSDM will seek to utilized existing research that is of acceptable quality and to supplement that research with well-designed, statistically-valid studies where necessary.

User-input will be heavily relied upon in developing the user interfaces, identifying appropriate operational and safety measures, and in selecting effective ways to display results from the model. To facilitate this process the FHWA, through its Office of Technology Applications, will be developing a prototype demonstration of the IHSDM. This prototype demonstration will allow a user group (consisting of representatives from several DOTs and design consultants) to review and provide input into the development of the IHSDM. This activity will be initiated in 1995.

- IHSDM must be developed in a modular process that allows the system to be tested and implemented in stages. Development of a fully operational IHSDM will be a 10-year, multi-million dollar effort. Interim results from this program must be developed and implemented if the program is to improve highway design in the near-term, be responsive to changes in user needs, and maintain support for this long-term commitment. As is described below, the research program has been designed around a number of stand-alone modules which are interrelated, but can also operate independently. Implementation of prototype modules is planned to provide for user input. In addition, initial IHSDM development efforts have been directed at two-lane rural roads. This area was selected because of the wide variety of geometric design conditions on these roadways and the potential to make significant improvement in their safety.

It is believed that by following these basic principles, the IHSDM can be developed in was way that allows it to become an integral part of the highway design process.

## IHSDM PROGRAM STATUS

The IHSDM program is currently focused on six major areas of research (as shown in Figure 1): Consistency, Vehicle Dynamics, Driver, Accident Analysis, Policy Review, and Traffic. From an end user standpoint these six major research areas are likely to result in four basic tools for the designer: Driver/Vehicle Performance, Accident Analysis, Traffic Assessment and Policy Review. A description of each of these tools is provided below along with a summary of ongoing research.

## DRIVER/VEHICLE PERFORMANCE TOOL

It is believed that many safety-related problems that occur in the highway design process are due to the inability of a designer to view the design from a driver's perspective. The designer is limited to working in a two-dimensional environment that does not lend itself to a visualization of how the final product will look or how it will operate with real vehicles and drivers. The designer has to rely on design policies such as the AASHTO document *A Policy on Geometric Design of Highways and Streets* which are based on the concept of design speed. Research has shown that the use of design speed in selecting geometric elements can result in designs that violate driver expectancy.

The IHSDM Driver/Vehicle Performance Tool will provide the designer with the ability to assess the consistency of the design. Initially, this will be done using consistency models that generate a speed profile and/or a driver workload profile for a design, and vehicle dynamics models that allow the designer to select a vehicle type and speed and obtain feedback on lateral acceleration and rollover potential. Plots of vertical sight distance as a function of station will also be provided to the designer. These tools will allow the designer to locate inconsistencies and identify potential problem areas for specific vehicle types (such as ramps with high rollover potential or acceleration or deceleration lanes of insufficient length).

When completed, the IHSDM will also include a driver module that contains profiles of a range of driver types (e.g. aggressive, impaired, young, elderly) that can be combined with various design vehicles. Using a virtual-reality approach the designer will be able to

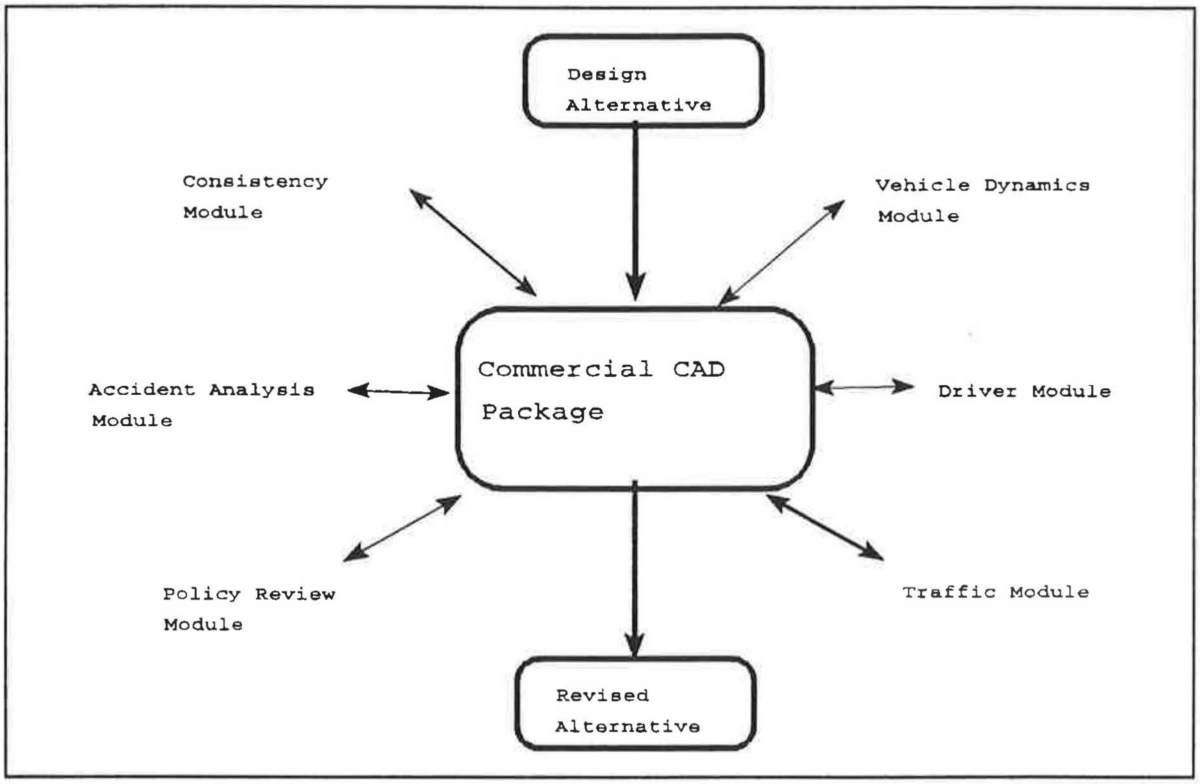

FIGURE 1 Interactive highway safety design model.

"drive" through a three-dimensional image of the design. This will give the designer a visual method of spotting "busts" in the design or inconsistencies that could affect driver performance. This visual review combined with data generated by selected driver/vehicle combinations will provide the designer with a much clearer understanding of the impacts of design decisions on driver performance.

Research is underway in each of the major areas necessary to develop the driver/vehicle performance tool:

- *Design Consistency* — As noted above, it is envisioned that the design consistency model will serve as a core component of the Driver/Vehicle Performance Tool until longer range research into the driver model can be completed. An initial research effort on design consistency, "Horizontal Alignment Design Consistency for Rural Two-Lane Highways" has been completed. This study developed a preliminary model for generating the speed profiles of passenger cars on two-lane rural highways. A preliminary driver workload model based on test track conditions was also developed. A follow-on effort is expected to begin in the fall of 1995. This study will validate the previously developed speed profile model under real-world conditions and expand the model to consider other vehicle types and environmental conditions. Additional work on the driver workload model and in the area of driver eye movement will also be performed.

- *Vehicle Dynamics* — Two efforts were initiated in September 1993 to develop the IHSDM vehicle dynamics module. The vehicle dynamics module will provide a realistic simulation of vehicle performance characteristics for the design vehicles listed in the AASHTO "Green Book." These vehicles can operate at a constant speed using a driver path-following model using a driver look ahead algorithm which incorporates a delay in steering wheel response to account for reaction time. Driver control capabilities will be expanded as work progresses on the driver module. Prototype vehicle dynamics models have been completed and are in the process of being integrated into a CAD environment. This work is expected to be completed by the fall of 1995. Selected State Departments of Transportation will beta test these models beginning in 1996.

- *Driver* — Development of a driver module will be a complex and long-range effort. The interactions between the driver, vehicle and roadway are not well-understood and will require a significant research effort. Two initial development efforts were initiated in March 1995. These studies are developing the functional requirements and design specifications for the driver module. These requirements and specifications are expected to be available in early 1996. They will guide follow-on behavioral research that will be initiated to collect the data necessary to represent the driver in an IHSDM environment.

- *Visualization* — Three-dimensional rendering of major highway design projects has become commonplace among highway agencies for use at public meetings. However, these images are created off-line and not available in real time. The IHSDM will provide the designer with the ability to obtain a three-dimensional view of the actual design, identify problem areas, and interactively correct the problems. Pilot research efforts in the area of virtual-reality have shown promise and work to determine the amount of detail, visual quality, and realism needed to make "design decisions" is schedule to begin in the fall of 1995.

## ACCIDENT ANALYSIS TOOL

The second tool that will be available to the designer will be an accident analysis tool. The purpose of this tool will be to allow the designer to both quantitatively and qualitatively assess the safety impacts of design decisions. In the preliminary design stage this tool is envisioned as a stand-alone computer program that would allow the planner/engineer to input information on the basic design characteristics (alignment, crosssection, intersections, design speed, ADT, etc.) and obtain an estimate of the expected number of accidents. This general information will then be available to the decision-maker as trade-offs between social, economic, and environmental effects are made.

Separate roadway and roadside accident modules are envisioned, along with a diagnostic review module. In the final design process the designer will use a combination of quantitative and diagnostic approaches to assess the safety impacts of the design. Work is underway in the following areas:

- *Roadway Accident Prediction* — The development of accident prediction models has been an area of considerable research in the highway safety field. Unfortunately, many earlier efforts have been constrained by data availability and/or flawed by the use of inappropriate statistical procedures.

The creation of the FHWA Highway Safety Information System (HSIS) provides much better data access. The HSIS contains traffic, geometric design, roadway inventory, and traffic volume data from eight states: California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah, and Washington. These data bases supplemented by additional laboratory (from videodisc photologs) and field data collection will form the basis for the development of the IHSDM models for evaluating preliminary designs. When combined with advances in the application of statistical techniques for highway safety analysis these data bases offer the potential to developed improved accident prediction models.

To provide a framework for development of these models, research in this area has been subdivided by roadway type (rural, urban), roadway class (freeway, multi-lane divided, multi-lane undivided, two-lane), and level of interaction type (roadway segment, intersections, interchanges). Preliminary research into the development of urban intersection models and rural multi-lane segment models has been completed. Development of operational rural, two-lane segment and intersection models is now underway.

- *Roadside Accident Prediction* — The encroachment model now under development under National Cooperative Highway Research Program (NCHRP) Project 22-9, "Improved Procedures for Cost-Effectiveness Analysis of Roadside Features" will be adapted for use in the IHSDM. It will form the basis of the roadside accident prediction module. Evaluation of roadside safety and the impacts of decisions such as the placement of guardrails, luminaire supports, and other appurtenances will be conducted using this module. Encroachments occur when the driver unintentionally leaves the roadway. Given information on the roadway design and the location of roadside obstacles the encroachment models will use a series of conditional probabilities to estimate the ran-off-road crash costs associated with a given design. The designer can use this information to evaluate alternative designs while seeking to minimize the potential crash costs.

Research to improve the trajectory data used in the encroachment model is included in NCHRP Project 17-11 "Recovery-Area Distance Relationships for Highway Roadsides," with supplemental funding being provided by the FHWA. This effort will develop relationships between recovery-area distance and sideslopes and other factors for various highway functional classes and design speeds. The Oak Ridge National Laboratory is modeling horizontal curvature and vertical grade and adjustment factors for rural 2-lane road encroachment rates using State data developed by FHWA.

- *Diagnostic Review* — The third component of the safety analysis tool will be a diagnostic review module. This module is a recent addition to the IHSDM and is still in a conceptual stage. Exploratory research in the accident predictive and vehicle encroachment area pointed out the difficulties of fully assessing the safety of a design in a quantitative model. Even with improved data bases and advanced statistical analysis techniques, quantitative models will not be able to provide the desired level of safety assessment. The diagnostic review module will serve as a storehouse of information that cannot be captured in a modelling context. As currently conceived, the diagnostic review model would be developed as an expert system that could automatically review a potential design and compare it to a knowledge base to identify potential safety problems. These problems would be raised as "flags" to the designer. In many instances, other constraints (cost, environmental, etc.) may preclude the designer from making a change to the design, but these decisions will then be made and documented explicitly.

The key to the diagnostic review module will be the knowledge base. This knowledge base could be developed through a combination of sources, including

- Expert knowledge from experienced designers,
- Utilization of existing research,
- In-depth accident investigation,
- Review of common problems identified by the Highway Safety Improvement Program, and
- Conduct of well-designed before-after studies.

Safety audit procedures developed in other countries may also be instructive in the development of the knowledge base. It is expected that the knowledge base will include both qualitative and quantitative guidance to the designer as available and appropriate. Work on a design for the diagnostic review module will be initiated in the fall of 1995.

## TRAFFIC ASSESSMENT TOOL

The third major tool that will be developed as part of the IHSDM will be a traffic assessment tool. The core of this tool will be traffic simulation models that have been developed by the FHWA for use in traffic engineering. These models will allow the planner/ designer to examine the design under full traffic conditions (as opposed to the driver/vehicle performance tool which will examine individual driver/vehicle combinations). The impact of design decisions on traffic flow can be assessed and insights into the safety impacts of these decisions can be obtained. For example, use of a traffic simulation model on a two-lane rural road design could be useful in identifying areas with large numbers of platooned vehicles and/or aborted passing attempts. This could point out the need for the addition of a short passing section. At intersections, traffic simulation models could identify inadequate turn lane storage lengths which may create traffic flow and safety problems.

It is expected that the models would be designed to operate in a stand-alone manner for use in preliminary design and as part of IHSDM for use in the detailed design process. The integration of the simulation models into the CAD environment will simplify their application. It will provide a direct link to the roadway data (alignment,grades and crosssection) data that is necessary as input to the simulation model. It is also anticipated that the driver model will serve as a source for the driver characteristics used in the simulation models.

Considerable research and development of urban network (NETSIM) and freeway simulation (FRESIM) models has been conducted. These simulation models are now routinely used as evaluation tools in many facets of transportation planning and engineering. Rural road simulation models are not as well developed. Research to improve the quality of existing two-lane simulation models will be initiated in 1995 as part of an NCHRP effort, "Capacity and Quality of Service for Two-lane Highways (NCHRP 3-55(3))." This effort is being jointly funded by NCHRP and FHWA and will develop improved methods and procedures for capacity and quality-of-service analysis of two-lane highways. The resulting model will be incorporated into IHSDM.

## POLICY REVIEW TOOL

This tool will insure that the proposed design complies with established design criteria. This module would identify design elements that are not in compliance and "flag" these elements for review by the designer. In many cases there may be valid reasons for a "design exception." This module will provide a means for explicitly documenting such decisions.

Existing CAD-based highway design packages handle the policy issue in different ways. This effort would review the existing packages and identify opportunities to improve their operation. For example, are there checks for adequate intersection sight distance or decision sight distance? Are there procedures available for ensuring the curvature and grades are in proper balance? Does the program discourage sharp horizontal curves from being introduced at or near the top a crest vertical curve?

The development of the policy review tool is believed to be a straight-forward effort that will require no new research. The major work to be accomplished will be performed in conjunction with the CAD software vendors.

When the IHSDM becomes fully-operational it may be that other modules such as the design consistency, driver/vehicle or diagnostic review make a separate policy module unnecessary.

## CONCLUSION

The IHSDM is an ambitious research program that seeks to enhance the consideration of safety in the highway design process. If successful, the IHSDM will become a standard part of CAD-based highway design packages and will routinely be applied by the State DOTs and their consultants. Explicitly considering safety in the design process will improve the quality of new designs, minimize the number of "black spots" due to highway design problems, and reduce the need to redesign these facilities in the future.

The IHSDM is envisioned as a fluid system that can be improved and updated as new safety research is completed. It can set a standard for the design of future research efforts and serve as the vehicle for translating new highway safety research into practice.

# USE OF FINITE ELEMENT ANALYSIS IN ROADSIDE HARDWARE DESIGN

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## THE PAST

### Introduction

Roadside safety research has progressed through several phases during the past 40 years. The first phase, accomplished in the years around 1960, was to recognize that there was a problem and that it was possible to improve the safety of roadways using engineering design.

In the infancy of roadside safety research it was possible to make significant improvements in safety just by using common sense and basic engineering judgement: keep the vehicle from leaving the road, rolling over, or underriding the barrier; make sure the occupant stays inside the vehicle and nothing harmful penetrates into the occupant compartment. Many of the most common guardrail systems date from this early phase.

The next stage took place in the 1970s and 1980s. More difficult problems were attacked like developing guardrail terminals, transitions and crash cushions. Roadside hardware was developed to address a broad range of specific applications and site conditions. While judgement and intuition were still valuable tools, crash testing became the primary method for exploring the collision performance of barriers. Designers, using their intuition about impact events, were able to produce many useful designs, most of which are still in service today.

Unfortunately, the era of intuitive design in roadside safety is over. The problems that have persisted over the past several decades are the most difficult, most complex and most demanding problems — guardrail terminals, side impacts, and non-tracking impacts and vehicle-barrier interaction problems to name just several. The roadside safety community is now entering a new phase of research where the effort and resources required to produce a successful roadside hardware design have increased as have the expectations of the public. Further improvements in roadside safety will require the use of the best analytical tools available in addition to crash testing and intuition.

This paper discusses only one particular analytical method: non-linear dynamic finite element analysis. Vehicle handling simulation codes represent another important area of research but these methods are not discussed in this paper.*(1)*

### History

The use of analytical methods are not new to roadside hardware design. Perhaps one of the most successful applications of finite element technology to roadside safety was the very first. Researchers at Cornell Aeronautical Laboratory investigated the mechanics of vehicle-barrier collisions for the New York Department of Public Works in the early 1960s.*(2)* Simple analytical models were developed using springs, dash-pots, beams and links to examine the dynamics of vehicles and the strength of barriers. This study was very successful, resulting in evaluations of many at-the-time common guardrails. This study was the first to recognize several now-commonly recognized safety problems with guardrails like (1) the importance of the rail separating from the post to prevent vehicle vaulting, (2) the potential for wheel snagging to occur on strong post guardrails and (3) the potential for pocketing when strong posts are combined with relatively weak rails. This research project was instrumental in improving the designs of the W-beam median barrier and the box beam guardrail designs used in New York to this day as well as the elimination of some poor designs like strong-post cable guardrails.*(3, 4)*

The New York Department of Public Works and the Cornell Aeronautical Laboratory also collaborated on using analytical methods for predicting the response of vehicles when impacting rigid barriers like the concrete safety shape.*(5)* This work eventually lead to the development of the Highway Vehicle Object Simulation Model (HVOSM) which has been widely used in the roadside safety community.*(6)*

The BarrierVII program was developed in the 1970s and has been widely used to simulate impacts with flexible barrier systems.*(7)* The program is a two-dimensional code that contains a variety of simple elements like springs, dash-pots, links, posts, and beams. While the relative simplicity of the code and its models made it very useful for many types of impacts, there were significant limitations to the types of simulations that could be performed because the code represented only two dimensions.

A series of ill-fated projects were initiated in the 1980s to try and develop the next generation of barrier analysis finite element codes. The codes GUARD, CRUNCH and NARD were the result of these efforts.

*(8, 9, 10)* Unfortunately, none of these codes ever gained the confidence of analysis due to a variety of problems including coding errors, poor analytical formulations, and restrictive assumptions. The roadside safety community's negative experience with the NARD and GUARD programs has left a lasting pessimism about the utility of analytical methods in roadside safety hardware design and evaluation.

In 1991 the FHWA sponsored three projects to recommend a plan for developing improved capabilities for analytical simulations of roadside hardware collisions. *(11, 12, 13)* All three plans recommended abandoning special-purpose analysis codes like NARD, GUARD, BarrierVII and HVOSM in favor of the general-purpose non-linear finite element program DYNA3D. *(14)* In a relatively short period of time, the roadside safety community has gone from having virtually no capabilities and experience with general-purpose codes like DYNA3D to building a network of Universities, a national laboratory, several offices in government agencies, and a variety of commercial software vendors.

While some aspects of the simulation effort have been frustratingly slow there has been an exceptional amount of progress in the past four years. Analytical methods are at a critical juncture where they can begin to make a dramatic contribution to the improvement of roadside safety.

## THE PRESENT

### Benefits of Safety Research

Despite the increasing difficulties, there is still a need for further roadside safety research. Two particular results of safety research demonstrate its continued utility:

- Reductions in the fatalities and injuries experienced on the roadside and a consequent reduction of accident costs, and
- Protecting the public's investment in roadside safety hardware.

Both FHWA and NHTSA share the goal of reducing the number, severity, and cost of highway accidents. In the past, NHTSA has concentrated on vehicle-to-vehicle collisions and occupant protection technology, leaving single-vehicle roadside accidents largely to FHWA to address. Single-vehicle accidents occurring off the roadway accounted for 1.4 million accidents in 1992, this represents more than 20 percent of all motor vehicle accidents. *(15)* Accidents occurring on the roadside represent a significant segment of all motor vehicle accidents. FHWA and NHTSA, therefore, share responsibility for 20 percent of the motor vehicle accident problem. Some emerging accident types, like side impacts with narrow objects and the interaction of wedge-shaped vehicles with roadside hardware, probably cannot be improved without a joint effort by both the roadside and vehicle design community.

Once installed, roadside hardware has a service life of 20 or even more years. Vehicles, in contrast, generally do not last more than 10 years and automobile manufacturers can radically change the characteristics of the vehicle population very quickly. The vehicle manufacturing industry can build vehicles that meet all applicable NHTSA safety standards but may not perform correctly with the majority of guardrails, bridge rails and other roadside hardware. For example, recent testing has shown that full-size pickup trucks roll over in 25 degree, 100 km/hr impacts with some strong-post W-beam guardrails. The light truck class of vehicles is rapidly approaching 50 percent of the vehicle fleet. *(16)* This type of longitudinal barrier is the primary guardrail in nearly every state in the United States, lining hundreds of thousands of miles of roadway. Minivans did not even exist a decade ago yet now they represent about 10 percent of the vehicle population. *(16)* No crash tests of minivans and roadside hardware have ever, to the author's knowledge, been performed so the roadside design community has no clear understanding of how such vehicles are performing in the field in impacts with roadside safety hardware. Public agencies cannot afford the investment required to modify hundreds of thousands of miles of longitudinal barrier to continuously chase the moving-target of vehicle characteristics. Even if public agencies could afford it, the time required to retrofit this much hardware would be enormous and the changes could be obsolete before they were completed.

State governments have a substantial investment in roadside safety hardware. Currently there are no standards that ensure that this investment is not made obsolete by rapid changes in the vehicle fleet. One way to protect the public's investment in roadside safety hardware would be to perform a "standard" test of new production vehicles on selected "standard" items of roadside safety hardware like the strong-post W-beam guardrail and the concrete safety shape (the so-called New Jersey shape). Given the relatively high degree of standardization in the roadside barrier community, it seems reasonable to require that vehicle manufacturers demonstrate that new vehicles will interact correctly with common types of roadside safety hardware.

### Vehicle-Barrier Interaction

Occasionally, roadside safety researchers run a full-scale crash test and observe an unexpected catastrophic failure that, after further investigation, seemed to be caused more by some feature of the test vehicle than the roadside hardware. This would prompt the question, "what is being tested, the hardware or the vehicle?" These types of vehicle-related failures have been observed more frequently during the past several years as researchers began to perform more tests with pickup trucks to comply with NCHRP *Report 350* and as tests with vehicles other than passenger cars became more common. *(17)* It is becoming increasingly difficult to treat the vehicle, the roadside barrier and the roadside geometry as independent elements that can be designed with little thought about the other two.

Side impacts with narrow objects like trees and utility poles accounted for more than 8 percent of all traffic related fatalities and 20 percent of all single-vehicle run-off-road accidents in the period between 1980 and 1985. *(18)* Better warrants for removing selected trees and relocating utility poles would reduce this somewhat but significant changes will require the attention of both the vehicle design community and the roadside safety and roadway design communities. Side impacts are also a problem with breakaway hardware like luminaire supports, small signs and guardrail terminals. *(19)* Testing has shown that it is nearly impossible to weaken a guardrail terminal sufficiently to improve side impact performance without destroying the terminal's effectiveness in end-on impacts. Improved performance for side impacts with guardrail terminals (thought to be about 1/3 of all guardrail terminal collisions) will require improvements to the side structure of vehicles as well as better terminal design. *(18)*

Poor performance has been observed recently in pickup truck impacts with guardrails and guardrail terminals. *(20)* A preliminary evaluation of these tests suggests the problem may be caused by (1) the inertial and stability properties of the truck, (2) particular aspects of the suspension design that promote failure in barrier collisions, and (3) the short overhang distance between the front bumper and front wheel. While improvement in the performance of some roadside hardware devices can probably be achieved for some specific impact conditions, this class of vehicles appear to have serious performance problems in barrier impacts that might only be solvable by improving the design of the vehicle or at least better understanding the interaction between the vehicle and barrier. Problems with the pickup truck suggest that there may be similar problems with the new cab-forward passenger car designs.

Aerodynamically shaped front ends on most new vehicles have been shown to perform catastrophically in end-on impacts with terminals. *(21)* Modifications to the terminal noses have not yet significantly improved the results. Anecdotal evidence has appeared in the literature to show that there can be problems with aerodynamically styled vehicles under-riding some types of guardrails. *(22)*

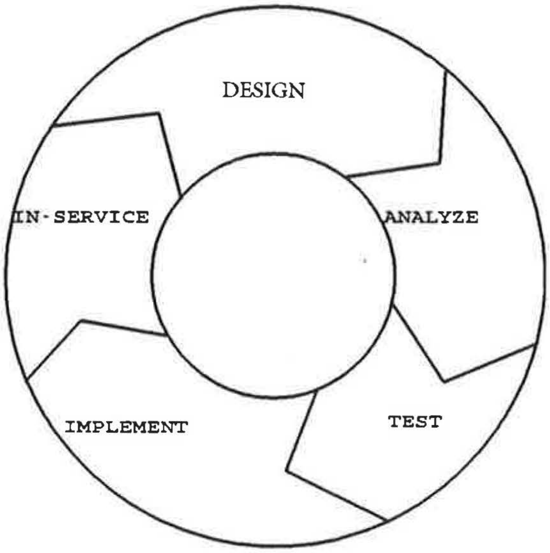

FIGURE 1 Roadside safety hardware development cycle.

These are just a few examples where the changing geometry and properties of vehicles have made obsolete barriers that once performed quite well with the vehicle fleet of five and ten years ago.

## Roadside Hardware Design

Finite element analysis should be incorporated as an integral part of the roadside safety hardware design process. In today's funding climate, with today's difficult research problems it is just not feasible to expect to test every impact scenario. Figure 1 shows a representation of the roadside safety research cycle: design, simulation, test, implement, and in-service evaluation. Currently a researcher designs hardware and tests it, repeating and refining until either a successful design is produced or funding evaporates. Hardware is installed based on the results of these research and development tests. Even though the need for in-service evaluation is universally recognized, an effective means of accomplishing an in-service evaluation has yet to be found so the "loop" in practice is seldom ever closed. The subject of this paper, however, is the increasing importance and utility of the analysis phase of the roadside hardware development cycle.

When designs are simple an analysis phase is often unnecessary. As designs become more complicated, however, an explicit analysis step should be performed. Analysis can help identify and correct problems in the design prior to testing. Several issues will necessitate the increased use of analytical methods in roadside safety research:

- Tests cannot provide enough information about the loads, accelerations, stress and strains of barrier components to develop designs based on the mechanical behavior of barrier components.
- Repetitive tests are expensive and not well suited to parametric analysis.
- It is impractical to test with the full range of vehicles that should be examined.
- It is not possible to examine the affects of a variety of test conditions like non-tracking pre-impact trajectories, side impacts, and driver braking and steering during impact.

There are three steps in integrating finite element analysis into the design process:

- Simulations that explain the results of tests,
- Simulations that predict the results of tests, and
- Simulations that evaluate impact scenarios that are untestable.

The first step is to use finite element analysis to examine tests that have already been run. Such analysis can be used to examine the stresses and strains, accelerations and velocities, and failure mechanisms in a particular impact scenario in order to gain a better understanding of the impact event. This improved understanding can then be used to develop better design alternatives, examine the sensitivity of particular design elements to impact conditions or variations in material properties, or to estimate evaluation criteria. Currently, nearly all the work in using finite element methods in roadside hardware fall into this category.

The next stage is to use finite element analysis to predict the likely outcome of a full-scale crash test before the test is performed. This might be used to pick the most promising of several possible design alternatives, to identify the most critical crash test, or to identify the worst-case test vehicle for a particular piece of hardware.

The last stage is to use finite element analysis to evaluate the performance of hardware in situations that cannot be tested. Examples of this type of use include examining non-standard impact conditions like yawing prior to impact, braking and steering during impact, traversing a non-level terrain prior to impact. Simulations could also be used to test non-standard vehicles or prototype vehicles. This use of finite element analysis will enable engineers to examine collisions that would be impossible to test and thereby design hardware that performs more reliably under a wide range of real-world conditions.

The emerging roadside safety environment will require roadside hardware that performs with a wide range of vehicle types over a wide range of impact conditions. While full-scale crash testing will always be a crucial part of roadside safety research it can no longer remain the sole tool for exploring the performance of the roadside.

### Analysis Codes

FHWA, NHTSA and LLNL have actively promoted integrating nonlinear finite element technology into the roadside hardware design and evaluation process. As with any large technical program there have been both successes and failures, exploited and missed opportunities, consensus and dissent.

The available analysis codes, DYNA3D and LS-DYNA3D, can be used to solve many roadside hardware design problems. Analysts have not yet come close to fully exploiting the capabilities of these codes in the area of roadside hardware. A series of meetings were held in 1992 and 1993 to assemble simulation users and experts and discuss approaches to take in integrating finite element methods into roadside hardware design. While much useful information was exchanged these meetings largely failed and were ultimately discontinued because they simply generated shopping-lists of "enhancements" rather than focusing on how finite element techniques could be used to produce useful results immediately. Focusing on "enhancements" to the numerical codes at this stage is unnecessary, premature and it is a distraction from the real task at hand — improving the design of roadside safety hardware. Enhancements should be driven by the practical problems of hardware designers rather than by the speculation of researchers.

### Vehicle Models

When the FHWA began its effort to use DYNA3D in roadside hardware assessment, no one anticipated how difficult it would be to obtain vehicle models. Table 1 shows all the vehicle models that are publicly available for roadside hardware research along with some summary information. These models were developed by a variety of organizations for a variety of purposes so the size, complexity and speed vary considerably. Size in Table 1 is defined as the number of elements in the vehicle model. Although characterizing models by the number of elements alone does not give a complete picture of the model's likely performance, it does serve as a good first indicator of model complexity. The model speed is perhaps the best characteristic to examine, where speed is the amount of event time (in

TABLE 1 F4 VEHICLE MODELS DEVELOPED FOR USE IN ROADSIDE HARDWARE ANALYSIS

| Model | Size* | Speed† | Preprocessor |
|---|---|---|---|
| Saturn | 2,260 | 100 | Ingrid |
| Honda | 10,100 | 8 | Ingrid |
| 820C | 5,200 | 20 | Ingrid/ TrueGrid |
| Taurus | 28,350 | 2 | Patran |
| C-1500 | 35,100 | 0.67 | Patran |

*Size is the size of the model in terms of the number of elements.
†Speed is the estimated amount of simulated time in msec per CPU hours on an IBM RISC 6000 Model 390 workstation.

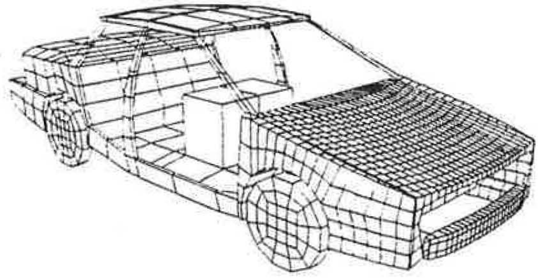

FIGURE 2 Model of a 1991 GM Saturn.

msec) that is simulated in one CPU hour of computation. As shown in Table 1, speeds of the available models vary from 0.67 msec/CPU hrs for the C-1500 pickup truck to 100 msec/CPU hrs for the Saturn. Clearly an analyst pays a heavy price in increased computation time when using the larger vehicle models. While a high degree of complexity may be required for designing vehicles, evaluating occupant restraint systems or assessing the likelihood of occupant compartment intrusion, it is still unclear how complex a vehicle model must be to provide good results in roadside hardware simulations.

The first model developed for roadside hardware research was a simple model of a 1991 GM Saturn shown in Figure 2. *(23)* This model was developed for FHWA by physically measuring the vehicle and building a simple mechanical analogue. The model was used to simulate a frontal impact with a slip-base luminaire support, a rigid wall, and a U-post sign support to demonstrate the utility and feasibility of using nonlinear finite element analysis. This model was the first successful application of DYNA3D to a roadside safety hardware problem.

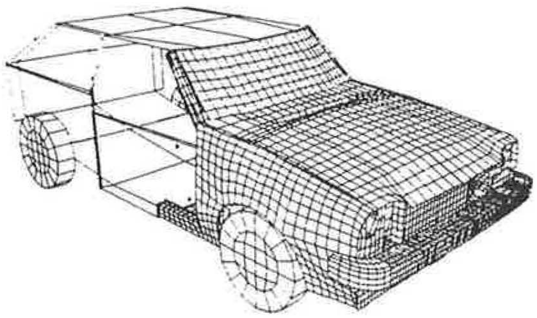

FIGURE 3 Model of a 1981 Honda Civic.

Concurrently with the effort to develop the Saturn model, the FHWA sponsored the development of a frontal impact model of a 1981 Honda Civic, a vehicle frequently used in past crash tests. The model, shown in Figure 3, was developed by a firm that specializes in developing vehicle models for the automotive industry. The model was developed using a forensic approach; the vehicle was taken apart, photographed, scanned, measured and otherwise documented. These data were then used to build the geometric representation and material characterization of the vehicle. There were numerous problems with this vehicle when other researchers tried to use it for roadside safety applications. Extensive additional work was required before reliable results could be obtained. *(24)*

A simple model of an NCHRP Report 350 820C vehicle, shown in Figure 4, was developed for FHWA to try and obtain a vehicle model quickly that would allow researchers to focus on developing roadside hardware rather than building vehicle models. *(25)* The model was intended to be relatively generic although it was largely based on a 1990 Ford Festiva. The model was initially developed for frontal impacts into narrow objects but it is also being used for frontal impacts with guardrail terminals and redirectional collisions with guardrails and bridge railings.

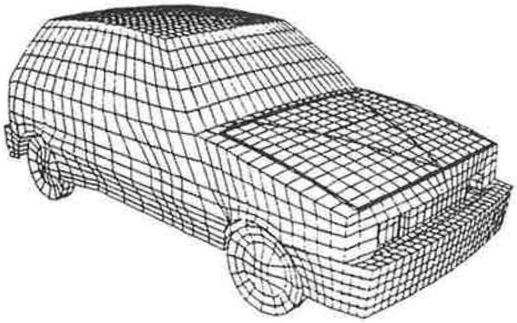

FIGURE 4 Model of an 820C vehicle.

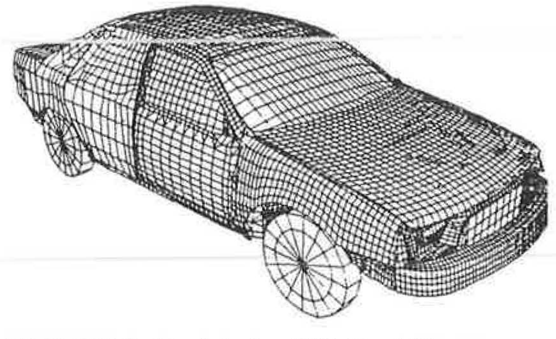

FIGURE 5 Model of a 1991 Ford Taurus.

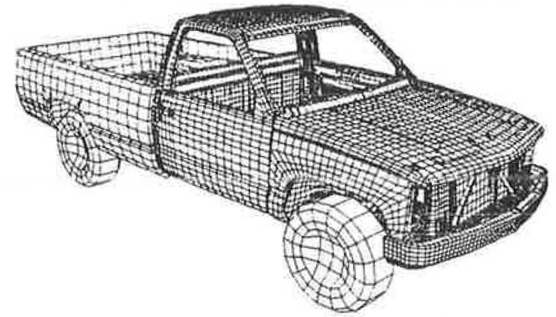

FIGURE 6 Model of a 1994 Chevrolet C-1500 pickup truck.

NHTSA sponsored the development of a 1991 Ford Taurus, also produced by an automotive crashworthiness analysis company. *(26)* This model has been extensively modified as it was used in a variety of new situations not foreseen when it was originally developed. *(27)* This model has not yet been used in roadside hardware simulations but has been extensively used in simulations of frontal rigid wall impacts, off-set frontal vehicle-to-vehicle impacts, and frontal narrow object impacts and occupant compartment intrusion studies. There is also a version of this model available for narrow-object side impact collisions. NHTSA is also sponsoring the development of models of a Dodge Intrepid and a GM Saturn at West Virginia University.

The most recent vehicle model to be developed, shown in Figure 6, is a 1994 Chevrolet C-1500 pickup truck. This model, which was jointly developed by NHTSA, FHWA, and George Washington University, was also developed using a forensic approach where the vehicle was disassembled, scanned and connections were meticulously documented. The result was a very large, very complicated model that, while being detailed, is difficult to use unless one has sophisticated computing facilities and is prepared for long run times. The Chevrolet C-2500 is the pickup truck conforming to the 2000P vehicle designated in Report 350. The differences between the C-1500 and C-2500 are relatively minor: heavier suspension, larger tires and a slightly longer wheel base on the C-2500. FHWA is currently sponsoring an effort to simplify this model so that it is more useful to roadside hardware researchers using DYNA3D on typical engineering workstations.

The most serious obstacle to using finite element methods in designing roadside hardware today is the scarcity of the right kind of vehicle models. There has been a presumption that the biggest, most complicated models would by definition provide the most accurate solution. Given the rapid advance of computing technology, the fact that large complex models require very large investments in computing hardware should only be a short-term irritation according to this view. While this may prove true in the long run, if finite element analysis cannot begin to produce practical results that solve operational hardware problems almost immediately, it is unlikely that a program in roadside hardware finite element analysis will survive.

Modelling vehicles using non-linear finite element analysis is not in itself new, in fact automobile manufacturers and NHTSA have been making extensive use of DYNA3D and LS-DYNA3D for nearly a decade. Using this type of analysis in roadside hardware design, however, *is* new and it is not necessarily true that the same techniques that worked in the automotive design arena will work in designing roadside safety hardware. Roadside hardware impact simulations must address inertial properties of the vehicle to a much more detailed degree. The roll-pitch-yaw rotations of the vehicle are a very important aspect of a roadside hardware test since these indicate the stability of the vehicle. Typical FMVSS tests do not generally involve rotational degrees of freedom to any great extent so modelling these features has not generally been a priority. Until very recently, there was no simulations of a vehicle in an angled impact where the rotation of the vehicle was physically reasonable. The affect of the suspension system on the kinematics of the vehicle is also generally not considered in vehicle models generated by the automobile industry yet in roadside hardware impacts, the suspension effects can frequently be critically important. Lastly, catastrophic failures can be observed in full-scale crash tests that are accompanied by relatively little vehicle damage. This illustrates that the kinematics of the vehicle are more important in roadside hardware simulations than they generally are in automotive crashworthiness simulations. The structural crashworthiness is seldom the deciding factor in whether a full-scale test passes or fails the Report 350 evaluation criteria.

At this time it is still unclear what types of models are needed. Some types of research, for example studying the toe-pan intrusion in a vehicle, will require large complex models of the vehicle. Other types of

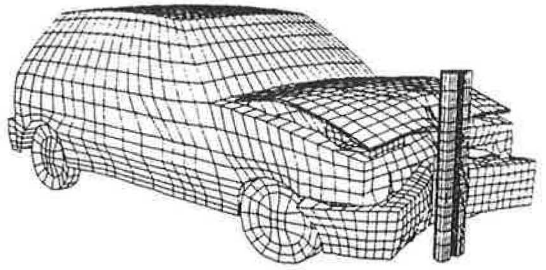

FIGURE 7 32 km/hr impact of an 820C vehicle with a rigid cylindrical pole.

impacts, for example the glancing-blow impact of a guardrail terminal (Test 3-32), depend almost completely on inertia and kinematics so a very simple model would be appropriate. Determining what types of model are appropriate in different situations and how to develop and maintain these models will doubtless be a point of debate for some time. Ideally, the vehicle models used by FHWA and NHTSA should be the same. Given the difficulty and expense of building these models it would be foolish not to collaborate. There are a variety of options:

- Develop high-order models and wait for computing hardware and software advances to erode the computational penalty.
- Develop high and low-order meshes at the same time.
- Develop models specifically targeted for each application.

Each strategy has its advantages and disadvantages and it is difficult at this early stage to predict the best strategy.

**Roadside Hardware Models**

There have been a variety of efforts to model roadside safety hardware during the past several years despite the difficulty of obtaining vehicle models.

The first several roadside hardware applications of DYNA3D were of small car frontal impacts like the rigid pole and U-channel post simulations shown in Figure 7 and Figure 8. The rigid pole simulations are very useful for validating frontal-impact vehicle models for narrow object impacts. Flanged-channel post simulations have been performed using the Honda Civic and 820C vehicle models. The flanged-channel sign support model has been investigated by several analysts, most recently with respect to finding an appropriate method for modelling the soil. *(28, 29)*

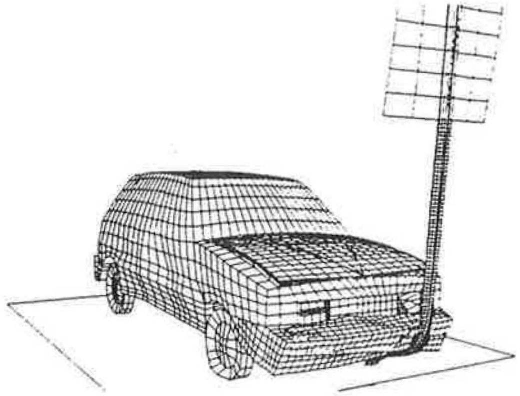

FIGURE 8 32 km/hr impact of 820C vehicle with a flanged-channel sign support (Test 3-60).

Recent poor test results of pickup trucks in impacts with several standard guardrail terminals have generated interest in simulating these types of impacts. A modified eccentric loader BCT (MELT) guardrail terminal was modelled and simulations of Report 350 Tests 3-30 and 3-32 were performed using the 820C vehicle model. The small car model was used first since there is test data available for the Test 3-30 conditions (820C — 100 km/hr — 20 degrees) which allowed the analyst to begin evaluating the performance of the model prior to investigating the performance of the pickup truck. Figure 9 shows the small car Test 3-30 impact. After the model of the MELT was found to perform well in small car impacts, the Chevrolet C-1500 pickup truck model was combined with the MELT model as shown in Figure 10. The simulation was encouraging but the vehicle did not roll, pitch, or yaw as it should have. The actual crash test resulted in a rollover whereas there were no stability problems apparent in the simulation. Further investigation found that there was a problem with the analysis code that has since been corrected although the model has not been rerun.

Performance problems have also been observed in pickup truck impacts with common guardrails like the G4(1S). As a first step toward modelling this system, an 820C vehicle impact under Report 350 Test 3-10 conditions (820C-100 km/hr-20 degrees) was modelled as shown in Figure 11. This was done so that the hardware model could be debugged and compared to existing test data prior to predict its performance in pickup truck impacts.

Some independent research (research not sponsored directly by FHWA) is also beginning to be performed as the DYNA3D code is made available to Universities and other research organizations with an interest in roadside hardware. Figure 12 shows an example of a turned-

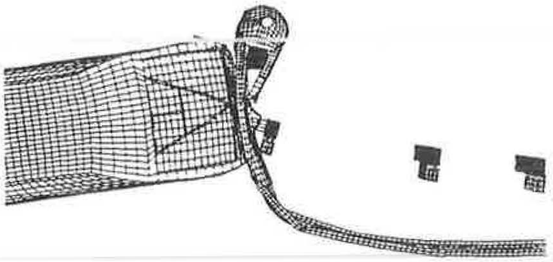

FIGURE 9 100 km/hr impact of an 820C and a MELT guardrail terminal (Test 3-30).

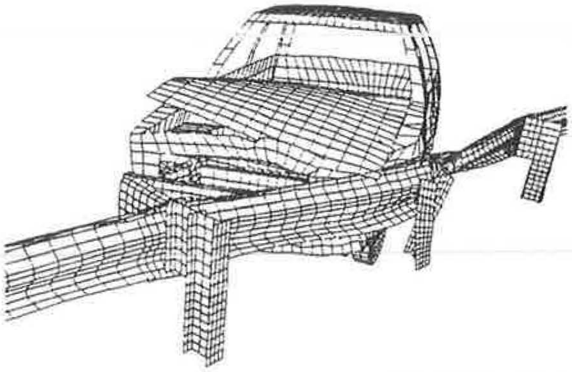

FIGURE 11 100 km/hr impact of an 820C vehicle and a G4(1S) guardrail (Test 3-10).

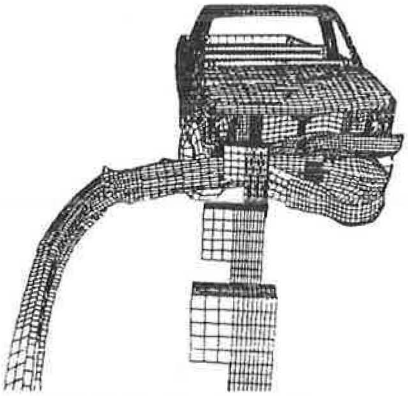

FIGURE 10 100 km/hr impact of a C-1500 pickup truck and a MELT guardrail terminal (Test 3-31).

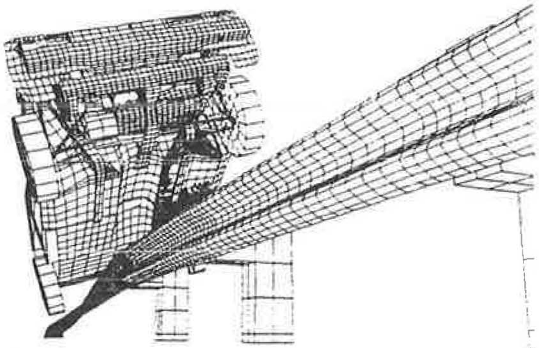

FIGURE 12 100 km/hr impact of an 820C vehicle with a turned-down guardrail terminal (Test 3-30).

down guardrail terminal being impacted by the Honda Civic model at 100 km/hr. *(30)* This simulation was performed as a part of a State-sponsored research effort to find a crashworthy retrofit for the once-popular turned-down guardrail terminal. This research was the first where nonlinear finite element analysis was used to examine a variety of design options that were then tested in a full-scale crash test.

As these examples illustrate, the use of finite element analysis steadily progressed from relatively simple impacts to quite complicated, realistic impact scenarios.

### Organizations

There are a variety of organizations, groups and individuals involved in bringing nonlinear finite element analysis to roadside safety research. NHTSA has been instrumental in funding research and promoting the use of these tools in crashworthiness and biomechanics research for many years. During the past four years, the FHWA has aggressively promoted both the use of these methods in roadside safety and closer collaborations with NHTSA. A natural and very positive collaborative spirit is beginning to link the finite element work in both agencies. Hopefully, this collaboration in finite element analysis will foster a broader appreciation of vehicle and barrier design in both agencies.

In 1992 FHWA, NHTSA and Lawrence Livermore National Laboratory established a cooperative agreement for advancing the capabilities of finite element technology for roadside hardware design and vehicle crashworthiness research. Establishing working relationships with the developers of the codes and experienced analysts has helped advance the community toward a higher level of expertise.

Perhaps the most significant thing that FHWA and NHTSA have done and can continue to do is to build a community of nonlinear finite element users in the roadside research arena. This community already includes FHWA and NHTSA as well as the Lawrence Livermore Laboratory, commercial code developers, Universities and consultants. Perhaps the key lesson from the FHWA's experience in trying to develop

TABLE 2 ROADSIDE HARDWARE MODELS BEING DEVELOPED BY UNIVERSITIES

| | |
|---|---|
| Carnegie-Mellon University | — IL 2399-1 bridge railing |
| Florida State University | — G2 weak-post W-beam guardrail |
| Texas A&M University | — Slip-base luminaire support |
| University of Colorado, Boulder | — Transformer base luminaire support |
| University of Mississippi | — Modified three-beam guardrail |
| University of Nebraska | — Dual-leg slip-base sign support |
| Vanderbilt University | — NCIAS crash cushion |

GUARD and NARD is that research performed in isolation from the end-users seldom succeeds. Building a network of collaborators is more difficult but more beneficial than harnessing competitors.

The FHWA is promoting the National Crash Analysis Center (NCAC) at George Washington University as the repository and developer of vehicle models for roadside hardware simulation. Modelling roadside hardware will be distributed among a variety of universities and contributors. In principal it is a natural mission for a center jointly funded by NHTSA and FHWA to be responsible for vehicle models since it is vehicles that link the two agencies. The success of this arrangement, however, depends on a close collaboration between vehicle model developers and hardware analysts that has, as yet, failed to developed.

In 1994 the FHWA initiated cooperative research programs with seven Universities to develop roadside hardware models. The Universities participating in the program, along with the hardware they are modelling are shown in Table 2. Each of these small research grants are beginning to generate useful roadside hardware models. The objective of the program was to begin to build a network of Universities with the experience required to build good production models and perform analyses.

## THE FUTURE

A great deal of progress has been achieved during the past several years in integrating non-linear finite element analysis into the roadside hardware design process. There is still, however, much work remaining before analytical methods achieve their full potential. The computer software tools are available and computing hardware continues to improve at a rapid rate making these analyses increasingly more feasible.

There is a critical need for vehicle models in addition to those shown in Table 1. Vehicle models are needed that:

- Are in the public domain.
- Accurately replicate the kinematics of a vehicle before, during and after the impact.
- Can run to completion a typical 200 msec or longer barrier impact on a workstation in less than 24 hours.
- Represent the types of vehicles used in barrier testing as well as emerging problem areas.

There is an immediate need for vehicle models that correspond to the Report 350 test vehicles, most particularly for test level four and below.

### 820C

The current 820C model was never intended to be anything more than an intermediate model that could be used while a better vehicle model was developed. Unfortunately, there appears to be no specific plan for replacing or upgrading this model. A project was recently initiated to investigate emerging small-car vehicle platforms but this effort will only recommend what platform should be used in testing and analysis. *(31)* This suggests that a new 820C vehicle is many years away.

### 2000P

The most troublesome operational issues in roadside safety hardware research today involve recent testing with pickup trucks. The large size of the current model greatly diminishes its utility to roadside hardware designers. It is simply not reasonable to expect users to devote 1000 or more CPU hours to a single run, especially since it has never been demonstrated that this level of detail is necessary. Obtaining a pickup truck model that can be used on a workstation should be FHWA's highest priority.

### 8000S

There are currently no models of trucks available for roadside safety research and there are no plans for the development of such models. The 8000S is a key vehicle for bridge rail testing since test level four corresponds roughly to AASHTO PL-2.

There will be a need for other types of vehicles as well in the coming years: minivans, sport utility vehicles, and cab-forward vehicles to name just several. At some point the roadside hardware community must determine what types of models are required to evaluate the performance of roadside appurtenances. The development of vehicle models has been expensive and time consuming. Given the vehicle model, developing and using barrier models can be done by a variety of Universities and research contractors. The government must, however, take the lead in developing and maintaining vehicle models in the public domain that can be used by roadside hardware researchers.

At this early stage it is vital that the FHWA concentrate its scarce resources on producing practical results that help address pressing operational questions: the performance of pickup trucks on common guardrails and terminals, the performance of mini-vans in hardware impacts, the effect of non-standard impact conditions on vehicle kinematics and many more. If finite element analysis is not part of the solution to these current problems, the simulation community will have missed a rare opportunity to prove the utility of analytical methods.

The use of finite element analysis has great potential for improving roadside hardware designs. Transforming this potential into action, however, requires leadership and a clear vision of how finite element analysis fits into the overall roadside safety program.

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# CRASH SIMULATION FOR IMPROVING HIGHWAY SAFETY HARDWARE: STATUS AND RECOMMENDATIONS

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## BACKGROUND AND PURPOSE

The Lawrence Livermore National Laboratory (LLNL) has been under contract to the DOT/FHWA's Turner-Fairbank Highway Research Center (TFHRC) since early 1992. Our work has focused on assisting TFHRC implement state-of-the-art vehicle crash simulation methodology for use in improving the design and evaluation of highway roadside safety hardware.

The impetus for LLNL involvement with TFHRC was born following the results from three independent studies contracted by TFHRC. All three recommended using finite element (FE) methodology and further that LLNL's DYNA3D, an explicit FE code that performs nonlinear large deformation dynamic analysis, was their code of choice. Essentially 100 percent of all vehicle crashworthiness analysis conducted by the automobile industry is performed using DYNA3D or one of its derivatives (e.g., LSDYNA, PAMCRASH).

LLNL's initial work was to assist TFHRC develop a comprehensive planning document that incorporated our DYNA3D*(1)* and NIKE3D*(2)* FE methodology as the basis for a multi-year program to develop the next generation computational tools for highway roadside design engineers and researchers. The resulting document is entitled *Vehicle Impact Simulation Advancement (VISTA): Planning Document (3)*. Major development tasks that were identified included: system architecture/user friendly interface; vehicle handling simulation program (NIKE3D); crash/impact simulation program (DYNA3D); vehicle, roadside hardware, and terrain models; and validation/correlation with crash test data. The plan suggests the development could take 7 years and cost as much as 7 million dollars.

Motivations for the VISTA planning document were numerous. Computational tools being employed at that time were inadequate to predict the interaction of vehicles and roadside structures. State-of-the-art computer hardware and software had evolved to the point where a powerful, versatile, user-friendly vehicle impact/handling simulation code could and should be produced. Full-scale crash testing of safety appurtenances such as longitudinal barriers, crash cushions, terminals, etc. are almost entirely limited to a few impact scenarios involving tracking vehicles. Most actual accidents bear little resemblance to these idealized conditions. Significant expense associated with full-scale testing, coupled with the practical limitations of crash testing technology, combine to limit the number and variety of impact scenarios which can be crash tested. An improved capability to accurately simulate vehicular dynamic responses and impacts with roadside features would result in more cost-effective roadway designs and roadside safety features. It would also permit a reduction in the number and expense of full-scale tests needed to develop new hardware. Most importantly, lives would be saved since a better understanding of hardware performance would improve hardware designs.

Along with the development of the VISTA planning document, TFHRC started to assemble a team of technical resources to assist them in the development and implementation of the program. Team members came from TFHRC, the National Crash Analysis Center (NCAC), and LLNL. In addition, LLNL contracted several consultants and formed a Technical Support Group (TSG) to provide advice and guidance. TSG members included experts from General Motors, University of Milan, Vanderbilt University, Momentum Engineering and University of Nebraska.

Over the last three and one-half years, as the result of assembling this team and the contributions of the TSG, TFHRC has made significant progress towards the implementation of FE methodology as the computational tool to perform vehicle crash simulation aimed at improving highway safety hardware.

The purpose of this paper is three-fold: (1) indicate major areas of progress made by TFHRC and their team; (2) identify areas where progress was slow; and (3) suggest how, with more focused management, progress could be accelerated even faster and in a more effective manner.

## RECAP OF THE LAST 3-1/2 YEARS

Over the last three and one-half years TFHRC has made significant progress toward developing and establishing state-of-the-art finite element technology, using DYNA software, as a crash simulation tool for highway roadside hardware design engineers and researchers.

Below is a list of progress:

- TFHRC appears to have abandoned, for the most part, the use of dated computer codes such as HVSOM, BARRIER IV, GUARD, and NARD.
- The TFHRC team is using state-of-the-art finite element analysis codes such as DYNA and LSDYNA and input/output software packages such as INGRID, LSINGRID, TRUEGRID, PATRAN, TARUS, LSTARUS, and GRIZ.
- TFHRC has purchased several workstations (IBM RS 6000 and Silicon Graphics) and have access to CRAY YMP computer time at the Universities of Mississippi and Alaska.
- TFHRC has assembled and funded a sizable team of technical resources to assist them. This includes: George Washington University (NCAC); faculty and graduate students from eight other Universities (via grants); consultants (e.g., Momentum Engineering, LS-Software and EASi Engineering) and LLNL.
- TFHRC has developed considerable experience applying the FE methodology to vehicle/roadside hardware crash simulation. Specific examples of accomplishments include: a Ford Festiva model for barrier impact studies; a digitizing procedure for vehicle surface definitions which was used to develop a C1500 truck model; numerous barrier models developed by Universities; enhanced features to DYNA3D; material evaluation for FE constitutive models; a Taurus model that was made available to Universities; a BCT barrier FE model; a U-channel FE model; and a MADYMO (occupant model) to DYNA3D linkage.
- TFHRC staff is starting to realize the advantages *and* limitations of FE analysis.
- TFHRC started developing closer collaborations with DOT/NHTSA.
- TFHRC is setting up an internet *crash simulation discussion group* where computer simulation problems, solutions, etc. are shared.

In contrast with the above achievements, below is a list of items and/or issues that did not progress as well as expected. In the future, more attention should be focused on these items.

- No specific overall implementation plan was adhered to. Changing plans brought considerable waste of time and effort. For example, the VISTA planning document was not implemented and more specifically, the plan to couple a real-time handling code to DYNA was suddenly funded without sufficient discussion.
- Crash simulation efforts performed by various resources are not being effectively coordinated and focused by the TFHRC team.
- The TRB Roadside Safety Features Committee (A2A04) and Subcommittee on Computer Simulation were underutilized.
- The quality and quantity of crash simulation work could be improved. TFHRC does not have resident staff that is sufficiently trained and experienced in FE analysis. The university collaborators are still in a learning mode and lack seasoned FE experience in vehicle and barrier model development and in simulation of actual crash events. In the near term, TFHRC could benefit greatly from associating more closely with institutions that possess experienced FE analysts.
- TFHRC's interpretation of what constitutes a "good" crash simulation calculation should be improved. Methods for measuring the success of a computer simulation application must be defined. Often insights and invaluable knowledge can be gained from crash simulation results using "not yet validated" vehicles and roadside hardware models. In general, the more simulation calculations made with various models and impact scenarios the more one gains.
- TFHRC must define a more efficient process to get validated vehicle and highway hardware models. All model development should be done within the context of the crash problems being addressed and should include an experienced code user (10+ years of FE code running experience) with a modeler who would provide model review during model development.
- Documentation available to the TFHRC team needs improvement. This includes: codes, vehicle, hardware and soil models; and crash analysis results. TFHRC could take a stronger role in encouraging more effective collaboration between experimenters and FE analysts to improve the simulation models and the physical test requirements.

## THE NEXT 5 YEARS

Great opportunity exists for progress. TFHRC is only just beginning to tap the potential of finite element technology as a computer simulation tool. Our goal is still new state-of-the-art software evolved to the point, where a powerful, versatile, user-friendly vehicle impact/handling simulation code(s) can be performed routinely. This will reduce costly testing, and permit analysis of hardware systems for a wide variety of vehicles, speeds and impact scenarios (including non-tracking) and post impact (i.e., trajectory simulation), provide hardware designers with a stress analysis and evaluation tool, permit evaluation of hardware designs and prototypes and the application of different materials.

The "best" way to maximize progress towards the incorporation of FE/DYNA-like methodology would be for TFHRC to hire a full-time in-house staff of 10 to 12 experienced FE code experts 10+ years DYNA-like code experience. Supplement this staff with vehicle modeling experts from auto industry and expert highway roadside hardware design engineers and researchers. This approach does not appear to be feasible. The "next best" approach, might be to contract a *single* organization that has the FE code expertise. Supplement that organization with the experts from the auto industry and highway community. A third approach, the one chosen by TFHRC, is to develop an external "team" to assist them. This approach can work provided that careful management controls are put into place to assure that "team" members are qualified to perform the functions assigned; that "team" member assignments are part of a well-defined action plan; that "team" members work together; and that the quantity and quality of work produced is high.

Below are four critical management issues that need attention if TFHRC wishes to speed progress towards the development and implementation of improved computer tools to address vehicle/roadside hardware crash simulation. Following these recommendations should help eliminate most of the concerns expressed in the previous section.

1. *TFHRC computer simulation efforts need stronger management.* Establish a single point-of-contact in the Design Concepts Research Division at TFHRC to be responsible for the development and implementation of improved computer tools for highway design engineers and researchers. This person needs to balance and coordinate design, testing and computer analysis activities in the Division and must recognize that the most practical, cost-effective way to improved roadside safety hardware is through computer simulation. The goal should be to limit vehicle crash testing only to validate computer simulation.

2. *TFHRC should develop a detailed 5-year crash simulation program development plan and be committed to the plan.* The 5-year program plan might use the VISTA planning document as a starting point and update it by incorporating insights gained over the past 3-1/2 years.

The plan should be consistent with the underlying philosophy of NCHRP 350*(4)*: (a) ensure structural adequacy (i.e., contain, redirect, permit controlled penetration of impacting vehicle or permit a controlled stop in a predictable manner), (b) minimize occupant risk (i.e., the degree of hazard to which the impacting vehicle occupant is subjected), and (c) predict after-collision vehicle trajectory (i.e., probable involvement of other traffic).

Technical issues for consideration in the plan could include

- Identify code development needs;
- Identify targeted computer hardware for both vector and parallel computational machines;
- Define type of impact analysis and simulation to be addressed: impact speeds and approach angles, frontal and side impact, rollover, pre-impact, and post-impact;
- Select vehicle types to be modeled: mini-compact and subcompact passenger cars, standard 3/4 ton pickups, single unit trucks, and tractor-trailer cargo trucks;
- Select highway hardware to be modeled: longitudinal barriers, crash cushions, breakaway or yielding supports for signs and luminaries, breakaway utility poles, truck mounted attenuators, and work zone traffic control devices;
- Define parameters for measuring success of computer simulation applications; and
- Define "validation" for vehicle and roadside hardware models.

The documentation should include a comprehensive implementation plan that (1) establishes tasks, (2) identifies specific TFHRC team member work, (3) includes schedule and costs associated with each task, and (4) and overall plan as to how all tasks will be coordinated to meet program goals and objectives. A prioritization of technical issues will be required as part of the implementation plan.

3. *Establish Crash Simulation Technical Review Committee (CSTRC).* CSTRC's charter should include (a) review and validation of the TFHRC's 5-year plan and (b) semi-annual reviews of all TFHRC contractor work (model development and crash simulation analysis) and report quality level to TFHRC management.

The CSTRC should report to the single point of contact identified in the Design Concepts Research Division at TFHRC. The CSTRC members should be made up of acknowledged technical experts in FE modeling and analysis, highway safety hardware design and regulatory issues. Experts could be sought from organizations such as the automobile industry, roadside hardware manufacturers, TRB Roadside Safety Features Committee (A2A04) and/or Subcommittee on Computer Simulation, NHTSA, and FHWA Engineering.

4. *Explicitly define roles of various TFHRC technical resources and a process that ensures that all work activities are integrated into a focused effort.*

## SUMMARY

Significant progress has been made by TFHRC and their team in adapting state-of-the-art FE methodology towards vehicle-roadside hardware crash simulation. A more focused and coordinated effort would expedite future progress and lead to vastly improved simulation results and a new level of computational tools. Recommendations are presented herein as to how to provide this improved focused and coordination.

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# ROADSIDE SAFETY HARDWARE — TIME FOR A NEW PARADIGM?

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## INTRODUCTION

TRB has recently published *(1)* a number of papers that were presented at the summer meeting of the Transportation Research Board Roadside Safety Features Committee (A2AO4) in August 1994. One of the presenters *(2)* discussed the evolution of roadside safety features focusing on the major milestones that have occurred in roadside safety in the last 35 years. This presentation should be required reading for all professionals involved in roadside safety issues. It is an example of how a significant safety problem was identified and the efforts of highway safety professionals to correct the problem. Although thousands were ultimately involved in the implementation of the roadside safety features, the bulk of the research and development was done by a relatively small group. Roadside safety features have been significantly improved and those involved in these efforts deserved our thanks.

This article only deals with one particular type of roadside safety feature - roadside safety hardware.

A number of events have occurred since the initial assumptions were made in the 1960s that affect these early decisions about how safety hardware should be designed, tested and evaluated. A short list would include the following:

- The efforts of the National Highway Traffic Safety Administration (NHTSA) to improve vehicle crashworthiness.
- The Corporate Annual Fuel Economy (CAFE) standards *(3)* which have led to a reduction in vehicle size and weight.
- The emergence of light duty pickups and vans as a significant part of the passenger vehicle fleet.
- The rapid increase in the computational power of desktop computers.
- The Program for the Next Generation of Vehicles (PNGV) *(4)* program.

In view of these events and our safety experience with roadside safety hardware over the last 35 years, there is a need to reexamine the philosophy upon which the evaluation of the safety performance of roadside safety hardware is based.

## CURRENT ROADSIDE SAFETY PHILOSOPHY

Each decade since the 1960 has produced at least one written procedure for evaluating the *safety performance* of roadside safety hardware. *(5, 6, 7, 8, 9)* These procedures are based upon several assumptions made in the early 1960s: roadside safety hardware was to (1) smoothly redirect the vehicle; (2) breakaway upon vehicle impact or (3) bring the vehicle to a controlled stop. Evaluation of the performance of the hardware would be based on the results of crash tests. Since it would be impossible to test all vehicles under all impacts conditions, "practical" worst case scenarios were developed. Two classes of automobiles were chosen to bracket the range of all light motor vehicles. It was felt that by testing vehicles at the extreme ends of the vehicle fleet, all vehicles would be covered. Impact speed and angles where chosen for crash tests that were also "practical" worst case scenarios. Most of the safety advances since the 1960s have been evolutionary - they built on and refined the original safety feature concepts.

## CURRENT PROCEDURE FOR DEVELOPING ROADSIDE SAFETY HARDWARE

This discussion is limited to the current procedure for approving roadside safety hardware discussed in NCHRP Report 350. The document was prepared by contract under the supervision of an NCHRP committee. The committee consisted of representatives from 3 State DOT's, one county representative, one city representative, 2 FHWA employees, one representative from the hardware manufacturers, one international representative, one member from academia and two staff members from TRB. There were no representatives from either the automobile industry or the NHTSA. NCHRP Report 350 is an update of NCHRP Report 230. It is a consensus document based largely upon experience and engineering judgement.

NCHRP 350 establishes three criteria for evaluating the *safety performance* of roadside safety hardware - structural adequacy, occupant risk and post-impact vehicle response. These criteria are summarized below.

1. Structural adequacy
   a. Test article contains and redirects the vehicle.
   b. Test article activates in a predictable manner.
   c. Test article redirects, controls penetration or brings vehicle to a controlled stop.
2. Occupant risk
   a. Debris from test article should not pose a threat to driver or bystanders.
   b. Debris from test article should not block the driver's vision.
   c. Vehicle shall remain upright.
   d. Preferred and maximum occupant impact velocities (m/s) based upon an unrestrained, front seat occupant calculated from vehicle accelerations.
   e. Preferred and maximum occupant ridedown accelerations (Gs) based upon an unrestrained, front seat occupant calculated from vehicle accelerations.
   f. Hybrid III dummy (optional) test for frontal or head-on impacts.
3. Post-impact vehicular response
   a. Vehicle does not intrude into adjacent traffic lanes.
   b. Occupant impact velocity (nte 12 m/s in the longitudinal direction) and occupant ridedown acceleration (nte 20Gs in the longitudinal direction).
   c. Exit angle from test article (nte 60% of impact angle).
   d. Vehicle trajectory behind the test article is acceptable.

The vehicle moves through three phases: pre-impact, impact and post-impact. Currently the evaluation criteria ignores the pre-impact conditions by assuming the vehicle is stable, not skidding and moving straight ahead. The impact phase deals with the interaction between the vehicle and the hardware and the effect of the collision on the occupant. The post-impact phase looks at vehicle trajectory after it leaves the hardware and subjectively assesses the risk of accidents resulting from re-entering the traffic stream. The evaluation criteria deal with the impact and post-impact condition. The final evaluation is somewhat subjective and based largely on the kinetic response of the vehicle rather than on the occupants's chance of inury.

Evaluations of the safety performance of roadside hardware are based upon crash tests. NCHRP Report 350 describes the vehicles to be used in testing, the test conditions, and the instrumentation that will be used in testing the hardware. The testing criteria are hardware specific - longitudinal barriers; terminals and crash cushions; and support structures. A brief outline is shown below.

1. Table 3.1 *Test matrix for longitudinal barriers:* 6 tests levels; two types of barrier sections; 3 impact conditions (3 vehicles, speed, and angle); and 1 impact point.
2. Table 3.2 *Test matrix for terminals and crash cushions:* 3 levels; 2 categories — terminal and redirective crash cushions or non redirective crash cushions; 2 feature types — gating or nongating; 3 impact conditions (3 vehicle types, speed, angle); and 1 or more impact points.
3. Table 3.3 *Test matrix support structures, work zone traffic control devices and breakaway utility poles*: 2 test levels; 3 features; 3 impact conditions (3 vehicles, different speeds, same angle); 1 impact point.

There are a number of problem areas associated with using full scale crash tests to evaluate the performance of roadside safety hardware. These include

1. Crash tests are not completely reproducible. The results may vary because of changes in impact speeds, angles, etc. Even under identical test conditions, different vehicles, within the same platform, may produce different results.
2. A method of assessing the severity of a collision with roadside safety hardware does not exist. Recent efforts *(10)* to do this by using the results of controlled crash tests and data from accident files have been unsuccessful.
3. Impact conditions — Accident studies suggests that many vehicle are yawing, rolling and pitching at the time of impact. In the current testing procedure the vehicle is stable and moving straight ahead.
4. Test vehicles are chosen to bracket the passenger vehicle population. The variety of vehicles on the road make this difficult, if not impossible. The spread in vehicle types is even greater today than in the past.
5. The test procedures do not encourage the use of new vehicles for crash tests. New hardware is being evaluated by crash test that use vehicles that can be 6 years old. By the time the new hardware is installed these vehicles are no longer in the fleet.
6. Changes in vehicle fleet can quickly make the safety hardware obsolete. For example, the Breakaway Cable Terminal (BCT) terminals (about 500,000 have been installed) do not work well with wedge shaped vehicles or with light vehicles and have not passed the NCHRP 350 criteria when tested with the 2000P vehicle.
7. Testing and development of hardware is done in isolation. The automobile and roadside safety hardware are a design system. Current procedures ignore the design system.

8. Testing is done under "practical worst" conditions. There is some evidence that the critical impacts conditions may be vehicle specific. In addition, vehicle in the middle of the bracket (the most popular models) are not tested at all.

Historically there has been some interest in using finite element analysis (FEA) to design and evaluate roadside safety hardware. HVOSM *(11)* was developed in the 1960s and the BARRIER VII *(12)* program in the 1970s. However FEA to date has focused on replication of crash tests in an effort to better understand the crash phenomenon. The use of FEA to analyses specific hardware and identify design changes that will improve the performance has been limited. The use of FEA as a tool for evaluating the safety performance and accepting the hardware for use has not been done. Past FEA models can be divided into two categories *(13):*

- Impact Models — WRECKER, Barrier VII, GUARD, CRUNCH, NARD.
- Handling Models — HVSOM, RD2 and VD2 versions.

These specialized models had several serious limitations — the limited computational power available in the 1970s required many simplifying assumptions. Due to their specialized nature there were few users of these models.

In summary the current procedure for the evaluating of roadside safety hardware is based upon crash tests conducted in accordance with NCHRP 350 and comparing the crash tests results with the evaluation criteria contained in NCHRP 350. NCHRP 350 is based upon a "practical" worst case scenarios. Two vehicles are used to try and bracket the light duty fleet as a whole and the impact conditions chosen are for extreme conditions.

## FUTURE PROCEDURES

Although it is difficult to define what future procedure will be used to design roadside safety hardware, it is possible to identify trends that will continue. The new procedures should recognize (1) computer power will continue to increase making analytical methods more feasible and (2) the uncertainty in predicting vehicle characteristics of the future.

The future procedures should build on our existing knowledge and to the extent possible, eliminate past problems. The future procedure for evaluating the safety performance of roadside safety hardware will resemble the current program in many respects. It will be based upon assumptions, it will require some sort of performance standards, it will involve full scale crash tests and finite element analysis. There are many factors that must be discussed and resolved.

The assumptions of the 1960s need to be reexamined. Currently the assumptions are that hardware should either redirect the vehicle, breakaway upon impact or bring the vehicle to a controlled stop. Are these still good assumptions? Are there better assumptions? Recent work *(14)* indicates that guardrail ends are 40% more hazardous than the line-of-run guardrail. It appears, based on this evaluation, that specific attention needs to be focused on terminals. Currently terminals are described in NCHRP 350 as either "Terminals and Redirective Crash Cushions" or "Nonredirective Crash Cushions". Which type of terminal is safer? Should there only be one type?

Line-of-run guardrail is designed to redirect the vehicle. Vehicles are either redirected parallel to the barrier or back into the traffic stream. What hazards does this posed to the vehicle occupants? What hazards does this pose to other users of the highway? Is there anything we can learn from accident data that provides insight into these problems? Should all errant vehicles that impact hardware be brought to a controlled stop?

These are key issues that deal with the performance of the hardware. Equally important is the design system — the vehicle and the hardware. As noted earlier NCHRP 350 specifies crash tests that use an 820C or a 2000P vehicle. These vehicles were chosen because they appear to bracket the existing vehicle fleet. Are these good choices? The risk of occupant injury during impact depends to a large extent upon the crashworthiness of the impacting vehicle. Should the most popular vehicle be used for evaluation and relative ranking developed for all other vehicles?

Observation of recent crash tests films have raised serious questions about the test vehicles themselves. In recent tests using pickup trucks (2000P), it appears that subsequent rollovers are caused by a damaged wheel system. What is being tested - the hardware or the test vehicles? Should crash tests be used to evaluate roadside safety hardware? Should NHTSA have a standard barrier test (similar to NHTSA's deformable barrier test) that vehicles must satisfy? Should we develop a surrogate vehicle/s and use then to test the system?

How do we optimize the vehicle/hardware system. Are there characteristics of the vehicle and characteristics of the hardware that should be optimized to minimize injury severity? Should vehicles and hardware be designed so that the cars are "caught" by the hardware?

All of these questions indicate there is a serious need to rethink the current procedures for designing roadside safety hardware. The development of new procedures must involve all of the parties responsible for vehicle crashworthiness and roadside safety.

It now appears that one of the most promising techniques for evaluating (and designing) roadside safety hardware is finite element analysis (FEA). Today FHWA and NHTSA use non-linear finite element codes, LLNL's DYNA3D and Livermore Software Technologies' LSDYNA, to study crash impacts. The motor vehicle industry also uses (among other methods), these same tools to evaluate motor vehicles impacts. Preliminary findings would indicate that FEA has the potential to both improve the design of roadside safety hardware and evaluate the safety performance. Given the difficulties associated with crash tests, is FEA a better technique? Is it affordable? Does it provide consistent and accurate data? How should the NHTSA's program on crashworthiness be factored into the development of roadside safety hardware?

One of the major problems associated with FEA is the development of FE models of motor vehicles. A limited number of FE vehicle models have recently been developed to replicate small cars. The Saturn and more recently two 820C small cars (Honda and Ford Festiva). A 2000P (pickup) is under development at GW University. These are very complicated models. It has been suggested that FHWA only needs a simple FE model to design hardware while NHTSA needs a detailed model to look at occupant injuries. Should FHWA and NHTSA use the same vehicle models? Can the automobile manufacturers supply FE models for testing? Should testing be done with future prototype models, perhaps from the PNGV program?

Finally, in the development of a new procedure for the evaluation of the safety performance of roadside safety hardware, collaboration must be sought from all of those involved in the motor vehicle/roadside safety hardware design problem. The vehicle manufacturers must develop safer vehicles that can compete in a global economy. NHTSA is involved in research to improve the crashworthiness of the motor vehicle, the Federal Highway Administrator and the States develop standards for highway design and operation. Manufacturers of roadside safety hardware are challenged to develop hardware that provide safe operation for a multitude of vehicle platforms. Any future program should recognized the contributions that each of these groups make and build upon the strengths of each group.

## FUTURE EVALUATION PROCEDURE

### Assumptions

All roadside safety hardware will be designed to bring the impacting vehicle to a controlled stop. Finite element analysis methods will be used to develop performance standards based upon the potential of occupant injury. FE models will be developed for each vehicle platform. Crash tests will be used primarily to validate vehicle models. Severity indices or rating will be developed for different for roadside safety hardware based on a standard test.

### Evaluation Criteria

1. Structural. Performance specifications for a test article that require that the test article contains the vehicle. (Test article cannot redirect or breakaway and must bring the vehicle to a controlled stop.)

2. Occupant risk. Numerical values based on vehicle crashworthiness (predicted probability based on crash tests) and severity indices (criteria based on FEA analysis and real world injury data).

3. Post-impact vehicular response. Vehicle brought to a controlled stop. It will not be allowed to encroach on the roadway and not allowed to roll over.

### Evaluation Techniques

1. Analytical techniques (FEA)

a. Structural. There will be a series of "generic" FE models of vehicles representative of existing vehicle platforms as well as future prototypes. There will be FE models of systems of roadside hardware. Libraries of vehicles and hardware will be maintained by FHWA. These models will have evolved to the point, and been validated to the extent that FEA can be used as a predictive tool.

b. Occupant risk. MADYMO is being incorporated into the Lawrence Livermore version of DYNA. It exists already LSDYNA. NHTSA is developing FE models of crash test dummies. Currently FHWA is using the NCHRP 350 flail space calculations.

c. Post-impact vehicular response. Work is underway with LSDYNA to handle vehicle trajectory after impact. The current effort is focused on making the finite elements rigid after the vehicle impacts the hardware. Initial efforts to have LLNL develop a capability to switch between DYNA and NIKE or perhaps from DYNA to a rigid body code such as VANDL has been delayed and may not be pursued.

2. Crash tests (model validation and severity assessment)
   a. Validate FE models of vehicle.
      (1) Joint test program with NHTSA to evaluate new vehicle performance characteristics with respect to safety ardware.
      (2) FHWA/NHTSA will cooperate to define appropriate performance specifications for vehicles.
   b. Develop severity assessments for vehicle/hardware impact.
      (1) Joint FHWA/NHTSA severity assessment procedures.
      (2) Standard test by NHTSA to assess vehicle barrier performance.

## CURRENT FHWA RESEARCH ACTIVITIES

The FHWA role has been to continue to support and coordinate the development of FEA as a tool for developing safer roadside safety hardware. The current approach is dictated by limited resources, both staff and fiscal. It is based upon a joint effort with NHTSA to further conserve funds and share technical data. Progress has been slow for several reasons - (1) general lack of technical expertise in using finite element methodologies such as DYNA to model crash impacts, (2) the difficulty in building finite element models of motor vehicles, (3) limited access to computer with the necessary computational power, and (4) some analytical problems that have yet to be resolved.

FEA models - FHWA will continue its efforts to improve the public domain version of DYNA. However, other tools may be necessary. For example, NCHRP 350 has a rollover provision that the public domain version of DYNA cannot address. We must also use the tools that industry uses. Example, if an automobile manufacturer gave us a vehicle model in PATRAN or HYPERMESH we must be able to use it.

FE models of vehicles - This will continue to be a joint project with NHTSA at the NCAC. NHTSA is responsible for crashworthiness and is involved in numerous activities (such as the Program for the Next Generation of Motor Vehicles (PNGV). Hopefully industry will supply some models. Because of the cost of developing FE models only a limited number will be developed. FHWA and NHTSA must jointly use some of the same vehicle models to address common problems, ie. impacts into narrow objects. The vehicle models are now available from FHWA though the INTERNET. I would hope as people use these models, the improvements would be reported to NCAC so the models can be updated. I'm somewhat skeptical about this.

Roadside safety hardware - This effort will be coordinated from the TFHRC. The program will probably evolve as a series of cooperative agreements with colleges and universities and industry. Future cooperative agreements will not be restricted to just colleges. The models developed will be reviewed and made available to the public from FHWA (TFHRC) through the INTERNET. This will broaden the technical base and provide developers of roadside safety hardware a new tool. I hope improvements to the models would be shared with FHWA. Again I am skeptical that this sharing will occur .

The analysis programs, FE models of vehicles and roadside safety hardware FE models will improve as they evolve. The day will come when FE methods will be the dominant tool in developing new roadside safety hardware.

Finally, the window of opportunity is closing. I expect funding for this program to decrease significantly. The TRB has established NCHRP Project Panel G17-13, whose charge is to develop "A Strategic Plan for Roadside Safety." Such a plan would prioritize our research needs on all roadside issues of which FE analysis is only one issue. However, it may be that analytical methods may be the best way to address other roadside issues.

## WHO IS INVOLVED IN ROADSIDE SAFETY HARDWARE?

The vehicle industry has to developed motor vehicles that are competitive in a global market. These vehicle have to be saleble and safe. The vehicle have to comply with a number of Federal Motor Vehicle Safety Standards (FMVSS). Based upon current literature and information supplied in trade magazines, a major effort is underway to shorten the time needed to bring a new car from concept into production and to make it safer. The US automobile industry in using a general purpose, non-linear, finite element codes similiar to DYNA3D to do vehicle modeling and analysis. Manufacturers also conduct crash tests to evaluate the performance of motor vehicles. Because of its competitive nature, the design and development of a new vehicle is a closely guarded secret.

NHTSA has the responsibility (National Traffic and Motor Safety Act of 1966) of developing FMVSS. A number of FMVSS have been promulgated by NHTSA. *(15)* In addition NHTSA developed and implemented the New Car Assessment Program (NCAP). The NCAP program provides consumer with information with a relative measure of the safeness of the vehicle. Both the FVMSS and the NCAP program are formally coordinated through the Federal register. NHTSA also publishes the R&D findings as they become available.

The Federal Highway Administration sets standards for highway design. In the case of roadside safety hardware, the FHWA has adopted NCHRP Report 350 and two AASHTO specifications *(16, 17)* as the standards for developing roadside safety hardware. To the best of my knowledge neither the vehicle industry nor NHTSA has been involved although the opportunity for involvement exist through the Federal Register process. The FHWA also certifies roadside safety hardware. This is a voluntary program provide by FHWA's Office of Engineering. This office review the information supplied by the manufacturer and decides if the hardware satisfies the requirement of NCHRP 350. If Engineering finds that the hardware meets all requirements of the standards, a memorandum is issued to the field indicating that it is approved for use on the Federal-aid system. This is a valuable service in that this finding is only done once.

AASHTO is involved because they promulgate specifications that the States follow and conduct research. The standards are developed by appropriate AASHTO committees. These committees are largely made up of State users who volunteer their time, and the standards are generally based on the state-of-the-practice considerations. The standards are reviewed by all States before their adoption and in reality are consensus standards. In 1962, highway administrators of the American Association of State Highway and Transportation Officials initiated a highway research program . This research program is administered by the TRB as the NCHRP. The States provides research problem statements and funds to Transportation Research Board to conduct an objective research program. NCHRP Report 350 was developed by a task committee selected by the Transportation Research Board.

The roadside safety manufacturers, like the automobile industry, operate in a competitive environment. The hardware they development must meet the criteria contained in NCHRP 350. As noted above, hardware that successful meets all test is sent to FHWA for certification.

State and Local governments are responsible for the location, selection, and maintenance of the barriers. Several States also have an active research program developing hardware for use within their State.

## CONCLUSIONS

FEA will be the dominant technology in developing future roadside safety hardware. It is the only methodology available that could allow

- Analysis of hardware systems for a wide variety of different vehicles, speeds and impact angles, including non-tracking vehicles. Example - the designer could build an envelop of performance limits and identify critical crash characteristics.
- Allow the designer to solve problems through stress analysis. Example - some current guardrails terminals develop a hinge about 10 -15 meters from the terminal nose. Is there something that could be done at this location to improve the performance of the hardware?
- Develop severity indices and evaluate injury in complex collision scenarios. Example - MADYMO dummy models have been incorporated into DYNA models.
- Allow designer to evaluate vehicle prototypes. We are shooting at a moving target Example - develop FE models based on projections from Delphi studies.
- Develop simpler roadside safety hardware. Example - there are numerous instances where roadside safety hardware has been installed wrong.
- Evaluate different types of materials for use in roadside structures. Example - FHWA is developing a traffic barrier system using composites.

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# STATUS OF ACCREDITATION OF ROADSIDE SAFETY EQUIPMENT CRASH TEST LABORATORIES IN THE UNITED STATES

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## INTRODUCTION

One of the duties that citizens expect of government is that it protects the health and safety of its citizens from the imposed risk of injury from products sold in the marketplace. One way a government protects its citizens is by establishing standards that must be adhered to for products. Let me list some examples — in the medical sector, pharmaceuticals and medical devices must pass certain laboratory tests and experimental trials before they are approved for use by physicians. In the power tool sector, electrical devices such as circular power saws must meet standards contained in an electrical code. Laboratories such as the Underwriter's Laboratories test to ensure that electrical devices meet this code. For highways, the traffic barriers and crash cushions that are installed in the medians and alongside the road to alleviate the harm to occupants in impacting vehicles must also meet certain standards by testing.

The method by which the traffic barriers meet standards is by being crash tested at an outdoor laboratory with a speeding vehicle under controlled conditions. The formal name for this process is "conformity assessment". Conformity assessment includes three processes. The first is the development of standards and procedures which define what a purchaser wants and what the supplier agrees to provide. The second is a quality system, and the third is laboratory accreditation. In this paper I'm only addressing the lab accreditation issue.

There are some very good reasons for the interest of the roadside safety hardware community in this subject. First, there is the increased emphasis of agencies on quality and the public on quality assurance; and second, there is the desire to interface with the international standards and procedures for increased safety and trade.

## WHAT IS A LABORATORY ACCREDITATION PROCESS?

It is a system for certifying that crash test laboratories have been found competent to perform specific tests. Competence is defined as the ability of a laboratory to meet defined conditions and to conform to the defined criteria for specific calibration and test methods.

Theoretically a United States road safety hardware laboratory accreditation program is one that would

1. Provide the technical and administrative mechanisms for national and international recognition for competent laboratories based on a comprehensive procedure for promoting confidence in testing laboratories that show that they operate in accordance with the defined requirements;
2. Provide laboratory management with documentation for use in the development and implementation of their quality systems;
3. Identify competent laboratories for use by regulatory agencies and purchasing authorities;
4. Provide laboratories with guidance from technical experts to aid them in reaching a higher level of performance resulting in the generation of improved engineering and product information; and
5. Promote the acceptance of test results between countries and facilitate cooperation between laboratories and other bodies to assist in the exchange of information and experience, facilitating removal of non-tariff barriers to trade and promoting the harmonization of standards and procedures.

## WHAT IS OUR STATUS?

In the United States, we are heading toward a more formalized acceptance procedure for crash test laboratories. In my opinion, the reason for this is not so much the pursuit of a carefully thought out national goal, but more the result of a need for more efficiency and effectiveness.

Mr. King Mak at our 1993 summer meeting in Newport, Oregon, in his discussion of accreditation from a testing laboratory perspective mentioned certain items of costs associated with maintaining accreditation that I suggest we use as gauges or milestones in measuring our progress.

The specific milestones are

- Periodic maintenance of accelerometers by a certified laboratory.

- Periodic calibration of electronics.
- Validation of software, e.g. digitization, calculation of occupant risk factors, etc. A standardized test data set can be used to check the validity of the software.
- Reporting requirements: documentation of activities regarding certification or re-certification requirements., e. g., date, nature and results of calibration of existing equipment, new equipment, etc.

The periodic maintenance of accelerometers milestone is required by NCHRP Report 350 as SAE J-211, "Instrumentation for Impact Test."

Most of the major credit for our progress in implementing the other three items belongs to the research and development arms of the Federal Highway Administration and the National Highway Traffic Safety Administration. They have been cooperating on harmonizing between the procedures to evaluate vehicles and to evaluate highway hardware. Messrs. Rex King and Charles McDevitt of the Design Concepts Division of FHWA along with Mrs. Randa Radwan Samaha of NHTSA are the responsible people for implementing these efforts.

Mrs. Samaha is responsible for leading the development of a method for calibration of electronics using the signal wave form generator (SWG). This is used to verify a testing agency's ability to accurately measure and record vehicular response parameters via the generated standard waveform.

NHTSA has performed or will perform the following actions to implement the SWG:

- One SWG system was adapted to output and process Class 180 precision waveforms which is allowed by NCHRP 350. Both the SWG hardware and the corresponding signal processing software were modified. The adapted system was used to evaluate the data acquisition system at the FHWA FOIL test facility for compliance to SAE J211 Class 180 requirements.
- An upgraded Class 1000 SWG system using a commercial PC based arbitrary waveform generator (ARB) and an output distribution box is under development (will be available 3/96).
    - Based on required specifications and extensive evaluation, the Keithley Metrabyte PCIP-AWFG/2 board has been selected.
    - A prototype output distribution box has been built and tested. Commercial fabrication of such a box is planned.
    - Software for turnkey operation of the ARB/SWG in the field is planned.
    - Final report will contain operator's manual for the new ARB/SWG, and the commercial specifications for both the ARB and the SWG output distribution box. The associated software will be made available for each testing site.

Mr. Rex King of FHWA has a project that prequalified crash test laboratories to perform tests. Not only did they have to qualify that they met the requirements of NCHRP 350 in addition they had to both calibrate their instrumentation using the SWG and be able to provide their test results in specified NHTSA data format. The labs were prequalified as to the largest type of vehicle they were approved to test as well as whether they were being qualified to perform compliance or research tests. Of the 7 crash test labs that perform work for the FHWA, four have been prequalified and one is pending.

Mr. Charles McDevitt is the COTR of a study being performed by the Texas Transportation Institute to develop software to calibrate crash test labs for occupant risk values. Verification of a testing agency's ability to accurately measure and record vehicular response parameters via the waveform generator is important. However, of equal importance is the agency's ability to accurately compute occupant risk measures from the recorded data. This will provide the ability to calibrate a test labs computation and provide a standard format for test results for the key factors used in evaluating impact performance of a safety feature.

## CONCLUSION

In conclusion, the U.S. is moving slowly — but it is adopting procedures that will serve as the foundation for a formal roadside safety hardware laboratory accreditation process.

# ASSESSMENT OF ITS SAFETY BENEFITS

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## INTRODUCTION AND BACKGROUND

The Intelligent Transportation Systems (ITS) program has become a very visible and important part of the surface transportation system since the early 1990s. It was the subject of specific legislation in the ISTEA of 1992 and has seen significant growth in its federal funding, national support and number of national activities. To those who have not followed the highway research program in previous decades, the ITS may indeed seem to be a major new program which makes large claims for an array of future benefits for the transportation system. These claims include significant safety benefits for highway users.

In fact, the present ITS program has evolved from a small set of studies and projects in the 1960s to today's reasonably complex set of technologies and systems which now support approximately 29 defined user services in the transportation arena. It's essential in understanding ITS and the safety benefits it will yield to recognize that ITS is not a single system or even a set of closely coupled systems. Rather, ITS is broadly scoped around the development and application of advanced communication and control technologies and systems focused on improving the operational performance of the transportation system. This broad evolutionary nature of ITS was recognized early by those instrumental in the late 1980s in developing national attention and support for what was then becoming known as Intelligent Vehicle Highway Systems (IVHS). An early group known as Mobility 2000 noted in 1990:

> IVHS includes a range of technologies and ideas that can improve mobility and transportation productivity, enhance safety, maximize existing transportation facilities and energy resources, and protect the environment. IVHS are based on modern communications, computer and control technologies.

Further, the program was correctly understood to be much more than a federal or even public sponsored program. It was a given that IVHS, to be successful, would require stakeholders throughout the public and private sectors. Again, its early organizers noted:

> the program will involve significant cooperation among government at all levels, universities, and industries such as those producing motor vehicles, electronics, communications, computers, and transportation services.

Thus, IVHS and now its renamed and broadened successor ITS, is simply a part, albeit a current major part, of the natural evolution of our surface transportation system in particular and our society in general. This perspective should not diminish the motivation of those associated with the program. But it does argue that much of ITS will naturally find its way into our everyday transportation journeys just as more and more we utilize increasingly advanced communications and computer based systems in our everyday business and private lives.

This is particularly true in the area of user safety which is the subject of this paper. ITS will not normally replace the need for today's safety design practices and safety systems which are fundamental to our modern streets and highways. What ITS does provide for is two levels of improved user safety. First, a general enhancement of user safety by reducing driver stress and indecision, achieving smoother vehicle flow, and generally, providing for a driving environment which yields improved safety as one of its byproducts. The second level, however, is much more specific. These are those unresolved specific safety issues where an ITS technology is being developed as a countermeasure. Central to these expected safety improvements is the ability for ITS technologies to provide critical advisory, warning and control information and action based on actual roadway, traffic, and environmental conditions. Thus, real and focused safety improvements are expected to result to the extent that the products are affordable, marketable and effective.

## ITS SAFETY FOCUS

Initially, the IVHS program was bundled around the following four major system application areas:

- Advanced Traffic Management Systems;

- Advanced Driver Information Systems (later to become *Traveler* Information Systems);
- Commercial Vehicle Operations; and
- Advanced Vehicle Control Systems.

As program interest increased, more potential applications were identified and today the program is described by ITS AMERICA and the US DOT to include 29 User Services consolidated into seven User Service Bundles shown in Figure 1. Collectively, these user services are expected to provide for a very broad set of national benefits as follows:

- Improved safety;
- Increased capacity and operational efficiency;
- Enhanced mobility;
- Enhanced trip quality;
- Reduced environmental and energy impacts; and
- Enhanced US productivity and world competitiveness.

Regarding safety benefits, much attention has been given since the late 1980s to trying to develop an objective and sound estimate of the types and quantity of safety benefits derivable from ITS. Initial estimates were obviously hampered by lack of specific system concepts, let alone specific designs. Thus, safety benefits were projected more in the context of what are the problems and, therefore, if you could achieve a reduction of x percent with an ITS system what the safety benefits would be.

Based on some preliminary work, the proceedings of the 1990 Mobility 2000 National Workshop suggested that IVHS technologies might be capable of saving over 11,000 lives per year by 2010. These estimates were of course recognized as preliminary and simplistic. Subsequent research was initiated to get a much better understanding of the safety issues and to provide a sounder basis for future government sponsored R&D activities. The National Highway Traffic Safety Administration (NHTSA) through its Office of Crash Avoidance undertook a set of research studies to better identify and describe operational safety problem areas that would be potential candidates for focused ITS systems. (See Additional Reading List). The Federal Highway Administration's Office of Safety and Traffic Operations R&D also undertook a broad, exploratory research contract in 1990 titled "Potential Safety Applications of Advanced Technology." This contract was completed in 1993 and the report became available in January, 1994.

Both the above FHWA and NHTSA set of studies focused on those ITS User Services bundled under the group titled Advanced Vehicle Control and Safety Systems in Figure 1. This ITS area places heavy emphasis on technologies located on-board the vehicle to improve safety in specific accident probable situations. The on-board equipment would operate either autonomously or, in selected cases, cooperatively with roadway located hardware to achieve its function.

Before exploring these systems and their projected safety benefits further, it should again be noted that the 29 User Services taken collectively are expected to achieve a wide range of benefits as previously noted. A quick examination of the titles of the individual User Services demonstrates that many of these do not have highway safety as their primary objective but are focused on other important needs such as congestion reduction, regulatory efficiency, etc.

To better classify those User Services that have primary safety focus, the author has classified the 29 User Services into three categories of expected safety benefits as shown in Figure 2.

- Category I are those User Services which incorporate technologies focused on a specific safety problem. These consist primarily of the Advanced Vehicle Control and Safety Systems. A well known example of this group would be some form of automated braking system which would apply the brakes in specific driving situations where some detector system and decision logic determined that a crash was imminent.
- Category II are those User Services which, while not focused primarily on safety, are still expected to have some meaningful safety component in their benefits. Among the many examples would be the electronic clearance of commercial vehicles. Here the focus is on improving the efficiency of the regulatory process but an expected benefit in doing so is to more effectively identify and remove from service the unsafe commercial vehicles and operators.
- Category III might be classified as generally creating a higher quality driving environment which yields an indirect, but positive highway safety benefit. This assumes that by implementing ITS technologies, such as pre-trip travel information, that a transportation environment results which has smoother flow, improved driver confidence and more accurate driving decision making, etc. and a by-product is enhanced safety.

Thus, to summarize to this point, the broad suite of projected ITS User Services differ substantially in their intended performance objectives. Improved safety is the primary goal in many but only a secondary or possibly by-product benefit in others. Establishing a numerical safety assessment of the Category II and III type systems is generally difficult but it is expected that the evaluations of a number of large scale field operational tests will eventually yield this information.

It should certainly be stressed, however, that there is clear evidence of the safety benefits of these Class II systems such as in ATMS. For example, in Minneapolis/St. Paul modern freeway management techniques including ramp metering provided for an increase in freeway speeds of 35 % and a reduction of 27% in accidents. Just recently Oakland County, Michigan has reported that an initial assessment of their new signal control system has shown a 6 % reduction in accidents.

## SAFETY ASSESSMENT OF ADVANCED VEHICLE CONTROL SYSTEMS

The primary ITS safety improvement directed at the driving process is expected from those User Services contained in the Advanced Vehicle Control and Safety Systems bundle. It is these systems, which if successfully developed and deployed, are presumed to directly improve the highway users ability to avoid vehicle crashes or, at least reduce the severity of those crashes. The remainder of this paper will focus on these systems and their projected safety benefits. The source of this summary is the previously noted FHWA funded research performed by the University of Michigan Transportation Research Institute and titled "Potential Safety Applications of Advanced Technology".

To provide a factual analytical base for this research study, a specially prepared set of data from the 1984-1986 NHTSA CARDfile was used by the researchers. Given the extremely large size of the file, a selected set based on five per cent of the cases at the accident level were drawn from each of the six States in the files for each of the three years. The data set was further reduced by restricting it to two or less vehicles in the collision and a requirement for at least one car, light truck or van to be involved. The final data set included 55,186 single vehicle records and 124,329 two-vehicle records. The collision type distribution for two-vehicle collisions is illustrated in Figure 3.

This data set served to develop a rationale as to the types of driving maneuver/crash situations which resulted in significant number of crashes and/or presented the type of driving situation where an ITS technology could be effective. Further analysis of these data resulted in identifying six predominant crash types: run-off-the-road, pedestrian or object, crossing paths, turn left into path, rear end and head on. (Figure 4).

These six situations accounted for 122,458 of the crashes in the total examined sample of 211,874 crashes. They further accounted for 892 fatalities and 24,152 injuries of Severity A & B out of the total 1,281 and 36,860 respectively. These six classes of crashes were then further analyzed from the available data as to such factors as night time, presence of alcohol, snow/ice, etc.

Next, the researchers postulated various countermeasure systems which could reduce the probability of the crash or its severity. A total of 18 such countermeasure systems were identified which included 14 distributed across the six crash types and four which were considered cross cutting. (Figure 5).

These countermeasures were then considered from the perspective of their high level system architecture requirements. That is, whether they required communications to another vehicle, and/or to the roadside, etc. Five general groups were described consisting of autonomous intelligent vehicle, inter-vehicle communicating, autonomous intelligent roadsite, vehicle-roadside communicating, and inter-vehicle and roadsite communicating. (Figure 6) This postulated system structure provided the basis for making estimates of market penetration such that projections could be made of actual reductions in crashes for the six types identified.

The results of the UMTRI analysis identified the following six systems as having the most potential for safety benefits:

- Headway control;
- Lane-edge detection;
- Lane-keeping;
- Night vision enhancement;
- Impaired driver warning; and
- Longitudinal control for avoiding objects in the road.

Systems believed to have lower potential than the above and labeled medium potential were

- Low-friction detection; and
- Cooperative intersections.

Finally, four systems were described as having spot improvement potential, but were otherwise not seen as cost effective for general deployment. These were

- Horizontal curve speed advisory;
- Pedestrian detection at mid-block crossings;
- On-coming vehicle warning; and
- Left-turn warning.

Although a detailed summary of the study's many conclusions is beyond the scope of this paper, a single figure which captures the essence of the study's results was a ranking of the previously defined 18 countermeasure systems by their percent reduction in total accident cost. The results are shown in Figure 7. This figure was based on the researcher's "generic" method which was the simplest of three assessment used in the study. The estimated reduction in accidents ranged from about 13.5 % for the universal application of headway control measures, to 12.5 % for lane-keeping countermeasures, and down to 1.2 % for impaired driver warning.

## CONCLUSIONS

The conclusion from the preceding discussion is that there are clearly real and important safety benefits that are realizable through the development and deployment of various ITS technologies and systems. These range from more subtle safety benefits which result from an improved driving environment through systems which increase safety by enhancing regulatory enforcement and, finally, to systems which are specifically focused on resolving particular known driving situations with large accident potential. The total number of accidents that could be eliminated and lives saved by full implementation of the full suite of the 29 ITS User Services remains a difficult unanswered question. However, the six collision types in the previously discussed study account for 68 % of all single and two vehicle accidents. Clearly, the study results demonstrate a real opportunity for highway driving safety improvement based on this advanced technology.

But, as was discussed in the beginning of this paper, these projected ITS safety benefits must be understood and used in the broader context of how ITS relates to the transportation system and our society. That is, ITS is part of the march of new technology which brings new tools to bear on transportation needs. These tools are the result of our nation's continued evolution of advanced communication and control technologies. Will these new advanced technology tools resolve all of the existing safety problems or eliminate the need for current safety practices and hardware? Of course not. The errant vehicle, resulting from whatever set of events, still needs barriers, guardrails, crash attenuators and whatever form of protective safety hardware we can apply. Similarly, safe geometric design practices, interstate design standards, etc. have conclusively demonstrated their safety value and will not easily be replaced by any particular ITS technology.

But, the advanced technologies which are the core of ITS do provide a tool in the safety arsenal which has not been available until now. This generic new tool is the ability to develop specific new systems which are aimed at many troublesome highway safety problems that are the result of poor driving behavior, lapses in attention, etc. which have been highly resistant to correction to date. To illustrate this further, the highway fatality rate has steadily dropped by a factor of three since the 1960s. The reasons are many ranging from improved roadside safety hardware, vehicle crashworthiness, seatbelts and airbags, more miles of interstate design level highways, to increased enforcement of drunk driving laws. But even with these tools the number of annual fatalities has appeared to hold around 40,000 and the reduction in rate appears to be leveling off around 1.8.

This is not particularly surprising given that upwards of 90 % of all accidents are the result of driver error. Further, despite intensified enforcement of drunk driving, approximately 40 % of all fatalities still involve one or more parties that are legally drunk. Again, ITS offers a new and perhaps the only realistic opportunity for dealing with many of these difficult safety problems.

So, in this author's opinion, there is clearly a whole new range of safety benefits that are possible through ITS. What is more difficult to assess is whether and/or how soon the more safety aggressive ITS systems will be available and deployed in sufficient quantities to see measurable national benefits. The realities of almost 4 million mile of roads and streets (or even just the National Highway System with its projected 150 plus thousand miles), 195 million registered vehicles and 175 million licensed drivers are just indicators of the lengthy time constant facing deployment of new safety technologies. On the other hand, the passenger vehicle fleet does turn over in something like 12-15 years and we do have national experience such as air bags which show that a meaningful percentage of the fleet can be affected in just a few years.

Achieving the safety benefits of ITS will be significantly driven by three factors. First, those systems whose operation requires hardware or some interconnection with the infrastructure will, as always, see their deployment controlled by public (federal/state/local) funding priorities. Given today's increasing funding needs and reduced budgets makes this a difficult problem.

Second, as most of the systems focused specifically on safety are based on technology which will be located primarily in the vehicle, their deployment will be controlled by consumer interest in these technologies, their affordability and the other market realities of liability issues, warranties, etc.

Third, there may be some safety systems which offer such important safety benefits that they are seen as being in the public's benefit to such an extent that they become required by safety standards — as were passenger restraint systems, high mount tail lights, etc. The issue here will also be the mood of the federal government, Congress, and society as a whole for mandating any new systems.

So, in conclusion, an assessment of ITS safety benefits results in a strong conviction of their real ability to reduce accidents, injuries and fatalities and especially in those unsafe driving situations which have been resistant to the safety design tools and hardware available today. But, also, this assessment does not see these ITS technologies displacing the need for maintaining a strong commitment to the existing and proven safety practices of the present. Further, many of the ITS safety benefits will evolve over many years as their deployment in the numbers required to influence significantly the national statistics will require a number of years.

## SUGGESTED ADDITIONAL READING

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# AN OLDTIMER SUGGESTS SOME ACTIVITIES FOR IMPROVING ROADSIDE SAFETY

*Roger Stoughton*
*CALTRANS*

## THE YEARNING FOR A SAFE LIFE

Safety in America! That is the desire of every one of our more than 200,000,000 US citizens. We want streets safe against crime and terrorists, safe water, safe schools, safe sex, safe toys, safe toasters and safe worksites to name a few. We believe it is our birthright to have life, liberty and the pursuit of happiness, all of which imply a safe environment where we work, live and play at all times. There are probably millions of our citizens who play some role in keeping our country safe in one of a thousand ways.

Our small community assembled here has carved out a special niche for our careers - the pursuit of better roadside safety. Our network has been formed over a period of 40+ years, ever since John Beaton at Caltrans ran cars over bridge curbs to see if they would serve as bridge barriers to keep the cars on the bridge. They didn't work very well, and so we were off on a 40 year adventure to design bridge rails, then median barriers and guardrails and finally all the other roadside safety furniture needed to create the "Forgiving Highway," which is our ideal.

Along the way we have collected crash test researchers at universities, state and federal agencies and in the private sector, AASHTO committees, safety hardware manufacturers and vendors, TRB committees and workshops, NCHRP research projects, computer simulation experts, accident data investigators, consultants and others in our roadside safety community. We have a fine web that stretches across the US and extends even to Europe, Canada, Japan and Australia.

We have toiled assiduously at our own specialized tasks and compared notes once or twice a year at our TRB committee meetings and elsewhere. Every few years we write and rank research problem statements. Now some wise people have suggested it is the right time to raise our heads from our work, look back where we have been, assess where we are now and how we are doing, and then to look into the future and try to see a vision for roadside safety and try to develop a strategic plan so that our work has greater direction, meaning and purpose and so that we are all pulling together in a common direction, if possible.

This white paper will be my personal assessment of where we are and where we might travel. It should be noted that this is my personal assessment and that my comments do not necessarily reflect the current or proposed policy of the management of Caltrans. I will not spend much time on where we have been because that was covered so well in several papers in our last TR Circular. I will begin with some accident data, summarize some trends that are under way with emphasis on ones we should promote, describe at least a partial vision of the future and propose some activities needed to get there. The ideas presented in this paper are intended to be at least a little bit provocative. They are not claimed to be the only path into the future, but it is hoped they will inspire some discussions about where we should put our greatest efforts.

## DATA ON DEATH BY ROADSIDE HAZARD: REPORT ON A GUERILLA WAR

The handiest accident data available to me was from the publication titled, "Facts, 1994 Edition" from the Insurance Institute for Highway Safety (IIHS). They state that their information is based largely on data from the US DOT's Fatal Accident Reporting System (FARS). The following tables contain information excerpted from the IIHS report.

These tables lead to the following observations:

1. The absolute number of deaths are going down - that is good news.
2. Roadside crashes have stayed at a constant percent of all vehicle crashes.
3. Overrepresented drivers are young, male, intoxicated and night travelers.
4. Rollovers and ejections are significant common factors.
5. A large majority of deaths are not on freeways or interstates - perhaps our work on freeways is paying off to some extent.
6. Curves are present in nearly half of all crashes, so road geometry is important.

TABLE 1 ROADSIDE HAZARD CRASHES IN THE UNITED STATES — OVERALL PATTERNS

| | |
|---|---|
| Deaths in 1980 | 15,232 |
| Deaths in 1993 | 11,300 |

Deaths in roadside hazard crashes as a percent of all motor vehicle deaths have stayed fairly constant at 28-30% in the years 1979-1993.

TABLE 2 SINGLE VEHICLE ROADSIDE HAZARD CRASH DEATHS BY OBJECT STRUCK/ROLLOVER

| Hazard | Deaths—Percent of Total | Percent with Rollover |
|---|---|---|
| Tree/Shrub | 28 | 17 |
| Utility Pole | 11 | 22 |
| Embankment | 10 | 63 |
| Guardrail | 9 | 50 |
| Ditch | 8 | 65 |
| Curb | 6 | 34 |
| Culvert | 5 | 56 |
| Fence | 4 | 43 |
| Sign Support | 3 | 39 |
| Other Post/Pole | 3 | 48 |
| Bridge Pier/Abutment | 2 | 15 |
| Concrete/Other Barrier | 2 | 45 |
| Bridge Rail | 2 | 51 |
| Wall | 1 | 28 |
| Building | 1 | 5 |
| Light Pole | 1 | 23 |
| Other | 8 | -- |

TABLE 3 SUMMARY OF ROADSIDE HAZARD CRASH DEATHS BY GENERAL HAZARD CATEGORIES

| Hazard Category | Deaths—Percent of Total | Percent with Rollover |
|---|---|---|
| Trees/Poles/Supports | 46 | 17-48 |
| Embankment/Ditch | 18 | 63-65 |
| Guardrail/Bridge Rail/ Other Barriers | 13 | 45-51 |
| Curb/Culvert/Fence/Pier/ Wall/Building/Boulder | 20 | 5-67 |
| Other | 7 | |
| Total | 104* | |

*Numbers are rounded; therefore, sum is more than 100%.

TABLE 4 ROADSIDE HAZARD FATAL CRASHES — DRIVER PATTERNS

| | |
|---|---|
| Age<13–24 | 35% |
| Men under 35 | 48 |
| Blood Alcohol Content over 0.10 | 53 |
| 9 p.m. to 9 a.m. | 60 |

TABLE 5 ROADSIDE HAZARD FATAL CRASHES — HIGHWAY PATTERNS

| | |
|---|---|
| Freeways/Interstates | 16% |
| Major Streets and Highways | 51 |
| Minor Roads | 33 |
| Curves | 42 |
| Wet/Slick Roads | 17 |

TABLE 6 ROADSIDE HAZARD FATAL CRASHES — CRASH PATTERNS

| | |
|---|---|
| Frontal Impact | 67% |
| Side Impact | 21 |
| Other | 12 |
| Rollover | 37 |
| Ejection | 31 |
| Single Vehicle | 96 |

7. Most crashes involve the front or side of the vehicle.
8. Trees, poles and supports are involved in almost half of all fatal crashes.
9. Barriers and a variety of other objects are involved in one-third of all fatal crashes.
10. Embankments and ditches are the other main hazards on the roadside in fatal crashes.

Papers presented in the past year lead us to believe that fatal barrier crashes include many that are into obsolete or improperly built barriers, or involve non-tracking vehicles or include vehicles such as motorcycles and trucks for which the barriers were not designed. In other words, my understanding is that the barriers we have tested that met current standards are probably performing quite well for impacts within the envelope of crash test conditions.

TABLE 7 MAJOR AND MINOR "A" SAFETY PROJECTS ON CALIFORNIA STATE HIGHWAYS IN 1992–1993

| Type of Project | Total (in Millions of Dollars) |
|---|---|
| New Median Barrier/ Upgrade Median Barrier | 8.7/0.9 |
| Curve Realignment | 6.7 |
| Spot Improvement | 2.7 |
| New Guardrail/ Upgrade Guardrail | 2.1/1.5 |
| Wet Pavement Correction | 1.6 |
| Miscellaneous Roadside Obstacles | 1.1 |

TABLE 8 MINOR "B" SAFETY IMPROVEMENTS ON CALIFORNIA STATE HIGHWAYS IN 1992–1993

| Type of Project | Total (in Thousands of Dollars) |
|---|---|
| Advance Flashing Beacon | 172 |
| Guardrail | 162 |
| Traffic Signal Modification | 105 |
| Guardrail Upgrade | 104 |
| Fencing Upgrade | 95 |
| Channelization | 94 |
| Overlay | 63 |
| 21 Other Categories | 752 |

## STATE DOT PROGRAMS: THE BAND-AID/BETTER MOUSETRAP APPROACH

This is the way I describe our current approach to roadside safety. To illustrate, here is a summary of the Caltrans "Highway Safety Improvement Program for 1992/93". This report pertains to California state highways only where there were 1497 deaths and 53,934 injuries with losses of $2.2 billion. In that year 4000 accident concentration locations were investigated. A total of 61 Major and Minor "A" projects were completed at a cost of $25.6 million, 74 Minor "B" projects at a cost of $1.5 million and 23 projects on state highways funded by local agencies at a cost of $5.4 million or a grand total of about 200 projects costing $32.5 million. The following two tables show the type of

TABLE 9 CALIFORNIA STATE HIGHWAY 1989–1990 FISCAL YEAR SAFETY IMPROVEMENT PROGRAM (2 YEARS BEFORE AND 2 YEARS AFTER)

| Type of Project | Benefit-Cost Ratio (Life) |
|---|---|
| Safety Lighting | 36.0 |
| Upgrade Median Barrier | 19.7 |
| Modify Traffic Signals/Channelization | 16.8 |
| New Bridges Constructed for Safety | 9.2 |
| New Median Barrier | 7.6 |
| Sidewalk Construction | 5.6 |
| Guardrails and Bridge Rails | 5.0 |
| Curve Realignment | 4.6 |
| Wet Pavement Improvement | 4.1 |
| Roadside Obstacle Removal | 4.1 |
| Others | 3.7 to –15.2 |

projects and costs for each type of project. Note that the tables which follow do not include safety features which are built on new construction projects which would increase the grand total of safety related expenditures on California highways.

Table 9 shows the benefit-cost ratios achieved with some of these projects. Only the highest ratios are included in this abbreviated table.

It is hard to criticize a program that spends $32,000,000 on 200 projects every year, many of which have strong benefit-cost ratios. It is a comfortable program, one which could continue indefinitely, one which sprinkles safety money all over the state, one which is obviously doing good. Nevertheless, there is a disturbing feeling that this is a machine set in motion years ago that keeps moving ahead, repeating itself, beating the drum like the Energizer bunny.

Now clearly these tables cover the entire category of highway safety, not just roadside safety. Still there was nothing in the Caltrans report that indicated the program was specifically based on the kind of accident data compiled by the FARS and analyzed and reported by IIHS. There was no vision of an ideal safe highway system. Instead, we have an ongoing incremental plan where band-aids are applied at perceived trouble spots. If a new barrier design (a better mouse trap) comes along during the year - fine, we add that to our band-aid collection. And there is something profoundly disturbing when we compare yearly expenditures of $32,000,000 (which seem quite generous at first blush) to yearly losses of $2.2 billion. That means expenditures are only 1-1/2% of total losses. Further, there is no indication, at least in this report, of the ongoing efforts underway within Caltrans to collaborate with groups such as NHTSA, the auto industry, etc. to find broad solutions to reduce the accident rate.

I do know, however, that Caltrans is working with many partners, among those NHTSA and other safety interests in California as they cooperatively develop a system for the establishment of safety goals through the use of the safety management system. This is certainly a step in the right direction. Also, the accident rate has been declining over the years. Note that the preceding criticism wasn't intended to single out California. Presumably, most other states have similar programs. The information about California's program was presented because it was conveniently available. I strongly suspect that many states have much less substantial programs in place.

## MIDDLE-AGED UNSAFETY HARDWARE

Over a period of forty years we have installed some roadside safety features that we now know are inadequate to meet current performance standards. Clearly, we cannot upgrade all roadside hardware every year. Much of the older hardware has a range of good performance that makes it useful; it just doesn't have the extended range of good performance that makes it useful; it just doesn't have the extended range of performance of the newest devices. Thus, careful thought and prioritizing must be carried out when deciding which hardware to upgrade.

That said, there are some blanket upgrading programs crying out for action. It was refreshing that FHWA recently leaned hard on the states to get rid of blunt end and sloping end guardrail terminals which we've known for many years to be poor performers. Caltrans has rejected the sloping end terminals for almost 30 years. Likewise, FHWA acknowledged that the "emperor has no clothes" when they stopped payment on the BCT which has a great deal of trouble handling light weight cars properly, also known for at least ten years, although, unfortunately, there have not been good replacement designs available.

Why then are there hundreds of miles of baluster type bridge rail still in place in the US that were built over 40 years ago, still there after several generations of new bridge rail designs, a slap in the face to our entire roadside safety community? Some traffic engineers may argue that they are hit so infrequently that the benefit-cost ratios don't warrant replacing them. In this case, perhaps they should at least be torn down and replaced with up to date delineation devices.

Decision makers and the public need to be persuaded that a purging of our roadside of obsolete barriers (plus other hazards) would yield great safety benefits, modernize our highways, create jobs, and yes, get lots of money to contractors. Other than the selling job, the toughest facet of this activity is devising a plan as to what types of safety devices should replace the old ones now and in the future. More on that as we continue.

## TRENDS OBSERVED/ACTIVITIES SUGGESTED TO IMPROVE ROADSIDE SAFETY

### The Roadside Safety Community Has Done Good (Mostly)

Here I give our roadside safety community high grades. We have labored diligently for forty years. We have been through several generations of design for most types of hardware. There has been much clever innovation in the past and it continues. Many of our designs appear to be very effective. Most, if not all of the tools we need are in place, or soon will be to design barriers that will handle any impact conditions we impose.

We have assembled NCHRP 350, a comprehensive set of recommendations for crash test procedures and evaluations. It covers all vehicle speeds and vehicle sizes in up to six different test levels. It will require fine tuning periodically, but I recommend that we not begin from scratch as we have in previous iterations in 1974, 1981 and 1993. Instead, at about five year intervals, I recommend that we only make needed changes to NCHRP 350 so that we have as much continuity as possible in the future after each review. Others here will describe the next changes we may wish to make.

## THE MULTIFACETED APPROACH/STRATEGIC PLAN

In our roadside safety community we have taken many roads to improve safety. Many have paid off. No doubt this trend will continue in the future. The lower the accident rate goes, the tougher it may be to make further gains. Thus, we will need to continue our multifaceted approach; we may need to spend more time on targeted groups. For example, in recent years some researchers have been looking for ways to help older drivers with larger letters on signs, wider edge stripes, etc. Young male drivers would be another group that should continue to be targeted. Our roadside safety community may be targeting utility poles and trees. Also, as mentioned in the earlier section on safe vehicle design, the auto industry still has areas that can be targeted for significant gains in safety.

With this in mind, it seems to me one of our most important activities in the future will be to improve communication and coordination between organizations and disciplines so that we can give an extra push to the most cost effective activities, and so we are all headed in approximately the same direction. I'm hoping our NCHRP project to develop a strategic plan will be one good step forward in that direction. It will need to address the many possible approaches to improving roadside safety.

## STATE DOTs: CAN THEY GRAPPLE WITH HIGHWAY SAFETY MANAGEMENT SYSTEMS?

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 requires the development and implementation of a Highway Safety Management System (HSMS) similar to pavement and bridge management systems that have been in place for several years. Obviously, roadside safety must be an integral part of an HSMS. Our summer workshop in 1992 centered on this topic, and the proceedings were collected in Transportation Research Circular No. 416.

It is noted in the Introduction to the circular that a good management system should include

- Information systems;
- Analysis techniques;
- Countermeasure installations;
- Countermeasure evaluations;
- Maintenance of safety system components;
- Policy development;
- Education; and
- Enforcement.

The Introduction adds that "because of limited resources, institutional constraints, and political realities, an organized and well managed highway safety system has been difficult to achieve". It is my opinion that a good HSMS is one of the keys to improving roadside safety. No matter how much brilliant research we do in the roadside safety community, it all goes for naught if it is not implemented. State DOT's are the major channel for implementing the research which we complete. We must ask ourselves why we still have roadside safety hardware on our state highways that has been obsolete since our first five years of crash testing almost forty years ago.

If we had a good HSMS, each state would have a complete detailed inventory of roadside hardware, with its location on the highway network. We would also have complete accident data with a similar location scheme that could be tied back to the hardware location. Analysis of these data would permit formulation of a plan to replace obsolete hardware with a ranking system based on probability of accident exposure. The inventory could also be analyzed to devise a regular routine maintenance program. The inventory could be made available to maintenance forces to reduce the burden of ordering replacement elements and to insure that current safety standards were recognized when replacements were made. The inventory and accident data could be analyzed to plan a replacement parts inventory that was ample but not excessive at each maintenance station. Accident and inventory records could be analyzed to prioritize the worst safety problems, for example impacts with utility poles and trees. Using this information and related information, each state DOT could develop its own strategic plan for attacking safety problems in that state. Once problem areas were isolated, the state could do literature searches and tap technology transfer centers to find solutions. If they found no satisfactory solutions, they could draw up a performance specification and/or request for proposals in search of innovators. Oftentimes, if a problem is clearly defined and publicized, a good solution will be forthcoming. In a good HSMS there would be a quality control unit that made spot checks of roadside safety hardware to insure it was installed, maintained and repaired properly. Recurring problems that were discovered might lead to a training program and/or training video. New safety hardware designs, after careful evaluation and testing, could be installed in large enough quantities to get some accident history. Analysis of this subset of accident data would lead to either full approval of the hardware, re-design and modification where needed, or complete and immediate removal if the hardware proved unsatisfactory. Further, all safety hardware should be evaluated periodically using the inventory and accident data to verify it is still effective and to plan replacement with improved designs when warranted.

The above thoughts probably sound simplistic. Most, if not all, of the above activities are done in bits and pieces by the states but not with a well organized system approach. The pieces of the HSMS may be scattered through several offices. Many activities may rely on the engineering judgment of seasoned employees. Many of the above activities are probably done incompletely because of lack of personnel and funds, with only one person trying to coordinate the work of several offices. The overall programs in most state DOT's probably do not have a rigorous plan to collect complete data, analyze the data, develop policies, take action, evaluate the actions, evaluate the system periodically, educate all members of the HSMS team, and enforce established standards.

What many states do have is a reactive system rather than the more proactive one described above. In a reactive system, a state DOT would locate high accident locations, prioritize them and dole out the funds available for corrective measures. This process would be repeated year after year without any long term planning or vision for improving highway safety. In a proactive program, improvement of high accident locations might still be an important segment, but it would be in the context of a much better analyzed, long term plan.

What are some of the reasons the states don't have a good HSMS - a system that sounds almost self-evident to a conscientious engineer? And what can be done to overcome these problems?

*Problem No. 1: Lack of personnel and funds.* We seem to be in an era of downsizing government. It is politically expedient for elected officials to blame government bureaucracies for problems, and to charge ineptness and corruption. It is politically expedient for elected officials to promote tax cuts no matter what the needs of the society or its financial health. The electorate, perhaps swayed by antigovernment political slogans, perhaps less willing to share their earnings in our materialistic and acquisitive culture, and perhaps unclear what resources it takes to provide the government services they would like to have - support tax cuts.

The upper level managers appointed by elected officials take these views as a mandate to downsize their agencies. They are more likely to order across the board cuts in personnel than to do a rigorous analysis of the importance of different units in the agency. For example, they may require a ten percent cut in personnel positions. Hence, the traffic engineers who have the potential to save lives are whittled away as much as the unit which is picking up litter (a not unimportant job - just lower priority in my mind). After a few years and a succession of managers who succumb to the mindless fix of 5% and 10% cuts, the traffic safety unit may be lucky to have a skeleton crew and a very thin layer of expertise centered on one or two old-timers. In this situation even the best intentioned and hardest working state employees cannot carry out a full fledged HSMS.

This downward spiral is demoralizing and frustrating. There do not appear to be any quick fixes. It takes a long time to change the cultural and political climate. We must compete for limited resources. The only possible solution I can dream up goes something like this:

1. The roadside safety (and highway safety) community develops a well thought out and detailed strategic plan.

2. Resources are sought to influence federal and state lawmakers. These resources are used on carefully crafted videos, white papers, and presentations. These papers and presentations describe the current roadside safety problem and its horrendous magnitude and malign influence on our society and economy, some past successes, and some specific plans for the future. High quality public relations consultants should be hired to help prepare these battle plans. Roadside safety organizations in the private sector may be the most appropriate ones to carry out this part of the campaign with input from the public sector.

3. Part of the pitch would be to get legislation passed at federal and state levels that would create tough organizational modules. It would be determined how many persons were needed as a minimum to run a good HSMS in that state. Funds would be dedicated to these modules and there would be a guarantee of at least, say ten years, before sunset of funds and personnel with some kind of inflationary factor included. There would be heavy penalties for assigning other work to these people or diverting their funds. Brief but useful reports would be required yearly. It would be required to present them to the president and the governors of each state and on the Internet. This would allow the states to have a program that was thorough and continuous. Unless the states assigned their worst slackers to these units, surely we could see some lives saved and injuries lessened in severity in future vehicle accidents.

*Problem No. 2: Lack of good management practices.* Again one would think that good managers would almost automatically develop good HSMS's. The few murmurings I hear are to the effect that not many states are jumping on the bandwagon immediately to implement vigorous fleshed out HSMS programs. They are doing the minimum paper work and reporting to FHWA. Clearly, if they lack resources, they have one big excuse. Nevertheless, they could be using good management techniques to optimize the resources they have.

Again, I must confess to being frustrated and a little cynical about the possibility of ideal managers in the state bureaucracy. (So perhaps the politicians' complaints are not completely without merit.) Viewed from my lower level in the "pyramid", managers often seem caught up in their own world, putting out fires, shuffling what resources they have, fighting turf battles, trying not to make waves etc. When has a manager ever gathered the working engineers down near my level and asked, "What are your problems and how can I help you get the job done?" And yet that is the essence of being a good manager — smoothing the way ahead so workers can be efficient and productive. Not only have they not asked these simple questions, they have barely communicated, if at all, what their expectations, long range goals, philosophies etc. were. The list could go on.

Managers need intensive training with frequent tune-up sessions in team building, communication skills, communication plans, conflict resolution, motivational skills etc. This training should come from well qualified professionals in the field of organizations and management. Managers should have key meetings involving strategic plans and policy setting, team building, brainstorming etc. facilitated by full time professionals. As a general rule engineers have not had this type of training, do not have these skills, and many probably don't even realize there are professionals who do this kind of work. Some managers with strong personalities and large egos will not understand the value of using professionals of this type. Unfortunately, a manager must accept the above ideas and want to pursue them; he or she cannot be forced to use them.

Improvement in this picture might come two ways. First, publicity and education are needed to entice managers to modernize and improve their management techniques. This would require assistance from professional organizations that specialize in management, organization theory, facilitation of meetings, etc. Perhaps they could be persuaded to tailor their promotional materials to the needs of state DOT managers. Second, federal legislation could include rewards for state DOT's that document high levels of management training and usage of modern management techniques documented by management professionals.

*Problem No. 3: Personnel regulations in a bureaucracy.* Civil service rules often bog down any half-way creative idea in state government and strangle it to death. For example, job classifications may be quite general. Thus, vacancies in the traffic engineering division may be filled with engineers with no expertise in the area at all. Furthermore, their main interest may be in having a secure job or getting a promotion for higher pay - not any special zeal for saving lives or improving roadside safety in general or improving their strategic plan. Also, civil service procedures usually require that all engineers and other disciplines start work at the entry level. There is no way of rewarding professionals who earn advanced degrees by hiring them at higher levels when they enter state service, or even of rewarding them if they earn advanced degrees after being in state service. Thus, a manager who suddenly had the resources to assemble a full fledged HSMS could be completely hamstrung by these rules. The manager could not search out the best traffic engineers, data analysts, computer specialists, etc. and hire them directly.

Again, we have another quagmire that seems almost hopeless to traverse. What could a stout-hearted crusader do to surmount this obstacle? First, federal legislation could include a model system for filling positions in an HSMS and reward states that quickly amend their civil service systems accordingly. The model system would have to include all the fairness concepts typical of a civil service system, but would allow special job classifications needed in a HSMS, would provide for hiring professionals with advanced degrees and/or other specialized experience, would have graduated pay level based on education and experience, would include demonstrated zeal for the HSMS program as one hiring factor, and would include accelerated dismissal procedures for employees who turned out to be poor team members. These special rules would be justified because of the high priority importance of improving roadside safety by establishing good HSMS's, and making the case for that high priority classification would be part of the plan to obtain legislation of this type.

*Problem No. 4: Lack of communication.* If the state Dot's had the proper resources to develop an HSMS, each system would probably turn out different from the others. Some programs might be much better than others. Ideally, the HSMS staffs should be able to meet occasionally to share ideas. Unfortunately, many states treat out-of-state travel like the plague. Here again, federal legislation could include funds for a national meeting once every two years for, say, up to ten HSMS staff members from each state DOT. This would allow the major disciplines in each HSMS all to be represented. It would allow sharing of ideas that worked and plans for the future. It would greatly enhance networking contacts so that staff members from one state DOT would feel more comfortable about contacting their counterparts in other state DOT's. And as everyone knows who attends a good convention, it would pump up the "zeal" factor. Further, a little publicity would demonstrate to citizens that government was really serious about attacking one of our society's most serious problems.

## THE ROADSIDE SAFETY COMMUNITY: SHOULD IT TURN SOME CORNERS?

### Low Maintenance Hardware

In Caltrans the last few years we have increasingly heard the plea for maintenance free hardware. This has led to a shift from metal mesh glare screen to concrete glare screens in some locations, a shift from metal beam guardrail to concrete roadside barrier on urban freeways, and to disapproval of some new crash cushions that are repair work intensive, for example. This trend will probably intensify as our highway system is built out and carries heavier and heavier loads of traffic. Under these conditions we do not want to close lanes of traffic for repairs because of increased congestion and potential safety degradation and we do not want to expose our employees to the hazards of traffic anymore than necessary. A few Caltrans workers are killed every year when they are run down on the highway.

### Non-Tracking Vehicle Crash Tests

FHWA led the way in conducting side impact tests into lighting standards a few years ago. Virtually all previous crash testing in this country was done with tracking vehicles. The FHWA tests had the vehicles oriented 90 degrees to the direction of travel. These tests showed the great hazard of light poles and the weak side structure of vehicles in their broadside impact tests.

Recently Caltrans conducted a side impact test where the vehicle was yawed with respect to the direction of travel, but not a full 90 degrees as in the FHWA tests. Now Caltrans is working with UC Davis to design and build a sturdier side impact carriage that will allow the vehicle to be towed at any yaw angle. It also has the potential to impart a yaw velocity to the vehicle before it is released from the carriage and travels into a test article.

We know that side impacts represent a significant number of all roadside impacts and they can be quite severe, even at lower speeds. Therefore, it appears it will be fruitful to develop side impact test procedures, evaluation guidelines and test equipment to try to design roadside safety hardware that is forgiving in side impacts. This activity provides further reason to work with the auto industry on vehicle/barrier compatibility, and to make use of computer simulation programs to find good design solutions.

### Computer Program Simulations of Vehicle/Barrier Impacts

These have been covered extensively elsewhere. I concur wholeheartedly that these programs have the potential to optimize our roadside safety hardware design and to determine their limits of performance. This quest should be pursued vigorously.

### New Materials

We should stay alert for new materials that become available. Composites that have special properties such as superior strength and durability may be good replacements for timber and metal roadside hardware. Recycled plastic and rubber elements may be useful in some roadside safety hardware in addition to being environmentally benign.

## THE AUTO INDUSTRY: IS A PERFECTLY SAFE VEHICLE ITS HOLY GRAIL?

We know with our present highway system that some drivers will get in trouble, their vehicles will leave the roadway for whatever reason and they will strike an object on the roadside and/or rollover. Ideally all vehicles would be designed in such a way that the passenger compartment was never damaged in an accident. In addition, seat belts, air bags and other restraints would cushion passengers in an impact so that they could survive high levels of deceleration with little or no injuries.

Although we have not reached this ideal state, great strides have been made over the years to improve vehicle safety. Besides the many safety components such as safe windshields, collapsible steering columns, crushable dashes, seat belts etc., that have been standard for over 25 years, there have been more recent improvements in side strength, rollover strength, energy management in frontal crashes, air bags etc. Some more gains may be possible. A recent issue of the Status Report newsletter from the Insurance Institute for Highway Safety claims that new NHTSA rules on anti-lock brakes for trucks and car occupant head impact protection might save 1400 lives per year. Simply using padded sun visors, like those required in Australia, could save many lives and the visors are not necessarily more expensive.

As vehicle safety improves, roadside safety devices do not have to be designed for such delicate vehicles. For example, whereas barriers that deflected during impacts have been preferred in the past, (cable and metal beam barriers), now more rigid barriers may be as good a choice. If rigid concrete barriers can be used more widely, they have several advantages. They take less space because they don't deflect, they require less repair and maintenance - hence lowering life cycle costs and reducing exposure of workers to traffic hazards, and they can more easily handle a wider range of vehicle geometry and weights which includes being less susceptible to changes in vehicle design that would make them obsolete.

In the past highway people have had almost no contact with the auto industry. Roadside safety people have tried to design barriers and other hardware to last over twenty years while the auto industry was changing designs every year.

A much needed future trend would be for increased dialogue between the highway agencies and the vehicle industry people to make roadside safety devices and vehicles more compatible. For example, if all barriers were eventually concrete, then the vehicle industry could design bumpers accordingly and could insure that air bags and other restraints could handle most impacts with concrete barrier. Similarly, bumpers and side structures of vehicles could be designed to resist impacts with trees and pole type structures.

The roadside safety community needs to initiate more communication with NHTSA and the auto industry for our own good. It could make our design process much easier. FHWA has made a good start by working with NHTSA in some of its side impact testing and its work on computer simulation programs. Let us hope that the quest for a perfectly safe vehicle becomes the quest of the auto industry.

## THE PUBLIC: IS IT POSSIBLE TO DEVELOP A HIGHWAY SAFETY CONSTITUENCY?

In the present political climate, laws are passed and resources allocated for those citizens who have organized powerful lobbies with large treasuries. It is a case of the "squeaky wheel" *AND* the "well greased wheel" getting the attention. These lobbies and support organizations spend large sums of money to "educate" the public and to sway legislators. Recent examples include all the anti-tobacco legislation which has passed. The only way that the powerful tobacco lobby could be challenged was through similar efforts by the American Lung Association, American Heart Association, American Cancer Society, ASH etc. They raised the public consciousness enough to get legislation passed that furthered their cause. Until that time, over 465,000 persons a year were dying from tobacco related causes and there was no organized effort to analyze and solve the problem. This is a simplistic analysis of that situation intended to show that concerted efforts by a few special interest groups can mobilize public opinion and influence legislators to begin solving a serious public health problem.

We know that about 40,000 Americans die in vehicle accidents every year, many more have incapacitating injuries and the economic loss is horrendous - billions and billions of dollars. Many less persons die each year from drugs, AIDS and some other highly publicized problems. The nation grieved for weeks after less than 70 people died in the Loma Prieta earthquake, less than 200 died in the Oklahoma City bombing, and less than 200 died in a recent major airline crash.

Tragic as these events were, they pale in comparison to our highway death toll where an average of about 110 people die every day of the year and several times that many are grievously injured. Why is there no public outcry? Perhaps it is because those 110 fatalities are scattered all over the country, and we only read about one vehicle in our own city every few days. Only a few family and friends grieve, and the rest of the community continues to worry more about crime and drugs etc. In effect, we have the equivalent of a guerrilla war taking place in our country where a sniper picks off one or two victims in isolated places at random times.

No constituency or lobby develops for highway safety because there is no economic payoff. We have small non-profit groups like MADD and the Center for Auto Safety which exert a little influence in narrow fields of interest, but no broad based group promoting highway safety. Such a group could be a great boon to those in roadside safety. It could educate the public about the death and injury toll and the economic loss so that an aroused citizenry might finally push for increased support for highway safety programs as being a high priority, high payoff program best coordinated by government agencies, but fully involving the private sector as well. The group could be called the American Highway Safety Association (AHSA). The roadside safety community can't collectively form such an organization, I assume, but we can encourage any who would do so and work with them, once formed, to make sure they have accurate information to dispense. For example, if we can develop a well thought out and detailed strategic plan for improving roadside safety that is updated regularly, that could be a very useful roadmap for an organization like AHSA and ensure its efforts had maximum payoffs.

## THE FUTURISTS: IS THE AUTOMATED HIGHWAY SYSTEM PIE IN THE SKY?

Surely most persons involved in highway safety have agonized many times about ways to improve safety and have resigned themselves to limited gains. This is because the key factor in the majority of accidents is the driver - our tragic black sheep cousins who drink, take drugs, lack sleep, lose control of emotions, speed, don't maintain their vehicles, and have no concept of the physics of auto collisions. They lack "driving intelligence." It is virtually impossible to change the attitudes, personalities, health and skills of most of these people. If this type of person survives that long, finally 20 or 30 years of adult living and several close calls may give them the driving and life experiences to temper their unfortunate highway behavior. Roadside safety engineers know that some of these folks will run into their barriers at 90 mph or 90 degree angles. Much as we'd like to save their lives for better days when they may "sober up" permanently, there is little we can do to protect them in such extreme impact conditions.

We understand that our highway system has three components - the highway, vehicle and driver - but it is not designed as a system. The vehicle and highway cannot compensate for the erratic behavior of some drivers. The only possible total solution is to take control away from the driver. That, of course, is what is done by the AHS. It uses electronics and mechanical systems to keep the vehicle moving safely on the highways with little or no input from the driver. It substitutes reliable artificial intelligence for the flawed "driver intelligence" in the present system.

Assume for the moment that AHS will work. If the components can be made almost perfectly reliable (no small task), then we could see a one or two order or magnitude improvement in safety. Vehicles would never leave the roadway; hence, roadside safety would be a moot issue. Embankments, rivers, trees, poles, barriers, ditches, curbs etc. would no longer be potential hazards. Roadside safety engineers could have a glorious and satisfying retirement.

Is AHS a pie-in-the-sky scheme that will never work? We know that such a complicated system will take many twists and turns, but (barring economic collapse in this country) the press of new technology will surely carry the AHS to some kind of national system on many, if not all, of our highways, and perhaps even down to the local level of streets and roads. Only the time table is uncertain.

If we assume that an AHS is inevitable, then roadside safety engineers need to keep one eye on the future, on the long term, so that we can integrate our short term and long term goals. What is the time table envisioned now? I spoke with an engineer at Caltrans who is working on AHS issues. He said that in 1997 Caltrans plans a demonstration on I-15 with 20 vehicles having lateral and longitudinal control capability. That means the vehicles will have collision avoidance systems and lateral guidance systems to keep the vehicles on the roadway. Concurrently, Caltrans is included in efforts to select the best concept proposal for an intelligent highway system. Sixteen proposals must be narrowed down to one, and a prototype of this system would be built in the year 2002.

Beyond that, it becomes increasingly hard to predict when such a system would be widely implemented. If a freeway lane is dedicated to AHS, then 20 to 25% of the vehicles must be equipped with AHS systems. That means a large number of car owners must be willing to pay the premium for these cars, but they may be reluctant until there are an ample number of roadways equipped with AHS systems. In other words, there is a "chicken and egg" dilemma here.

Changes in the vehicles will probably be incremental, the first being an advanced cruise control with a collision avoidance system. Only a younger generation who grow up with AHS may be completely accepting of such a system, according to the AHS engineer. Hence, widespread use of the AHS may take 40-50 years. That sounds like a long time into the future. Nevertheless, many incremental changes will be occurring well before that milestone. If experimental sections of highway are built in 10-15 years, it is not too soon to begin thinking how our roadside safety concerns will coincide with the AHS.

In preparation for this paper I skimmed through a dozen or so reports from the PATH program. According to the report, "The California PATH is a joint venture of the University of California, the California Department of Transportation and private industry to develop more efficient transit and highway systems. The goal of PATH is to increase the capacity of the most frequented highways and to decrease traffic congestion, air pollution, accident rates and fuel consumption. PATH is part of the Institutes of Transportation Studies at the University of California at Berkeley, Davis and Irvine, in collaboration with California Polytechnic State University at San Luis Obispo, and the University of Southern California." PATH is deeply involved in AHS research. Most of the reports which I reviewed were written by a consultant to PATH, Anthony Hitchcock, who was employed to analyze the safety problems of an AHS. Following is a brief description of an AHS and some miscellaneous ideas related to its safety. This particular scheme has not been adopted and is not necessarily the final concept of choice. It was considered better than some other schemes and was used in order to have a specific basis for a safety analysis.

The following is a description of an AHS taken from a draft report titled, "Layout, Design and Operation of a Safe Automated Highway System," by Anthony Hitchcock, dated March 1994.

> We must first define terms. Operation in platoons means that vehicles follow one another very closely (our nominal close intraplatoon spacing is 1 m), in groups of between 2 and about 20. Between platoons there is a gap of 60-80 m or more, which is such that vehicles in a following platoon can brake to rest if a leading one stops as quickly as it can. Dividers are physical barriers between lanes. They contain gates, gaps in the dividers (no moving parts!) through which vehicles can change lanes. We permit two kinds of dividers. The first is a high divider, probably 0.7 - 1.2 m high, (Figure 2) which will resist cars approaching perpendicularly. The second is a low divider, (Figure 3) which will permit

> a car door to be opened over it, and is ankle-high. Dividers must be designed not to present a danger if struck end on at a gate.
>
> In the preferred design, automated vehicles operate, in platoons, on one or more automated lanes (AL), from which manual vehicles are excluded. Entry and exit are from a transition lane (TL), which is separated from the ALs by a divider. Entering vehicles join at the immediate rear of an existing platoon: If more than one has to join the same platoon, they do so as a preplatoon which has been formed, at low speed, on the TL . . . acceleration of the preplatoon occurs on a stretch of the TL called the entry maneuvering length (EML) of which part at least is separated from the manual lanes by a high divider, while between EML and AL there is a low divider (permitting communication and sensing). The EML is probably of AL width, narrower than the parts of the TL open to manual vehicles.

Platoons are considered to be the safest way of moving vehicles. If a vehicle in a platoon has a failure, the following vehicles in the platoon may have low relative impact speeds that cause minimal injuries to occupants, but following platoons will have enough space to be slowed or stopped. The divider would prevent a crippled platoon from straying into other lanes. The author says the accident rate should be less than 10% of the current freeway accident rate, but it is impossible to prevent all accidents. The few accidents that do occur will probably be multi-vehicular, hence, more spectacular in a news sense. Other miscellaneous information from the report:

- Automated lane widths could be about eight feet wide.
- The safety analysis assumed only cars and light trucks in the automated lanes. Trucks and buses might need to be in their own automated lanes.
- A previous analysis, assuming an automated lane was added to the Santa Monica freeway, which now has about 8 fatal accidents per year, would add 0.4 of a fatal accident if dividers were used with the automated lane, but 4-5 fatal accidents per year (ten times as many) if dividers were not used.
- As usual there will be trade-offs between cost and performance (includes capacity and safety).
- Estimate 6000 vehicles/lane/day with an automated lane versus 2000 vehicles/lane/day maximum with a conventional lane.
- Fence (divider) materials and height might be controlled in part by requirements for electronic communication between highway and vehicles.
- As new vehicle safety components are developed (building blocks in the AHS), they can be evaluated for safety by determining what types and how many injuries they would prevent. In depth accident data, not now available in quantity according to the author, would be needed for this type of analysis.
- Gates (gaps) in the dividers are about 80 m long.
- The AHS is designed so no single fault will cause an accident, only multiple faults occurring simultaneously will do that. Faults are not uncommon and two or more may interact.
- In the AHS, driver errors are replaced by designer errors. The AHS must be designed by "complete verification" and the design must be verified as safe using a fault tree analysis. Separate teams must perform these two critical tasks.
- The author claims 90% of road accidents are now caused by human error.

One of the key features of AHS is that vehicles will be able to receive information from receptacles along the highway. These information stations may also be gathering traffic information from counters, TV cameras etc. to be fed into traffic operations centers. This could require many posts, poles, blocks or other fixed objects to mount the electronic devices that are needed. Already, we have seen a "forest" of call boxes erected which may be used later to support other information systems also. In the near future we expect to see numerous closed circuit TV towers erected on the roadside. Perhaps some of these devices will be mounted on the dividers mentioned above.

This has been a long detour to sketch a possible AHS scheme. It seemed relevant to me because I just became aware that barriers (or "dividers") may be critical elements in an AHS. The author spent almost no words describing the barriers he needs, and his concept sketches appeared relatively naive. Thus, it seems clear to me we need to make some strong links with the AHS community, work with them on suitable barrier designs and draw on our 40 years of experience with barrier analysis and testing.

## THE OLDTIMER STICKS HIS NECK OUT WITH THE FLUME CONCEPT

Having mulled over the foregoing ideas, I have tried to speculate on some possible future barrier designs. Again, I should emphasize that the ideas which follow are intended to provoke discussion, and, if there is interest, would lead in the future to some rigorous studies with input from many sources to work on an "ideal" future freeway cross section. This search for the ideal roadside hardware system may be part of our strategic plan. Following is a proposal for busy urban highways that could be called a "flume freeway" design. It is intended to channel traffic just as a flume channels water, even when the flow is turbulent. This design is all concrete for strength, durability, appearance and flexibility to handle a range of vehicle sizes. It is a continuous barrier with no gaps and placed on the outer edge of the shoulder. it assumes more impact resistant vehicles. It attempts to capture vehicles rather than rebounding them. It prevents vehicle rollovers. It shields all roadside obstacles behind the barriers from possible impact. It can be slipformed and is easy and inexpensive to construct. It lends itself to separation of traffic by vehicle size as noted in the figure. Whereas placing guardrail and bridge rail here and there is a "gambler's approach" and a "band-aid approach" (trying to guess the locations where accidents will occur), the proposed design is a complete continuous solution. It can easily be adapted to contain AHS information equipment. It may be an appropriate transition into the AHS era highway. It may be desirable to provide separate roadways for trucks over 20,000 lbs. or to down size trucks into 20,000 lb. modules that are three or four modules long. This would help keep the standard concrete barrier down to a reasonable size. The continuous concrete barrier could house or support any AHS equipment as needed. The curb/wheel trap trough probably wouldn't work as shown. It is included to represent the desire for 1) a method of trapping vehicles, rather than reflecting them back into traffic and 2) minimizing the chance of rollovers.

High traffic volumes and limited access on urban highways may make the flume freeway design a reasonable approach. On rural highways there may be many locations where a flat, wide, clear roadside completely free of obstacles is the ideal to shoot for. Some rural highways, however, may warrant the flume approach because there is no other completely safe solution. This might be true on narrow mountain highways that can barely have room for a shoulder, let alone a clear roadside. Once even the most safely designed vehicle goes over a steep embankment, there is little chance of saving the passengers other than by pure luck (vegetation on the slope that slows the plunge). A continuous concrete barrier that did not deflect when struck would prevent all embankment accidents.

If it was placed on the other side of the highway also, it might serve to trap rockfalls as well as contain errant vehicles. We have not placed continuous barriers on mountain highways in the past. Perhaps we have not placed a high enough value on saving lives and preventing injuries, and a good barrier system should be on every design checklist, just as environmental concerns have been added to design checklists in recent years.

Many rural highways and urban streets do not fall into the clear cut design categories above. At these locations we must still use a combination of strategies including the clearing of roadside obstacles to the maximum distance possible (including on city streets), adding roadside safety hardware where necessary and setting speed limits that relate to current vehicle safety design. And perhaps we should lobby for AHS facilities to reach these areas as soon as possible. Where continuous barriers were impractical, speed limits could be set based on vehicle impact survivability speeds, assuming there continue to be more improvements in vehicle safety. Not much attention has been given to the needs of local agencies in our roadside safety community. This is fertile ground to do research on safety solutions specifically for local areas.

*The Whole Enchilada: The Power of Positive Thinking.* Within our own roadside safety community I observe much cooperation, information sharing and consensus building. I would urge we continue this kind of positive approach as we begin dealing with the broader highway safety community. Again, let us employ expert consultants, as needed, to help us with"win win" conflict resolution of critical issues. Where we are proposing or supporting legislation or new rules, let us promote the use of rewards instead of penalties to provide motivation to make changes in an organization or program. Let us reach decisions by consensus rather than by vote whenever possible. Let us be open minded about promoting the best ideas whether they came from our agency or somewhere else. This suggestion may have a Pollyanna sheen, but I am convinced there is much power in positive thinking and acting.

## SUMMARY: SECOND CHANCE FOR THOSE WHO DOZED IN THE MIDDLE

Following are some future trends that are either under way or should be soon:

1. Establish high-quality HSMSs in every state DOT.
   a. Pass legislation to ensure they have adequate funds and personnel for a continuous ten year period.
   b. Promote good management practices in state HSMSs and hire well-qualified professionals in the

fields of organization and management to assist with some parts of the program.

c. Pass federal legislation with model civil service rules and reward state DOT's which adopt these or similar rules in order to staff the HSMS's with well trained and zealous persons.

d. Pass federal legislation requiring bi-yearly national meets of state HSMS personnel with funding for travel and meeting expenses to enhance communication of good ideas.

e. Use the HSMS to help initiate robust programs to quickly remove the most obsolete roadside safety hardware.

2. Coordinate long-term roadside safety goals and research with the Automated Highway System community.

3. Communicate and coordinate efforts between the highway safety community and the auto industry to improve vehicle/highway compatibility, thus lessening the severity of accidents.

4. Encourage highway safety constituency organizations that could educate the public and lobby legislators on behalf of the highway safety community.

5. Continue a multifaceted approach to solving roadside safety problems.

6. Brainstorm roadside safety barrier schemes that reflect current trends, will work short term and long term and that limit the number of schemes used by states to a small collection of simple and cost effective designs. This exercise might help state DOTs get a vision of their long-term goals in roadside safety.

7. Continue work on computer programs that simulate vehicle/barrier/roadside geometry impacts.

8. Continue development of side impact test procedures, evaluation guidelines and test equipment, and coordinate with the auto industry.

9. Participate in a rigorous process to formulate a strategic plan for improving roadside safety that defines specific tasks and time goals; establish a communication network, if possible, by newsletter or computer; make plans for regular gatherings of the broad highway safety community to report results of the assigned tasks and to review and update the strategic plan.

10. Give higher priority to preventing roadside accidents than softening them, while continuing to improve ways to lessen the severity of roadside accidents that still occur.

11. Use positive methods of conflict resolution, motivational rewards and consensus building to reach safety goals when dealing with all members of the highway safety community.

# SUMMARY OF BREAKOUT GROUP DISCUSSIONS AND RESEARCH PROBLEM STATEMENTS

## BREAKOUT GROUP A: DEVELOPMENT OF A STRATEGIC PLAN FOR ROADSIDE SAFETY

*Leader: Roger Stoughton, CALTRANS*

### Background

Group A was actually a meeting of NCHRP Project Panel 17-13 for the project titled "Strategic Plan for Improving Roadside Safety". This project was requested by the AASHTO Committee on Research to help them prioritize proposed NCHRP research projects dealing with roadside safety. The project was funded at $180,000. I'd like to begin with some quotes from the second-stage problem statement to give you a little background on the project.

The research problem statement reads as follows: "A significant amount of research is being sponsored by FHWA, TRB and the States to improve roadside safety. However, these efforts appear largely uncoordinated and the work appears to be fragmented because there is no overall plan, or vision, or list of priorities. New technologies are emerging that have the potential to improve roadside safety. For example, IVHS, nonlinear finite element simulations of vehicle/object impacts, GIS, CAD, expert systems, and highway safety management systems. There is a need to develop a strategic plan that will identify the areas with the highest potential payoffs for improving roadside safety."

The section on proposed research states, "The objective of this research is to develop a comprehensive strategic plan for improving roadside safety. This will be done through the following tasks." Then two options are suggested including first, four regional conferences in the four AASHTO regions for maximum State input, and the other option was to have a single national conference with "representatives from the States, TRB, NCHRP panels, NHTSA, FHWA, vehicle manufacturers, testing agencies, private government laboratories, materials suppliers, roadside hardware manufacturers and the academic community." After this session there would be a draft that the panel would review and then it would go out to the community, and they would review it. Through these iterations, we would come up with the final strategic plan.

This problem statement came out later than most NCHRP projects and was fast tracked. Our panel of 17 members was assembled quickly and met for the first time on May 22 and 23 of 1995. We had trouble making progress until, part way into the session, Tom Hollowell showed us a booklet with the NHTSA strategic plan. It wasn't until then that I realized there was a specific definition for a "strategic plan." There are several key elements that are usually included in strategic plans and there are some specific processes that are usually used to generate a strategic plan. The four state representatives on the panel realized they had all been through the process using a professional facilitator and felt that the use of a facilitator had been quite beneficial. Therefore, they proposed that we use a facilitator at our next meeting. The next meeting was then scheduled to take place concurrently with this summer workshop.

The original workplan was written to provide a strategic plan for roadside safety *research*. The decision was made at our first meeting that the strategic plan would not just be for roadside safety *research*, it would be for improving roadside safety in general. For many years our TRB A2A04 community has developed research problem statements, prioritized them and conducted the research, pretty much staying on this straight and narrow path. Now we may be at the point of diminishing returns with our research. We must be more careful in the projects we select to be sure they improve safety. I believe this is a concerned, activist group and that most of us are not here just to perpetuate our research careers until we retire, whether they do any good or not. I believe most of us really want to do work that causes change and that really improves roadside safety. I believe we are coming to realize now that we must expand the bounds of our community, and collaborate with other communities to determine what techniques will be best for improving roadside safety.

Clearly, we have a complex society with many people and agencies involved — some with counter purposes. It is difficult to know how to get these groups together and focused on common goals. A facilitated procedure is one way of getting these diverse groups together.

The facilitator we used is a full-time facilitator for Caltrans. The process he led us through Sunday and Tuesday was slow and deliberate and frustrating. It involves first generating lists and getting out what is in the minds of different people and then writing a purpose. The purpose is a short simple statement of the main goal that everyone can subscribe to, and then that is expanded to get a mission or vision for the future. After the strategic plan is done, an implementation plan is needed to list and assign tasks in order to accomplish the missions, goals, objectives and actions in the strategic plan. Finally, a business plan must be written that sets priorities, deadlines, and budget amounts to get the needed work done. During the facilitation process we generated a tremendous amount of information and ideas, which were all posted on large sheets of paper on the wall. These were

- Development of a Strategic Plan for Improving Roadside Safety
- Accomplished
  - 15-year time frame
  - Scanned the external environment (past, present, future)
    - trends
    - events
    - features
  - Defined and identified partners
  - Defined and identified other stakeholders
  - Identified what we think the stakeholders need and want
  - Drafted the purpose, mission and vision
  - Started drafting goal statements

We did not get to

- Draft criteria for priority setting, apply to goal statements
- Develop business plan

Group decision:

- We recognize that there are other players who need to be involved. We will for now take the lead.

What is our external environment?

- Seatbelts static
- Aging population
- Speeds increasing
- Reduced respect for the law
- DUI down
- Emerging ITS technology
- Limited resources
- Changes in vehicles (mix, design and equipment)
- Environmental concerns
- Increased computer horsepower
- Losing DOT experience

The Future Scenario: What Will We See in 2010?

- Roadway infrastructure to remain about the same
- Median width changes
- New generation of barriers
- More truck traffic
- More car phones/Mayday devices
- Two turnovers of the vehicle fleet
- Technological advances
- Telecommunication
- Internationalization
- Intermodalism (price of gas)
- Increased congestion
- Reduction in clear roadsides
- New materials

Who should be involved?

- Partners who contribute and are involved in making the plan
  - FHWA
  - NHTSA
  - AASHTO
  - Research community
  - Manufacturers/contractors
- Stakeholders who are affected by the plan
  - Advocacy groups
  - Lobbyists
  - Professional groups
  - Adversary groups
- Stakeholders: Who are they?
  - The driving public
  - All partners
  - Taxpayers
  - Manufacturers
  - Trucking industry
  - Insurance industry
  - Healthcare providers
  - Politicians
  - State DOTs and other owner agencies
  - Contractors
  - Law enforcement
  - Advocacy groups

**Vision**

We have a highway system where people do not pay with their lives when vehicles inadvertently leave the roadway. In this system drivers rarely leave the road, but when they do, the vehicle and roadside work together to minimize harm.

**Purpose**

Our purpose is to improve highway safety by reducing the frequency and severity of roadside accidents.

### Missions

1. Establish and nurture an ongoing partnership involving organizations with responsibilities for or interest in roadside safety. This partnership will advocate for improvements in roadside safety and coordinate efforts toward accomplishment of the other two roadside safety missions.
2. Formulate a plan for improving roadside safety that considers roles for various partners and continual updating based upon success in improving safety.
3. Implement a broad-based plan for improving roadside safety.

### Strategic Goals

Goal 1.1 — Establish the organizational framework to involve key partners.
Goal 1.2 — Broaden the organizational framework to include other partners.
Goal 1.3 — Inform elected officials and the public concerning the public health and economic consequences of roadside safety issues.
Goal 2.1 — Establish sound information resources with adequate detail.
Goal 3.3 — Conduct research and implement cost-effective programs to (a) keep vehicles off the roadside, (b) make roadsides more forgiving and (c) make vehicles and roadsides compatible.

At present there may be some concerns that our plan is too broad, that it involves too many partners, that the plans will just gather dust on the shelf after they are done, that some folks may not buy into the process and are worried that we did not get down to the specific details and a desire by a few to just prioritize our research as we have in the past and let it go at that without any big national meeting with all the stakeholders. My own preference and hope now is that we can fine tune and write up the work we have done to date, and plan a workshop where we draw in our key partners to get their input, but don't try to include every single stakeholder we have listed.

## BREAKOUT GROUP B: SEVERITY INDICES DEVELOPMENT

*Leader: King Mak, Texas Transportation Institute*

### Introduction

This group differed from the other groups in that a Task Force was previously set up under the Committee to review issues pertaining to severity indices. The missions for the Task Force are as follows:

1. Review the severity indices that are currently in the ROADSIDE program.
2. Review severity indices in the new cost-effectiveness analysis program currently being developed under NCHRP Project 22-9. The program will be going into beta testing later this year and should be available some time next year.
3. Review the definition of severity indices or severity estimates to determine if the definition needs to be improved or refined.
4. Review current methodologies used to establish severity estimates and develop research problem statements for incorporation into the long-term strategic research plan.

Three problem statements were developed by the breakout group for incorporation into the long-term strategic research plan.

### Research Problem Statement B-1: Accident Severity/Surrogate Measure Relationships

The performance of roadside safety features is usually evaluated through full-scale crash testing and/or computer simulation, using surrogate occupant risk measures such as occupant impact velocity, ridedown acceleration, and peak acceleration. The results are then used to determine compliance with safety performance standards. Severity indices or estimates used in cost-effectiveness analysis are also developed based on these surrogate measures. Unfortunately, little research has been devoted to establishing links or relationships between surrogate occupant risk measures and accident severity or probability of injury. Moreover, there are questions raised about the accuracy and validity of these surrogate measures, such as the effects of increased seatbelt usage and availability of airbags for drivers and front seat occupants in passenger cars and light trucks since the occupant risk measures are based on unrestrained occupants. Establishing these links or relationships would greatly improve crash test evaluation standards and cost-effectiveness analysis procedures.

#### *Research Objective*

The objective of this study is to develop a methodology(ies) for establishing links or relationships between surrogate occupant risk measures and accident severity or probability of injury. The methodology(ies) should take into account recent advances in vehicle safety systems, such as airbags and side impact protection. A pilot study in which the relationship(s) is established for at least one type of roadside feature should be included as part of the study to demonstrate the applicability of the methodology(ies).

### *Research Approach*

The methodology(ies) for establishing these links and relationships between surrogate occupant risk measures and accident severity or probability of injury may not be well defined. The researchers are requested to propose the technical approach deemed most likely to succeed in meeting the study objective within the available funding. Potential methodology(ies) may include computer simulation, occupant modeling, in-depth accident data collection and reconstruction, full-scale crash testing, and/or combinations of one or more of these approaches.

The work plan should include a pilot of demonstration study in which the developed methodology(ies) is applied to at least one roadside feature to develop the desired links or relationships.

Reporting requirements should include documentation of the developed methodology(ies) can be applied to other roadside features.

Multiple awards to more than one research agency are recommended.

### *Estimate of Problem Funding and Research Period*

The estimated funding for each award is $100,000. Assuming three awards, the total funding is $300,000. The research will require approximately 18 months to complete.

### *Urgency, Payoff Potential, and Products*

Economic analysis procedures for determining the feasibility and effectiveness of alternative roadside treatments, both new and retrofit, are dependent upon knowing the severities of all likely incidents involving a specific treatment. There is a severe lack of accident severity information needed for these economic analyses. Thus, there is an urgent need to develop these severity relationships to ensure the best use of available resources to improve roadside safety and for use in the formulation of safety policies.

Links between surrogate measures and accident severity can also lead to a major improvement in future crash test standards. Findings from this research can be implemented into revisions of the Roadside Design Guide and NCHRP 350.

## Research Problem Statement B-2: Feasibility of Collecting and Utilizing Airbag Crash Sensor Data

The increasing need to optimize limited safety resources has led to the development and use of improved cost-effectiveness analyses. These analyses require the ability to correlate collision conditions to probability of injury. There is currently a lack of reliable data upon which these relationships can be formulated

A necessary requirement for deployment of an airbag is the sensing of vehicular accelerations. Technology has progressed to the point that this information is available from airbag systems which have been deployed during an accident. Availability of this data, along with detailed accident injury information, provides a direct link between accident severity and surrogate occupant severity measures. If a correlation between this information can be developed, it will provide necessary input to cost-effectiveness analyses.

### *Research Objective*

The objectives of this study are to: (a) determine the feasibility of collecting airbag crash sensor data from vehicles involved in collisions resulting in airbag deployment, and (b) provide recommendations regarding how this data can be used in support of roadside safety analyses.

### *Research Approach*

This study will be accomplished through the following tasks:

1. Determine the state of the art (practice) in airbag crash sensor data technology. This task should establish what information is available, how it is stored, and how the data can be accessed. Differences among different automobile manufacturers should be considered.
2. Investigate institutional barriers to accessing the crash sensor data. Ownership issues and liability concerns surrounding use of this data should be explored.
3. Recommend data collection methodologies and protocol. Determine how data should be collected,

where the data should be stored, and an appropriate format for distribution.

4. Report findings.

*Estimate of Problem Funding and Research Period*

The estimated funding for this project is $50,000. The research will require approximately 12 months to complete.

*Urgency, Payoff Potential, and Products*

There is currently a lack of reliable data upon which the relationships between impact conditions and probability of injury can be established. Data from airbag crash sensors on vehicles, if available, could potentially provide the needed data. The relationships between impact conditions and probability of injury will be invaluable as inputs to cost-effectiveness analysis procedures.

### Research Problem Statement B-3: Extent of Unreported Accidents

Accident data provides one or the more objective means of estimating accident severity or probability of injury. However, available accident data is based on reported accidents only and the resulting severity estimates may be biased or even erroneous. It is necessary to include unreported accidents in the severity estimates to get the true picture. Also, the extent of unreported accidents vary significantly by object struck.

*Research Objective*

To determine extent of unreported accidents for selected roadside features.

*Research Approach*

- Identify roadside features to be evaluated and other pertinent factors, e.g. highway type.
- Develop various approaches to identify unreported incidents, e.g. maintenance records, field monitoring of damage to roadside features, assistance from hardware manufacturers.
- Match reported accidents to unreported incidents to determine ratio of reported to unreported accidents.

*Estimate of Problem Funding and Research Period*

The estimated funding for this project is $250,000. The research will require approximately 24 months to complete.

*Urgency, Payoff Potential, and Products*

Estimates of accident severity or probability of injury are crucial to cost-effectiveness analysis procedures. Current accident severity estimates are mostly based on reported accident data, which may be biased or even erroneous since unreported accidents are not included in the estimates. It would be highly desirable if the extent of unreported accidents can be established for various roadside features in order to improve upon the accident severity estimates.

## BREAKOUT GROUP C: VEHICLE FLEET CHARACTERISTICS, ITS RESEARCH NEEDS, DRIVER BEHAVIOR, ACCIDENT DATA COLLECTION AND ANALYSIS RESEARCH NEEDS

*Leader: Lyle Saxton, Federal Highway Administration (retired)*

### Introduction

This group had several different areas of study and structured the given questions around five general areas. Each subject area was discussed to see if there was a research problem statement or statements that would naturally flow out of that area. In the afternoon the group broke into small subgroups to develop the problem statements. The areas were

1. Vehicle fleet characteristics and hardware interfaces — How are vehicle fleet changes influencing present design? What are the trends and how will they affect the hardware that already exists?
2. Occupant restraint systems and how they affect the safety of the driver — This should be accounted for in collision with roadside safety hardware.
3. Driver behavior issues — Ninety percent of accidents are caused by driver error. This is still considered an errant vehicle, however, and a research problem statement was not found for this category.
4. ITS opportunities and research needs.
5. Accident data collection and analysis.

In addition a statement on the need for in-service evaluations was prepared separately by Bill Wendling.

### Research Problem Statement C-1: Update NCHRP 350

NCHRP 350 is the latest in a long series of documents aimed at providing guidance on testing and evaluating roadside hardware and other roadside features. It was adopted without doing any additional test validation of the specified conditions. There is a need to determine whether or not existing state of the art hardware and current vehicle designs can pass the recommended test conditions

Experience has shown that updating the recommended test and evaluation criteria is a lengthy process. Therefore, it is time to update NCHRP 350 to reflect current and future roadside safety needs performance and their interface with the changing safety environment. These changes include occupant restrains system advances, technological innovations, and improved knowledge of vehicle/hardware interaction.

There is also a need to revisit NCHRP 350 to see if further advances can be made in international harmonization of test and evaluation criteria; and to see if the occupant risk measures can be made compatible with those used by the Europeans.

#### *Research Objective*

The objective of this NCHRP project is to review the guidance in NCHRP 350 and update the document performance requirements and evaluation criteria based on the best current technology.

#### *Research Approach*

NCHRP 350 is based upon a number of tacit assumptions (i.e. occupants of errant vehicles are unbelted, that vehicles should be contained and redirected, and that the test should reflect worst case scenario conditions). It is also assumed that the vehicles are stable and tracking and that the potential for occupant injury can be calculated from the vehicle changes in velocity. NCHRP 350 assumes that the only way to evaluate roadside hardware is through laboratory and full-scale tests. However, the state of the art of using finite element analysis for design and evaluation of hardware is rapidly advancing.

The researchers will re-examine these assumptions and re-evaluate the test and evaluation criteria. As a minimum, they will complete a literature survey, perform detailed analyses of accident data and field performance, evaluate existing vehicle safety performance standards, and evaluate the results of recent crash tests. They will re-examine the current occupant risk measures in NCHRP 350 and the effects advances such as airbags, side airbags, pretensioners, and new child restraint technology requirements.

#### *Estimate of Problem Funding and Research Period*

It is estimated that the proposed research will require $500,000 and the research effort including preparation of the draft final report will require 2 years for completion.

#### *Urgency, Payoff Potential, and Products*

There is an urgent need to revisit and re-evaluate NCHRP 350 to reflect the latest advances in technology to assure that the recommended test conditions reflect needed safety performance as indicated by accident data and field performance, and that the recommended procedures are cost effective in improving safety.

### Research Problem Statement C-2: Vehicle and Roadside Safety Hardware Compatibility and Reconciliation of Motor Vehicle Safety Standards and Roadside Hardware Evaluation Standards

Currently roadside safety hardware is designed to safely interact with a range of vehicles defined by NCHRP 350. Recent testing has revealed some vehicle characteristics that can lead to less than desirable results. A study needs to be conducted to identify vehicle characteristics that can negatively effect the impact performance with roadside safety hardware.

Currently automobile manufacturers design new vehicles to meet an existing set of federal motor vehicle safety standards. Roadside safety hardware designers use a different set of safety standards to test and qualify their designs. Both groups verify that their designs meet required parameters through both computer modeling and full scale crash testing. A study needs to be done to identify and reconcile conflicting issues between these standards. Specific effort will be made to identify desirable vehicle and roadside hardware characteristics to maximize acceptable impact performance to ensure occupant safety.

#### *Research Objective*

The objectives of this research are as follows:

1. Identify existing vehicle characteristics that can negatively effect how they interact with roadside safety hardware.

2. Review NCHRP 350 and applicable federal motor vehicle safety standards to identify compatible and conflicting issues.

3. During above review, identify deficient areas (Ideas: Define desired vehicle frontal area needed to interact with roadside safety hardware, define acceptable bumper heights and bumper stiffness (a state standard), define acceptable center-of-gravity height that will yield acceptable impact results, etc.).

*Research Approach*

This will be done through the following tasks:

1. Literature search. A survey of groups that have recently conducted tests to NCHRP 350 will be conducted to gather feedback on vehicle characteristics that can negatively effect impact performance with roadside safety hardware. NCHRP 350 and applicable federal motor vehicle safety standards will be reviewed. The search will focus on identifying standards for vehicle and roadside hardware components that influence total impact performance.

2. Reporting. A report will be prepared that summarizes project findings and gives recommendations for future action.

*Estimate of Problem Funding and Research Period*

The estimated funding for this project should be $100,000 for the tasks noted above. The project will take 12 months to complete.

*Urgency, Payoff Potential, and Products*

This project will conclude by making recommendations relative to existing standards to maintain and/or improve the impact performance between the new and existing vehicles and roadside safety hardware.

### Research Problem Statement C-3: Effect of Airbags in Roadside Safety Crashes

The conversion of the car, light truck, and van fleet to airbags is now well underway, and deployment of the airbag in crashes with roadside safety features should result in injury reductions. As more crashes take place involving vehicles equipped with airbags, quantifying the benefits associated with airbags in ran-off-road crashes can be done with more confidence. Such knowledge would be of benefit to the roadside safety community.

*Research Objective*

The objective of this research is to quantify the effect of aribags in crashes with roadside safety features. Quantification would be in the form of reduction in the proportion of serious and fatal (A+K) injuries in these crashes.

*Research Approach*

The deployment of the air bag can be easily identified by those investigating such crashes. This event is now becoming more routinely reported on state crash forms. If not directly reported on the crash form, decoding of vehicle identification numbers (VINS) is another way to identify airbag-equipped vehicles.

The objectives of this problem statement will be met through the following tasks:

1. Identify state databases that can be used to study these crashes (i.e., states that code airbag deployment or that routinely report vehicle identification numbers) — try to involve states in the Highway Safety Information System (HSIS) database because of good roadway/roadside data.

2. Select the cases where the airbags are used, as well as the cases with non-airbag deployment.

3. Group the cases by roadside safety feature struck.

4. Compare injury outcome of airbag crashes to those without airbags — try to control for other variables of interest such as speed limit or impact speed, urban/rural location, curvature and grade information, and distance to object.

5. Quantify the proportion of A+K injuries for airbag versus non-airbag crashes and compare to determine the safety benefits associated with airbags — determine if the benefits vary by roadside safety feature.

*Estimate of Problem Funding and Research Period*

Recommended funding: $150,000-$200,000. Research period: 18 months.

### Research Problem Statement C-4: Assessment of Crash Avoidance Methods Through ITS Technologies for Application to Roadside Safety Systems

Collision avoidance methods are currently being developed for vehicles through Intelligent Transportation Systems (ITS) technologies. To this end, it is appropriate to assess the potential of collision-avoidance technologies as an additional form of roadside safety systems. In this sense, this assessment would involve the appropriateness of collision avoidance technology to enhance roadside safety systems for certain situations. The focus would be on existing technology and hardware that prevents the vehicle from leaving the highway pavement and/or the traveled lane in safety related situations.

*Research Objective*

The objectives of this research are

1. Assess and evaluate current collision avoidance technologies including active and passive elements.
2. Assess the suitability of these techniques for incorporation into roadside safety systems.
3. For the most promising techniques (established as a result of objectives (a) and (b) conduct limited experiments to establish the efficacy of the most promising techniques as applied to roadside safety systems.

*Research Approach*

In order to meet the research objectives, the following tasks, at a minimum, must be conducted. These tasks will be performed through two distinct phases. Phase 1 will address objectives a) and b) and phase 2 will address objective c). At the end of phase 1, a review will be conducted to identify and plan the experimental activities of phase 2.

The following describes the tasks for each phase.

- Phase 1: Assessment and evaluation
  Task 1 — Review literature.
  Task 2 — Select most suitable techniques (including costs, compatibility and effectiveness) for application to roadside safety.
  Task 3 — Develop scenarios for utilizing the techniques in various roadside safety features.
- Phase 2: Experimental evaluation
  Task 4 — Develop a plan for the scenarios developed in task 3.
  Task 5 — Conduct tests as identified through Task 4.
  Task 6 — Summarize results of test reports and provide recommendations and conclusions for the project.

*Estimate of Problem Funding and Research Period*

The estimated funding for this is $500,000 for a period of 30 months.

*Urgency, Payoff Potential, and Products*

It has been established that with the most effective crashworthiness techniques, there are limitations to the reduction of highway injuries and fatalities. Additionally, the influence of the ever-changing fleet characteristics requires constant upgrading of roadside safety hardware. It is impractical to expect the roadside safety hardware as it presently exists to be able to accommodate the added requirements imposed by the change in fleet characteristics. Therefore, use of ITS technologies, particularly collision warning/avoidance techniques can provide the capability to bridge the gap between the current roadside safety hardware and the safety requirements associated with the changing vehicle fleet.

This research will result in the use of off the shelf crash avoidance hardware to enhance the performance of the roadside safety features.

### Research Problem Statement C-5: Vehicle and Hardware Compatibility/2010

1. Currently developers of roadside safety hardware react to changes in the nation's vehicle fleet design. Their approach is reactive instead of pro active (i.e. increased use of three quarter ton vehicles, increased use of composite materials and light weight plastics in vehicle manufacture, small light weight electric city vehicles and a wide change of cg.
2. Conduct a Delphi type committee study to identify the nature of vehicle characteristics in the future (2010) in relation to roadside feature design.

*Research Objective*

To ensure that current and future roadside safety devices will interact safely with current and future vehicle fleet up to and inclusive of model year 2010. To analyze potential changes in technology affecting roadside hardware and design. This study will be a Delphi type study that will identify the anticipated vehicle changes.

The overall research objectives are as follows:

- An analysis of the present vehicle fleet.
- An inventory of road safety hardware.
- A projection of future vehicle fleet characteristics.
- Development of appropriate roadside hardware design and specifications for anticipated vehicle changes.

*Research Approach*

This study will be done through the following tasks:

1. Literature search.
2. Analytical technique on data base.
3. Identification of vehicle design trends.
4. Identification of roadside safety feature trends and philosophies.
5. Development of appropriate cost-effective analysis.

*Estimate of Problem Funding and Research Period*

Funding estimate is $200,000 over a period of two years.

*Urgency, Payoff Potential, and Products*

There is a need for our profession to pursue a proactive approach to roadway design and specification in order to optimize existing infrastructure utilization and future input. We need to close the lag or catch-up time between roadside hardware and the nation's fleet and develop roadside safety products that more effectively interface with current vehicle rolling stock.

### Research Problem Statement C-6: In-Service Field Performance Evaluation of Roadside Hardware

Roadside hardware is developed through research and standard crash test performance criteria. Hardware after testing is accepted for implementation. Even though crash test information may be adequate for acceptance in service field applications, conditions may be different than those tested. Field performance evaluations would afford information on field performance of systems and information on changes in performance as related to the changes in performance of systems due to changes in the vehicle fleet.

*Research Objective*

Develop procedures for performing and evaluating the in-service performance of roadside hardware.

*Research Approach*

1. Establish through literature research and state surveys current procedures, if any, being used to evaluate field performance of hardware.
2. Evaluate practices.
3. Develop recommended procedures.
4. Test procedures.

*Estimate of Problem Funding and Research Period*

$100,000 — Research period: 1 year plus testing time.

*Urgency, Payoff Potential, and Products*

There are no standard or widely accepted procedures for obtaining hardware field performance. In-service evaluations would provide data concerning performance of hardware with changes in vehicle fleet, maintenance practices, and maintenance performance. We need a procedure for evaluation of the in-service field performance of roadside hardware.

## FURTHER INTEREST GROUP C

### Clinical In-Depth Accident Studies

Are clinical in-depth accident studies a good way to understand accident scenarios? Is it possible to ever gather "enough" data to gain understanding about accidents.

The clinical in-depth accident studies have proven very useful in understanding the occupant injury patterns in vehicle crashes. These studies also help to identify the load characteristics and cause of injuries in crashes.

The accident data and information is used to develop vehicle crash countermeasures, and ultimately, improve vehicle safety performance. The same accident data can assist the physicians in trauma centers to look for particular injuries that are anticipated from specific types of crashes.

At present, the accident data is successfully used in clinical studies at the Jackson Memorial Hospital, Ryder Trauma Center in Miami, Florida. Through a contract with NHTSA, the center has established an automated method to record accident data which is used for various applications.

An expert accident reconstructionist is sent to the accident site to gather data. The pertinent information for emergency care is electronically transferred to the physicians at the trauma center. Additionally, the recorded accident data is used in clinical studies leading to a better understanding of injury patterns in vehicle crashes.

Similar methods can be devised to gather accident data concerning roadside hardware and their contributions to occupant injuries.

Research is needed in the following areas:

1. To review the procedures of data collection at Jackson Memorial Hospital, Ryder Trauma Center and assess how that method can be applied to collecting accident data pertaining to roadside safety hardware.
2. To adapt the format of the collected data to incorporate various features of the roadside hardware which may either directly cause or indirectly contribute to occupant injuries in crashes.

### Research Scope and Funding

The scope of the first phase of the research is limited to learning the existing method and adapting it to incorporate roadside safety features.

If the outcome is promising, the follow-up work will be more extensive.

The anticipated budget for the first phase is $75,000 for a duration of 12 months.

## BREAKOUT GROUP D: CRASH-TESTING AND SIMULATION RESEARCH NEEDS

*Leader: John Durkos, Energy Absorption Systems, Inc.*

### Introduction

Group D developed four research problem statements, all of which are shown below. Only the group's top choice was expanded to include a research objective and research approach.

Changes in the vehicle fleet over the past 10 years have resulted in the higher center of mass 2000 kg light truck vehicles (vans, mini-vans, pickup trucks and 4-wheel drive utility sport vehicles). Recent statistics have shown these light trucks comprise approximately 25 percent of the passenger car fleet and 40 percent of the new vehicles sold. The highway safety hardware on our nations highways today was designed for a class of vehicles that did not include the high center of mass vehicles. The changes in the vehicle fleet have been identified as a problem relative to the performance of the existing highway hardware. This may result in much of the current approved hardware becoming obsolete. Cost effective methods of modifying the hardware to meet the new vehicle fleet characteristics are needed.

Properties of vehicles need to be characterized in crash tests. We must prevent certain vehicles within a class from being chosen for a test on the basis of whether a particular vehicle would cause a given test condition to pass or fail.

In addition, there needs to be more interaction between the vehicle manufacturers and the hardware industry. Often the question arises of what is being tested, the vehicle of the hardware? If some small modification can be made in the vehicle to make it perform better in crashes with barrier hardware than this should be identified and communicated to the automobile industry.

### Research Problem Statement D-1: Feasibility of Retrofitting Existing Barrier Hardware to Meet Changes in Vehicle Fleet

Recent crash testing has shown that the increased variation in the size, weight, distribution, and shape (geometrics) of the test vehicles is raising the concern that existing longitudinal barrier cannot fulfill its safety function. Due to the large investment in the existing roadside safety infrastructure, a cost effective method of correction for modifications to the hardware may be necessary.

#### *Research Objective*

The objectives of this research are the following:

1. Identify the magnitude of the problem and issues influencing the problem.
2. Develop remedial measures to correct the problem to show that the barrier hardware (longitudinal barriers) is performing its intended function.
3. Evaluate the cost versus benefit ratio of these remedial measures.

#### *Research Approach*

This will be done through the following tasks:

1. Perform literature search — A literature search should be conducted to
    a. Identify vehicle fleet mix.
    b. Identify accident data.
2. Conduct a survey of selected highway personnel — Prepare an inventory of representative sample of existing highway hardware.
3. Compile existing barrier crash database.
4. Select appropriate vehicle computer models for use in simulation.

5. Select existing or develop models of barriers.
6. Simulate vehicle/barrier interaction of existing crash tests and compare with test behavior.
7. Modify computer model barrier with goal of improving barrier performance.
8. Perform full-scale crash tests to verify the computer simulations.
9. Perform benefit-cost analysis of the modified hardware.
10. Prepare a final report that summarizes the research results.

*Estimate of Problem Funding and Research Period*

The estimated funding for this project is $500,000 for the tasks noted above. The research will require approximately 36 months to complete.

*Urgency, Payoff Potential, and Products*

The urgency of this project is based on the changes in the vehicle fleet which are making existing hardware perform not as effectively as it was originally designed.

The project should identify cost-effective barrier modifications that will improve the safety performance of roadside safety hardware.

### Research Problem Statement D-2: Development of a Crash Test Matrix for the Family of 2,000 kg Light Truck Vehicles

Current research has identified 8 classes of 2,000 kg light truck vehicles which comprise nearly 25% of the current vehicle fleet and 40% of new vehicles sold in the United States. NCHRP Report 350, in its current form, only includes the 3/4 ton pickup truck. Baseline information on the performance of the other vehicles with roadside hardware is needed.

### Research Problem Statement D-3: Develop an Interim Revision to NCHRP Report 350

NCHRP Report 350, in its present form, does not consider the full cross-section of today's vehicle fleet, "real world" conditions, or international harmonization. Current research has identified 8 categories of 2,000 kg light truck vehicles, but only tests one vehicle. It does not include the effects of aerodynamic vehicle design or anticipated vehicle designs of the future. In addition, NCHRP Report 350, in its current form, does not address conditions specific to barrier hardware used in work zones.

### Research Problem Statement D-4: Identification of Factors Causing Vehicle Rollovers on Slopes

Changes in vehicle geometrics may have affected previous recommendations identifying traversable slopes. An evaluation of vehicle weight, center of gravity, wheelbase, tires, etc.,and their relationship to various slopes and soil conditions should be examined.

## BREAKOUT GROUP E: IN-SERVICE EVALUATION AND BARRIER PERFORMANCE DATA RESEARCH NEEDS

*Leader: Richard Powers, Federal Highway Administration*

### Introduction

For the last two decades, roadside barriers have been considered acceptable for use on public roads based primarily on their performance in specified, controlled crash tests. In a few instances, new devices were also evaluated for a limited period after installation to ascertain their performance under actual service conditions. As the vehicle fleet has changed, so too have test vehicles and recommended crash test matrices. Following publication in 1993 of the National Cooperative Highway Research Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features," new tests were run on selected roadside barriers that are in common use throughout the United States. Several of these tests did not meet the appropriate evaluation criteria, the implication being that the barrier is not "acceptable" for continued use.

Regardless of individual test results, most highway agencies believe that their traffic barriers are performing acceptably in the field under actual impact conditions. Unfortunately, this contention is based on limited data. With the exception of severe accidents involving fatally or critically injured persons, a high percentage of barrier accidents are not reported. Of those that are reported, the information gathered is seldom adequate to determine impact conditions with much certainty.

Thus, there may be a significant disparity between "normal" impact conditions and those prescribed by NCHRP Report 350. If the latter are too severe, efforts to upgrade existing barriers and terminals may be neither warranted nor cost-effective. Only by knowing with some degree of certainty how existing barriers are performing under actual field conditions can a determination be made as to whether or not the "standard" crash tests are realistic, or if, and to what extent, should existing installations be replaced or upgraded. A systematic approach for documenting how well hardware is performing in the field and identification of typical failure modes is needed. Establishing this approach is the intent of the problem statement that follows.

### Research Problem Statement E-1: In-Service Performance Evaluation of Traffic Barriers and Terminals

Generally state highway agencies do not know precisely how well their traffic barriers (including terminals) are performing. Severe failures are reported, and sometimes investigated in depth, but usually not analyzed from a barrier performance perspective. Successful performance is seldom documented. This lack of information can result in existing systems being considered non-crashworthy based on controlled testing (NCHRP 350), whereas they may be performing satisfactorily in the field.

#### *Research Objective*

The objective of this research is to (a) develop a systematic approach for evaluating field performance of traffic barriers and end treatments and (b) test this methodology in two to four states.

#### *Research Approach*

This will be done through the following tasks:

1. Literature search. Review current information to identify systems commonly in place.
2. Performance characteristics. Obtain standards and become familiar with design and performance characteristics of the selected systems.
3. Data definition. Determine the type and amount of data that needs to be collected to provide all pertinent details of a barrier system installation at a location, the conditions before impact, and all details of the performance of the barrier in crashes. Crash data should include angle of impact, vehicle type, speed of vehicle at impact, failure mode of the barrier, trajectory of vehicle, and injury to occupants; and final condition of barrier system after impact.
4. Data collection. Develop a data collection triggering mechanism, such as maintenance or collision reports and train data collectors to gather appropriate data. Develop a method and system to organize the resulting data.
5. Scope of data. Collect the prescribed data for a statistically significant sample per system.
6. Analyze the data both clinically and statistically to compare performance of barriers and end treatments.
7. Prepare a final project report which documents the findings and conclusions of the study.

#### *Estimate of Problem Funding and Research Period*

The estimated funding for this project is $500,000 for the tasks noted above. The research will require approximately 24 months to complete.

#### *Urgency, Payoff Potential, and Products*

Recent FHWA policy directives suggest need for changes in existing barrier standards and in states' upgrading practices. Data is needed to assess the cost-effectiveness of suggested changes and to determine an appropriate phase-in period.

The information obtained could be useful in determining guidelines for multiple-performance level barrier selection. The data may also give early indications of barrier performance in relation to vehicle fleet changes and/or the need to modify NCHRP 350 certification tests.

This project will provide an acceptable methodology that can be expanded for in-service evaluations by others.

# SUMMARY OF ROADSIDE SAFETY ISSUES

*Malcolm H. Ray, University of Iowa*
*John F. Carney III, Vanderbilt University*
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## INTRODUCTION

Although catastrophic accidents involving airliners, ships and trains receive a great deal of media attention, 94 percent of all transportation fatalities occur on roadways and highways.*(1)* These traffic deaths, occurring one or two at a time all over the nation on each day of the year, do not usually receive widespread attention but the cumulative toll is more than 40,000 deaths and more than 3.5 million disabling injuries with a societal cost exceeding $100 billion every year.*(1)*

Thirty years ago more than 50,000 Americans died in traffic accidents.*(2)* Each year from 1966 until 1992, the total number of fatalities dropped such that in 1994, just over 40,000 people were fatally injured in traffic accidents.*(3)* Although this reduction is laudable on its own, the fact that it was made with a concurrent increase in vehicle miles travelled is remarkable. The number of vehicle miles travelled was almost 2.5 times greater in 1992 than it was in 1966. In 1966 5.5 people were fatally injured for every 100 million vehicle miles travelled. In 1992 this rate was 1.8 fatalities per 100 million vehicle miles travelled, less than one third the rate of thirty years ago. If the fatality rate had remained unchanged since 1966, 123,000 people would have died on U.S. roadways in 1992 alone. Ultimately, safety must be measured in terms of lives saved and serious injuries avoided. The statistics above demonstrate that the many efforts at improving highway safety have indeed been effective.

Sustaining this laudable record in highway safety may, however, become more difficult. Some projections suggest that to keep the annual number of highway fatalities at the current number (about 40,000), the fatality rate on **all** roadways will need to be reduced to about 1.4 fatalities per 100,000 vehicle miles travelled. Present-day interstates, the safest highways in the world, had a fatality rate of 1.1 in 1993. It will be very difficult to reduce the system wide fatality rate to this level without significant advances in highway safety.*(1)* Even if it is possible to reduce the system fatality rate to this level, it is unclear whether the deaths of 40,000 citizens is acceptable to our society.

Determining the effectiveness of particular highway safety programs and initiatives, however, is very difficult. There are numerous federal and state agencies with important missions affecting highway safety including Departments of Transportation (state and federal), local law enforcement agencies, citizen groups, professional organizations, automobile manufacturers and the insurance industry. Each of these groups has played a role in making highways safer. One such group is the roadside safety community. Roadside safety professionals have worked behind-the-scenes for more than thirty years using engineering design to improve the safety of roadways. The roadside safety community has traditionally stressed engineering solutions to typical roadside safety problems like designing traversable side slopes, specifying minimum clear zones, and designing roadside safety hardware. The changing highway and legislative environment make it prudent to assess the past accomplishments and future directions of roadside safety research to ensure that the scarce resources available for improving roadside safety can be most effectively used to reduce the number of injuries and deaths resulting from roadside accidents.

The purpose of this meeting was to assemble experts in the area of roadside safety to discuss

- What has been accomplished in the past 30 years in that area of roadside safety,
- What are the major challenges for the future, and
- How the wide variety of organizations with an interest in roadside safety can be mobilized to meet the challenges of the future.

This conference was a follow-on effort to a meeting held in the summer of 1994 in Woods Hole, Massachusetts which resulted in Transportation Research Circular 435, *Roadside Safety Issues.(4)* The conference consisted of fourteen invited presentations from a variety of researchers, policy makers, and practicing engineers. Twelve of the presentations are documented earlier in this Circular. The invited presentations focused on three broad areas:

1. Accomplishments in roadside safety from the perspective of state DOT personnel, the Federal Government, and the research community.

2. The use of new technologies and methods like nonlinear finite element analysis in evaluating roadside hardware, accreditation of crash testing agencies, and emerging Intelligent Transportation Systems (ITS) technologies.

3. The changing vehicle fleet including the increased proportion of light trucks, minivans and multi-purpose vehicles, the possible affects of the Partnership for a New Generation of Vehicles (PNGV) program, and recent crash test experience with full-size pickup trucks.

After receiving the background information provided by the invited papers, participants were divided into the following five discussion and work groups:

A. Development of a strategic plan for roadside safety;
B. Severity indices development;
C. Vehicle fleet characteristics, ITS research needs, driver behavior, accident data collection and analysis research needs;
D. Crash testing and simulation research needs; and
E. In-service evaluation and barrier performance research needs.

### Development of a Strategic Plan for Roadside Safety

With the current climate of reduced governmental funding and distributed control over highway programs, it is vital that there be a strategic, multi-organizational approach to improving highway safety in general and roadside safety in particular. All the participants of the roadside safety community need to know how to maximize the effectiveness of their efforts by coordinating and entering partnerships with other groups interested in improving safety. Group A was composed of members of the NCHRP Project 17-13 panel and several guests. They held professionally facilitated discussions to develop statements about the purpose, vision and mission of the group as it relates to improving highways safety.

During the discussions of Group A, it was recognized that highway safety encompasses a very broad range of organizations including

- State and Federal Departments of Transportation,
- Local law enforcement agencies,
- Emergency services providers,
- Citizen action groups,
- Automobile manufacturers, and the
- Insurance industry.

Each of these groups has its own specific areas of expertise and concern which sometimes complement each other and other times work against each other. The primary purpose of a strategic plan for roadside safety is to form a framework to unite all these different organizations in coordinated action for improving the roadside. The group developed the following Vision, Purpose and Mission Statements:

*Vision*

A highway system where people do not pay with their lives when vehicles inadvertently leave the roadway. In this system, drivers rarely leave the road; but, when they do, the vehicle and roadside work together to minimize harm.

*Purpose*

To improve highway safety by reducing the frequency and severity of roadside accidents.

*Mission Statements*

- Mission 1: Build a network of organizations that will be partners in the effort to improve roadside safety research.
- Mission 2: Develop and implement methods to keep vehicles on the roadway.
- Mission 3: Develop and implement methods for minimizing the potential for vehicles striking objects on the roadside.
- Mission 4: Develop and implement methods that minimize the risk of injury when objects are struck on the roadsides.

The discussions held at this meeting are only the first step in developing a roadside safety strategic plan. The group plans to further refine the plan developed at this meeting by defining goals, objectives, action items, and research needs. They also cited the need to begin to broaden the circle of participants to bring other organizations that may not traditionally interacted directly with the roadside safety community.

### Severity Indices Development

This discussion group was composed of members of the Task Force on Severity Indices of TRB Committee

A2A04 (Roadside Safety Features). This group was organized to review

- The severity indices used in the ROADSIDE program,
- Severity indices in the new cost effectiveness analysis program being developed in NCHRP Project 22-9,
- The definition of severity indices, and
- Current methodologies used to develop severity indices.

The group identified several areas where additional research is needed. One issue that was discussed was finding methods to more formally link crash test performance and field evaluations to the expected behavior of devices under real-world conditions. Current severity indices have tended to be subjective and there is no specific technique for developing a severity index based on specific crash test performance or real-world experience. Research is needed to provide up-dated indices for cost-benefit programs that are being developed in NCHRP 22-9 (Table 1, Research Need 15). Research is also needed to develop methods that result in more quantifiable measures of severity (Table 1, Research Need 4).

With recent changes in the Federal Motor Vehicle Safety Standards (FMVSS), airbag equipped vehicles are becoming a larger segment of the vehicle population. Airbag sensors installed in vehicles collect information about the accelerations being experienced during the deployment of the airbag. If this data could be collected, it may prove a valuable source of information about the dynamics of real-world collisions. Unfortunately, this information is not readily available to researchers so a study to determine exactly what is retrievable from airbag sensors and how it might be obtained needs to be performed (Table 1, Research Need 6).

One of the most fundamental problems in performing cost-effectiveness analysis for roadside hardware is estimating the number of unreported accidents. Generally, unreported accidents are low severity collisions where the vehicle and driver were able to leave the scene without notifying a law enforcement agency. Such collisions are the "successes" in assessing the effectiveness of the system since they resulted in an accident of such low severity that the occupants could leave the scene. Obtaining better estimates of the number of unreported accidents is vital to performing realistic cost-benefit analyses. Most of the data that is used in current cost-benefit programs date from very old studies that were performed under very limiting conditions. These studies have been extended and generalized well beyond the data that was gathered at the time (Table 1, Research Need 10).

Issues discussed by this group are vital to the development of selection and location criteria that can be used by owner agencies to make decisions about installing and maintaining roadside appurtenances.

### Vehicle Fleet Characteristics, ITS Research Needs, Driver Behavior, Accident Data Collection and Analysis Research Needs

This group addressed a wide variety of important topics including

- Vehicle fleet characteristics and trends,
- Vehicle-roadside hardware compatibility,
- Occupant protection technology and its affect on roadside safety hardware,
- Driver behavior and behavior modification,
- Safety opportunities from Intelligent Transportation Systems (ITS) technologies, and
- Improved accident data collection and analysis procedures and technologies.

NCHRP Report 350, published in 1993, recommended a number of changes in crash test and evaluation procedures as well as retaining many of the features of NCHRP Report 230, its predecessor. Past experience has shown that updating test and evaluation procedures is both a lengthy and an iterative process. Several issues need to be re-examined including (1) the compatibility of the current vehicle fleet and roadside hardware, (2) the use of occupant restraint systems in evaluating crash tests, (3) international harmonization of testing procedures, and (4) identifying reasonable worst case impact scenarios (Table 1, Research Need 11). In addition to revising the current recommended procedures, there is a need for the roadside safety community to become proactive rather than reactive. In the past the roadside safety community has reacted to changes in the vehicle fleet and improvements in occupant technology. This has resulted in a long lag between the identification of an emerging trend and the implementation of hardware design to address the trend. There is a need to find methods that allow roadside safety researchers to address potential problems before they show up in accident data (Table 1, Research Need 8).

Historically, the vehicle design and roadside hardware design communities have worked without much interaction. This never was a desirable state of affairs but with the changes in the vehicle fleet it has become impossible to design roadside hardware without considering the design of vehicles. Vehicle-roadside hardware compatibility is an important issue that needs to be examined. Methods need to be that ensure that barrier designs are not made obsolete by rapid changes in vehicle designs (Table 1, Research Need 1).

Roadside hardware has traditionally been designed assuming that the occupant of the impacting vehicle was not using any occupant restraints like seat belts. In decades past when belt usage was relatively low this was a reasonable assumption. Increasing belt use as well as the availability of new active and passive restraint systems suggest that a review of this assumption is warranted. NHTSA studies of airbag equipped vehicles has shown that the types and patterns of injuries in airbag equipped vehicles is different that those found in non-airbag equipped vehicles. Designing hardware only for the unrestrained occupant may be putting the restrained occupant at risk in another injury mode. Designing for the unrestrained occupant may also be too demanding for many difficult impact scenarios (Table 1, Research Need 5).

The Federal Department of Transportation is involved in several major initiatives in developing Intelligent Transportation Systems (ITS). These systems may dramatically change the operating conditions and characteristics on many roadways. There may be important safety implications to ITS technologies that should be considered by roadside designers. One example is the integration of crash avoidance technologies into the vehicle fleet (Table 1, Research Need 14).

In-service evaluation was another area where more research needs to be performed. Methods for performing in-service evaluations need to be developed and owner agencies need to be encouraged to perform these types of studies (Table 1, Research Need 3). There is also a great deal of uncertainty about what type of data needs to be collected. Clinical in-depth accident investigations provide a great deal of information but lack statistical significance. Broadbased statistical studies provide adequate numbers of cases but lack the detail required to determine exactly what happened in the accident.

## Crash Testing and Simulation Research Needs

Crash testing has been the principal method for evaluating roadside safety hardware for more than 30 years. The past several years have seen some surprising crash tests, notable those involving full-size pickup trucks striking guardrails.

Vehicles have changed dramatically since the days when the most common roadside hardware was developed. In years past, the vehicle fleet changed relatively slowly and these changes could be accommodated by gradual changes in roadside hardware. Now, however, new types of vehicles are being developed, vehicles that were once "specialty" vehicles now represent a significant part of the vehicle population, and other vehicle types have essentially disappeared. These changes necessitate a re-evaluation of the compatibility between the present day vehicle fleet and the current generation of roadside safety hardware.

One particularly important vehicle is the 2000-kg pickup truck recommended as one of the crash test vehicles in NCHRP Report 350. The performance of this vehicle has been shown to be poor in impacts with a variety of roadside hardware. In addition to being recommended by Report 350, this vehicle is also a popular vehicle and growing portion of the vehicle fleet (Table 1, Research Need 13).

## In-Service Evaluation and Barrier Performance Research Needs

The importance of in-service evaluations has been widely recognized by the roadside safety community for more than a decade although in-service evaluations are still relatively uncommon. NCHRP Report 230 was the first evaluation procedure to recommend that formal in-service evaluations be routinely performed. More than a decade later, NCHRP 350 re-emphasized the importance of in-service evaluation.*(5) (6)* The authors of Reports 230 and 350 recognized that without effective in-service evaluations, it was impossible to determine if barriers developed and tested under laboratory conditions performed as expected in the field. Performing research, developing more effective roadside hardware and developing public policy without in-service evaluations has been very difficult. Unfortunately, no accepted procedures or criteria have ever been developed for performing in-service evaluations so they are rarely performed. Today, hundreds of thousands of miles of roadside hardware are installed on the nation's highways and there is only a very limited appreciation for how these devices are performing under real-world operating conditions. This group discussed possible methods and procedures that could be used by the states and other highway agencies to perform in-service evaluations (Table 1, Research Need 2).

## CONFERENCE RESULTS

Several of the discussion groups produced research needs statements and the conference attendees ranked the 15 research needs in terms of their importance as shown in Table 1. Each attendee was asked to rank the top five research needs, a score of five for the most important and no score for the least important. The total scores are shown in Table 1 in order of their final ranking.

In can be noted that several different groups independently produced virtually identical research needs statements or closely related ones. This was recognized in the closing session of the conference and suggestions made for combining, modifying, or supplementing the research needs in the final plenary session of the Workshop. After the Workshop these suggestions were used to formulate nine Research Problem Statements. Table 2 summarizes the nine Research Problem Statements and the full text is provided in Appendix A. The individual research needs scores were combined to obtain a ranking of the problem statements. It is important to note that research problem #1 has already been used to prepare a request for proposals for NCHRP Project 22-13 "In-Service Performance of Traffic Barriers." It is expected that this research will be initiated in early 1996.

## SUMMARY

A great deal has been accomplished in improving the effectiveness of roadside safety hardware during the past several decades. The always-changing vehicle fleet and highway environment do not allow the roadside safety community the luxury of complacency. There are significant challenges ahead in improving roadside safety. These challenges can only be met by openly discussing difficult issues as they emerge and focusing the efforts all those with an interest in roadside safety on coordinated action.

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TABLE 1 RESEARCH NEEDS AND RANKINGS

| No. | Score | Group | Research Problem Statement Title |
|---|---|---|---|
| 1 | 30 | C | Vehicle and roadside safety hardware compatibility and reconciliation of motor vehicle safety standards and roadside hardware evaluation standards. |
| 2 | 29 | E | In-service performance evaluation of traffic barriers and terminals. |
| 3 | 27 | C | In-service field performance evaluation of roadside hardware. |
| 4 | 26 | B | Accident severity/surrogate measure relationships. |
| 5 | 24 | C | Effect of airbags in roadside safety crashes. |
| 6 | 22 | B | Feasibility of collecting airbag crash sensor data. |
| 7 | 21 | D | Identification of factors causing vehicle rollovers on slopes. |
| 8 | 20 | C | Vehicle and hardware compatibility/2010. |
| 9 | 17 | D | Feasibility of retrofitting existing barrier hardware to meet changes in vehicle fleet. |
| 10 | 17 | B | Extent of unreported accidents. |
| 11 | 15 | C | Update NCHRP Report 350. |
| 12 | 15 | D | Develop an interim revision of NCHRP Report 350. |
| 13 | 13 | D | Development of a crash test matrix for the family of 2,000-kg vehicles. |
| 14 | 8 | C | Assessment of crash avoidance methods through ITS technologies for application to roadside safety features. |
| 15 | 7 | B | Revise severity estimates used in NCHRP 22-9. |

TABLE 2 RESEARCH PROBLEM STATEMENTS AND RANKINGS

| No. | Score | Research Problem Statement Title |
|---|---|---|
| —[1] | 56 | In-Service Performance Evaluation of Roadside Safety Hardware (combination of research needs 2 and 3). |
| 1 | 67 | Assessment of Means to Improve the Compatibility of Vehicles and Roadside Safety Hardware (combination of research needs 1, 8, and 9). |
| 2 | 52 | Assessment of Updating Needs for the Procedures for the Performance Evaluation of Roadside Safety Features (combination of research needs 11, 12, and 13). |
| 3 | 46 | Effect of Airbags on Roadside Accidents and Potentials for Post-Crash Utilization of Airbag Crash Sensor Data (combination of research needs 5 and 6). |
| 4 | 33 | Development of Accident Severity Indices and Surrogate Relationships (combination of research needs 4 and 15). |
| 5 | 21 | Identification of Factors Causing Vehicle Rollovers on Slopes (research need 7). |
| 6 | 11 | Determination of the Extent of Unreported Accidents (research need 10). |
| 7 | 8 | Assessment of ITS Crash Avoidance Methods for Application to Roadside Safety Features (research need 14). |
| 8 | —[2] | Clinical In-Depth Accident Studies. |

Notes:

[1] Write-up not included because it was used to formulate the request for proposals for NCHRP Project 22-13, "In-Service Performance of Traffic Barriers."

[2] Late submittal, not rated by workshop participants.

# APPENDIX: RESEARCH PROBLEM STATEMENTS

## RESEARCH PROBLEM STATEMENT 1: ASSESSMENT OF MEANS TO IMPROVE THE COMPATIBILITY OF VEHICLES AND ROADSIDE SAFETY HARDWARE

Recent roadside safety research has noted that the increased variation in the size, weight, distribution, and shape (geometrics) of vehicles in the U.S. fleet is raising the concern that existing barriers, related hardware, and other features cannot fulfill their safety functions. Currently developers of roadside safety hardware react to changes in the nation's vehicle fleet design, instead of being proactive to changes in vehicle design (i.e. increased use of three quarter ton vehicles, increased use of composite materials and light weight plastics in vehicle manufacture, small light weight electric city vehicles, and a wide range in centers of gravity). Roadside safety hardware is designed to meet the testing requirements for a range of vehicles defined by NCHRP Report 350. Recent testing has revealed that some vehicle characteristics can lead to undesirable results. A study is needed to identify vehicle characteristics that can negatively effect the impact performance with roadside safety hardware.

Currently automobile manufacturers design new vehicles to meet an existing set of federal motor vehicle safety standards. Roadside safety hardware designers use a different set of safety standards to test and qualify their designs. Both groups verify that their designs meet required parameters through both computer modeling and full scale crash testing. It is important that means to modify these standards be investigated to assure the compatibility of vehicles and roadside hardware.

Due to the extensive existing roadside safety infrastructure, it is extremely costly to retrofit hardware to meet changes in vehicle fleet. Over the past three decades, this was necessary to accommodate the small car and it appears that similar efforts may be necessary to accommodate the light truck class of vehicles and aerodynamically designed vehicles.

### Research Objectives

The objectives of this research are to 1) identify vehicle characteristics that are potentially incompatible with existing roadside safety hardware, 2) assess opportunities to improve compatibility, and 3) prepare materials to increase the awareness of vehicle and hardware manufacturers and decision makers of the problem.

### Research Approach

This research will involve the following tasks:

1. Review the literature to describe the current and future vehicle fleet, define the nature of the problem, and identify possible approaches to resolving the compatibility problem. Review recently conducted crash tests to gather feedback on vehicle characteristics that can negatively affect impact performance with roadside safety hardware. Review federal motor vehicle safety standards to identify elements that influence total impact performance. Document areas of deficiency or incompatibility (e.g. Define desired vehicle frontal area needed to interact with roadside safety hardware, define acceptable bumper heights and bumper stiffness, define acceptable center-of-gravity height that will yield acceptable impact results).
2. Establish perspectives on the issue through contacts with selected highway agency, NHSTA, manufacturer personnel, and others.
3. Prepare an representative inventory of roadside hardware and compile barrier crash database. Identify the magnitude of the problem and factors influencing it.
4. Identify approaches/tools for evaluating compatibility issues. Consider the use of analytical, simulation, and crash testing methods. Identify appropriate vehicle and barrier computer models for use in simulation.
5. Project the future vehicle fleet characteristics and identify future roadside safety trends, philosophies, and hardware.
6. Identify strategies and tactics to improve the compatibility of vehicles and roadside safety hardware. These may include the development of appropriate roadside hardware designs and specifications, modification of vehicle safety certification tests, and imposition of more stringent vehicle design standards.
7. Evaluate the costs and benefits associated with measures to improve the compatibility of vehicles and roadside safety hardware.
8. Conduct a Delphi-type session of knowledgeable professionals to identify the nature of vehicle characteristics in the future (2010) in relation to roadside feature design and to insure that roadside safety devices will interact safely with future vehicles. Analyze potential changes in technology affecting roadside hardware and design.
9. Prepare a final report that summarizes the research results and includes materials that can be used

to increase awareness of this problem among vehicle and hardware manufacturers and transportation agency managers.

### Estimate of Problem Funding and Research Period

The estimated funding for this project should be $300,000. The project would be expected to take 36 months to complete.

### Urgency, Payoff Potential, and Products

This project will increase awareness of this problem and recommend actions to modify existing standards to maintain and/or improve the impact performance between the new and existing vehicles and roadside safety hardware. There is a need for our profession to pursue a proactive approach to roadway design and specification in order to optimize existing infrastructure utilization and future input. It will help close the lag or "catch up" time between roadside hardware and the nation's fleet. The overall safety of the motoring public will be improved by roadside safety products that more effectively interface with current and future vehicle fleets. The urgency of this project is based on the changes in the vehicle fleet which are reducing the effectiveness of the existing roadside safety hardware infrastructure. The project should identify cost effective barrier modifications which will improve the safety performance of the roadside safety hardware.

## RESEARCH PROBLEM STATEMENT 2: ASSESSMENT OF UPDATING NEEDS FOR THE PROCEDURES FOR THE PERFORMANCE EVALUATION OF ROADSIDE SAFETY FEATURES

NCHRP Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features" is the latest in a series of documents aimed at providing guidance on testing and evaluating roadside hardware and other features. NCHRP Report 350 incorporated significant additions over NCHRP Report 230 including criteria for multiple performance levels, procedures for testing features not previously addressed, and translation to metric units. It addressed needs associated with the changing character of the highway network and the vehicles using it. For example, it includes the requirement for testing with a 2000 kg pick-up truck, based on data which indicated that approximately 25% of the U.S. vehicle fleet was comprised of "light truck" type vehicles. Current research has identified eight categories of light truck vehicles, but the 3/4 ton pick-up truck represents the only test vehicle for this subset of the vehicle fleet. The authors of NCHRP Report 350 recognized this problem and were aware that there had only been limited crash test experience with this type of vehicle, but resources were not available for additional testing to validate the specified test conditions. Recent tests under NCHRP Report 350 have indicated that some existing hardware and current vehicle designs have difficulty passing the recommended test conditions. These problems have raised questions about the appropriateness of the test criteria for these vehicles.

NCHRP Report 350 is based upon a number of tacit assumptions (i.e., occupants of errant vehicles are unbelted, that vehicles should be contained and redirected, and that the test should reflect worst case scenario conditions). It is also assumed that the vehicles are stable and tracking and that the potential for occupant injury can be calculated from the vehicle changes in velocity. NCHRP 350 assumes that the only way to evaluate roadside hardware is through laboratory and full-scale tests. However, the state-of-the-art of using finite element analysis for design and evaluation of hardware is rapidly advancing. It has also been noted that the NCHRP Report 350 does not include the effects of aerodynamic vehicle design or anticipated future vehicle designs and does not address conditions specific to barrier hardware used in work zones.

Past experience has shown that updating the recommended test and evaluation criteria is a lengthy process. The need exists to determine how continuing changes in the vehicle fleet (e.g., impacts of air bags and anti-lock brakes) are affecting the number and severity of crashes. The findings of current research projects to investigate the speed and angles at which vehicles leave the roadway, the propensity for rollovers, and the in-service performance of barriers need to be considered. Further, changes in occupant restraint systems, technological innovations in barriers, and improved knowledge of vehicle/hardware interaction may necessitate modification of the evaluation procedures. Baseline information on the performance of the other vehicles with roadside hardware is needed. There is also a need to revisit NCHRP 350 to see if further advances can be made in international harmonization of test and evaluation criteria; and to see if the occupant risk measures can be made compatible with those used by the Europeans. Therefore, it is time to assess the need for an update to NCHRP Report 350 to reflect current and future roadside safety needs performance and their interface with the changing environment.

### Research Objectives

The objectives of this research are to review the guidance provided in NCHRP Report 350, assess the needs for updates to the document, and develop a strategy for updating performance requirements and evaluation criteria based on the projected vehicle fleets, current research, and emerging highway safety technology.

### Research Approach

The researchers will need to re-examine the assumptions and re-evaluate the test and evaluation criteria in NCHRP Report 350. As a minimum, they will complete a literature survey, perform detailed analyses of accident and field performance data, review the findings from on-going research, evaluate other vehicle safety performance standards, assess the results of recent crash tests, and prepare a summary of possible deficiencies in Report 350. They will need to re-examine the current occupant risk measures, assess the effects advances such as airbags, side airbags, safety belt pretensioners and new child restraint technology requirements, determine the feasibility of incorporating new test procedures (e.g., side impact tests), and review the potentials for changing basic philosophies providing roadside safety to exploit emerging technologies. Past efforts to develop evaluation procedures have included the preparation of white papers, expert review and debate, comparative analyses, and investigations of potential implications of revised procedures.

### Estimate of Problem Funding and Research Period

It is estimated that the proposed research will require $500,000 and the research effort including preparation of the final report will require 2 years to complete.

### Urgency, Payoff Potential, and Products

There is an urgent need to revisit and re-evaluate requirements specified in NCHRP Report 350 to reflect the latest advances in technology to assure that the recommended test conditions reflect needed safety performance as indicated by accident and field performance data, and that the recommended procedures are cost effective in improving safety.

## RESEARCH PROBLEM STATEMENT 3: EFFECT OF AIRBAGS ON ROADSIDE ACCIDENTS AND POTENTIALS FOR POST-CRASH UTILIZATION OF AIRBAG CRASH SENSOR DATA

The conversion of the car, light truck, and van fleet to airbags is now well underway, and deployment of the airbag in crashes with roadside safety features is believed to have resulted in reductions of fatalities and injuries. As more crashes take place involving vehicles equipped with airbags, quantifying the benefits associated with airbags in run-off-road crashes can be done with more confidence. Such knowledge would allow improvements in the design of vehicles and roadside hardware and sounder decision making relative to the application of safety treatments. The increasing need to optimize limited safety resources provides further impetus for improved cost-effectiveness analyses. These analyses require the ability to correlate collision conditions to probability of injury. There is currently a lack of reliable data upon which these relationships can be formulated.

Gathering crash data related to vehicles equipped with airbags is possible and has begun in some states. The deployment of the air bag can be easily identified by those investigating such crashes and this event is now routinely reported on some state crash forms. If not directly reported on the crash form, decoding of vehicle identification numbers (VINS) is another way to identify airbag-equipped vehicles involved in crashes. Only limited effort has been made to analyze the effects of airbags on accident severity using this information.

A related research need involves investigation of opportunities to capture vehicle dynamics data from the sensors provided to measure vehicular decelerations in determining when airbags should be deployed. This technology is believed to have the capability to store pertinent vehicle dynamics information from airbag systems which have been deployed during a crash. Research is needed to determine if it is possible to capture this data, and correlate it with other detailed accident injury information to provide a direct link between accident severity and surrogate occupant severity measures. The resultant measures will provide a basis for the development of better severity indices and lead to improved cost-effectiveness analyses.

### Research Objective

The objectives of this research are to (1) quantify the effect of airbags in crashes with roadside safety features,

(2) determine the feasibility of collecting airbag crash sensor data from vehicles involved in collisions resulting in airbag deployment, and (3) provide recommendations on the uses of this data.

### Research Approach

It is envisioned that the following work activities would be necessary to satisfy the above objectives:

1. Identify state databases that can be used to study crashes involving vehicles equipped with airbags (i.e., states that code airbag deployment or who routinely report vehicle identification numbers). The research should try to involve states in the Highway Safety Information System (HSIS) database to exploit the good linkages of crash data to roadway and roadside data.
2. Select the cases where the airbags are used, as well as the cases with non-airbag deployment over a range of roadside features.
3. Compare the injury outcome of airbag crashes to those without airbags, controlling for other variables such as speed limit or impact speed, crash location (e.g., urban/rural), roadway alignment (e.g., curvature and grade information), and distance to object struck from roadway. Quantify the proportion of A+K injuries for airbag versus non-airbag crashes and compare to determine if there are the expected safety benefits associated with vehicles equipped with airbags for various roadside safety features.
4. Determine state-of-the-art (practice) in airbag crash sensor data technology. This task should establish what information is available, how it is stored, and how the data can be accessed. Differences among different automobile manufacturers should be considered.
5. Investigate institutional barriers to accessing the crash sensor data. Ownership issues and liability concerns surrounding use of this data should be explored.
6. Recommend data collection methodologies and protocol. Determine how data should be collected, where the data should be stored, and an appropriate format and controls on distribution.
7. Prepare a Final Report documenting the efforts and findings of this research.

### Estimate of Problem Funding and Research Period

The estimated funding for this project is $250,000. The research will require approximately 24 months to complete.

### Urgency, Payoff Potential, and Products

There is currently a lack of reliable data upon which the relationships between impact conditions and probability of injury can be established. Data from airbag crash sensors on vehicles, if available, could potentially provide valuable data over the long term. Comparative analysis of crash data for vehicles with and without airbags can provide important insights into the design of vehicles and roadside hardware. The relationships between impact conditions and probability of injury will be invaluable as inputs to cost-effectiveness analysis procedures.

## RESEARCH PROBLEM STATEMENT 4: DEVELOPMENT OF ACCIDENT SEVERITY INDICES AND SURROGATE RELATIONSHIPS

The performance of roadside safety features is usually evaluated through full-scale crash testing and/or computer simulation, using surrogate occupant risk measures such as occupant impact velocity, ridedown acceleration, and peak acceleration. The results are then used to determine compliance with specific safety performance standards. These results are also used to establish, primarily in a subjective manner, estimates of relative severity (e.g., severity indices) for use in cost-effectiveness analysis. Unfortunately, little research has been devoted to quantitatively establishing links or relationships between surrogate occupant risk measures and accident severity or probability of injury. There are questions about the accuracy and validity of these surrogate measures, such as the effects of increased seatbelt usage and availability of airbags for drivers and front seat occupants in passenger cars and light trucks since the occupant risk measures are based on unrestrained occupants. Establishing these links or relationships would greatly improve crash test evaluation standards and cost-effectiveness analysis procedures.

Various methodology(ies) for establishing these links and relationships between surrogate occupant risk measures and accident severity or probability of injury are possible. This research is needed to identify viable methods and recommend the technical approach deemed most likely to succeed in meeting the study objective. Potential methodology(ies) may include computer simulation, occupant risk modeling, in-depth accident data collection and reconstruction, full-scale crash testing, and/or combinations of one or more of these approaches. Multiple contract awards should be considered to solicit ideas from more than one research agency.

### Research Objective

The objective of this research is to develop a methodology(ies) for establishing links or relationships between surrogate occupant risk measures and accident severity or probability of injury that reflect recent advances in vehicle safety systems, such as airbags and side impact protection. The methodology(ies) should also provide the basis for future updating of these estimates to reflect further safety improvements.

### Research Approach

It is envisioned that the project will involve the following tasks:

1. Conduct a review of the literature to determine the nature of available severity and surrogate measure information and the methods that have used to derive this information and correlate it to real crash experience. Attention should be given to both foreign and domestic research.
2. Contact researchers and practitioners to solicit information on the needs for severity information and thoughts on how it can be compiled and related to crashes.
3. Conceptualize a methodology(ies) and describe the process that would be needed to implement it. Prepare an interim report which describes the methodology(ies), the implementation process, and the associated costs and time frames. The interim report should consider a pilot demonstration of the developed methodology(ies) applied to at least one roadside feature to explicitly show how the relationships are developed.
4. Upon approval of the interim report, proceed to develop severity relationship(s) for various roadside features. Document the efforts, data gathered, and resulting relationships for each roadside feature.
5. Establish a process for storing, disseminating, and updating the severity data. Implement a process for periodic updates of this data to reflect external influences on severity.
6. Prepare a final report which documents the efforts and findings of the research.

### Estimate of Problem Funding and Research Period

The estimated funding for this research $300,000 (Consider multiple awards at $100,000 each). The research will require approximately 18 months to complete.

### Urgency, Payoff Potential, and Products

Economic analysis procedures for determining the feasibility and effectiveness of alternative roadside treatments, both new and retrofit, are dependent upon knowing the severities of all likely incidents involving a specific treatment. There is a need for better accident severity information for use in economic analyses to improve the decision making process. Links between surrogate measures and accident severity can also lead to a major improvement in future crash test standards. Findings from this research can be implemented into revisions of the Roadside Design Guide and NCHRP Report 350.

## RESEARCH PROBLEM STATEMENT 5: IDENTIFICATION OF FACTORS CAUSING VEHICLE ROLLOVERS ON SLOPES

Over the past forty years there have been significant changes in the design of vehicles. While these changes are thought to have led to lower, lighter, and more powerful vehicles, the reality is that the range of vehicle design characteristics has increased. For example, while the fuel economy standards have led to many small, light passenger vehicles there has also been explosive growth of the use of "light truck" type vehicles for passenger purposes. There have also been changes in the crashworthiness, braking and handling capabilities, and occupant protection provided by new vehicles. Since guidelines for the design of highways, particularly roadside features, have not changed as rapidly as the vehicle fleet, recommendations for features such as traversable slopes are being questioned. Rollovers are being noted in a large percentage of crashes suggesting that an evaluation of design guidelines is needed relative to vehicle weight, center of gravity, wheelbase, tires, and other factors is needed for various slopes and soil conditions.

NCHRP Project 17-11 "Recovery Area Distance Relationships for Highway Roadsides" is investigating the characteristics of encroachments onto the highway roadside with the intent of providing updated relationships between side slope, vehicle type, speed, angle of encroachment, and other factors. It is expected that new insights about the nature of encroachments will result, including insights about the propensity of a vehicle to roll when leaving the roadway. The results of this effort will provide the basis for revisions to highway design standards, but they will not be addressed directly as part of the project. NCHRP Project 17-14 "Effect of Median Width and Slope on the Frequency and Severity of Cross Median Accidents of Rural Roadways" will utilize data gathered in the 17-11 project to determine if revisions are needed in the design standards for medians. Additional research is needed to determine if revisions to other design standards to reduce the rollover potential are needed. Research is also being sponsored by the FHWA in an attempt to define generic vehicle platform descriptions. These should represent the basic vehicle categories focused on in this research.

### Research Objective

The objective of this research is to examine the ranges of vehicle design parameters and correlate these to the current values assumed in the design of highway facilities, control strategies, and roadside hardware to reduce the potential for rollover.

### Research Approach

It is envisioned that the project will involve the following tasks:

1. Conduct a review of the literature to determine the changes that have taken place in the vehicle fleet and the associated evolution of highway design standards. Attention should be given to both foreign and domestic research.
2. Contact researchers and practitioners to solicit insights into the nature of rollover problems that have been noted and the nature of treatments that are being used to counteract the tendency for vehicles to rollover.
3. Identify the factors associated with the rollover problem and determine the relative influence of the various factors.
4. Identify approaches/tools for investigating the rollover problem. Review the use of analytical, simulation, empirical, and crash testing methods to establish parameters for defining the potential for rollover.
5. Project the future vehicle fleet characteristics and analyze the implication on the rollover problem.
6. Analyze the various factors for current and future vehicle fleets using the most viable analysis method. Conduct appropriate sensitivity analysis to assess the robustness of the findings. Document the results of these analyses.
7. Identify the necessary changes to design standards based upon the results of the analysis.
8. Evaluate the costs and benefits associated with measures to reduce the potential for vehicle rollover.
9. Prepare a final report that documents the research efforts and results. The report should recommend appropriate changes in highway design standards.

### Estimate of Problem Funding and Research Period

The estimated funding for this research $250,000. The research will require approximately 18 months to complete.

### Urgency, Payoff Potential, and Products

This project will provide recommendations modifying existing design standards to reduce the potentials for vehicles to rollover on side slopes. Efforts to reduce rollover crashes will lead to significant reductions in the number and severity of accidents.

## RESEARCH PROBLEM STATEMENT 6: DETERMINATION OF THE EXTENT OF UNREPORTED ACCIDENTS

Accident data provides one of the more objective means of estimating accident severity or probability of injury. However, available accident data is based on reported accidents only and the resulting severity estimates may be biased or even erroneous. The extent of unreported accidents vary significantly by object struck. It is necessary to include unreported accidents in the severity estimates to get the true picture of the effectiveness of roadside safety treatments.

Various methodology(ies) for establishing estimates of unreported accidents are possible. This research is intended to identify viable methods and recommend the technical approach deemed most likely to succeed in meeting the study objective. Potential methodology(ies) may include computer simulation, occupant modeling, in-depth accident data collection and reconstruction, full-scale crash testing, and/or combinations of one or more of these approaches.

### Research Objective

The objectives of this study are to 1) determine the extent of unreported accidents for selected roadside features, and 2) develop a methodology(ies) for monitoring unreported accidents that reflect recent advances in vehicle safety systems, such as airbags and side impact protection. The methodology(ies) should also provide the basis for future updating of these estimates.

### Research Approach

It is envisioned that the project will involve the following tasks:

1. Conduct a review of the literature to assess past efforts to identify the extent of unreported accidents. Identify roadside features to be evaluated and the pertinent factors to be considered. Attention should be given to both foreign and domestic research.
2. Contact researchers and practitioners to solicit information on the needs for determining the extent of unreported accidents and thoughts on how it can be compiled.
3. Conceptualize a methodology(ies) for establishing an estimate of unreported accidents by roadside hardware type and describe the process that would be needed to implement it. Develop various approaches to identify unreported incidents (e.g., maintenance records, field monitoring of damage to roadside features, assistance from hardware manufacturers, police reports, public complaints). The methodology should address the needs at the national, state, and local levels.
4. Prepare an interim report which describes the methodology(ies), the implementation process, and the associated costs and time frames. This report should be reviewed by a group of knowledgeable professionals to determine whether the methodology is feasible.
5. Upon approval of the interim report, proceed to gather the data necessary to determine the extent of unreported accidents for various roadside features. Document the efforts, data gathered, and resulting relationships for each roadside feature.
6. Analyze the data gathered to match reported accidents to unreported incidents to determine ratio of reported to unreported accidents for various roadside hardware.
7. Determine options for improving the ability to determine the extent of unreported accidents through additional data collection, improved record keeping, or other methods.
8. Prepare a final report that documents the research efforts and results.

### Estimate of Problem Funding and Research Period

The estimated funding for this project is $250,000. The research will require approximately 24 months to complete.

### Urgency, Payoff Potential, and Products

Estimates of accident severity or probability of injury are crucial to cost-effectiveness analysis procedures. Current accident severity estimates are mostly based on reported accident data, which may be biased or even erroneous since unreported accidents are not included in the estimates. It would be highly desirable if the extent of unreported accidents can be established for various roadside features in order to improve upon the accident severity estimates.

## RESEARCH PROBLEM STATEMENT 7: ASSESSMENT OF ITS CRASH AVOIDANCE TECHNOLOGIES FOR APPLICATION TO ROADSIDE SAFETY FEATURES

Collision avoidance methods are currently being developed for vehicles through Intelligent Transportation Systems (ITS) technologies. To this end, it is appropriate to assess the potential of various collision-avoidance technologies as an adjunct to roadside safety systems. In this sense, this assessment would involve the appropriateness of collision avoidance technology to enhance the effectiveness of roadside safety systems in certain situations. The focus would be on existing technology and hardware that prevents the vehicle from leaving the highway. The research needs to assess the types of crashes that could be addressed, analyze the potential effectiveness and associated costs, and evaluate the time frame over which benefits could be realized.

### Research Objective

The objectives of this research are to: 1) assess and evaluate current collision avoidance technologies including active and passive elements; 2) assess the suitability of these techniques for incorporation into roadside safety systems; and 3) demonstrate the most promising techniques through limited experiments to establish the efficacy of the application to roadside safety systems. This research will result in the use of off-the-shelf crash avoidance hardware to enhance the performance of the roadside safety features.

### Research Approach

In order to meet the research objectives, the following tasks, at a minimum, must be conducted. These tasks will be performed through two distinct phases. Phase 1 will identify and assess the technologies that can be used in conjunction with roadside safety systems and assess the applicability of these systems in different situations. Phase 2 will focus on a field demonstration of the most viable technology. The following tasks are envisioned for each phase.

*Phase 1: Technology Assessment and Evaluation*

1. Conduct a literature review to identify the available collision avoidance technologies and efforts to utilize these to improve roadside safety.
2. Select most suitable techniques (including costs, compatibility, implementability, and effectiveness) for application to roadside safety.
3. Develop scenarios for utilizing the techniques in various roadside safety features.

*Phase 2: Field Evaluation*

1. Select a technology suitable for field testing and develop a plan for testing under specific application scenarios.
2. Implement the technology and conduct tests as described in the plan. Compile and document the data gathered in these tests.
3. Summarize results of test reports and provide recommendations and conclusions for the project.
4. Prepare a final report which documents the efforts and findings of the research.

### Estimate of Problem Funding and Research Period

The estimated funding for this is $500,000 for a period of 30 months.

### Urgency, Payoff Potential, and Products

It has been established that with the most effective crashworthiness techniques, there are limitations to amount of reduction of highway injuries and fatalities that can be realized. Additionally, the influence of the ever-changing fleet characteristics requires constant upgrading of roadside safety hardware. It is impractical to expect the roadside safety hardware as it presently exists, will be able to accommodate the added requirements imposed by changing fleet characteristics. Therefore, use of ITS technologies, particularly collision warning/avoidance techniques need to be explored to bridge the gap between the current roadside safety hardware and the safety requirements associated with the changing vehicle fleet.

## RESEARCH PROBLEM STATEMENT 8: CLINICAL IN-DEPTH ACCIDENT STUDIES

As accident data is used to develop vehicle crash countermeasures, and ultimately, improve vehicle safety performance, the same data can assist the physicians in trauma centers to look for particular injuries that are anticipated from specific types of crashes. At present, the accident data is successfully used in clinical studies at the Jackson Memorial Hospital, Ryder Trauma Center in Miami, Florida. Through a contract with NHTSA, the center has established an automated method to record accident data which is used for various applications. Under this system, an expert accident reconstructionist is sent to the accident site to gather data. The pertinent information for emergency care is electronically transferred to the physicians at the trauma center.

Are clinical in-depth accident studies a good way to understand accident scenarios? Is it possible to ever gather "enough" data to gain understanding about accidents and the injuries that are associated with them? Clinical in-depth accident studies have proven very useful in understanding the occupant injury patterns in vehicle crashes and they may also be useful in identifying the leading causes of injuries in crashes and the associated characteristics of driver behavior. Research is needed to determine if these studies can be useful for understanding the severities of crashes involving roadside hardware.

### Research Objective

The objective of this research is to investigate the feasibility of extending to clinical in-depth accident studies for purposes associated with improving roadside safety.

### Research Approach

The scope of the first phase of the research should be limited to learning how the
existing method is applied and identifying potentials for adaptations for the analysis of roadside safety issues. It is envisioned that the following tasks will be undertaken:

1. Review the procedures of data collection at Jackson Memorial Hospital, Ryder Trauma Center and assess how that method can be applied to collecting accident data pertaining to roadside safety hardware.
2. Adapt the format of the collected data to incorporate various features of the roadside hardware

which may either directly cause or indirectly contribute to occupant injuries in crashes.

3. Determine other data that could be gathered or opportunities for extended application of the information for the analysis of roadside safety features. Identify constraints or limitations associated with this approach.

4. Prepare a final report which documents the efforts and the findings of the research.

### Estimate of Problem Funding and Research Period

The anticipated budget for the first phase is $75,000 for a duration of 12 months.

### Urgency, Payoff Potential, and Products

There is a constant need for more and better information about the severity of crashes. It is prudent to explore non-traditional sources of information to capture such data.