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Post–*NCHRP Report 350* Issues and Research Needs

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POST-*NCHRP REPORT 350* ISSUES AND RESEARCH NEEDS

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INTRODUCTION

This circular provides a record of a symposium held July 26-27, 1993, in Newport, Oregon. The symposium was sponsored by TRB Committee A2A04 Roadside Safety Features.

The circular provides some background on the symposium topic, overviews of presentations made by invited speakers, and summary discussions from breakout groups.

Since the first crash test guidelines (one-half page in *HRB Circular 482 (1)*) in 1962, there has been a succession of hardware testing procedure documents. Each succeeding document has been more definitive and complex regarding how crash tests should be conducted, evaluated, and reported.

NCHRP Report 230 (2) entitled, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances" was published in 1981. Although published as a guideline, this document has been used as a standard and certification document for the past decade. In 1993 this document was updated by *NCHRP Report 350 (3)*, "Recommended Procedures for the Safety Performance Evaluation of Highway Features." *Report 350* is a consensus document that incorporates "current technology and the collective judgment and expertise of professionals in the field of roadside safety design." The major changes reflected in *Report 350* when compared to *Report 230* include: 1. changes to the test vehicles; 2. changes to the number and impact conditions of the test matrices; 3. adoption of "test levels" as opposed to "service levels"; 4. changes to the evaluation criteria; and 5. adoption of the International System of Units (SI).

As would be expected, the publication of *Report 350* has raised questions concerning its effects on the development and testing of both current and future hardware and safety features. As an example, the 2000P, or 4400-pound, 3/4 ton pickup truck, is the replacement for the vanishing 4500-pound passenger car. Given the differences in physical properties between these two vehicles, including a higher center of mass and bumper height, what will be the result of crash testing with a pickup?

It was decided that a symposium on the issues and research needs related to the publication of *Report 350* would be timely. Three main topics were identified and led to the development of breakout groups. The topics centered around the following questions:

A. Should selection guidelines (warrants) be developed for hardware designed according to *Report 350*?

B. Should testing labs be certified? If so, should a product be self-certified?

C. Does *Report 350* satisfy the requirements of the Intermodal Surface Transportation Efficiency Act (ISTEA)? What are the implications of the innovative barrier requirements of ISTEA?

The symposium provided for three-fourths of the first day being devoted to invited speakers presenting background on each of the three main topics. For Category A concerned with selection guidelines or warrants, the agenda was the following:

- Overview of *Report 350* Test Requirements, Hayes Ross, Texas Transportation Institute;
- Federal Perspective, Dick Powers, Federal Highway Administration;
- State Perspective, Don Gripne, Washington State Department of Transportation; and
- Methodologies for Developing Guidelines, King Mak, Texas Transportation Institute;

For Category B and the issue of testing laboratories, the agenda included six presentations:

- European Plan, Vittorio Giavotto, Politecnico de Milano;
- Federal Perspective, Harry Taylor, Federal Highway Administration;
- State Perspective, Roger Stoughton, CALTRANS;
- Industry Perspective, Owen Denman, Energy Absorption Systems;
- Industry Perspective, John Durkos, Syro Steel; and
- Testing Lab Perspective, King Mak, Texas Transportation Institute.

Category C included task presentations concerning the requirements of ISTEA:

- Performance of Current Hardware for *Report 350* Vehicles, Roger Bligh, Texas Transportation Institute;
- Implications of ISTEA Special Vehicles, Charlie McDevitt, Federal Highway Administration; and
- ISTEA Innovative Barriers What is Happening?, Dick Powers, Federal Highway Administration.

Symposium attendees were assigned to breakout groups in the following manner:

Group A

Dean Sicking, Moderator; Wayne Cobine; Don Gripne; Sam Johnston; Robert Mileti; Robert Quincy; Hayes Ross; Kenneth Shearin; Dale Stout; Frank Tokarz; and William Wendling.

Group B

Maurice Bronstad, Moderator; Joseph Batley; Bill Bishop; Owen Denman; John Durkos; Jon Frank; Vittorio Giavotto; James Hatton; King Mak; John Strybos; Roger Stoughton; and Harry Taylor.

Group C

Ken Opiela, Moderator; Roger Bligh; John Carney; Bill Dearasaugh; Sam Grossberg; Bill Hunter; Charlie McDevitt; Richard Powers; Jerry Reagan; David Lewis; and Roger Logan.

The groups spent a total of six hours discussing the topics. Summary reports were then provided. This circular includes overviews of the invited presentations, background, and recommended discussion questions for each group, and group summary reports.

REFERENCES

1. Highway Research Board Committee on Guardrails and Guide Posts," Full-Scale Testing Procedures for Guardrails and Guide Posts." *TRB Circular 482* (September 1962).
2. Michie, J.D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," *NCHRP Report 230*, Transportation Research Board, Washington, D.C. (March 1981).
3. Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., "Recommended Procedures for the Safety Performance Evaluation of Highway Features," *NCHRP Report 350*, Transportation Research Board, Washington, D.C. (1993).

AN OVERVIEW OF *NCHRP REPORT 350*

Hayes E. Ross, Jr.
Texas A&M University

I will be discussing National Cooperative Highway Research Program (NCHRP) Project 22-7, in which an update to *NCHRP Report 230* was developed. The project was indeed a team effort. Input was provided by a large number of people in various disciplines, not only nationally but internationally. The document, which will be published as *NCHRP Report 350*, is a consensus document and I am indebted to all those who provided comments and reviewed the drafts, especially the NCHRP advisory panel, chaired by Roger Stoughton of the California Department of Transportation, and Kenneth Opiela, NCHRP Senior Project Specialist.

This presentation will include a general overview of the document and how it differs from *Report 230*. It will also include a brief discussion of the potential impact *Report 350* will have on current practices, policies, and international harmonization.

The project began in June of 1989 and was completed in August, 1992. It was conducted at the Texas Transportation Institute, and Jarvis Michie with Dynatech Engineering Incorporated was a consultant/subcontractor on the project. We were fortunate to have Jarvis on the research team since he had written *Report 230*, and guidelines that preceded *Report 230*.

CHANGES INCORPORATED IN *REPORT 350*

Report 350 incorporated several major changes. The first one concerned the adoption of the International System of units (SI). To the extent possible a "hard conversion" procedure was used, in which English units are converted to the equivalent SI unit and then rounded. By so doing, it increased the requirements of some tests and it diminished the requirements of others, but in all cases the changes were not major. For example, a 60 mph test speed, which has been a standard value for high speed tests, converts to 96.6 km/h. The decision was made to round to 100 km/h, which is 62.1 mph.

The critical test speed for many breakaway features is at the lower end of the spectrum rather than the high end. The test speed on the low end has been 20 mph. In *Report 350* the speed was set at 35 km/h, or 21.7 mph. It was initially decided to round to 30 km/h, which is 18.6 mph. However, it was brought to our attention by those who design and use breakaway hardware that such a conversion would create an unnecessarily conservative test requirement since the 20 mph requirements of *Report 230* were believed to be very conservative. Not only are these features required to breakaway at low speeds, they are also required to do this for vehicles at the low end of the weight spectrum. Furthermore, the acceptable vehicular velocity change (and hence occupant risk measures) for breakaway features is much lower than for other features such as crash cushions, end treatments, etc.

Other major changes which will be discussed subsequently include test vehicles, more specific features, the contents and number of the test matrices, modifications to the evaluation criteria, and guidelines on selection of the impact point for redirection-type tests.

Also to be noted is that *Report 350* contains *guidelines*, as opposed to absolute standards, for testing and evaluating safety features. Adoption of the guidelines, in whole or in part, as a standard is at the discretion of federal and state transportation agencies. It is also to be noted that *Report 350* contains no selection criteria, or warrants, for features addressed therein. Features tested and evaluated according to the guidelines will have specific applications, but identification of these applications remains to be determined by the user agency or perhaps by the American Association of State Highway and Transportation Officials (AASHTO) or the Federal Highway Administration (FHWA).

TEST VEHICLES

The "basic" test vehicles, which are passenger vehicles, are the 820C and the 2000P. The 820C is a small car with a mass of 820 kg, essentially the same small car test vehicle used in *Report 230*. A major change was made in the adoption of the 2000P, which is a "3/4-ton" pickup truck with a curb weight or mass of approximately 2,000 kg, or 4,400 lb. The primary reason for selecting the 2000P vehicle was that it is believed to be a reasonable representative of the light-truck population. Light trucks, which include pickups, vans, and sport/utility vehicles, now make up a significant portion of the total passenger vehicle population in the USA, and indications

TABLE 1 COMPARISON OF 4500S AND 2000P VEHICLES

Parameter	Typical Values	
	4500S	2000P
Mass (kg)	2,040	2,000
Center of Mass		
Height (cm)	60	70
Fore-aft mass distribution (%)	55/45	58/42
Dimensions		
Wheelbase (cm)	305	335
Front overhang (cm)	110	80
Bumper height (cm)	45	55
Tire radius (cm)	38	41
Tire width (cm)	155	165

are that sales and use of light trucks will continue to increase for the foreseeable future. It was also selected since its mass approximated that of the 4,500 lb car so widely used in the past.

Other vehicles also can be used in the design and evaluation of a feature. The 700C test vehicle is a very small car with a mass of approximately 700 kg, or about 1,500 lb. Use of this vehicle is optional. If a developer or manufacturer of a safety feature feels confident the feature can meet test requirements using the 700C vehicle the option is available. Tests with the 820C vehicle are not necessary if tests with the 700C are acceptable. A manufacturer may have an advantage over the competition if his feature is the only one that satisfies test requirements with the 700C vehicle.

The 8000S vehicle is a 8,000 kg (about 17,600 lb) single unit truck. This vehicle has been used in recent years in the USA for the development and evaluation of bridge railings, in accordance with the AASHTO guide specifications published in 1989. Then there are two very heavy vehicles: the 36000V or 36,000 kg (about 79,300 lb) tractor van trailer, and the 36000T or 36,000 kg tractor tanker-type trailer vehicle that can be used in the testing. These vehicles are to be used in the development of high performance, or high containment, barriers.

Table 1 provides comparisons of the 2000P pickup truck with the 4,500 lb car previously used. It is only about 100 lb, or 45 kg, lighter than the 4,500 pound car. So there is not a lot of difference in the mass but there are differences in some of the other properties. Center of mass height of the 2000P vehicle is about 70 cm whereas the 4,500 lb car had a height of about 60 cm. With regard to the fore-aft mass distribution, the 4,500 lb car typically has about 55 percent on the front axle and 45 percent on the rear axle, whereas the pickup truck typically has about 58 percent on the front and 42 percent on the rear. The wheel base of the car is about 305 cm whereas the wheel base of the pickup is somewhat longer. The front overhang is shorter on the pickup truck 80 cm for the pickup versus 110 cm for the car.

With regard to the effect these changes will have on performance, a higher center of mass probably means the 2000P vehicle will be less stable and more prone to overturn. The shorter front overhang of the 2000P vehicle means the tire nearest the impact point will tend to impact a redirective feature, such as a guardrail, sooner than would have occurred on the 4,500 lb car. Further, the tire/wheel radius of the 2000P vehicle is larger. These changes may result in a greater tendency for the 2000P vehicle to climb up and over the face of the feature. Bumper height is another parameter of concern. The bumper height of the 2000P vehicle will typically be about 55 cm whereas the car was about 45 cm. All other factors being the same, performance is expected to degrade for many features as the bumper height increases.

Other factors that will potentially influence performance include crush stiffness and body design of the 2000P vehicle. It has a stiffer front end and it has two distinct body shells. For energy absorbing devices such as a crash cushion, the pickup will not absorb as much energy as the 4500 lb car did. Thus, an energy absorbing device whose performance is near recommended limits may not pass the pickup truck test. Tests have shown that the body design of the 2000P vehicle tends to reduce the impact loads slightly on a redirective feature.

TESTING AND EVALUATION

There are up to six test levels in *Report 350*, depending on the feature being evaluated. All six test levels apply to longitudinal barriers, test levels 2 and 3 apply to breakaway features, and test levels 1, 2, and 3 apply to crash cushions and end treatments.

Although selection guidelines or warrants do not presently exist, it is assumed that devices developed for test level 1 would be used for very low service level conditions such as in a work zone in an urban area where speeds are on the order of 50 km/h or less. Test levels 2 and 3 are the more basic test levels and the devices developed would have application on high speed facilities. Of these, level three is considered to be the basic level, but perhaps level 2 will also be widely used. Levels 4, 5, and 6 are for special, higher service level longitudinal barrier requirements.

Test and evaluation criteria are given in *Report 350* for the following features:

- Longitudinal barriers;
- Terminals and crash cushions;
- Support structures, traffic control devices, and breakaway utility poles;
- Truck mounted attenuators; and
- Geometric features.

Longitudinal barriers include roadside barriers, median barriers, and bridge railings; these types of barriers are referred to as safety barriers in Europe. There are three distinct parts of a longitudinal barrier of concern: the length-of-need section, the transition region in which the barrier may be connected to a longitudinal barrier of different lateral stiffness, and the end of the barrier. The first two are addressed within the longitudinal barrier test series, and the latter is addressed within the terminal and crash cushion series. Longitudinal barriers can be developed to any test level.

The next category includes longitudinal barrier terminals and crash cushions. The first three test levels apply to this category. That category is further subdivided into (a) terminals and redirective crash cushions and (b) non-redirective crash cushions. There was considerable discussion among members of the advisory panel and others from whom we sought advice as to required test conditions for crash cushions and terminals. Some felt that the tests should be selected so as to require all crash cushions to have redirective capabilities. However the consensus was that the updated test procedures for crash cushions should not be selected so as to eliminate future use of non-redirective systems. As a general rule the non-redirective sand-tub crash cushion has proven to be a reliable, cost-effective system, and is widely used throughout the USA.

Also addressed are test and evaluation procedures for support structures, work-zone traffic control devices, and breakaway utility poles. Included under the support structure category are sign and luminaire supports, emergency call boxes, and mailbox supports. Included under the work-zone traffic control devices are plastic drums, barricades, cones, chevron panels and their supports, and delineator posts and lights that may be attached to drums or barricades. Features within these categories can be designed and evaluated to test level 2 or 3. It was concluded that it would not be cost effective to develop one of these features for test level 1. In other words, it is believed that a feature developed for level 2 or 3 would also be cost effective for test level 1 as well.

Specific test guidelines are presented for truck-mounted attenuators (TMA). Whereas a TMA can be developed to test levels 2 or 3, most of the current designs were developed for level 2 conditions.

Very general guidelines for testing geometric features such as side slopes or ditches or median cross-overs, are also presented. However, there are no specific test levels for features of this type.

Table 2 shows tests designed to evaluate the strength or containment capabilities of longitudinal barriers. The first three test levels are conducted with the 2000P vehicle, at impact speeds of 50 km/h, 70 km/h, and 100 km/h, and an impact angle of 25 degrees. The corresponding speeds in miles per hour are also shown. It is noted that requirements of level 3 do not vary significantly from the basic requirements of *Report 230*, in terms of impact speed and angle and vehicular mass. For levels 4, 5, and 6, test vehicles range from the 8000S up to the 36000T. All three tests are conducted at 80 km/h, which is about 50 mph, and at a 15 degree impact angle.

Some of the criteria used to evaluate a given test were changed. There are no major changes in the structural adequacy requirements of *Report 230*. With regard to occupant risk criteria, it was decided to retain the "Flail Space Model." In this model the occupant is represented by a lumped mass that is allowed to move within a specified space until it impacts a surface. At initial contact, the impact velocity normal to the surface is computed, and is referred to as the occupant impact velocity (OIV). Following impact the mass is assumed to remain in contact with the surface and to experience the "ridedown" acceleration (RA) of the vehicle. Recommended limits of OIV and RA are given in two categories, "preferred" and "maximum." For all features except support structures and work-zone traffic control

TABLE 2 STRENGTH TESTS FOR LONGITUDINAL BARRIERS

Test Level	Vehicle	Impact Conditions	
		Nominal Speed (km/h,mph)	Nominal Angle (deg)
1	2000P	50, 31	25
2	2000P	70, 43	25
3	2000P	100, 62	25
4	8000S	80, 50	15
5	36000V	80, 50	15
6	36000T	80, 50	15

devices, the preferred and maximum OIV are 9 m/s and 12 m/s, respectively. For all features the preferred and maximum RA are 15 g's and 20 g's, respectively. Similar limits were given in *Report 230*. In addition, the lateral and longitudinal components of the OIV have the same limits in *Report 350* whereas in *Report 230* the lateral limit was approximately 30 percent less than the longitudinal limit. Based on a review of the literature and on discussions with experts, it was concluded thatlimits in the lateral and longitudinal directions should be equal. The OIV limits for support structures and work-zone traffic control devices are essentially the same as those in *Report 230*, 3 m/s preferred and 5 m/s maximum.

Some changes were made with regard to the post-impact trajectory criteria. The 15 mph (24.2 km/h) vehicular velocity change limit for redirective features was increased to 12 m/s (26.8 mph or 43.2 km/h).

Report 350 contains guidelines for identifying the critical impact point for a redirective feature. That is the point along the feature judged to have the greatest potential for causing snagging or pocketing of the vehicle with the barrier, or for causing structural failure of the feature.

THE POTENTIAL IMPACTS OF *REPORT 350*

Key issues related to *Report 350* include its adoption by FHWA, potential changes to current designs as a result of its use, selection guidelines or warrants for features developed according to *Report 350*, certification of testing agencies, and harmonization with European test standards. I will briefly discuss each of these issues.

Report 350 was officially adopted by FHWA through the Code of Federal Regulations to determine acceptability of safety features for use on the National Highway System. The effective date is August 16, 1993 for all new designs developed subsequent to that date. There is a nine-month transition period beginning August 16, 1993 for designs under development prior to that date. Also, there is a five-year grace period beginning August 16, 1994 for existing designs satisfying *Report 230* guidelines.

Based on limited testing to date, no changes are anticipated for concrete safety shaped barriers, sand-tub crash cushions, and breakaway support structures. There are indications that standard, 27-inch high W-beam barriers may have difficulty containing the 2000P vehicle at test level 3. There are also questions relative to the performance of some end treatments, crash cushions, and truck-mounted attenuators for impacts with the 2000P vehicle. It is also anticipated that multi-service level designs will be developed above and below the basic test level (level 3).

There are only minimal objective guidelines that can be used to determine where multi-service level features should be used. As previously discussed, *Report 350* permits design and evaluation of safety features for up to six test levels. Thus, there is a need for guidelines to identify conditions for which multi-service level features are warranted. TRB and AASHTO have identified development of such guidelines as a high priority research need. In a 1993 summer workshop, TRB Committee A2A04 strongly endorsed the need to develop use guidelines.

Another issue raised as a result of the publication of *Report 350* and the interest in international harmonization, is the certification of testing facilities. FHWA is considering the development of an electronic "black box" with accompanying software to establish the ability of an agency to accurately record and reduce crash test data. TRB committee A2A04 rated the need for certification as a high priority item.

Three items are related to the harmonization of USA guidelines and European standards for the impact performance of safety features. First, as previously discussed, *Report 350* is written with SI units. Furthermore, it is recommended that testing agencies calculate and report occupant risk parameters adopted

by the European Community (CEN). Finally, also as noted, the small car used in USA and CEN tests has similar characteristics, and test requirements for crash cushions and terminals are expected to be similar.

It has been a pleasure to have had the opportunity to work with many highway safety professionals, both nationally and internationally, in the preparation of *Report 350*. It is expected that the document will foster uniform test and evaluation procedures for highway safety features throughout the USA and other countries. More importantly, it is expected that use of the document will result in the design and implementation of improved safety features, thereby reducing the severity of accidents.

FEDERAL PERSPECTIVE ON WARRANTS FOR HARDWARE DESIGNED TO MEET *NCHRP REPORT 350* REQUIREMENTS

Richard D. Powers
Federal Highway Administration

With the formal adoption of the *NCHRP Report 350* as the document governing the testing and eventual acceptability of roadside hardware, the highway designer's task has become more challenging. Whereas previously a single series of crash tests determined acceptability for use, the new guidelines specify six distinct test levels for longitudinal barriers, three for terminals and crash cushions, and two each for sign and luminaire supports, utility poles, and truck mounted attentuators (TMA's).

Before, a designer had only to determine if a barrier or breakaway support was warranted and to specify a standard piece of hardware if the answer was yes. Now, in addition to deciding if a barrier or other safety feature is warranted, a designer must also select an appropriate performance level. In other words, a decision must now be made regarding the degree of protection to use, or looked at slightly differently, how much risk can reasonably be assumed in the selection process. Should the system selected be capable of redirecting vehicles larger than a 2000 kilogram pickup truck, for example, or would a system tested only at 50 or 70 kph suffice? The designer's task would be greatly simplified if guidelines or warrants for each test level existed. My remarks will be limited to barrier warrants because, with six test levels available, the designer has a great deal of latitude in the selection of an appropriate system.

How are barriers currently selected? Informal warrants generally exist to determine if any barrier is needed, but the specific type of barrier seldom requires a conscious decision. Each agency has its favorites, be it w-beam on strong posts (wood or steel), one of the weak post systems or a concrete safety shape (usually the New Jersey profile). Thus, the current barrier selection procedure is quite subjective. In addition, the distinction between warranted and cost-effective is often vague. Simply stated, a barrier is warranted if it will reduce the severity of a run-off-the-road accident, i.e., hitting the barrier would be less damaging than leaving the roadway and striking the shielded hazard. However, since resources are limited, the likelihood of such an occurrence is a valid and necessary consideration. This generally means more hazards are left unshielded on lower volume, lower speed roads. Guidelines used by an agency should reflect this consideration.

Developing guidelines for the higher test levels should be relatively easy, since test levels 4, 5, and 6 are intended to retain and redirect trucks. Thus, the guidelines would consider total traffic volumes, percent trucks, truck types, operating speeds, likelihood of impacts (geometrics) and the consequences of such impacts. Many State agencies look at these factors subjectively now, but few if any have formal warranting procedures or selection guidelines. The use of higher test level median barriers and bridge pier protection are two examples of continuing concerns where little has been done to date to develop and use more stringent warrants.

Guidelines for the lower test levels (1 and 2) become more problematical, since these levels are for speeds of 50 and 70 kilometers per hour (30/42 mph) and do not include truck tests. If there were roads where motorists drove at these lower speeds, guidelines might be useful and easy to develop. Judgment and experience suggest that few motorists run off the road while travelling at these speeds, and when they do, the consequences are not generally life-threatening. If the highway engineer's goal is to reduce accident severities with the judicious use of barriers, these barriers must be designed to function at anticipated impact speeds. Thus, for the class of highways currently under the Federal sphere of influence, mostly high speed, high volume roads, test levels 1 and 2 for barriers may not be appropriate. State highway agencies are cautioned to use barriers (and other roadside features) that meet the real needs of the travelling public.

Low volume roads may very well be a separate issue. This term is, of course, not synonymous with low speed-oftentimes just the opposite. Operating speeds on these roads are governed by what the drivers feel comfortable with, and are often significantly faster than the posted speed limit. Volume alone should not be the sole determining factor for selecting a barrier. However, it can be used to set more stringent warrants. In other words, a barrier will still need to contain and redirect a 2000 kilogram pickup truck impacting at 100 kilometers per hour, but it will be used only at the sharpest curves and steepest slopes along a given section of roadway.

So what then, is the Federal position on guidelines for selecting an appropriate test level for roadside barriers?

First, a rational selection procedure is critical to answer the question what type of barrier (performance level) is best, given that a barrier is warranted. This is not generally done at present, except after-the-fact as a result of a serious accident or series of accidents.

Second, guidelines should be developed by the State highway agencies, ideally as a cooperative, coordinated effort. The important issue is to decide when higher test level barriers are appropriate. Those States using lower test level barriers should proceed with caution as suggested above.

Finally, the highway community should keep the end result or goal in clear sight: a logical, rational selection process (or warranting procedure) whereby the most cost-effective barrier system will be installed at any given roadside location. The selection of the best barrier for each site should not be left to chance.

NCHRP 350 A STATE'S PERSPECTIVE ON DEVELOPING GUIDELINES

Don Jay Gripne
Washington State Department of Transportation

With the introduction of NCHRP 350, the states will be faced with questions that they did not face with NCHRP 230. NCHRP 230 had only one set of test criteria for each system. It had a specific set of vehicles and angles, but only one speed. NCHRP 350 changed this. It introduced six test levels. The first three are pretty straightforward. The last three will cause problems regarding when to use them. NCHRP 350 doesn't provide these criteria.

Who should take the lead in developing the guidelines for the use of each level? NCHRP 350 states, It is the responsibility of the user agency(s) to determine which of the test levels is most appropriate for a feature's intended application. This will require over 50 user agencies to reinvent the wheel, and there will be many different versions. Consistency of application will be needed. A solution might be to have the committee that prepared NCHRP 350 develop the guidelines, then have the states review them for applicability.

The FHWA must be involved because they will provide the interpretation of the guidelines, and we will need to know what that interpretation will be.

NCHRP 350 opens the door to developing systems that more accurately reflect what is happening in the real world. There could be the opportunity to develop criteria for bridge rails other than for Test Levels 4, 5, and 6. Why not have a test level for bridge rails using lower speeds or lighter vehicles or both?

Another question is, do we develop the warrants based on benefit costs? We have done this on embankment curves for the placement of guardrail. Is it practical to do this for all levels, or just for the top three? Doing it for all levels will increase the amount of engineering work, whereas the top three would be used only for unique situations.

When warrants are developed, what factors should go into them? Several factors are speed limit, operating speed, truck percentage, and volume (ADT). Another thing that comes to mind is a warrant for high speed and low volumes. Do we need warrants for urban areas? I believe we do.

What can these warrants do for the states? First, they will provide for consistency in design work, just as the AASHTO Green Book on Geometric Design has. Second, the warrants will reduce the states' tort liability.

NCHRP 350 offers the opportunity to refine the way we provide new systems. Somebody needs to take the lead to make this happen.

METHODOLOGIES FOR DEVELOPING GUIDELINES

King K. Mak
Texas Transportation Institute

INTRODUCTION

Do we need guidelines or warrants for all six test levels? If not, what test levels are to be used for developing guidelines or warrants? I would argue that, even though *NCHRP Report 350* has six test levels, we can concentrate on only two basic levels, which are test levels 2 (70 km/h and 3 (100 km/h).

It is questionable that we will ever develop roadside safety features under Test Level 1 at 50 km/h (30 mph). First, 30-mph roadways are mainly urban streets where the use of roadside safety features is very infrequent. Second, the current vehicle population is designed for survivability at 30 mph, i.e., for a belted occupant and/or vehicles with airbags, a 30-mph head-on impact into a rigid barrier is a highly survivable impact. Finally, there is probably very little cost saving by designing for 30 mph instead of 45 mph (Test Level 2).

Test levels 4 through 6 all pertain to heavy trucks. Again, roadside safety features designed for truck impacts will have very limited applications. We simply cannot afford them except under special conditions, which are generally recognized by the highway agencies without the need for specific guidelines.

At the most basic level, one or more engineers responsible for the design, construction, and maintenance of the roadside safety features can get into a room and formulate the guidelines or warrants based on their expert opinion and engineering judgement as well as their collective expertise and experience. There is not much that can be said about decisions that are strictly based on expert opinion and engineering judgement or the collective expertise and experience of the decision-makers. However, in today's litigious society, such decisions are harder and harder to defend in court.

THE BENEFIT/COST ANALYSIS APPROACH

The benefit/cost analysis approach provides a more objective, systematic, and defensible means of arriving at the guidelines or warrants. The remainder of the presentation will concentrate on the benefit/cost analysis approach. However, it should be borne in mind that, even with the benefit/cost analysis approach, expert opinion and engineering judgement are still crucial to the development of the guidelines or warrants. Decisions, such as the selection of typical input values and benefit/cost ratio to be used with the analysis, still require expert opinion and engineering judgement on the part of the individuals developing the guidelines or warrants.

The basic concept of benefit/cost analysis is very simple. For any given safety improvement, there are benefits and costs associated with the improvement. Benefits are expressed in terms of reduction in accident costs and costs are related to construction and maintenance costs. To justify the improvement, the benefits should, as a minimum, equal to the costs (i.e., benefit/cost ratio of 1.0) for the improvement to be even considered. Since we are typically working with a limited budget that is much smaller than the identified need, we will try to prioritize the spending to maximize the return for the spent funds. In other words, we would like to spend the funds on projects that are most cost-beneficial.

The most commonly used benefit/cost procedures are:

- 1977 AASHTO Barrier Guide,
- Benefit Cost Analysis Program (BCAP),
- ROADSIDE Program,
- TTI Benefit/Cost Program,
- New Cost-Effectiveness Procedure, and
- NCHRP Project 22-9.

A benefit/cost procedure consists of:

1. An algorithm to predict the frequency of accidents;
2. An algorithm to predict the severity of accidents; and
3. A procedure to estimate accident costs and determine benefit/cost ratio.

Accident Frequency Prediction

There are two basic approaches for predicting accident frequency.

Most existing benefit/cost procedures are based on the encroachment probability model. Encroachment may be defined as the inadvertent or uncontrolled departure from the travelway by a vehicle.

The basic premise is that accident frequency and severity are directly related to encroachment frequency and severity. This model predicts accident frequency and impact conditions given encroachment frequency and characteristics, vehicle speed and angle, and a number of adjustment factors.

The primary advantage of the encroachment probability model is its versatility it can be used with any roadside object or feature, newly constructed or reconstructed roadways, and it is not based on historical data. The model suffers from several disadvantages: encroachment data are limited, numerous assumptions are made, and there is a lack of validation.

Accident data based regression models relate accident frequency and rates to independent variables such as ADT, horizontal curvature, and clear zone width. The accident data based regression model is a more simple and direct approach. On the other hand, police-level data may be of poor quality, the ADT term tends to dominate, predictability is poor, and human factors are unaccounted for. Also, many accidents go unreported.

Accident frequency prediction will probably play a lesser role in the development of guidelines or warrants for different test levels since the effect of test levels is mainly on the severity of accidents.

Accident Severity Prediction

Accident severity prediction is the second component of a benefit/cost procedure.

Accident severity is a function of:

- Nature of roadside object/feature;
- Test level;
- Effectiveness of safety appurtenances;
- Potential outcomes, e.g., penetration, rollover, redirection, etc.;
- Impact conditions; and
- Other factors, e.g., vehicle type and weight.

Severity indices are used surrogate for injury probability and severity. They may be obtained from accident data, full-scale crash testing, computer simulation, and field experience.

Cost Estimation and Benefit/Cost Determination

Finally, costs are estimated and the benefit/cost ratio is determined.

Direct costs include installation costs, routine maintenance, and salvage value. They are easily estimated with good accuracy.

The benefits are reduced accident frequency and/or severity.

Most states use National Safety Council estimates to measure accident costs. Accident costs may also be measured by willingness-to-pay or using NHTSA estimates.

To develop guidelines using the benefit/cost model, the following inputs are needed:

- Roadside safety feature for evaluation, e.g., guardrail;
- Test levels for evaluation, e.g., test levels 2 and 3
- Highway types for evaluation, e.g., two-lane undivided roadway;
- Typical values for site characteristics, e.g., ADT, lane width, horizontal curvature, vertical grade, lateral offset, etc.;
- Typical values for severity;
- Typical cost figures; and
- Benefit/cost ratio.

Once the input values listed above are selected, the mechanics of actually running the program are very direct. The program will then be executed repeatedly by varying the key variables over pre-selected ranges.

FEDERAL PERSPECTIVE ON CERTIFICATION OF TESTING LABS

Harry W. Taylor
Federal Highway Administration

INTRODUCTION

There are some very good reasons for interest in this subject. First, there is the increased emphasis of highway agencies on quality assurance; and second, there is the desire to interface with the international standards and procedures for increased safety and trade. Consequently, because of these pressures, the US procedures for determining acceptance will likely become more formalized and detailed, which may necessitate a revision of *NCHRP Report 350*.

Let me discuss this starting with the general then going to the specific.

WHAT ARE THE ISSUES?

Testing is a technical process which uses a specified procedure to measure one or more characteristics of a product. The *accreditation* of test laboratories and certification or inspection bodies formally recognizes their competence by a *process of expert technical assessment* against agreed criteria. This involves regular surveillance and periodic assessment. *Certification* is a statement by an impartial body that a product, process, or service conforms with a specified standard or similar document. Certification bodies certify either companies' *quality systems* or their *products*. This generally involves assessment and regular surveillance and often draws on the results of testing and inspection. The parallel activity of *calibration* is concerned with correlating the readings (of instruments, etc.) with a standard.

The federal perspective is simply to discern what is in the public interest. Let me continue to place the issue in perspective.

Laboratory accreditation is part of a conformity assessment system. This system includes development of standards (procedures) which define what the purchaser wants and what the supplier agrees to provide; quality systems and laboratory accreditation. The advantage of this is that laboratory accreditation increases user confidence in the validity of the data produced by the laboratory. When properly conducted, a laboratory accreditation program can increase efficiency, expand opportunities for international trade, conserve resources, and improve safety. It also provides a way to deal with the different levels of development in national quality infrastructures. It must also be recognized that, improperly conducted, laboratory accreditation can suppress free and fair competition, impede innovation and technical progress, exclude safer and less expensive products, or otherwise adversely affect trade or commerce. It is important that any system not impose additional burden or changes that add little value.

The official Federal position as expressed by the Office of the United States Trade Representative is, "Laboratory accreditation is an important form of conformity assessment in the United States. While the United States has many programs for the accreditation of laboratories, most of these are specific and narrow in scope, addressing the limited needs of the implementing agency. A few programs, both governmental and non-governmental, are general in scope and capable of addressing the needs of those parties that wish to have laboratories recognized for their technical competence, but do not wish to administer the accreditation programs themselves. The general guidelines for accreditation typically follow the applicable international guidelines, in particular ISO/IEC guides 25, 38, 54, and 55. These guidelines set forth requirements for assessors and their training, for on-site evaluations and factors to be considered, and all the requirements that laboratories must meet to be judged technically competent." *(1)*

For roadside safety features, the issue of accreditation of crash test laboratories from the federal perspective diverges into two almost opposite issues: (1) assuring and improving the competence of existing laboratories, and (2) assuring that a one-time-only test laboratory meets standards.

ACCREDITATION OF EXISTING PERMANENT LABORATORIES

In developing and implementing an accreditation program for crash tests we have the following concerns:

1. Providing assurance of quality, uniformity for critical systems such as crash cushions which often have occupant risk values near the maximum limits;
2. Ensuring fairness for appurtenance developers "A level playing field";
3. Ensuring fairness for individual testing labs;
4. Ensuring fairness to the State Highway Agencies (the customers); and
5. Being of reasonable cost to implement.

TABLE 1 ASSESSMENT CRITERIA AND PROCEDURES REQUIRED BY THE FEDERAL GOVERNMENT

Requirement	Number of Programs with Requirement		
	YES	NO	N/A
Submission of Appropriate Documentation	28	3	
Independence (No Conflict-of-Interest)	9	2	1
Financial Stability	7	23	
On-Site Inspection	26	5	
Staff Qualifications Requirements	26	5	
Adequate Q.A. System	23	8	
Sample Control/Integrity Requirements	21	10	
Recordkeeping Requirements	26	5	
Test Report Content/Format Requirements	24	7	
Available Operational Manuals/Instructions	21	10	
Periodic Random Re-audit of Facilities	13	18	
Periodic Scheduled Re-audit of Facilities	17	14	
Participation in Proficiency Testing Program	18	13	
Adequacy of Facilities & Equipment	28	3	
Equipment Maintenance/Calibration Requirements	25	6	
Other	6	25	

The FHWA would envision such a system to be based on existing guidance such as ASTM E548, "Practice for Preparation of Criteria for Use in the Evaluation of Testing and Inspection Bodies," or ANSI version of the ISO 9000 standards *(2)*, or the National Institute of Standards and Technology's National Voluntary Laboratory Accreditation Program.

Table 1 from the National Institute of Standards and Technology, summarizes the number and types of assessment criteria and procedures required by the federal government laboratory accreditation type programs identified in the "Directory of Federal Government laboratory Accreditation/Designation Programs" *(3, 4)*.

All or most programs have equipment, facility, personnel, initial on-site inspection, and recordkeeping requirements. There are, however, considerable differences in requirements for laboratory independence from any direct control by the manufacturer/producer/user, the financial stability of the laboratory, for participation in a proficiency testing program and for re-audit requirements.

None of the assessment criteria above seem too difficult to meet if care is taken to have reasonable requirements. There is also a program for a fee by the National Institute of Standards and Technology that would operate an accreditation program.

The Design Concepts Research Division of FHWA is taking the lead in laboratory accreditation. It has made some initial efforts by funding a contract for prequalification of crash test labs that provides for calibration of the electronics. It is also willing to provide software that will encompass the signaling rates, band widths of the different labs. We are also

considering cooperation with the European Community in the calibration of data acquisition systems.

FHWA is considering implementing software to evaluate both electronics and ability to use the standard waveform to accurately compute occupant risk values. The NHTSA, in its use of the generator and software, found significant variations in its crash testing facilities. The NHTSA found up to 20% variations in HIC's, 10 msec time shifts. Only six facilities passed sampling requirements.

PROBLEM WITH DEVELOPER OWNED AND OPERATED "BARE BONES" TEST FACILITIES

The genesis is the concern in providing an accurate method to compare the crashworthiness of road hardware to user highway agencies. There is a convergence of factors. First, the inclusion in NCHRP 350 inclusion of test procedures of work zone devices and safety features. Second, the desire for a competitive edge in marketing by developers of new products. Also the American Traffic Safety Service Association and one state highway agency have expressed interest in evaluating all work zone traffic control devices.

The problems are that:

1. Products claim to be crash tested but don't adhere to established test procedure.
2. Product may increase safety but does not adhere to agreed upon crash procedures.
3. The tests are conducted by developer, often using a live driver. Sometimes the developer appears to "fudge" results.

The possible benefits are:

1. Evaluations are substantially cheaper and may be as discerning as more sophisticated testing procedures.
2. Increased ability to develop products that may not have been affordable if fully instrumented test facilities are used.
3. These facilities may provide the public more safety than products that have no testing.
4. These facilities are all the instrumentation necessary if you are mainly interested in the interaction between the device and the vehicle.
   a. Did parts of the device penetrate the windshield?
   b. Did the small car overturn when it impacted the device?
   c. Did it get hung in the undercarriage causing loss of steering control?

I expect our procedures to continue to evolve, especially as we continue to want to harmonize acceptance of roadside safety hardware with the rest of the world.

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2. Jenkins, Mary, A look at ISO 9000, ASTM *Standardization News*.
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4. US Department of Commerce, *National Institute of Standards and Technology*, NIST, 15 CFR Parts 7 and 285.

STATE PERSPECTIVE ON CERTIFICATION OF TESTING LABS

Roger L. Stoughton
California Department of Transportation

I'd like to start out with a Calvin and Hobbes comic strip that has a tenuous connection to the subject at hand and deals with the general subject of crash test research. As you may recall, Calvin and Hobbes go on wild daredevil rides in their little red wagon in the summer and on their sled in the winter. This, of course, is Hobbes happily welcoming Calvin home from school with a 100 km/h tackle.

In the first panel Calvin's dad is fixing the little red wagon and Calvin says, You know Dad, it disturbs me that this wagon has no seat belts and wouldn't survive a 30 mph impact with a stationary object." Dad says, "Um...Why do you bring this up?" with a worried look on his face. Calvin replies evasively, "Oh, no reason." Now the wagon is fixed and Calvin and Hobbes are about to take a ride. Calvin says, "Want to help me test the theory of relativity?" Hobbes says, "Sure." Hobbes gives the wagon a big push as Calvin steers and Calvin says, "The idea is that the faster we go, the slower time goes." Hobbes says, "Gotcha. It"s 10:23." Now they are accelerating down a steep hill and Calvin asks again, "What time is it now?" Hobbes says, "10:24. Go faster." In the next panel they are streaking down hill and Calvin asks again, "We're going pretty fast! What time is it? Hobbes replies,"10:25. Time still hasn't stopped." Now they've just catapulted over a cliff and Calvin, Hobbes and the little red wagon are all flying separately through blue sky at mach 1. Calvin repeats, "Has time stopped now? Hobbes pants, "No, just my heart." In the final panel they are cracked up in a little crater at the bottom of the cliff and Calvin grumbles, "Well, it looks like Einstein's a fraud, wouldn't you say?" And Hobbes picks up his watch which is totally smashed and gleefully replies, "No, he's right! My watch isn't going at all anymore!

CRASH TESTS FOR BACKYARD INVENTIONS

Well, I can remember a few CALTRANS crash tests that weren't much more successful than that. I wouldn't want to tell you about those, but I would like to tell you about some tests by others we witnessed several years ago that bear on the subject at hand.

About 15 years ago we met with a backyard inventor who ran a beauty salon with his wife and who had devised a rubber tire and sand crash cushion. He was hoping to sell this to local agencies to shield power poles and other fixed objects and hoped to get CALTRANS approval to improve his sales pitch. We explained that he would need to conduct crash tests and that the process was long and expensive.

He did not appear to be a good listener and managed to set up a test in the Bay Area where he was able to get a street closed off for a day and I believe hired a university professor to hook up a couple of accelerometers. One of my staff went over to observe the process and came back with this report. Our inventor used another vehicle to push the crash vehicle up to speed. The test vehicle missed the crash cushion completely, hit a power pole down the street, totaled the test car and we never heard from him again.

A few years later we had a couple of amateur inventors who normally worked mounting school buses on truck frames and they had designed a truck mounted attenuator (TMA) that used plastic foam blocks for energy absorption. As usual we explained the process needed to qualify their device. At one point we requested a drawing of the TMA and eventually we received a crude one page sketch that was about junior high drafting class level. We then recommended that they find a licensed engineer who could draw up the plans for them.

In the meantime, they had found an auto racetrack in the Bay Area where they could conduct their test and had hired a stunt driver to do a live driver test of their TMA. The test speed was supposed to be 45 mph but the driver only got up to about 40 mph so we told them that was not a satisfactory test.

Being persistent they scheduled another test, hired the same driver again, but told him that he wouldn't be paid unless his speed was 45 mph or more. Well, on the day of the test the driver packed foam blocks all around the front of his body and tied his helmet to the seat so it wouldn't snap forward. He proceeded to drive into the TMA at 60 mph. Fortunately I wasn't there and fortunately the driver was uninjured as far as I know but he must have had a sore body the next day. The two inventors didn't have enough resources and talent to follow through with their design and they soon faded from the scene.

Although these stories are amusing because the inventors were so inept, I don't mean to belittle inventors. I realize that sometimes the most

revolutionary new concepts come out of someone's garage. I believe some of the first water tube cushions were tested at low speed in someone's driveway. And being a public agency we must entertain anyone with an idea and explain the rules to them and give due consideration to their proposals. Originally I planned to tell these stories to illustrate why certification is needed. As I've thought about it, though, I tend to think this kind of amateur test group is self eliminating.

Well, let me tell one more story before I describe our approval process and draw some conclusions. Twenty years ago we used to witness some bare bones crash tests that were performed by a colorful but innovative engineer contracting with a company developing safety products. In particular I recall that in a few of his proof tests he used his son as the crash car driver. Right after the crash he would tell his son to back up the car and drive off while the cameras rolled to show how little damage was done to the car. In the meantime I was scrambling to get some measurements of barrier deflections and car position before he drove the car off. In those days my measurements were usually much more thorough than those of the crash tester.

He used another car to push his crash vehicles up to speed and then backed off at the last minute with his pusher car, hoping the crash car would hit the barrier. Some of his first developmental tests were with old junkers so he could, as he said, "get a feel for conditions" which I thought was a pretty amusing concept for crash testing.

Back in those days it was difficult to get decent measurements, photos, movies, drawings and so on from that company but we did have the advantage of being invited to most of the tests so that we could check out the testing process in person. Eventually the colorful crash tester went on to other inventor challenges and the company he was testing for made other arrangements.

Over the years the tests on their products became much more rigorous and the documentation came pretty close to the ideal requested in NCHRP 230. However, in the meantime for whatever reasons, we were no longer invited to their tests. Consequently, we must pretty much accept on faith that the documents they present to us were generated properly. I believe all their submittals are vouched for by a licensed engineer not working for the company who has unknown qualifications.

THE CALTRANS APPROVAL PROCESS

Next I'd like to describe our CALTRANS method of evaluating new roadside safety products submitted to us for approval. We require a written report of the required crash tests--the report to include the sections specified in *NCHRP Report 230* (now *NCHRP Report 350*). They must also submit copies of their 16 mm movies, engineering drawings of the device, material specifications of critical materials in the device, sometimes a brief summary of their quality control program, and a copy of the FHWA approval if they have one. If available, we review accident experience from other states.

For the past year we have had a new products evaluation committee specifically for roadside safety features at CALTRANS with representatives from traffic, structures, maintenance, construction, the lab, and one district traffic engineer. Various committee members review the submittal as appropriate and the committee makes a recommendation to the chief of our division of traffic operations who has the final approval for most types of products.

Except for the committee we have been using the same approval process for many years. It has always been a struggle to get all the documents we wanted from manufacturers but cooperation and quality of documents seem to have improved in recent years. We do believe that a fairly rigorous review is worthwhile to 1) protect the safety of motorists in our large state and 2) to protect ourselves from tort liability suits as much as possible.

SHOULD TEST AGENCIES BE CERTIFIED?

As you know we have less than a dozen agencies in the U.S. doing crash testing on a regular basis. Most of them have been in business for several years and generally speaking they all seem to be competent and capable of doing reasonably good work. Considering only these companies, certification doesn't seem overly necessary. I'm not sure we would gain that much with the possible exception of checking out instrumentation equipment and instrumentation data processing procedures where it would be nice to insure that we had uniformity around the country. On the other hand, it might be nice to have some kind of certification procedure available for new crash test companies or for teams assembled for a short time only to conduct a small number of tests.

I conducted a last-minute mini-survey of a few other state DOT engineers. I'd like to give you the flavor of their thinking.

Brett Gilbert of Ohio said they approve products by looking at all available data, library sources, and discussing the product with FHWA, other states etc. He thought certification might help their comfort level and self certification could shift some liability to manufacturers. He thought the problems of certification could be worked out.

Ron Canner of Minnesota said their approval process is similar to Ohio's. They call Charlie McDevitt if in doubt. Ron doesn't *perceive* a problem. A rigid certification process could discourage new companies, hence, competition. Nevertheless, Minnesota is going to more certification. They trust vendors but periodically verify vendor claims. He might support test agencies *voluntarily* requesting outside certification.

Jimmy Lynch, the North Carolina State Traffic Engineer, said their specification requires the vendor to certify conformance to *NCHRP Report 230*. He believes in crash testing, says devices they use are working and thinks if the system isn't broke, don't fix it.

Duane Hofsteder of Oregon described a product approval method similar to Ohio and Minnesota--they review all available information and then decide. He seemed to support certification to get uniformity provided it didn't get bogged down in excessive red tape.

Jim Bryden of New York sends his greetings. Jim believes all data presented by vendors should be viewed with a little suspicion and checked for authenticity, but he leaned away from requiring certification of test agencies. At most, he might go for a mid-level process to check instrumentation only. He believes a licensed P.E. employed by the manufacturer should certify test results. Independent observers at crash tests wouldn't prevent manipulation of test devices to get successful tests. Certification, if used, should be contracted out to someone like Jack Carney, who doesn't have his own crash test facility but is very knowledgeable, rather than certification by FHWA or AASHTO.

Bill Crozier, my boss, who has just been working on uniform CALTRANS standards for qualifying new products, gave this example. He says that AISC certifies bridge shops to fabricate bridge girders for a rather large fee with follow-up inspections for a lesser fee. CALTRANS supports this process but doesn't require it and we send our own inspectors to the bridge shop anyway. Hence, certification may help the little states, but a state with more resources may want more assurance that the products they buy meet specifications and standards. Nevertheless, Bill says our director and upper management support more self certification of highway products.

Considering all of the above, my state-oriented recommendation (based on very minimal input from a handful of states plus my own opinions) would be that we start out with a simple and limited process whereby all crash test entities, both permanent and temporary, be *invited* to obtain certification of their instrumentation equipment and instrumentation data processing procedures from a team contracted by FHWA available upon request in, say, one month or less from date of request. Results of the certification review should be available within, say, two weeks or less. Help in establishing certification procedures could be obtained from a task force of TRB A2A04 committee members. This would help gain uniformity in the validity and accuracy of instrumentation data, would pick up inadvertent mistakes, but would not necessarily prevent manipulation of test results. Crash test agencies should self certify their products; their certification should be signed by a licensed engineer. Ideally, their proof tests should be witnessed by a qualified engineer from a state DOT and/or FHWA so there is an independent observer present. State DOT's would, of course, have the option of requiring the submittal of test reports, films, drawings etc. Hence, small states and local agencies would have a minimum level of protection from bad tests and larger states would have the option of doing more thorough reviews if they believed that was necessary or useful.

ERRANT DRIVERS AND CRASH TESTERS A PHILOSOPHICAL COMMENT

In closing, I'd like to get back to the book of Calvin with a little more philosophical comment on the whole subject of errant drivers and crash testers. In the first panel Calvin and Hobbes are at the top of the hill with a small sled and Calvin says, "Boy, is this hill big. We'll have a good long ride down!" Hobbes cautions, "Provided we improve our steering." As they start down the hill Calvin says, "Hobbes, do you think human nature is good or evil?" Hobbes nervously says, "Look out for those trees." The hill gets steeper and the sled is partly airborne as Calvin asks, "I mean, do you think people are basically good, with a few bad tendencies, or basically bad with a few good tendencies?" Hobbes shouts, "There's a rock up ahead! Look out!"

Unconcerned, Calvin drones on, "Or, as a third possibility, do you think people are just crazy and who knows why they do anything?" Hobbes is frantic, "Not so close to the ledge!" By now they are going 100 km/h and Calvin looks over his shoulder and repeats, "Well? What do you think? Are people good, bad or crazy?" Hobbes has his paws over his eyes and shrieks, "Aughh! I can't look!" There is a loud "wump!" And the front of the sled is impaled in the trunk of a large tree. In the last panel we see Calvin and Hobbes in a huge drift of snow buried up to their eyeballs and Calvin says, "You know, its very rude of you to keep changing the subject after every sentence." And Hobbes sighs, "Good, bad, crazy...I choose crazy."

"SHOULD TESTING LABS BE CERTIFIED?" "IF SO, SHOULD A PRODUCT BE SELF-CERTIFIED?"

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SHOULD TESTING LABS BE CERTIFIED?

The act of certifying indicates that there are some prescribed criteria that must be met, some means of validating that the criteria are met and that there is an official body to regulate, control and/or sanction the process. While we can see this process is in effect in other industries, there is not a certification process with these elements in place for testing and evaluating highway safety appurtenances.

The general answer to the question from an industry perspective should be yes, testing labs should be certified. The explanation of this answer and the specific type of certification programs developed will require much discussion.

The reasons that labs should be certified include:

1. Ensuring consistency in testing procedures and accuracy of test data/results between testing labs.
2. Providing the ability to compare results of system performance between "certified labs".
3. Providing the ability to monitor the quality of results of each certified lab.
4. Reducing the "suspicion coefficient" where the testing service has an interest in the test article or testing program.

The certification process should include at least the following items:

1. Critical review by an independent "agency" of the detailed testing procedures used, acceptability of testing equipment, calibration of data collection devices, traceability of measurements to national standards, traceability of test article design/documentation, ability to store/retrieve *unalterable* raw data, quality assurance procedures (checks and balances) and the ability of the laboratory to conduct, measure and document tests in an acceptable manner.
2. Issuance of a detailed report on the ability of the testing service to meet an acceptable standard and if no deficiencies are noted, the issuance of a certificate of compliance.
3. An audit/review process by the independent agency to ensure continued compliance.

If the certification process is effectively implemented and enforced by an administrative body, developers and evaluators alike can have a high degree of assurance that the reasons for having the certification process mentioned earlier will be met. Thus, there will be testing labs capable of conducting certification tests that can be evaluated by approval agencies to determine whether or not to accept the performance of a particular appurtenance. This sequence leads to the possibility of having certified testing labs, conducting certification tests in the development of certified products (certified by an approval agency, not the testing laboratory). However, the testing lab only conducts tests and reports performance. The approval agency evaluates and then either accepts, accepts with limitations or rejects the system based on the performance demonstrated.

Three types of testing should be conducted in developing a new appurtenance: proof of concept testing, developmental testing and finally certification testing. Proof of concept testing is typically performed using crude elements of systems that are configured in a way to demonstrate whether the system has the potential of performing in an acceptable manner if it were developed. These tests do not need to be done by a certified testing lab nor do they need to follow any particular testing criteria. Thus, these tests may be very low cost.

The developmental tests are done to verify that system components are designed properly to be able to pass the certification tests. These tests allow the developer to try several different designs and refine the system to a point where it is ready for certification testing. These tests are typically conducted to basic criteria close to that used in certification testing but the instrumentation, procedures, etc., are at a much lower level. These tests are more costly than proof of concept tests but substantially less than certification tests.

The certification tests are the ones that should be used by the approval agency to evaluate and approve an appurtenance. Therefore, the system being tested cannot be altered in any way once the certification testing begins. Subsequent testing of this system by other certified test labs should yield the same performance. Due to the high level of instrumentation, documentation, quality assurance and procedures being followed, certification testing is very expensive.

This process will represent a major change to most (but not all) testing labs. Most testing being done for state and federal agencies are being conducted and priced as certification tests. However, the system components may undergo numerous design changes throughout the testing program. It would be unusual for early tests in the matrix to be rerun after a design change is made.

"IF SO (TESTING LABS BEING CERTIFIED), SHOULD A PRODUCT BE SELF-CERTIFIED?"

The simple answer to this question is yes, provided that the certification process is applied equally to all certified test labs.

There are several issues that need to be explored to fully appreciate the answer. These issues include who might be defined as an independent test lab, what financial or business interest does the testing lab have in the article being tested, whether the tests are conducted in a manner where the results cannot be altered and what is the level of competence of the testing lab to do certification testing.

When these issues are evaluated, the conclusions reached include:

1. None of the current testing labs are truly independent. The testing labs or their mother organizations have financial and/or professional interests in the test article or in the research program associated with the tests.

2. The procedures, quality assurance programs, methods used to positively ensure that results cannot be altered, traceability of component materials and designs, assurances that design and material changes do not occur after certification testing has started, etc., that are used by the only "self-certification" test lab are equal to or better than those used by other current test labs in attendance.

3. The certification process, auditing and recertification features, etc., should be sufficient to ensure credibility of test results regardless of who conducts the test provided the test is done by a certified test lab.

The industry should encourage and support the process of developing a certification program for highway safety appurtenance test labs. The results will be more accurate and consistent test results between test labs and a more consistently level playing field being created as safety devices are developed and tested.

AN INDUSTRY PERSPECTIVE

John C. Durkos
Syro, Inc.

Since 1981, the *National Cooperative Highway Research Program (NCHRP) Report 230* has served as a reference document used widely by people and agencies concerned with improving highway safety. Researchers, designers, specifiers, testing labs and others who evaluate highway safety products -- both nationally and internationally -- have relied upon this reference tool for guidance. Now it is being proposed that *NCHRP Report 350* replace *NCHRP Report 230*. Although this new and broader publication (*Report 350*) addresses previously unresolved issues, other issues remain to be addressed. One of these issues in particular is: Should testing labs be required to become certified and if so, can a product be tested and certified by the entity that developed it?

Whether one is part of industry, a State Department of Transportation (DOT), the Federal Highway Administration (FHWA), an independent testing lab or a research facility, the objective we all share is the same. It is to do our part to make highways safer places to travel today as well as into the 21st Century. No individual in his/her right mind would intentionally certify a product containing flaws. Even if one was tempted, the risks of credibility and liability would quickly come to mind. Remember The Ford Motor Company and its Pinto?

The issue of developing and testing one's own products is not a new topic. The state of New York did it in the 1960's. The FHWA took it one step further when it developed, tested and approved for national use its own system known as the MELT (the Modified Eccentric Loader Breakaway Cable Terminal). This development within the industry is not all bad when we think about it. After all, a new crashworthy product became available and is currently emerging on many roadways.

Unfortunately, the cost of research and development is extremely high and the FHWA has been directing more efforts towards computer simulations than full scale crash tests, resulting in less product development by the FHWA. Unless the developer is able to earn a return on his/her investment, no new and innovative highway safety products will be developed and/or marketed. Testing facilities that support this process are necessary and generally productive in accomplishing the ultimate goal of providing safer highways and saving lives.

If a research facility patents its own invention, it owns that invention and all the rights thereto. At that point, should the product be taken away and tested elsewhere? Is the potential for conflict of interest such that it should be tested at another facility? If the product is designed and then tested by the research facility, it would be more familiar with every aspect of the product or system than anyone else. It would then be in the foremost position to provide guidance for the product's intended use based on specific crash test results it would have the ability to access. The capabilities of the product or system are therefore established before being offered for general service. The developers could give recommendations on the design features as well as limitations. In the past, this area of expertise has not been exercised to its fullest. On occasion, state DOTs or other authorities will request a product strictly based on price or allow alternatives simply for the sake of competition. This price sensitivity exists to the point that sometimes the only criteria being used to make decisions is price. The actual performance and capabilities of the product or system are not even considered. That stand, of course, is not in the best interests of the public. It's an indisputable fact that no one single product exists to protect drivers from every real world hazard. Possibilities are endless, precluding a scope of testing required to assess them all. Therefore, we need, and should welcome, the experts to provide guidance for actual field applications on the wide variety of products they have brought into the marketplace.

In addition, the FHWA's October 9, 1991 memo states, "The decision whether FHWA accepted traffic barriers should be deployed as experimental or operational should be made by the states." This statement provides even more reason for states to approach the inventors and qualified testing firms to obtain guidance on the application of each particular products' or systems' safety features.

The question still remains, should testing labs be required to become certified? If nothing more than testing cones, drums or barricades for a work zone was performed, the simple pass/fail criteria would not warrant a certified testing facility. If no instrumentation was required and a live driver was used, not much exists to be certified. However, if a respectable amount of valuable data with measurable results were able to be

generated, certification would certainly increase the testing agency's credibility as well as the user's confidence. The definitive test to measure the success of any device will remain the in-service evaluation. Still, anything one can do to enhance both the quality and consistency of the testing process will only improve our industry.

As we begin to address the requirements of *Report 350* along with new concerns such as side impacts, testing at curbs, testing at slopes, and testing with wedge shaped front end vehicles, it is becoming increasingly important that consistency be established across the industry throughout the testing sequence.

Report 350 discusses setting up tests. The product or system is installed per the manufacturer's specifications and a vehicle is chosen. Not much to certify here. Then the test is run. Again, *350* provides guidelines. The recording of data both visually and electronically and the interpretation of the results is where certification would become an issue. We should be able to directly compare time elapse, flail space, occupant impact velocity, Delta V, ridedown decelerations, barrier and vehicle damage and vehicle trajectory, among other data. The high speed film analyzers and the accelerometers could all be calibrated, but would a paper trail along with certification insure reliable and therefore comparable results among all participating labs?

Any of the eight or more labs currently performing tests, whether the tests are full scale crash tests, pendulum, bogie, or computer simulations, would probably meet certification tests. All the development testing could still be done behind closed doors because such activities are nothing more than developmental. It is the compliance testing that needs to be closely monitored and the objective results publicized.

Certification, however, raises more questions than it answers. For example, what entity would certify the test labs? Staff to monitor the process and an agency to enforce the standards would have to be found. The FHWA, the National Highway Traffic Safety Administration (NHTSA), NCHRP, industry, or a newly created representative committee are all possibilities. But who would want to take on that task and at what cost?

Secondly, who would establish the standardized criteria and what level of performance should be considered acceptable? Each test matrix for a given project or design has particular requirements. The normal sequence of awarding contracts for testing is to solicit proposals, rank the proposals and make the award based on the technical qualifications and price. Only those testing labs qualified to perform the tests could submit proposals.

Third, but not necessarily the last question, what real benefits would be realized? If all the data acquisition systems were identical, we could calibrate them. However, this process would not insure repeatable results with what appears to be an identical test. Virtually all systems are sensitive to fabrication, installation and the environmental conditions to which they are subjected. Vehicles will always vary slightly and no two crash dummies are exactly the same or will be placed identically within different vehicles. A combination of any or all of the above mentioned instances could lead to significant variances in the data collected.

If some of these issues could be resolved, certification would be beneficial. But we certainly do not want certification to increase testing costs, which will ultimately increase the cost of the finished product, if quality is not increased by the same proportion. If the only goal of certification is to instruct a facility how to run a test and measure results, it could be accomplished by conducting a seminar in conjunction with a TRB meeting.

In conclusion, the efforts of this industry to make highways safer have been favorable. It was reported that traffic deaths in 1992 hit a 30 year low. This statistic marks the first time since 1962 that yearly fatalities dipped below 40,000. Improved quality roadside safety hardware was an important contributor to the improved industry statistics. No ideas of any value will ever make it to the marketplace unless someone takes charge to support the product through its life cycle. Industry has made the investments and commitments to elevate highway safety to the next level. Congress enacted the Intermodal Surface Transportation Efficiency Act (ISTEA) and the FHWA has restricted the use of certain outdated technologies on our highways. We also appear to be moving from NCHRP *230* to NCHRP *350*, greatly contributing to international harmonization, and are in the process of converting to the metric system (although not everyone feels this process is a step forward). All of these actions are intended to be progressive and at times, appear aggressive. In the final analysis, the purpose of test labs is to run the test and report the results. Anything we can do that will improve the overall process without significantly affecting development costs should be done, but first we must conclude that the move is definitely forward and not lateral. If so, the time may be right to standardize and certify testing procedures, whether performed by independent agencies or developers of the product subject to these tests.

TESTING LABORATORY PERSPECTIVE

King K. Mak

This presentation represents my personal opinion not necessarily that of the Texas Transportation Institute (TTI). I am generally in favor of a certification process. Most existing testing laboratories should not have any problem with meeting certification requirements. There are, however, issues that are important to a testing laboratory and need to be considered.

ITEMS TO BE CONSIDERED IN CERTIFICATION REQUIREMENTS

Certification requirements need to be specific, explicit, and clearly defined. Requirements should be performance based to the extent possible, i.e., specify the desired end result, but not necessarily the exact means or equipment to accomplish the result. A lot of the equipment, instrumentation and software are custom made and not easily standardized among the testing laboratories. Updates to the certification requirements should be kept to a minimum since it takes a long time to establish the proper procedures and to train the crew. Efficiency will suffer with frequent changes in the requirements and the potential for mistakes will increase. The requirements should cover both Initial certification and periodic update or re-certification. There needs to be some mechanism for inputs from users and testing laboratories in developing the initial requirements and future updates or modifications to the requirements.

COST CONSIDERATIONS

Cost is a major consideration for testing laboratories unless the laboratory does not engage in competitive bidding for projects. Cost considerations can be broken down into two areas:

1. Capital outlay, i.e., purchase of specific equipment items that are required for a testing laboratory to be certified initially. The required capital outlay will probably be small for existing testing laboratories, but can be prohibitive for a new testing laboratory.

It should be kept in mind that some of the testing laboratories, especially those affiliated with universities and governmental agencies, typically have problems acquiring new equipment. For example, at TTI, capital equipment is generally purchased with capital funds which are appropriated by the State Legislature. Needless to say, the capital funds are hard to come by and usually require very long lead times.

2. Periodic maintenance, i.e., costs associated with maintaining the certification. The key items are:

a. Periodic calibration of accelerometers rate transducers by a certified laboratory, e.g., manufacturer, National Bureau of Standards, etc. Besides the cost of the actual calibration, the process takes 4 to 6 weeks, and the laboratory will need spare equipment during calibration.

For example, TTI calibrates its accelerometers under steady state conditions (using a centrifuge), but sends them back to the manufacturers for dynamic calibrations.

b. Periodic calibration of electronics, including telemetry, filters, etc. A device similar to the NHTSA Data Acquisition System Evaluation Test System, but at the appropriate frequency, i.e., 180 Hz instead of 1,000 Hz, would serve well for this purpose.

c. Validation of software, e.g., digitization, calculation of occupant risk factors, etc. A standardized analog (or digital) test data set can be used to check the validity of the software.

d. 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 cost for testing will probably go up some because of added expenses associated with these maintenance requirements. However, since all testing laboratories are subjected to the same requirements, there should not be any cost advantage or disadvantage to a testing laboratory except in initial capital outlays.

OTHER CONSIDERATIONS

Four more questions pertaining to certification and product testing are discussed in this section.

1. Who should decide on the certification requirements and who should administer and monitor the certification program?

These questions are very important questions and will have great impact on the testing laboratories. However, from the perspective of a testing laboratory, there are no unique concerns regarding these questions.

2. Should there be different levels of laboratory certification, e.g., level I for tests without electronic instrumentation, level II for pendulum and bogie vehicle testing, and level III for all testing, including full-scale crash testing?

This issue is actually of little concern to existing testing laboratories since we already can handle all testing, but would have a great impact on new testing laboratories, particularly those that do not want to develop full-scale crash testing capability (an extremely expensive endeavor).

3. Currently, testing laboratories are expressing an opinion on the pass/fail of a device based on the evaluation criteria, but the opinions are only recommendations. It is up to the FHWA to actually decide on the pass/fail of a device, either at the headquarters or at the division level. Should the current practice be continued or should other options be considered, such as having the testing laboratory actually decide on the pass/fail of a roadside safety appurtenance, or simply report the data and have another agency, such as FHWA, to determine the pass/fail of the device?

From the standpoint of a testing laboratory, I would oppose leaving the final decision of pass/fail of a safety device to the individual testing laboratories. The reason is that the approval authority and responsibility should rest with FHWA or the state or local highway agency, and not with testing laboratories. I would not have any problem with reporting only the data and not even express an opinion or recommendation, but I suspect that this is not a viable approach since too much work would be required of the agency making the decision. I think maintaining the current practice is probably the best approach.

4. Should a manufacturer qualify its own products? Similarly, should a testing laboratory qualify its own designs?

The concern is that there may be some built-in biases because of self interest, either financial or professional, that may affect the interpretation of test results. It is just human nature to be favorably biased toward one's own design and project and *total* objectivity is very difficult. On the other hand, I also believe that the professionalism in us will keep us reasonably objective in most, if not all, cases.

Another consideration is that it is very difficult, if not impossible, to separate developmental tests from compliance tests during the design and development process for a new safety device. We typically start out with an initial design and then modify the design based on the results of the crash tests. If the test is a failure, we will term the test a "developmental test" and then modify the design and test again. If the test is a success, it becomes a compliance test.

A related issue is the uniformity and consistency in the interpretation of data and results among the testing laboratories. In other words, for a given crash test, will all testing laboratories interpret the evaluation criteria in the same manner and arrive at the same conclusion? I believe that is the case in most of the tests, but there are some exceptions. Some of the evaluation criteria are subjective in nature and open to interpretation. Examples of such criteria are occupant compartment deformation and intrusion and vehicle stability and trajectory.

One potential solution to this concern is to set up an independent review or oversight panel, consisting of personnel with expertise and experience in the area of testing and evaluation of roadside safety appurtenances from FHWA, state highway agencies, testing laboratories, and any other related agencies. The panel will review selected tests from the various testing laboratories and determine if the tests are properly conducted, the data and results appropriately evaluated, and the findings and conclusions valid.

This can be set up as part of the certification process. The independent review panel will serve as a safeguard against major biases and also as a check and balance to ensure uniform and consistent results and interpretations from the various testing laboratories.

Of course, this review panel will require some funding, but the expenses will be minuscule compared to the costs of installing and maintaining roadside safety hardware.

PERFORMANCE OF CURRENT SAFETY HARDWARE FOR *NCHRP REPORT 350* VEHICLES

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Since its publication in 1980, *National Cooperative Highway Research Program (NCHRP) Report 230,* "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," (*1*) has served as the primary reference for full-scale crash testing of roadside safety features. However, significant changes in the vehicle fleet, and continued evolution in design concepts and technology necessitated an update to *Report 230.* A comprehensive update of the procedures for safety performance evaluation of highway features was published as *NCHRP Report 350* (*2*) in 1993. This document contains a wider range of recommended tests for evaluation of a wider range of roadside safety appurtenances including longitudinal barriers, terminals, crash cushions, breakaway support structures and utility poles, work zone traffic control devices, and truck-mounted attenuators.

DESIGN TEST VEHICLES DEFINED IN *REPORT 350*

The test conditions used for evaluation under the basic test level, test level (TL) 3, in *Report 350* are fundamentally the same as those as those used in *Report 230* with small differences in impact speed attributed to the hard conversion to SI units of measurement. For instance, the impact speed for TL-3 is 100 km/hr or 62 mph which is slightly greater than the 60 mph nominal test speed used under *Report 230.* The greatest departure between *Report 350* and its predecessor lies in the definition of its standard test vehicle. Although *Report 350* defines several supplemental test vehicles as the basis for optional testing at higher performance levels, most of our current hardware has been designed and tested to the equivalent of the basic test level, TL-3. *Report 350* specifies the use of a 3/4-ton pickup truck, designated 2000P, as the new design vehicle for evaluating structural adequacy under TL-3. This vehicle replaces the 4,500 lb passenger sedan (4500S) used under *Report 230* and is intended to represent the class of "light trucks" (vans, mini-vans, pickup trucks, utility/sport vehicles) which comprise a significant and growing portion of the vehicle fleet.

In order to assess the performance of the 2000P pickup upon impact with current roadside hardware, it is helpful to understand the differences in characteristics between the 2000P and 4500S passenger sedan, and how these differences may affect impact behavior. A comparison of the overall dimensions of these two design vehicles is shown in Table 1. The dimensions shown for the 4500S are average values obtained from vehicles used in full-scale crash tests conducted in accordance with *Report 230* requirements. The properties shown for the 2000P are average values for 3/4-ton pickup trucks obtained from crash tests, parking lot surveys, and the literature. As shown in Table 1, the overall length, width, and track width of these two vehicle classes are very comparable. There is approximately a 10 percent difference in wheelbase and, not surprisingly, there is a significant difference in overall height.

Some of the major differences between the 2000P and 4500S which are potentially very significant in terms of influencing impact behavior are summarized in Table 2. Center of gravity (c.g.) height of a 4500S passenger sedan is approximately 22 in., whereas the 2000P pickup truck has an average c.g. height of 28 in. With regard to bumper height, the 4500S typically averages 12.5 in. to the bottom of the bumper and 21 in. to the top of the bumper. In comparison, typical bumper heights for the 2000P average 18.5 in. to the bottom and 28 in. to the top. The average front overhang of a typical 4500S passenger sedan is 43 in. whereas the front overhang on the 2000P pickup is only 31 in.

These differences in vehicle characteristics can have a significant effect on impact performance with certain roadside features, and little, if any, effect on others. With regard to flexible longitudinal barriers, the impact performance is expected to degrade. The higher c.g. height of the 3/4-ton pickup renders the vehicle less stable and more susceptible to rolling on top of or over the barrier. Higher bumper height increases the potential for the bumper of the 2000P vehicle to override the rail element, thus increasing the propensity for vaulting. Furthermore, the shorter front overhang of the pickups increases the degree of interaction between the front tire of the vehicle and the barrier components which results in a greater tendency to climb the face of a barrier. This is particularly true for strong-post guardrail systems such as the G4(1S) and G4(2W),

TABLE 1 TYPICAL OVERALL DIMENSIONS OF DESIGN TEST VEHICLES

Vehicle Property	2000P	4500S
Length, in.	214	219
Width, in.	78	76
Height, in.	73	56
Wheelbase, in.	132	120
Track Width, in.	66	62

TABLE 2 PERTINENT PROPERTIES OF DESIGN TEST VEHICLES

Vehicle Property		2000P	4500S
C.G. Location, in.	above ground	28	22
	aft of front axle	61	51
Bumper Height, in.	top	28	21
	bottom	18.5	12.5
Front Overhang, in.		31	43

where significant wheel contact with the guardrail posts can occur prior to any significant redirection of the vehicle. For transitions from flexible to rigid barriers, such as occur at a bridge end, this additional wheel interaction attributed to the short front overhang can result in more severe wheel snagging and greater vehicular decelerations.

The increased c.g. height and shorter overhang of the 2000P are also potentially detrimental to its impact performance with commonly used rigid barriers such as the concrete safety shape. The shorter front overhang distance allows the front tire to interact more readily with the face of the barrier, potentially resulting in increased vehicle climb. This behavior, combined with the increased c.g. height of the vehicle, could increase the propensity for rollover.

The geometrics and increased frontal stiffness of the 3/4-ton pickup may pose a problem for some energy-absorbing devices such as crash cushions and truck mounted attenuators (TMA). Since a pickup truck has a stiffer front end than a passenger car, it will not absorb as much energy during a frontal impact. This behavior can be detrimental for devices which are at or near the required performance limits. In addition, the increased bumper and c.g. heights of the 2000P pickup may increase the propensity for overriding or vaulting during frontal impacts with some crash cushion or TMA designs.

For some roadside features, such as breakaway luminaries and sign supports, work zone features, and traffic control devices, the small 1800 lb (820 kg) passenger car is typically the critical test vehicle. Since the test conditions for this vehicle remain essentially the same, the implementation of *Report 350* should have little impact on these devices. Little difference in impact performance with pickup trucks is expected other than a somewhat increased potential for rollover during post-impact trajectory.

CRASH TEST EXPERIENCE

Although much remains to be learned regarding the safety performance of roadside features with the 2000P test vehicle, some testing has been conducted with pickup trucks from which preliminary assessments can be drawn. Much of our current knowledge regarding the impact performance of pickups stems from bridge

rail tests conducted in accordance with the requirements of the 1989 AASHTO *Guide Specification for Bridge Rails* (*3*). The test matrix for a performance level (PL) 2 railing includes a 5400 lb pickup truck impacting at 60 mph and 20 degrees. Although the test vehicle description contained in the *Guide Specification* specifies parameters such as wheelbase and c.g. height, it does not indicate whether the pickup should be a 1/2-ton or 3/4-ton design.

Bridge Rails

Several concrete, steel, and combination bridge railings were tested to performance level two (PL2) of the AASHTO *Guide Specification* under a recently completed FHWA Pooled Fund study which was conducted at TTI (*4*). The railings that were tested include:

- 32-in. vertical concrete parapet;
- 32-in. New Jersey safety shape;
- 32-in. F-shape;
- Illinois 2399-1 (steel post and tubing mounted on 7-in. curb);
- BR27C (steel post and tube mounted on 24-in. concrete parapet); and
- Illinois side mount (steel post and tubing mounted on side of deck).

Although not stipulated in the *Guide Specification*, all of the tests were conducted with a 3/4-ton pickup ballasted to 5400 lb. In each test, the pickup truck was redirected in a stable manner and the performance was considered to be satisfactory. However, it should be noted that the lateral kinetic energy that must be managed in a 5400 lb/60 mph/20 deg impact is 25 percent less than that resulting from a 4409 lb/62 mph/25 deg impact as required under test level (TL) 3 of *Report 350*.

More recently, several concrete barrier systems, both rigid and portable, were tested with the 2000P design vehicle of *Report 350*. In one study, a standard New Jersey concrete safety-shaped barrier connected to a bridge deck with 1 1/4 in. steel pins was successfully tested with a 2000 kg, 3/4-ton pickup truck impacting at a nominal 100 km/h and 25 degrees (*5*). Although the barrier was not completely rigid, the results of these tests and tests of other safety-shaped barriers with the 5400 lb pickup appear to indicate that the widely used safety-shaped barrier provides acceptable performance for test level 3 of *Report 350*.

A 32-in. tall single-slope concrete bridge rail was also successfully tested with the 2000P vehicle under test level 3 of *NCHRP Report 230* (*6*). Although the vehicle became completely airborne and the amount of climb was substantial, the vehicle remained upright and stable, and the test was judged to be a success.

In another study, a low-profile portable concrete barrier was developed and tested (*7*). This barrier, which is 20 in. in height and has a negative slope on the traffic face, was successfully tested with a 3/4-ton pickup at 45 mph and 25 degrees, which is nominally equivalent to test level 2 of *Report 350*. It is of particular interest to note that almost immediately after impact, the bumper of the pickup truck overrode the top of the 20-in 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.

Based on these results, it seems reasonable to conclude that most of our common bridge rail systems will perform adequately with the 2000P vehicle when evaluated under *Report 350* criteria.

Guardrails and Transitions

Crash test experience with pickup trucks impacting flexible barriers is much more limited than that for bridge rails, and the testing that has been performed has yielded mixed results. A 32-in. high nested thrie beam transition with 3 ft-1 1/2 in. post spacing and W6x15 posts successfully passed a test with a 5400 lb pickup impacting at 60 mph and 20 deg. This test was conducted under the FHWA pooled fund study mentioned previously.

Undesirable behavior was observed when a 2,000-kg (4,409-lb) pickup truck impacted a strong-post W-beam guardrail system with 12 ft-6 in. post spacing at a nominal speed and angle of 45 mph (72.5 km/h) and 25 degrees (*8*). The bumper of the pickup truck overrode the W-beam rail element shortly after impact. It should be noted that the top of the bumper was at a height of 27 in. which placed it at the same height as the W-beam rail. Prior to any significant redirection of the vehicle, the vehicle pocketed at the first post immediately downstream of impact. The short front overhang of the pickup allowed the front tire to impact the post and load the front suspension. The vehicle subsequently vaulted the rail with virtually no damage to the vehicle or barrier.

In a test conducted as part of an earlier FHWA study which evaluated the performance limits of guardrails, median barriers, and embankments for different classes of vehicles and impact conditions (*9*), a Ford F150 pickup impacted a standard G4(1S) guardrail system at 56.9 mph and 23.5 degrees. The 1/2-ton pickup had a

weight of 3,834 lb, a c.g. height of 26.1 in., and a bumper height of 21.5 in. During the impact, the tire of the vehicle snagged severely on the second post downstream from the point of impact and the vehicle achieved a maximum roll angle of about 35 degrees before being redirected.

Other experience with flexible barriers is largely comprised of a recently completed study which evaluated special roadside features and geometry such as guardrails behind curbs, guardrails on curves, and guardrails on slopes (*10*). The tests conducted under this study were conducted with either a 1/2-ton or 3/4-ton pickup truck ballasted to 5,400 lb and impacting at a nominal speed and angle of 60 mph and 20 degrees, respectively. In this study, a G4(1S) installed on a 6:1 downslope successfully redirected a 3/4-ton pickup truck. The maximum roll angle was reported to be 15 degrees. A 3/4-ton pickup was also successfully redirected by a G4(1S) placed on a 1,192-ft radius curve. Since the curve tends to effectively increase the angle of impact and, hence, the impact severity, the results of this test are somewhat encouraging. However, this same installation with a 10 percent superelevated roadway section and 2 percent upsloping shoulder failed to redirect a 1/2-ton pickup. A subsequent test on a modified thrie beam guardrail with the same geometry successfully redirected a 1/2-ton pickup truck.

Other tests performed in this study evaluated the performance of curbs placed in front of a standard G4(1S). In a test with an 8-in. curb, a 3/4-ton pickup impacting at 60 mph and 20 degrees, vaulted the barrier in much the same manner as observed in the test of the low service level, 12 ft-6 in. guardrail system described above. When evaluated with a 4500-lb 1/2-ton pickup impacting at 45 mph and 25 degrees, a G4(1S) with a 6-in. curb also failed to redirect the vehicle.

Limited testing of other appurtenances was conducted in another study which evaluated the initial feasibility of replacing the 4,500 lb passenger sedan with a 5,400 lb pickup truck (*11*). As part of this assessment program, a G4(1S) was tested with a 5,400 lb pickup impacting at 65 mph and 20 degrees. These impact conditions generate an impact severity roughly equivalent to a 4,500 lb car impacting at 60 mph and 25 degrees. A 1/2-ton pickup truck with a bumper height of 21.5 in. was used for this test. The pickup was successfully redirected with a maximum reported roll angle of approximately 20 degrees. Although this test was successful, it is difficult to extrapolate the safety performance of the G4(1S) with a 3/4-ton pickup which has a much greater bumper and c.g. height.

Although definitive tests have not been conducted to date, these results raise concern regarding the capabilities of our widely used W-beam guardrail systems to contain and redirect the 2000P test vehicle under TL-3 of *Report 350*.

Crash Cushions and Attenuators

Generally speaking, tests of crash cushions and energy-attenuating devices with pickup trucks have had satisfactory results. A Fitch sand barrel attenuating system successfully passed a test with the 2000P head-on at 100 km/h (*12*). On the other hand, two previous tests with Energite sand barrels impacted by a 1/2-ton pickup ballasted to 5,400 lb and impacting a speed of 55 mph were unsuccessful due to vehicle ramping (*11*). However, there was some concern expressed in regard to these failures that the properties of the 1/2-ton pickup may have been significantly altered by the large amount of ballast required to achieve a test inertial weight of 5,400 lb.

Other crash cushions such as the vehicle attenuating terminal (VAT), the Connecticut impact attenuating system (CAIS), and the GREAT (Guardrail Energy Absorbing Terminal), have all reportedly passed tests with a 5,400 lb pickup at a nominal speed of 55 mph (11). In terms of kinetic energy, these impact conditions are equivalent to a 4500 lb vehicle impacting at 60 mph.

Although the data are limited, it appears that most currently approved designs will satisfy *Report 350* requirements for end-on impacts. However, as discussed previously, the geometrics of the 3/4-ton pickup may increase the propensity for vaulting for certain designs.

Other Appurtenances

A few other miscellaneous appurtenances have also been tested with pickup trucks. A test with an eccentric loader terminal (ELT) was judged as marginally passing (*11*). The test involved a 1/2-ton pickup ballasted to 5,400 lb impacting at a speed of 51 mph. During the test, the vehicle ramped and achieved a maximum roll angle of 43 degrees. In another test, a bull-nose median barrier terminal was found to exhibit acceptable impact performance when impacted by a 5,400 lb pickup at 55 mph and 0 degrees (*11*).

SUMMARY

A summary of the tests described above is presented in Table 3. As shown in this table, most of the crash tests with pickup trucks that have been performed to date have involved a full-size pickup ballasted to 5,400 lb. Since some of these tests involved a 1/2-ton vehicle, and since the impact conditions typically used in conjunction with the 5400-lb test vehicle 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, these

TABLE 3 SUMMARY OF CRASH TESTS CONDUCTED WITH PICKUP TRUCKS

System Tested	Vehicle Description		Impact Conditions		Comments
	Type	Weight (lb)	Speed (mph)	Angle (deg)	
Bridge Rails					
32-in. Vertical Parapet	3/4 ton	5797	59.7	20.5	passed
32-in. N.J. Safety Shape	3/4 ton	5724	57.7	20.6	passed, 23 in. climb
	1/2 ton	5408	65.0	19.0	passed, 11 deg. roll
32-in. F-Shape	3/4 ton	5780	65.4	20.4	passed, 20 deg. roll
Illinois 2399-1	3/4 ton	5797	63.6	20.9	passed
BR27C	3/4 ton	5570	58.3	19.6	passed
Illinois Side Mount	3/4 ton	5565	60.4	20.4	passed
32-in. Constant Slope	3/4 ton	4573	60.4	25.5	passed, 30 deg. roll
Concrete Beam and Post	3/4 ton	4500	61.9	25.6	passed
Guardrails and Transitions					
Nested Thrie Transition	3/4 ton	5750	62.7	19.0	passed
G4(2W), 12'-6" post spacing	3/4 ton	4409	43.2	24.5	failed, vehicle vaulted
G4(1S)	1/2 ton	3834	56.9	23.5	marginal, 35 deg. roll
	1/2 ton	5390	65.9	18.8	passed, 19 deg. roll
G4(1S), 6:1 downslope	3/4 ton	5710	59.7	20.0	passed, 15 deg. roll
G4(1S), 1,192-ft radius	3/4 ton	5712	61.1	20.0	passed, 20 deg. roll
G4(1S), 1,192-ft radius, 10% superelevation	1/2 ton	5727	60.9	20.0	failed, vehicle rolled
Modified Thrie, 1,192-ft radius, 10% superelev.	1/2 ton	5743	61.0	20.0	marginal, 45 deg. roll
G4(1S), 8-in. curb	3/4 ton	5742	61.3	20.0	failed, vehicle vaulted
G4(1S), 6-in. curb	1/2 ton	4562	46.1	25.0	failed, vehicle intrusion
Crash Cushions and Attenuators					
Fitch Sand Barrels	3/4 ton	4500	60	0	passed
Energite Sand Barrels	1/2 ton	5400	54.7	0.3	failed, vehicle ramped
VAT	1/2 ton	5420	54.3	1.9	passed
CAIS	1/2 ton	5387	56.8	1.5	passed
GREAT	3/4 ton	5573	54.8	11.1	passed
Other Appurtenances					
ELT	1/2 ton	5722	51.4	0.2	marginal, 43 deg. roll
Bull-Nose Median Terminal	1/2 ton	5390	54.9	0.1	passed

tests do provide considerable insight into the safety performance of current hardware with the 2000P test vehicle from which some general conclusions can be drawn.

Certain roadside features such as breakaway devices, small sign supports, and traffic control devices should not be a concern from the standpoint of occupant risk. However, the potential for occupant compartment intrusion with some designs may warrant further investigation.

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 will satisfy the requirements of test level 3 in *NCHRP Report 350*. The results of tests on crash cushions appear to indicate a strong potential for good impact performance.

The most critical area of concern appears to be the performance of widely used flexible barriers with the 2000P. The short front overhang and increased c.g. and bumper heights of the 3/4-ton pickup significantly increase the potential for vaulting and rollover during impacts with many standard guardrail systems.

Further research is clearly warranted to better quantify the safety performance of roadside features with the 2000P pickup truck and other subclasses of light trucks, particularly for flexible barrier systems. Since the 2000P will be the design test vehicle of the future, it should also be established whether or not it is an appropriate surrogate for the other vehicles it is intended to represent.

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IMPLICATIONS OF ISTEA SPECIAL VEHICLES

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INTRODUCTION

Section 1073 of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) is concerned with "Roadside Barriers and Safety Appurtenances" *(1)*. This section reads as follows. "(a) INITIATION OF RULEMAKING PROCEEDINGS. Not later than 30 days after the date of enactment of this Act, the Secretary shall initiate a rulemaking proceeding to revise the guidelines and establish standards for installation of roadside barriers and other safety appurtenances, including longitudinal barriers, end terminals and crash cushions. Such rulemaking shall reflect state-of-the-art designs, testing, and evaluation criteria contained in the National Cooperative Highway Research Program Report No. 230, relating to approval standards which provide an enhanced level of crashworthy performance to accommodate vans, mini-vans, pickup trucks, and 4-wheel drive vehicles. b) FINAL RULE.-Not later than 1 year after the date of the enactment of this Act, the Secretary shall complete the rulemaking proceedings initiated under subsection (a), and 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 guidelines and 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."

This section of the ISTEA made it clear that roadside barriers and other safety appurtenances had to be able to accommodate what the motor vehicle manufacturers refer to as the "light truck" class of vehicles. When this law was written in 1991, about 25 percent of the vehicle fleet consisted of light trucks *(2)*. Projections from vehicle sales data indicate that these light trucks could be as much as 1/3 of the vehicle fleet in the near future *(2)*.

NCHRP Report 230 contains multiple service levels and recommends tests for these levels in a supplementary matrix *(3)*. However, it does not call for tests with the light truck vehicles listed in the ISTEA. The standard strength test in *NCHRP Report 230* is with a 4,500-lb car impacting at 60 mi/h and 25 degrees.

Until recently, the 1989 AASHTO Guide Specification for Bridge Rails was the only recognized document that recommended crash testing with ISTEA vehicles *(4)*. A crash test with a 5,400-lb pickup truck at 45 mi/h is used to define the strength of a bridge rail for Performance Level One (PL-1). A 5,400-lb pickup truck is also recommended for testing bridge rails to the two higher performance levels.

On July 16, 1993, the Federal Highway Administration (FHWA) published a Final Rule in the Federal Register in which it adopted *NCHRP Report 350* *(5)*. This Final Rule amended the "guides and references" section in 23 CFR part 625 by listing *NCHRP Report 350* for guidance in determining the acceptability of roadside barriers and other safety appurtenances for use on National Highway System (NHS) projects *(6,7)*.

The Final Rule pointed out that *NCHRP Report 350* had been developed under an NCHRP project as a replacement for *NCHRP Report 230*. It went on to say that,"The replacement, *Report 350* "Recommended Procedures for the Safety Performance Evaluation of Highway Features," 1993 addresses testing and evaluating appurtenances with pickup trucks and with smaller and larger vehicles. The FHWA believes that following the testing and evaluation guidance contained in *NCHRP Report 350*, along with appropriate roadside features selection procedures, will result in highway design and upgrade practices that will safely accommodate the vehicles cited in the ISTEA" *(5)*.

THE SURROGATE VEHICLE

The issue has been raised as to how well the 3/4-ton pickup truck represents the spectrum of vehicles in the light truck category. There is no "generic" pickup truck. Due to various vehicle models and optional features, there is as much variation within each class as there is among the classes of light trucks.

NCHRP Report 350 recommends tests with a 2000P vehicle, which is essentially a 3/4 ton pickup truck ballasted to 4,500-lb. This test vehicle was originally intended to be a replacement for the 4,500-lb car. Cars weighing about 4,500-lb were widely used as test vehicles until downsizing made them scarce. In general, pickup trucks have higher centers of gravity, higher bumpers

and larger wheels than cars. Therefore, some differences in performance are to be expected.

Since pickup trucks have been used as test vehicles for about 4 years, quite a bit is known about their characteristics and behavior. Both full-size cars and pickup trucks have vaulted after impacting guardrail/curb combinations. Tests of NJ-shape concrete median barriers have shown that the exit trajectories of pickups are different from those of cars. Crash tests of bridge rails have shown that the frame of a pickup truck can twist and flex between the cab and the truck bed. This flexing of the frame makes the pickup truck behave more like an articulated vehicle than a rigid mass. Consequently, the peak impact force is a little lower for a pickup truck than for a car of the same weight. The front wheels of pickup trucks have flown off after impacts with rigid, vertical walls. When a pickup truck impacted an aesthetic guardrail made of logs, the sloping end of its bumper impacted the curved rail face and lifted the vehicle. A G4(1s) W-beam on strong post guardrail with a 1194-ft horizontal radius smoothly redirected a 5,400-lb pickup truck on level terrain. However, the pickup truck rolled over after impacting this guardrail at the top of a superelevated section of roadway. Overall, the available test data seems to indicate that pickup trucks are more critical test vehicles than full-size sedans.

Very few crash tests have been conducted with other ISTEA vehicles, i.e. vans, mini-vans and 4-wheel drive vehicles. Therefore, not much is known about their behavior and characteristics when interacting with safety hardware and other safety features. Vehicle handling studies suggest that these light truck vehicles have a greater potential for rollovers. However in 60 mi/h tests on a embankment with a 3 to 1 slope, a pickup truck and a van were steered remotely down the slope and back onto the roadway. A 1,800-lb car rolled over at the bottom of the slope in a test conducted when the soil was softer. Test results are highly sensitive to test variables that may be even more important than the differences in vehicle characteristics.

It should be kept in mind that the problem of a surrogate vehicle is broader than simply deciding what test vehicle should be selected to represent the light truck class of vehicles. The test conditions, i.e. the test weight of the vehicle, the impact speed and the impact angle are probably at least as important as the model or class of vehicle selected. For example, a test of a traffic barrier with a 3/4-ton pickup truck impacting at 5 mi/h and 3 degrees would not be a discerning test. *NCHRP Report 350* recognizes that more than one test and more than one test vehicle are necessary to represent the range of behavior and characteristics found in passenger cars and the light truck class of vehicles. Consequently, tests are recommended with two sizes of small cars as well as pickup trucks. There are inconsistencies between the test conditions for the pickup truck tests in *NCHRP Report 350* and the AASHTO Guide Specification for Bridge Railings that will have to be reconciled.

The FHWA has expressed willingness to change the test vehicles and test conditions if this becomes necessary. The Notice of Proposed Rulemaking, which was published in February, 1993, stated, "Should the previously cited FHWA and NCHRP studies to examine the performance characteristics of ISTEA vehicles and the compatibility with them show that the 3/4-ton pickup truck, recommended as a test vehicle in *Report 350*, is not suitable or sufficient as a test vehicle to represent the light truck segment of the vehicle fleet, the FHWA will look for another test vehicle or an additional test vehicle or vehicles" *(2)*.

CUSTOM VEHICLES

It is a common practice for vehicle manufacturers, vehicle owners or custom shops to make significant modifications to pickup trucks, vans and the other vehicles in the light truck class. In some cases, these modifications result in vehicles with very large wheels, special extended suspensions and high centers of gravity. The stability of these vehicles can be greatly diminished by such design features. The FHWA has found that, "It is not economically feasible to design safety features to accommodate vehicles of this type" *(2)*.

IMPLICATIONS FOR HARDWARE DESIGNERS

There is enough variability within the light truck class that efforts to fine tune existing designs for these vehicles may not be fully successful. For example, the construction tolerances on guardrail height (27-in, plus or minus 3-in) could be tightened. However, a more economical approach may be to use a higher-performance guardrail system for new construction, such as the Modified Thrie Beam Guardrail. This 34-in high thrie beam guardrail is an operational system that can even redirect heavy vehicles such as a 32,000-lb bus at 60 mi/h and 15 degrees. New warrants and selection procedures are needed so that designers can make cost-effective decisions. Warrants for the multiple test levels in *NCHRP Report 350* are currently being developed under NCHRP Project 22-9,"Improved Procedures for Cost-Effectiveness Analysis of Roadside Safety Features."

During the rulemaking action, a manufacturer expressed doubts that Truck Mounted Attenuators (TMAs) can be made to pass the off-center head-on and off-center angle tests in *NCHRP Report 350 (5)*. Since these tests are considered optional until the state-of-the-art indicates otherwise, the FHWA has stated that it will not consider it essential that the acceptance criteria be met for tests nos. 2-52, 2-53 and 3-52 and 3-53. However, it is recommended that these tests still be run for reference and comparison purposes *(5)*.

IMPACT ON HIGHWAY AGENCIES

The Final Rule stated that,"...the FHWA anticipates that approximately five years after adoption of this rule that all installations of traffic barriers and other roadside safety features on NHS projects will be only those that have been judged to meet the testing and evaluation criteria in Report No. 350." *(5)* There will be no massive retrofit program. Therefore, "the potential economic impact on highway agencies will be minimal." *(5)*

ADDITIONAL RESEARCH

Obviously, additional research will be needed to obtain more information about the behavior and characteristics of the light truck class of vehicles. Some of this research can be performed under a $450,000 research study entitled, "Assessment of Motor Vehicle Characteristics" that FHWA has programmed for FY'94. A companion $500,000 study entitled,"Roadside Safety Hardware Testing" will test and evaluate various roadside safety features in accordance with *NCHRP Report 350*. This study has been structured so that interested States can contribute funds to have their hardware designs tested. It is expected that NCHRP Project No. 22-11, "Evaluation of Current Roadside Barriers and Other Safety Appurtenances to Accommodate Vans, Mini-Vans, Pickup Trucks and 4-Wheel Drive Vehicles" will look at accident data and crash test results to help identify any safety problems associated with the various types of light trucks. This NCHRP project will probably also address the issue of the appropriateness of the 3/4-ton vehicle as a surrogate for the light truck class of vehicles.

SUMMARY AND CONCLUSION

Warrants and guidelines for selecting and designing roadside safety features and appropriate test conditions may be more important than selecting the "perfect" test vehicle in improving safety for the light truck class of vehicles.

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ISTEA INNOVATIVE BARRIERS WHAT IS HAPPENING?

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Section 1058 of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) requires each State highway agency to certify annually that a minimum of 2.5 percent of the kilometers (mileage) of new or replacement permanent median barriers included in awarded contracts on Federal-aid highways consist of innovative barriers. Innovative barriers are defined in the legislation as those considered experimental by the Federal Highway Administration (FHWA) or declared operational after January 1, 1985.

When the 1991 Act became law, however, the FHWA was no longer classifying tested barriers as experimental or operational but rather leaving this decision to each highway agency. Therefore, a modified definition of innovative barrier was developed. For purposes of Section 1058, an innovative median barrier became one which (1) was considered experimental by a State; or (2) was not already in use (or was in limited use) by that State and differed significantly in material, size, shape, performance/test level or operational characteristics from median barriers in common use elsewhere. In order to allow maximum flexibility to each State, the FHWA did not publish a list of barriers considered innovative under this new definition, but responded informally to questions of eligibility posed by individual States.

The information included in the certifications received for CY 1992 are summarized in Table 1. Of the 52 State highway agencies submitting certification information (50 States, plus the District of Columbia and Puerto Rico), 42 reported the inclusion of median barrier totalling approximately 837 km (520 miles) in Federal-aid contracts on the National Highway System (NHS). Twenty-seven of these States reported almost 145 km (90 miles) (17 percent) of the total as innovative barrier. The most commonly used innovative barrier was the single-slope concrete barrier developed by Texas (12 States), followed by New Jersey barrier higher than 810 mm (32 inches) (8 States), a concrete F-shape higher than 810 mm (32 inches) (2 States), and the Ontario Tall Wall, Modified Thrie-beam, IBC Mark VII, New Jersey barrier painted white, and Quick-Change barrier (1 State each).

As noted above, eight different types of barriers were considered innovative by the certifying States. A brief description and a subjective analysis of each follows:

• Single slope concrete median barrier.

This median barrier was originally developed and tested by the Texas highway department. It is nominally 1070 mm (42 inches) high and has a front face that slopes away from traffic at an angle of 10.8 degrees from vertical. Originally intended for use at locations where planned roadway overlays would change both the effective height and shape of a standard New Jersey concrete median barrier, testing indicated that for small cars (820 kg = 1,800 pounds) redirection was smoother with significantly less roll than with the New Jersey shape. Large car redirection, however, was very much like comparable impacts with the New Jersey shape. Large car redirection, however, was very much like comparable impacts with the New Jersey shape in that the vehicle's bumper climbed to a height of 1020 mm (40 inches) before the car lost contact with the barrier, resulting in a high roll angle. The single slope concrete median barrier has not been tested with any vehicle larger than 2040 kg (4500 pounds), although tests with an 8165-kg (18,000-pound) single-unit truck are planned. While it appears unlikely that a large truck would penetrate or roll over a 1070-mm (42-inch) tall single slope barrier, the distance the top of the trailer would lean over the top of the barrier is not known. This factor becomes critical if the barrier is used immediately in front of a fixed rigid object such as a bridge pier or overhead sign support.

• Tall New Jersey concrete median barrier.

Increasing the height of the standard New Jersey barrier has little or no effect on most impacts, but does offer advantages for vehicles with higher centers of gravity. As with the single slope barrier discussed above, the degree to which a truck or bus rolls beyond the top of the wall must be considered when using the barrier to shield rigid objects. Additionally, a taller wall may act to some extent as a low-maintenance glare screen.

• Tall F-shape concrete median barrier.

Full scale crash tests with vehicles ranging from 820 kg (1,800 pounds) to 36 290 kg (80,000 pounds) have indicated that the F-shape (or a New Jersey barrier with the 75-mm (3-inch) reveal covered), with its slope break-point 250 mm (10 inches) above the roadway surface, compared to 330 mm (13 inches) for the New Jersey barrier, performs significantly better than the standard New Jersey shape. Impacting passenger-size vehicles tend not to climb as high up the F-shape as on the New Jersey shape and are redirected more smoothly. High-center-of-gravity vehicles do not lean as far over this shape as they do with either of the barriers discussed above. The extra heights used (up to 1420 mm = 56 inches) provide additional shielding from large trucks and buses for rigid objects directly behind the barrier and also serve as glare screens under some circumstances.

• Ontario tall wall.

This barrier is essentially a 1040-mm (41-inch) high F-shape with no reinforcing steel. When tested, it successfully contained and redirected a 36 290-kg (80,000-pound) tractor-trailer combination impacting at 80 km/h (50 mph) and 15 degrees. To compensate for the elimination of reinforcement, it is more massive than similar height New Jersey or F-shape barriers. The barrier used by Indiana was 1170 mm (46 inches) high to accommodate future overlays.

• Quick-Change median barrier.

This moveable concrete barrier is described in Chapter 9 of the AASHTO's 1989 *Roadside Design Guide* as a temporary work zone barrier. When used for this purpose, it does not qualify as a Section 1058 innovative barrier. However, when this barrier is used for a permanent lane change operation to balance peak traffic flows, it does meet the intent of the law. The barrier itself has exhibited good redirectional capability for passenger-sized vehicles. It has not been tested with trucks.

• International Barrier Corporation (IBC) Mark VII barrier.

This proprietary, sand filled, metal-bin barrier stands 1070 mm (42 inches) high, has a good performance record, although its use has been limited. Based on available information, however, the IBC barrier is not currently available and States that presently have some IBC installations are having difficulty obtaining replacement parts to repair damaged sections.

• Modified Thrie-beam median barrier.

This barrier is described in Chapter 6 of the AASHTO's 1989 *Roadside Design Guide*. When tested, this double-faced metal railing contained and redirected an 18 140-kg (40,000-pound) bus at 80 km/h (50 mph) and 15 degrees. However, the bus rolled onto its side after impact. Since this type of barrier usually needs repair after a hit, it is generally not recommended in locations subjects to frequent impacts or where repair work would necessitate closing one or more median lanes.

• Painted concrete median barrier.

Although painting a standard concrete barrier white (or using white cement and light-colored aggregate) can increase its visibility and theoretically reduce accidents. The FHWA's initial reaction was that, while probably advantageous, such treatment does not meet the intent of Section 1058. However, a more liberal view of the law would encourage use of any treatment that reduces accidents as well as ones that limit their severities. This interpretation is discussed in the final section of this Report.

Of the 15 States that did not include any innovative barrier in their total median barrier, five installed less than 0.4 km (1/4 mile) of total median barrier and did not believe it cost-effective to include any innovative barrier in such limited quantities. Most of the remaining States indicated there was insufficient time to add innovative barrier to projects that were ready for bid or that planned CY 1992 projects that included innovative barrier were not awarded in CY 1992. One State proposed that the 2.5 percent requirement be applied over the entire six-year period covered by the 1991 ISTEA rather than on an annual basis. Ten States reported no median barrier installations at all. A few agencies suggested that the certification requirement be rescinded.

While Section 1058 of the ISTEA indicates a minimum annual usage of innovative barriers, the FHWA believes the intent of Section 1058 will be met if a State can show a good faith effort in each calendar year to select projects for the installation of innovative barriers and the percentage of such barriers over a multi-year period meets or exceeds the minimum amount specified by law. A State that is not in compliance in any calendar year should, however, indicate in its annual certification the reasons why it was not able to install the required amount and its plans for future compliance. We can conclude, however, judging by the high percentage of median barrier considered innovative by the States in their 1992 certifications, that the 2.5 percent requirement is relatively easy to attain.

Since the 2.5 percent is a minimum annual goal, the installation of only a small total amount of barrier is not necessarily a valid reason to install no innovative barrier. Under some conditions, it could very well be appropriate to install 100 percent innovative barrier. Also, short sections of innovative barrier within a run of median barrier might be appropriate. Annually, several accidents occur when large vehicles, usually tractor semi-trailer combinations, strike bridge piers that are shielded with conventional traffic barriers. Taller and stronger barriers can be used to good advantage at many such locations. For example, the State of Louisiana uses a 1370-mm (54-inch) tall concrete safety shape in advance of and through bridge piers on its Interstate system, an innovative practice other States might wish to consider.

Twenty-seven of the 42 States that installed median barriers on the NHS reported installing barrier that they considered innovative. This resulted in a total of 17 percent innovative barrier out of the 520 miles of median barrier installed nationally. However, over a third of the 42 agencies installing median barrier installed no innovative barrier in 1992. Since lead time on major highway projects is often over two years, several States installing no innovative barrier in 1992 reported that some would be included in contracts advertised in 1993 and subsequent years. The FHWA has taken this factor into consideration in its review and acceptance of the first year certifications.

Some confusion exists regarding the specific types of barriers that can qualify as innovative. Since the assumed intent of Section 1058 is the improvement of

TABLE 1 SUMMARY DATA FROM REPORTING AGENCIES IN CALENDAR YEAR 1992

	Total Median Barrier (miles)	Total Innovation Barrier (miles)	% Innovative Barrier
Region 1			
ME	0.21	0	0
NH	0	n/a	n/a
VT	0	n/a	n/a
MA	11.82	0.10(a)	0.8
CT	15.91	0	0
RI	3.37	0	0
NY	15.04	0.90(b)	6.0
NJ	14.02	0	0
PR	0.19	0	0
	60.56	1.00	1.65
Region 3			
PA	12.70	1.43(b)	11.2
MD	7.20	0	0
VA	22.70	0.71(b)	3.1
DE	3.59	0.53(b)	14.8
WV	1.89	1.89(b)	100.1
DC	0	n/a	n/a
	48.08	4.56	9.48
Region 4			
NC	23.25	17.11(c)	73.6
SC	8.71	1.78(d)	20.4
TN	19.35	0	0
KY	22.47	0.66(b)	2.9
GA	37.64	0	0
FL	24.94	13.97(f)	56.0
AL	11.88	0.40(c)	3.4
MS	4.32	2.21(c)	51.2
	151.56	36.13	23.84
Region 5			
OH	16.69	0.56(b)	3.3
IN	31.06	1.28(e)	4.1
IL	27.75	17.37(c)	62.6
MI	10.00	4.40(b)	44.0
WI	17.70	3.30(c)	18.6
MN	3.27	0.89(g)	27.2
	106.47	27.80	26.61

TABLE 1 SUMMARY DATA FROM REPORTING AGENCIES IN CALENDAR YEAR 1992 (continued)

	Total Median Barrier (miles)	Total Innovation Barrier (miles)	% Innovative Barrier
Region 6			
AR	1.62	0.54(b)	33.3
LA	6.20	0	0
OK	0	n/a	n/a
TX	29.90	12.30(b)	41.1
NM	3.09	0	0
	40.81	12.84	31.46
Region 7			
MO	9.66	1.10(b)	11.4
NE	0.90	0.90(c)	100.0
IA	0.18	0	0
KS	3.81	0.20(g)	5.3
	14.55	2.20	15.12
Region 8			
ND	1.48	0.22(c)	14.9
SD	0	n/a	n/a
MT	0.19	0	0
WY	0.11	0	0
CO	2.00	0.29(c)	14.5
UT	0	n/a	n/a
	3.78	0.51	13.49
Region 9			
CA	40.00	2.30(h)	5.8
AZ	0	n/a	n/a
NV	0	0	n/a
HI	0	n/a	n/a
	40.00	2.30	5.75
Region 10			
WA	15.80	0.97(b)	6.1
AK	9.0	0	0
OR	28.90	0	0
ID	0	n/a	n/a
	53.70	0.97	1.81
TOTALS	519.51	88.31	17.0

highway safety, the FHWA will continue to place emphasis on barriers that are more effective in one or more ways than the current national "standard", the 810-mm (32-inch) high New Jersey concrete median barrier. To assist and encourage each State to use such barriers, the FHWA will accept as innovative for 1993 and subsequent years any crashworthy median barrier that: 1) was considered experimental by the FHWA on or after January 1, 1985, or 2) has been declared crashworthy by the FHWA since that date, or 3) a State chooses to call experimental.

An appropriate in-service evaluation to assess performance and other aspects of the innovative barrier is strongly recommended for any median barrier considered innovative under Section 1058 of the ISTEA. An evaluation will be required of any barrier that does not qualify as innovative under categories 1 or 2 in the last sentence of the preceding paragraph and achieves innovative status only on the basis of a State declaring it to be experimental. Construction costs, accident frequencies and severities, barrier performance, and maintenance requirements are the most common factors for analysis and comparison. Chapter 7 of National Cooperative Highway Research (NCHRP) *Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features*, provides general guidelines for in-service evaluations. This approach should afford each State highway agency maximum flexibility in designing its median barriers and will permit the use of barriers such as the 810-mm (32-inch) high F-shape concrete barrier or enhanced visibility barriers that would not otherwise qualify as innovative.

All State highway agencies planning to install median barriers are encouraged to examine the actual performance of their standard barriers and to review the specific site conditions where the barrier will be used to see if an innovative barrier is more appropriate. States using even limited quantities of median barrier may find that an innovative barrier may be the best choice for a particular location.

With the publication and FHWA acceptance of *NCHRP Report 350* with its six test levels for longitudinal barriers, both existing and new barriers are likely to be classified or tested for classification under the new test matrices. Although at present there are no definitive warrants for the use of higher or lower performance barriers, subjective selection factors such as highway speeds, roadway geometrics, percent trucks, consequences of penetration, and past accident histories can be used, as they have been for many years. Some efforts are underway to develop more objective selection procedures to match barriers to site conditions. Designers should remain abreast of future developments in this area.

INNOVATIVE BARRIER TYPES

a. International Barrier Corporation (IBC) Mark VII sand-filled metal bin barrier;

b. Single slope concrete barrier;

c. Tall New Jersey barrier (variable heights from 42 to 56 inches);

d. New Jersey barrier painted white.

e. Ontario tall wall (46-inch high un-reinforced concrete);

f. Modified thrie-beam median barrier;

g. F-shape concrete barrier (51-inches and 56-inches high); and

h. Quick-Change concrete barrier (permanent lane-change operation);

(1 inch = 25.4 mm)

BREAKOUT GROUP ACTIVITIES

GROUP A SHOULD SELECTION GUIDELINES (WARRANTS) BE DEVELOPED FOR HARDWARE DESIGNED ACCORDING TO *NCHRP REPORT 350*?

Background/Issues (by Hayes Ross, TTI)

According to *Report 350* a safety feature may be developed to meet one of up to six "test levels" (TL), depending on the type of feature. For example, a longitudinal barrier can be developed for one of six TL's, a crash cushion for one of three test TL's, and a TMA for one of two TL's. The feature may be for temporary (work zone applications) or permanent applications. Features developed for the lower TL's will usually be applicable for low speed, low volume conditions and will have minimal containment capabilities; features developed for the higher TL's will usually be applicable for high speed, high volume conditions and will have high containment capabilities, i.e., for heavy trucks.

Report 350 has no selection guidelines for safety features. User agencies (states, counties, manufacturers) will be forced to make decisions as to the development and/or use of features developed within the *Report 350* recommendations. In general, there is an absence of objective guidelines on which these agencies can base their decisions.

Discussion Questions

1. How should selection guidelines be developed? On a local, state-by-state, or national level?
2. If developed on a national level, which agency(s) should sponsor the project? FHWA? NCHRP/ AASHTO? Counties? Cities? All of the above?
3. Which methodology should be used in developing the guidelines? Benefit/cost analysis? Past experience (including accident history where available) and practices? Expert opinion? All of the above?
4. Should the guidelines be developed and presented according to feature type, i.e., (1) longitudinal barriers, (2) crash cushions and end treatments, (3) truck mounted attenuators (TMA's), etc., or should guidelines for all types be developed and presented in one document? Should guidelines for temporary features be treated separately from permanent features?
5. What key factors should be considered in formulating the guidelines? Should the guidelines focus on rural conditions only, or should they include urban conditions as well? Should they focus on the higher service level roads only, or should all classes of roads be considered, including local roads and city streets? Should the guidelines consider "site specific" conditions (for example, should they address not only the need for a type of feature but also the specific type of feature recommended for the conditions, such as a redirective versus a nonredirective crash cushion)? Should they identify specific features, including proprietary devices?
6. What would be required in terms of funds and time to develop these guidelines? Is this a high-priority research need? If so, how can it be brought to the attention of potential sponsors?

Summary of Discussions

Group A included a good mix of state highway engineers, researchers, and industry representatives (see the Introduction to this Circular). Unfortunately, no federal or NCHRP representatives were involved in the discussion. This group addressed the questions of how warrants for the use of roadside barriers should be developed. The group held a lively and informative discussion in which many views were represented.

The group was able to reach a consensus on most of the questions addressed. The most significant recommendation coming out of the discussion was that warrants for the use of safety hardware should be developed through a two stage effort. An NCHRP research project would be used to generate a benefit-cost analysis of roadside safety hardware. The end product of this research would not be guidelines for implementation, but curves or tables showing benefit-cost ratios for various situations. These findings would then be used by the AASHTO Task Force for Roadside Safety or the AASHTO Technical Committee for Guardrail and Bridge Rail to generate guidelines. In this way, the guidelines would be well founded in benefit-cost analysis, and AASHTO would be able to assure that the resulting guidelines were reasonable and practical.

Guideline development is recommended for all roadway applications, including urban and rural as well as high and low speed facilities. There was a consensus that urban areas involve an additional difficulty due to the differences in run-off-road accident frequencies and the number of other obstacles, such as parked cars in these areas. There was a great deal of concern that the guidelines might inappropriately recommend safety hardware on very low speed streets, such as residential

areas where operating speeds are 30 mph or less. Test level 1 was recommended for inclusion in this analysis as an alternative for roadways with operating speeds in the 30 to 45 mph range. Some members of the group questioned whether hardware would ever be developed for this level.

All hardware classifications, even down to gating versus non-gating terminals, were recommended for inclusion in the analysis. However, specific hardware features, such as proprietary items, should not be included in the analysis. Separate guidelines are also recommended for the various roadside features, such as longitudinal barriers and crash cushions. However, some features are so integrally related that separate guidelines would be inappropriate, such as longitudinal barriers and end treatments.

Warrants for permanent features are recommended as a very high priority, while there is still an important need for warrants for temporary barriers. It is also recommended that separate research studies be conducted for different roadside hardware classifications. Longitudinal barriers have the highest priority among the permanent hardware items.

The group also concluded that different test levels should be developed for different classes of hardware. For example, numerical warrants were recommended for test levels 1 through 5 for median barriers, bridge rails, and for bridge underpasses, while roadside barrier warrants were recommended only for test levels 1 through 4. Test level 6, and test level 5 for roadside applications, would only be addressed through broad recommendations that these are not generally warranted except at some very special sites.

Problems associated with analysis of low test levels, i.e., a lack of hardware for test level 1, were noted. However, most of group A was not concerned with the concept of incorporating a higher service level at the sites where test level 1 is recommended, even though it would mean that barriers are frequently used where they are not cost beneficial.

Separate warranting procedures were recommended for each roadside hazard classification. For example, separate recommendations should be developed for safety treatment of embankments, rigid hazards, roadside culverts, etc. Warranting procedures would be developed on a site-by-site basis, without regard to the fact that hardware test level would change from one site to the next along the highway. Guidelines developed by AASHTO are recommended to include a discussion of the option for using a uniform test level, after recommended test levels are identified from the warranting procedures.

The group felt that it was appropriate to join two different test levels in some cases, such as with bridge rails and approach rails. Since concrete safety shaped barrier is so inexpensive when constructed on a bridge job, it is often cheaper than lower performance railings. Thus, a lower performance approach rail would be appropriate when a lower performance bridge rail is warranted, even though a higher test level bridge rail is installed.

There was no real concern about using low speed hardware on low-volume, high-speed highways, provided a rational analysis indicated that it was the most cost-beneficial alternative. Further, the group did not object with implementing the multiple performance level guidelines, even though it would sometimes lead to using lower performance level hardware than currently recommended.

As previously stated, development of warrants for multiple performance level hardware is a very high priority. The development of guidelines for permanent hardware is estimated to cost approximately $750,000, with approximately $250,000 dedicated to roadside guardrails. The cost of analyzing temporary hardware could be approximately twice the cost of permanent barriers. The group was unanimous in the conclusion that bridge rails should be included in the analysis of permanent barriers. This is the only way to have all safety hardware developed to a consistent approach. However, inclusion of bridge rails would require up-front coordination with AASHTO Technical Committee for Guardrail and Bridge Rail. The goal would be to gain input and concurrence with the subcommittee as well as include subcommittee members on the review panel for the project.

A problem statement on this topic has been submitted and is currently under consideration by NCHRP. The group encourages the AASHTO Task Force for Roadside Safety to support this problem statement as it moves through the NCHRP approval process. Further, it is recommended that an attempt be made to gain the support of AASHTO's Technical Committee for Guardrail and Bridge Rail.

GROUP B SHOULD TESTING LABS BE CERTIFIED? IF SO, SHOULD A PRODUCT BE SELF-CERTIFIED?

Background/Issues (by Maurice Bronstad, Dynatech Engineering, and King Mak, TTI)

Since the first half-page testing criteria set forth in HRB Circular 482 (1961), there has been a succession of highway hardware testing procedure documents. Each succeeding document has been more definitive and complex regarding how the tests should be conducted, evaluated and reported.

The design and development of roadside safety devices has ranged from large-scale involvement by the industry in breakaway supports and crash cushions to mostly government sponsorship in longitudinal barriers. More recently, there has been a concerted involvement by industry in barrier end terminals. Most of the testing and evaluation have been conducted by independent laboratories, but there is also some testing and evaluating conducted by manufacturers.

A significant portion of the crash testing and evaluation procedures involves the collection, processing and reporting of electronic data generated from transducers attached to the vehicle. Post-processing of the data produces the occupant risk values for evaluation of the results. The electronic data can be readily calibrated and validated, but there is presently little guidance or requirements for such calibration and validation for laboratories conducting crash testing and evaluation on highway roadside safety appurtenances.

Other evaluation criteria are more subjective in nature, such as occupant compartment deformation and intrusion, post-impact vehicle trajectory, etc. These subjective criteria are open to interpretation and may vary significantly among test laboratories. Some standardization in the evaluation of these more subjective criteria may be helpful to promote more uniformity and consistency among the testing laboratories.

There are also a number of safety devices, such as construction zone traffic control devices, that produce insignificant vehicular velocity change or acceleration. The concerns regarding these devices are mostly associated with debris from these devices impacting and penetrating the windshield or posing potential hazard to adjacent traffic and workers and vehicle stability and trajectory. As such, these tests could potentially be conducted without the electronic instrumentation.

Discussion Questions

1. What is certification definition?
2. Who wants certification? Why is it necessary or desirable?
3. Who should decide on the certification criteria and who should be responsible for administering and monitoring the certification program?
4. Should there be different levels of laboratory certification; e.g., level I for tests without electronic instrumentation, level II for pendulum or bogie vehicle testing, and level III for all testing?
5. What needs to be done to ensure uniform and consistent results from different test laboratories; e.g., calibration of electronic instrumentation, round robin evaluation of subjective criteria, etc.?
6. What are the costs associated with such a certification program and who would pay for the expense?
7. Should a manufacturer be permitted to certify test compliance of its own product? If so, are some forms of safeguard or oversight necessary?
8. Are there international concerns that should be addressed in a certification program?

Summary of Discussions

The members of this group (see the Introduction) represented a wide spectrum of activity including:

- The FHWA approving office for roadside safety products;
- The FHWA Office of Highway Safety;
- Three major producers of highway safety products
  Includes one currently doing its own development, and
  Qualifying testing;
- A University professor from Italy with crash test experience;
- All but one of the major testing labs presently doing roadside safety crash testing in this country;
- The major testing lab in England;
- The only State currently performing crash tests of roadside safety features; and
- A researcher/designer with over 600 crash tests supervised.

It is believed that the members represented most of the groups interested in this question. (Note: It was early agreed that the term "accreditation" was more appropriate than "certification" regarding lab approval by some body or agency. The results of tests performed by a lab might lead to certification.)

Each succeeding crash test procedure document used in the U.S. has been more specific in terms of testing procedures and report documentation. There is an apparent lack of uniformity among testing labs and even different principal investigators at test labs regarding the characterization of components of test installations. In most cases reports do not include such items as material thickness or chemical/physical properties. While these properties may be known, they are seldom included in the test report documentation.

There is a need for a more definitive minimum report requirement in this regard as competitive test labs will generally document and report such values that are known to be required.

The levels of instrumentation and high speed camera coverage required for various tests could lead to

different levels of accreditation (e.g., traffic control device, pendulum tests, and full-scale crash tests).

The Group reached a consensus on the following recommendations:

1. The laboratory accreditation movement is necessary. The Group believed that this is desirable and should be considered to be in harmony with a similar movement in the European Community (EC).

2. Standard validation of instrumentation/software is a necessary part of accreditation process. The FHWA has plans to implement at least part of this objective. It was agreed that consultation with the test labs is desirable in this FHWA process.

3. Characterization of material/installation of the test article should be documented/reported according to *NCHRP Report 350.* Minimum procedures/requirements should be more definitive. There is concern among the group participants and the lone test lab not represented in the group that this should be considered carefully so as not to increase test costs significantly and/or unnecessarily.

4. The group recommends convening a testing lab/government/industry panel for guideline development of accreditation procedures/criteria. It is further recommended that a knowledgeable third party separate from these groups be the organizer/facilitator of this activity.

The group recommends that the A2A04 Chairman be the point man for seeking out funding of this third party effort. This third party effort would include straw man document preparation and organization of the meeting(s).

The makeup of this panel should be of minimal size, but include all testing labs and selected representatives from FHWA/industry, A2A04 Committee members and friends.

Further, this activity should track the EC accreditation progress and analyze/use existing frameworks (e.g., ASTM/ANSI/FHWA/ISO, etc.).

5. The accreditation guidelines would include such things as:

Requirements/procedures,

Group granting accreditation,

Periodic review for continued conformity,

Use of independent observer for compliance tests, and

Levels of accreditation possible:

- No instrumentation, vehicle testing of work zone devices, etc.,
- Full-scale vehicle, full instrumentation,
- Bogie, full instrumentation,
- Pendulum, required instrumentation, or
- Side impact, required instrumentation.

GROUP C DOES *NCHRP REPORT 350* SATISFY THE REQUIREMENTS OF ISTEA? WHAT ARE THE IMPLICATIONS OF THE INNOVATIVE BARRIER REQUIREMENTS OF ISTEA?

Background/Issues (by Roger Bligh, TTI)

Report 350 specifies the use of a 3/4-ton pickup truck (2000P) as the new design vehicle to replace the large passenger sedan used under *Report 230.* This vehicle is intended to represent the class of "light trucks" which comprise a significant and growing portion of the vehicle fleet. "Light trucks" as used here constitute vehicles such as vans, mini-vans, pickup trucks, suburbans, utility/sport vehicles, etc. Recent legislation contained in the Intermodal Surface Transportation Efficiency Act (ISTEA), enacted December 1991, requires that roadside safety hardware and appurtenances be designed to accommodate this class of vehicles.

Questions have been raised regarding the crashworthiness of existing hardware when impacted by these vehicles. Although a pickup truck was adopted in the 1989 AASHTO Guide Specifications for Bridge Railings and has been used to evaluate numerous bridge rail systems, the performance of these vehicles with other appurtenances such as guardrails, end treatments, transitions, and crash cushions is largely unknown. If some of these widely used systems are found to be deficient, the implications will be far reaching. In addition, it must be ascertained to what extent the 2000P is representative of other light trucks and whether or not the intent of ISTEA is satisfied through its use and adherence to the criteria set forth in *Report 350.*

Discussion Questions

1. How should we proceed to evaluate current hardware, meeting *Report 230* requirements, according to *Report 350*? Of immediate concern is the widely used W-beam guardrail systems. In a recent test, the 2000P test vehicle of *Report 350* vaulted a W-beam system thought to be of sufficient strength to meet *Report 350* requirements for test level (TL) 2 (i.e., 70 kph and 25 degrees). The barrier was a G4(2W) system with posts spaced at 12'-6". Should the standard, and widely used, W-Beam guardrail system(s) be subjected to *Report 350* TL-3 (the "basic" test level) if there is a reasonable risk it will not satisfy requirements therein, *and* if acceptable alternatives are not available in the event it does not work? Note that if the standard W-beam is found to be deficient, new end treatment and transition designs may also be necessitated. What are the possible alternatives for new and/or retrofit designs, and what would their impact be in terms of costs? To what extent would

existing W-beam systems need to be upgraded, i.e., what criteria would be needed to develop upgrading guidelines?

2. ISTEA requires that roadside safety appurtenances accommodate vans, mini-vans, pickup trucks, and 4-wheel drive vehicles. What is implied by this broad statement in ISTEA as to the types of vehicles for which barriers should be designed? Does the 2000P test vehicle represent these types, or is it representative of a range of "normal" vehicles mentioned in ISTEA? "Normal" vehicle is defined here as an as-manufactured model, as opposed to a customized model constructed or modified by an individual owner, local shop, or a company whose business is customizing vehicles. To what extent, if any, should we be designing our hardware to accommodate these special, customized vehicles? Can a national policy be developed that clearly describes the types of vehicles roadside hardware should be designed for? If so, how and by whom? An answer to this question is needed to respond to claims that unquestionably will be made concerning the duty of highway agencies to design barriers to accommodate vehicles mentioned in ISTEA. As an example, if left undefined, it will surely be claimed that DOT's should have barriers to contain "jacked-up" vehicles with high centers of mass, and other obviously unstable vehicles.

3. *Report 350* recommends the use of a production model, conventional cab, 3/4-ton pickup as a design test vehicle. It further places recommended tolerances on vehicle properties such as mass, center of mass location, and various dimensions such as front overhang, wheelbase, track width, etc. However, recent data obtained from parking lot surveys and the literature have shown that production vehicles meeting the above criteria can vary considerably in terms of bumper height due to the various tire and suspension options offered by the manufacturers. These variations in vehicle properties can have a significant effect on the impact behavior of various safety appurtenances. Should the properties of the 2000P test vehicle be more specifically defined? For example, should acceptable bumper heights, tire sizes, suspension options, and/or gross vehicle weights be specified? How would such a change be implemented?

Summary of Discussions

Objectives

Group C began its discussions with a broad look at the impacts of the Intermodal Surface Transportation Efficiency Act (ISTEA) on roadside safety. It was noted that ISTEA's impact included:

- Mandates for the evaluation of roadside barriers and the light truck class of vehicles,
- Requirements for innovative barriers, and
- Mandates for highway safety management systems.

However, it was agreed that the most direct impacts were likely to be related to the requirement that roadside safety appurtenances accommodate light trucks which include vans, mini-vans, pickup trucks, and 4-wheel drive vehicles. In response to this requirement, a rule was issued adopting *NCHRP Report 350* as the standard for evaluating the impact performance of roadside features. *NCHRP Report 350* specifies a 2000-kg, 3/4-ton pickup truck, designated 2000P, as the design test vehicle. It is uncertain how this vehicle will perform with current safety appurtenances or if it is representative of the various subclasses of light trucks. Consequently, the discussions of the group focused on the issues, factors, approaches, and research needs associated with this requirement.

Issues

Based on the papers presented prior to group breakouts, many relevant issues and questions that need to be addressed were identified . Other general issues in this area were identified in subsequent discussions. The issues which were discussed, and the associated questions which were raised, are summarized below.

Retesting Existing Hardware

How should we proceed to evaluate existing hardware, which currently meets *Report 230* requirements, according to *Report 350*? Can field experience justify continued use of some systems? Of immediate concern is the widely used W-beam guardrail systems. In a recent test, the 2000P test vehicle of *Report 350* vaulted a W-beam system thought to be of sufficient strength to meet *Report 350* requirements for test level (TL) 2 (i.e., 70 km/h and 25 degrees). The barrier was a G4(2W) system with posts spaced at 12 ft-6 in. Should the standard, and widely used, W-beam guardrail system(s) be subjected to *Report 350* TL-3 (the "basic" test level) if there is a reasonable risk it will not satisfy requirements therein, and if acceptable alternatives are not available in the event it does not work? Note that if the standard W-beam is found to be deficient, new end treatment and transition designs may also be necessitated. What are the possible alternatives for new and/or retrofit designs, and what would their impact be in terms of costs? To what extent would existing W-

beam systems need to be upgraded, i.e., what criteria would be needed to develop upgrading guidelines?

Accommodating Light Truck-Type Vehicles

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) requires that roadside safety appurtenances accommodate vans, mini-vans, pickup trucks, and 4-wheel drive vehicles. What is implied by this broad statement in ISTEA as to the types of vehicles for which barriers should be designed? Does the 2000P test vehicle represent these types, or is it representative of a range of "normal" vehicles mentioned in ISTEA? "Normal" vehicle is defined here as an as-manufactured model, as opposed to a customized model constructed or modified by an individual owner, local shop, or a company whose business is customizing vehicles. To what extent, if any, should we be designing our hardware to accommodate these special, customized vehicles? Can a national policy be developed that clearly describes the types of vehicles roadside hardware should be designed for? If so, how and by whom? An answer to this question is needed to respond to claims that unquestionably will be made concerning the duty of highway agencies to design barriers to accommodate vehicles mentioned in ISTEA. As an example, if left undefined, it will surely be claimed that DOTs should design barriers to contain modified vehicles with high centers of mass, and other obviously unstable vehicles.

Efficacy of the 2000P Test Vehicle

Report 350 recommends the use of a production model, conventional cab, 3/4-ton pickup as a design test vehicle. It further places recommended tolerances on vehicle properties such as mass, center of mass location, and various dimensions such as front overhang, wheelbase, track width, etc. However, recent data obtained from parking lot surveys and the literature have shown that production vehicles meeting the above criteria can vary considerably in terms of bumper height due to the various tire and suspension options offered by the manufacturers. These variations in vehicle properties can have a significant effect on the impact behavior of various safety appurtenances. Should the properties of the 2000P test vehicle be more specifically defined? For example, should acceptable bumper heights, tire sizes, suspension options, and/or gross vehicle weights be specified? How would such a change be implemented? What should be the best course of action to show whether the *NCHRP Report 350* 2000P test vehicle, in the context of six test levels, is or is not an acceptable surrogate for all ISTEA vehicles? If not, how should we proceed to determine if the mismatch is a significant safety problem and, if it is, how should we select a better surrogate vehicle or vehicles?

Cost Implications

It was noted that there will be cost implications with the new requirements. A variety of questions were raised in this regard, including: Does NCHRP 350 impose higher testing costs? What would be the cost implications of determining that a barrier does not meet 350? How should an upgrading or retrofit program be structured and financed?

Vehicle Design

It was noted that vehicle designs change often and seemingly without regard to the design features of roadside hardware. Is it necessary or desirable to design the vehicle and hardware as a system? It was argued that some roadside safety problems could be addressed by requiring that vehicles be designed to specific standards.

Are standard design vehicles needed? The questions that arose from this discussion included: What vehicle features are critical in terms of safety performance with roadside features? Is more specification of vehicle dimensions and characteristics possible? It was noted that NHTSA already imposes a number of design requirements on vehicle manufacturers. What about controls on custom vehicles? Is this covered in rulemaking?

Implementation

Implementation questions were also identified, including: Who will enforce these provisions? What is the role of NHTSA? Can the specific finite element vehicle models used in crashworthiness assessment be used to analyze vehicle-hardware interactions? How much time will be needed to address these issues? Is there a better way to focus the efforts through standardization? What interfaces are appropriate to foster continued cooperation with NHTSA?

Analysis Approaches

It was noted that many approaches could be used to analyze the extent of the problem, but there was no consensus on an approach. Questions raised included: What is the proper mix of accident studies, simulation,

and crash testing to address the problem? Does simulation offer the most effective approach? Are the computer models sophisticated enough to analyze the effects of slight modifications in vehicle design and situational features? Do we know too little about real-world performance? What are the tracking/non-tracking effects on impact performance? Are there bounds that need to be defined? What validation efforts are needed to support simulation? Is a strategy to physically test the bounds (or worst cases) and then model conditions in-between appropriate? Are the NHTSA simulation vehicles representative of the vehicle fleet?

General

A variety of general issues arose during the discussions including:

• What is an appropriate age for a crash test vehicle to ensure adequate representation of the vehicle fleet? Is the current 6 year time period sufficient for this purpose?

• Should roadside safety devices be designed more conservatively to make them less sensitive to vehicle type and future vehicle design changes?

• What scenarios should be addressed using simulation? Can simulation replace the need for full-scale crash testing? What vehicles and impact conditions should be used to evaluate different roadside features?

• Are the current innovative barrier provisions a problem? How much emphasis needs to be placed on in-service evaluations? What level of data collection is appropriate?

• Should roadside safety devices be designed to capture a vehicle rather than to redirect or provide controlled penetration?

Factors

In order to scope the research needs, it was felt that it would be useful to identify the vehicular factors that influence crash performance, define complicating factors, and note significant gaps in knowledge about performance. Much of the discussion was related to the light-truck class of vehicles, but it is apparent that these factors apply to other classes of vehicles as well. While these discussions focused on vehicular characteristics, in retrospect they should have also considered the factors associated with the design, installation, and maintenance of the roadside hardware as well.

Vehicular characteristics that may influence the impact behavior of the light-truck class vehicles include:

• Total Mass. Perhaps the most significant vehicle parameter, in terms of influencing impact performance, is the total mass of the vehicle. Since the amount of energy an appurtenance must manage is directly proportional to the mass of the impacting vehicle, heavier vehicles, such as many of the light trucks, are more functionally demanding on appurtenances such as longitudinal barriers and crash cushions.

• Bumpers. There exists various types of production and custom bumper having varying heights, widths, stiffness, and configuration. These differences may influence the vehicle's interaction with roadside features. For example, the higher bumper heights of certain light trucks increase the propensity for overriding or vaulting during impacts with longitudinal barriers and crash cushions.

• Front Overhang. The distance from the front bumper to the centerline of the front axle can have a significant influence on impact performance. The shorter front overhang of the light truck population increases the degree of interaction between the front tire and suspension of the vehicle and the barrier components. This can result in severe wheel snagging, excessive vehicular decelerations, substantial intrusion into the occupant compartment, and/or increased vehicle climb and instability.

• Center of Gravity. Light trucks, because of their construction, tire size, and suspension characteristics, typically have a much higher center of gravity than passenger vehicles. The higher c.g. height renders these vehicles less stable and more susceptible to rolling on top of or over a barrier.

• Front-end Stiffness. The stiffness of the front end of light trucks is known to be greater than that of passenger cars. Crush or crumble zones are typically designed into the front end of passenger cars to absorb impact energy. This design renders the front end of passenger cars "softer" and more energy absorbing than the front end of light trucks. This may adversely affect the performance of some energy-absorbing devices such as crash cushions and truck mounted attenuators (TMA) which take the energy absorbed through vehicle crush into account in the design.

• Suspension. The suspension of light trucks is typically much stiffer than that of passenger cars to accommodate a greater payload capacity and off-road type driving. A stiff suspension contributes to increased roll of the vehicle during turns and instability of the vehicle during evasive or emergency maneuvers.

• Body Configuration. The geometrics of the light trucks may potentially pose a problem for some roadside safety features. Certain combinations of side profile, bumper height, and c.g. height can result in degraded

performance of the crash cushion or TMA such that a vehicle can underride or override.

• Wheels/Tires. The diameter and size of the tires influence the center-of-gravity height and bumper height.

• Drive System. The type of drive system (e.g. 2-wheel drive versus 4-wheel drive) can affect the center-of-gravity height and bumper height of a vehicle. In addition, there may be other related factors (e.g. tire size, suspension type) that influence impact performance.

It was noted that there exist complicating factors and unknowns which limit the ability to definitively understand vehicle-hardware interactions. These include:

• Differences in vehicular characteristics. Because the cost of full-scale crash testing is prohibitive, most testing has been conducted with selected design vehicles on extreme ends of the vehicle population. For example, *NCHRP Report 350* requires testing with a small passenger car (820C) and a 3/4-ton pickup truck (2000P). The 820C vehicle is on the low end of the passenger vehicle spectrum in terms of mass and size, and is generally used to examine occupant risk. The 2000P classification is on the other end of the spectrum, and is intended to examine the strength or containment capabilities of a roadside safety feature. The characteristics of other intermediate vehicle classifications can vary substantially, and little is known how these differences may affect impact performance. Even within a particular vehicle platform, such as the 2000P classification, there can be significant variations in properties that affect impact performance (e.g. bumper height) among the different makes and models that comprise the platform. Furthermore, the characteristics of a particular production make and model can be altered through customization.

• Complex interactions between barrier and vehicle components. Little is understood regarding tire-soil interaction and how terrain irregularities and differences in soil properties affect impact performance and vehicular stability. Soil properties, such as soil type, compaction, moisture content, and frozen conditions, can also affect the behavior of soil-dependent features such as guardrail posts and small sign supports. How do bumper properties (shape, height, depth, and stiffness) and front profile affect vehicle-barrier interaction, and more specifically, the propensity for vehicular override or underride?

• Real-world impact conditions. Crash tests of roadside safety devices are typically conducted at a prescribed speed and angle on level terrain with the test vehicle tracking and free-wheeling at impact. However, real-world impacts seldom conform to these ideal conditions. Safety appurtenances are often installed on sloping terrain and impacted at a wide range of speeds and angles. Furthermore, the errant vehicle may be in a non-tracking mode with its orientation at impact influenced by various driver inputs (i.e., steering and/or braking). How do these variations affect impact performance?

• Limited evaluation of field performance. Real-world impacts can vary considerably from crash testing in terms of installation details, vehicle type, impact conditions, etc. The extent of field performance evaluations on most safety devices has been very limited and further study is necessary to answer questions such as: How well are approved devices performing in the field? What are the failure mechanisms and capacity of the system? How sensitive is the device to variations in installation details?

• Limited correlation of data. Correlation of in-service (field) experience with information derived from crash testing and other analyses has been very limited. Therefore, it is unknown how occupant risk indices, which are used to evaluate the performance of a system based on crash testing and computer simulation, relate to injuries in real-world impacts.

Approaches to Analyzing the Problem

Tremendous progress has been made over the last 30 years in achieving safer roadsides. The basic goal has been to provide the greatest level of safety possible under the constraint of available resources. For this reason, cost-effectiveness procedures are becoming increasingly important to the roadside safety community as a means of optimally allocating these limited resources. In addition, it is necessary that roadside safety hardware and practices be ever-evolving in response to technological advancements and changes in the vehicle fleet. In order to accomplish this in a cost-effective manner, analysis procedures must also continue to improve and evolve. Discussions specifically addressed the ability of various analysis approaches to evaluate the impact performance of pickups and other light trucks with various roadside features. However, advancements in these areas would assist in the analysis of numerous other safety concerns as well. A brief summary of the capabilities and limitations of the various approaches is given below.

• Full-Scale Crash Testing. The most definitive method currently available for analyzing the dynamic interaction of a vehicle and roadside safety appurtenance is full-scale crash testing. It is likely that some level of crash testing will always be necessary, either as a direct means of evaluation or as a source of validation of other analysis methods such as computer simulation. However, it is not practical to use crash testing as the sole means of evaluation of a particular hardware system. The cost of testing is prohibitive and the

combinations of vehicle type, impact conditions, etc. are too numerous to address. With the adoption of *NCHRP Report 350*, it will become necessary to retest many existing roadside safety features for purposes of assessing their performance with the 2000P design vehicle. In addition, the number of required tests for some safety devices such as end terminals and crash cushions has increased, thus requiring even further tests to re-certify current hardware. Since funds may be limited and since the cost of testing is relatively high, there is a need to review the performance of these devices and prioritize them based on perceived deficiencies, frequency of application, and/or some other criteria. Initially, some additional testing with vehicles from some of the other subclasses of light trucks will also be necessary in order to determine whether or not the 2000P is an acceptable surrogate for future testing and development of new hardware.

• Computer Simulation. Although existing codes such as Barrier VII and HVOSM have and will continue to provide useful information in the design and analysis of roadside features, they lack the ability to fully and accurately simulate the dynamic interaction of light trucks with certain roadside appurtenances such as flexible barriers and end terminals. In order to rigorously model these types of impacts, which may involve vehicular override, rollover, etc., a code must be capable of modeling the interaction of various vehicle components (e.g. bumper, wheel) with barrier components such as guardrail posts and rail. In addition, it must have the ability to model various vehicle and barrier failure modes, such as rail rupture, wheel and suspension damage, etc., that might arise from these interactions. Toward this goal, work has begun on the development of a state-of-the-art simulation program based on the DYNA3D finite element code. However, although the program lends itself nicely to collision analysis, there is a large amount of work that must be accomplished to extend its application to roadside safety problems. This includes the development of sophisticated finite element vehicle and hardware models. Once these areas have been addressed, the DYNA3D code will become a valuable tool for exploring numerous roadside safety issues. The program will enable researchers to assess current hardware with pickups and other ISTEA vehicles, conduct parametric studies to investigate the effect of changes in vehicle and hardware characteristics, and evaluate hardware under impact conditions which are difficult to test, such as non-tracking situations.

• In-service evaluations. The extent of field performance evaluations on most safety devices has been very limited. However, the potential for useful data from this form of analysis is great. Crash tests are typically conducted under ideal conditions with the device installed according to specifications and on level terrain. In the field these devices may be installed on sloping terrain (sometimes improperly) and are impacted by a variety of vehicle types at a broad range of speeds, angles, and orientations. It would be very useful to conduct in-service evaluations to examine in-field impact performance as well as obtain information regarding installation and maintenance of the device. This evaluation could be conducted to one of several levels depending on the status of the device being investigated, i.e., whether or not the device is newly developed. However, requiring this type of analysis would put an additional burden on already limited resources. Questions arise in regard to where the additional resources would come from and who would be responsible for collecting and reporting the data. Such an analysis requires a great deal of commitment in terms of training, time, etc.

• Accident studies. Most accident data files are based on police-level accident data and contain information on general variables such as highway type, first and/or most harmful event, object struck, and vehicle type. Analysis of these data files can provide some rough estimates on the relative severity of accidents involving roadside safety hardware for light trucks and passenger cars. However, given that all these data files are based on police reported accident data, there are limitations to the analysis results. Resources and the amount of available data are typically too limited to provide an in-depth analysis addressing more detailed questions surrounding the performance of different vehicle types with different types of hardware. Conceivably, with sufficient resources, more detailed information pertaining to a given accident could be captured for use in the evaluation of roadside hardware. If data collection procedures can be advanced to the point of hand-held equipment which prompts for information, records pictures of the accident scene, and automatically updates accident databases, perhaps the cost of the additional collection could be kept to reasonable levels.

• Human factors studies. Further research is needed in the area of human factors studies to help quantify driver response and input during encroachments under different roadway and roadside conditions. This information would provide input to other methods of analysis such as computer simulation.

Short Term Actions and Research Needs

The need exists to address the questions about the ability of current roadside-safety hardware to pass the requirements of *NCHRP Report 350*. It is important to address this question to ascertain where deficiencies

exist so that the level of safety on our highways can be increased. The concern is greatest for the vehicles in the light-truck class for which testing was not required under *NCHRP Report 230*. Of the various barriers, transitions, terminals, and crash cushions which were discussed, the implications associated with the ability of the standard strong-post W-beam guardrail to pass the *Report 350* test requirements were of greatest concern. This is due primarily to the widespread use of this guardrail throughout the country and the potential cost that would be incurred if a replacement or upgrade program becomes necessary. A research program needs to be advanced which will synthesize what is known about the safety performance of the various roadside features and various subclasses of vehicles in the light-truck category.

A related need that must be immediately addressed is the validation of the 2000P vehicle specified in *NCHRP Report 350*. The vehicles in the light-truck class need to be defined, and dimensional/dynamic properties need to be compared to ascertain whether the 2000P vehicle will adequately represent the impact performance for this class of vehicles. Further investigations using simulation or crash testing are likely also necessary to validate assumptions about impact performance.

Another major area in which further research is necessary is the development of state-of-the-art computer simulation models that will permit more detailed analysis and comparison of safety performance as influenced by vehicle, roadside, and hardware features. Among the areas that need attention and could be investigated with a sophisticated computer simulation tool are:

- Driver behavior and reactions just prior to a crash. How do braking and/or steering input influence vehicular interaction with a barrier?
- Tire-ground interaction. Under what conditions do tire plowing and soil buildup contribute to vehicular instability and rollover?
- Tire-barrier interaction. Virtually all crash testing to date has used rear-wheel drive vehicles. Do front-wheel drive vehicles have a greater tendency to climb or ride up barriers during impact?
- Roadside encroachments. Computer simulation can be used to investigate vehicular stability and severity during roadside encroachments considering the influence of side slopes, ditch configuration, coefficient of friction, and other factors.

Associated with the development of simulation codes is the need for finite element models of vehicles and roadside hardware, the validation of these models, and the development of techniques to analyze the effects on occupants.

Several current or soon-to-occur research efforts were identified. These included:

- NCHRP Project 22-11. This project will review accident, crash test, simulation, and anecdotal data to determine where critical gaps in knowledge exist relative to the safety performance of various roadside features with the various subclasses of light trucks. This project is expected to start in mid 1994.
- FHWA Project. This project with EASi Engineering is expected to provide a comparison of critical vehicle dimensions and characteristics, and a finite-element model for three types of vehicles for use in future simulation efforts.
- FHWA Project. This project will provide funding for task-order crash testing. The candidate tests have not yet been defined, nor has a contractor been selected.
- FHWA/NHTSA Project. The Vehicle Impact Simulation Technology Advancement (VISTA) and PREVISTA programs are collaborative agreements among FHWA, NHTSA, and Lawrence Livermore National Laboratory (LLNL) through which the use of DYNA3D and associated codes are being explored for use in roadside hardware analysis, vehicle crashworthiness, and occupant biomechanics research. In the area of roadside safety, these efforts are intended to lead to the development of an integrated suite of computer simulation programs capable of replicating vehicular dynamics prior to, during, and subsequent to an impact. In addition, through the use of sophisticated finite element vehicle and hardware models, the code will also be capable of simulating the interaction and failure of various vehicle and barrier components.

These efforts will define the critical gaps in knowledge with regard to the safety performance of roadside features relative to the light-truck class of vehicles, and provide at least a limited opportunity to conduct crash tests and/or computer simulations to fill some of these gaps in knowledge.

Long Term Research Needs

The research needs for the longer term include the following:

- Improve accident data and processing. Efforts are needed to advance the application of microcomputer-based tools which will allow the investigators of accidents to capture more information about the

environment, vehicles, and roadside safety hardware. Some agencies are using equipment which prompts the investigator for more specific information, based upon the characteristics of an accident. Conceivably, more detailed information on the type of hardware, the nature of the vehicle interaction, and other information could be captured for use in the monitoring and development of roadside hardware. It is even possible that pictorial representations could be used to allow more specific identification of the hardware involved. Such systems would also permit immediate updating of accident databases.

• Develop improved roadside safety management schemes in order to more optimally allocate resources. Such a management plan could include guidelines on which features are appropriate for specific roadway and roadside conditions, recommended maintenance schedules and practices, and repair/upgrading procedures. As part of the management plan, data regarding the field performance of new and existing roadside safety features could be collected. More specifically, information is needed on in-service experience with installation, maintenance, and repair of safety appurtenances in order to identify where problems exist and develop cost-effective solutions to those problems. Data are also needed regarding the impact performance of these devices under various field conditions. This would provide valuable feedback into the design, analysis, and testing process.

• Develop warrants. Because safety resources are limited, the concept of matching highway-safety features to the type of roadway facility and its traffic conditions is being promoted. Under *NCHRP Report 350*, a safety feature may be developed to meet one of up to six test levels, depending on the type of feature. Objective guidelines are needed not only to identify site conditions where a safety feature is warranted, but also to identify the most appropriate feature for that site so that scarce resources can be more optimally allocated.

• Further development of highway safety management systems (HSMS). Advancements such as new cost-effectiveness procedures, computer simulation models, accident data, field experience, etc. can be integrated into evolving HSMS.

• Interaction and cooperation between the automobile manufacturers, NHTSA, and the roadside safety community should be highly encouraged. Vehicle crashworthiness and hardware impact performance are interrelated, with occupant protection the primary focus of both areas. It would therefore appear to be more efficient and effective to design vehicles and roadside hardware using a system approach. To help foster this concept, formal channels of communication should be established to provide a feedback mechanism for the sharing of information. Through the use of shared finite element vehicle models, the VISTA program should provide a tool for future cooperation and interaction.

• Review roadside design philosophy. In light of the changing vehicle population, evolving test guidelines, technological advancements, and limited resources, it may be appropriate to review current roadside design philosophy. For example, when the requirement to test with an 1800 lb vehicle was included in *NCHRP Report 230*, many existing roadside safety devices required retesting. Some of these were found to be deficient, and required replacement or upgrading. With the adoption of the 2000P as a design test vehicle in *NCHRP Report 350*, a similar set of circumstances may arise. Is it cost-effective to overdesign certain roadside appurtenances for the purpose of prolonging service life and avoiding the periodic cost of retesting, redesigning, replacing, and/or upgrading? In other words, is it feasible to design hardware to accommodate anticipated changes in the vehicle fleet and, thereby, postpone the need for future replacement or upgrading? A more fundamental question is, should roadside safety devices be designed to capture and bring an errant vehicle to a controlled stop rather than to redirect or provide controlled penetration? Would such a philosophy necessarily provide a greater level of safety, and what implications would such a change in philosophy have in terms of cost?