PART 2 PRESENTATIONS

EVOLUTION OF ROADSIDE SAFETY

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Motor vehicle fatality rates have been on a general decline over the past twenty five years. In 1965, rates of 25 deaths per one hundred thousand population and 5 per one hundred million vehicle miles traveled were occurring; 1992 rates were 15.4 deaths per one hundred thousand population and 1.8 per one hundred million vehicle miles traveled. While the trends are noteworthy and very encouraging, approximately 40,000 people are still being killed annually in motor vehicle accidents. Of this total, approximately 30% result from single-vehicle, run-off-the-road accidents.

Unquestionably, improvements in roadside safety design have contributed significantly to these rate decreases, especially during the past 30 years. Safety advancements have resulted from the development of cost effective and crashworthy hardware, improved geometric features, use of safe recovery areas, improved guidelines for the design, selection, and maintenance of safety features, and general acceptance of the "forgiving roadside" philosophy.

This paper presents an overview of progress made during the past 30 years or so and identifies problems and key areas that need to be addressed in the near future. Selected references and accomplishments thought to be fundamental to the advancement of roadside safety are identified. However, the paper is by no means exhaustive and in all likelihood some major omissions have inadvertently been made.

MILESTONES

The vast majority of improvements in roadside safety have occurred since 1960. Prior thereto little attention was given to safety of the roadside; run-off-the-road accidents were attributed to "the nut behind the wheel." This philosophy resulted in unyielding sign and luminaire supports, untreated guardrail ends, non-traversable ditches, untreated culvert ends, etc.

An effort is made in this section to briefly describe selected publications, documents, activities, events, etc. since 1960 that have contributed significantly to roadside safety.

1960's

The decade in which serious concerns about roadside safety emerged.

- *"Roadside Design for Safety,"*[1] This paper identified common roadside hazards such as blunt guardrail ends, rigid supports for light poles and signs supports, trees, utility poles, steep side slopes, and unsafe ditch sections. Potential solutions to these problems were presented which were subsequently developed and implemented by the states, such as sloping and burying the end of the guardrail, use of breakaway supports, clearing the roadside of unnecessary obstacles, and flattening and rounding slopes and ditches.
- *"Proposed Full-Scale Testing Procedures for Guardrails,"*[2] This was the first formalized set of guidelines for testing guardrails, and was contained on one page.
- *"Highway Guardrail: Determination of Need and Geometric Requirements, with Particular Reference to Beam-Type Guardrail,"*[3] This study provided guidelines establishing where guardrail was needed and how it should be installed dimensionally and geometrically. There were no comprehensive guidelines prior to its publication.
- *Development of the slip-base breakaway system* - Through support from the Texas Highway Department, the Bureau of Public Roads, and other states, Texas Transportation Institute (TTI) researchers developed workable slip-base breakaway systems for sign and luminaire supports. Major safety benefits have been derived from extensive use of these designs.
- *National Traffic and Motor Vehicle Act of 1966* - This act required the establishment of minimum safety performance standards for motor vehicles and motor vehicle equipment.
- *Highway Safety Act of 1966* - This act intended to strengthen state and local safety programs, and for the first time placed the federal government in a leadership role to help guide and finance state programs.
- *"Highway Design and Operational Practices Related to Highway Safety,"*[4] This was the first of the two so-called "Yellow Books" that addressed highway safety issues. It pointed out the increasing number of "run-off-the-road" accidents and identified ways to mitigate roadside hazards. It established the 30 ft. clear recovery area, currently denoted the clear zone.
- *Development of initial crash cushion designs* - The 1960's saw the development of the steel drum crash cushion at TTI, the water-filled plastic tubes at Bringham Young University, and the sand-filled plastic drums by John Fitch of Connecticut. Major safety benefits have been derived from extensive use of these and other cushion designs subsequently developed.
- *"Guardrails, Barriers and Sign Supports,"*[5] Included in this record were fundamental papers dealing with tests and further development of the W-beam barrier(J. L. Beaton, et al), development of new highway barriers

(M. D. Graham, et al), and development of guardrail warrants (J. C. Glennon et al). The study by Beaton, et. al., established basic height and post spacing requirements for W-beam guardrail still in use today. The paper by Glennon, et. al., developed warrants for guardrail to shield embankments still in use today. The paper by Graham, et. al., presented results of an extensive theoretical and experimental study in which new barrier designs were developed, including the strong-beam, weak-post guardrail, median barrier, and bridge rail systems; improvements were also made in the cable guide rail system.

- *"Location, Selection and Maintenance of Highway Guardrails and Median Barriers,"*[6] This report provided recommended standards for nationwide consistency of practice by highway design engineers as related to warrants, design, and maintenance.
- *Development of median barriers* - Adoption of the New Jersey and General Motors concrete safety-shaped barriers (CSSB) by a number of states began in the 1960's. By the end of the decade, most of the states had installed CSSB's to some extent, and their use was on the increase. Eventually the New Jersey shaped proved to be the preferred design, and it is now the most widely used median barrier in the U.S. Precast segments of the New Jersey CSSB are also widely used to shield workers and hazardous areas from traffic. Other median barriers developed and/or refined during this decade included the widely used back-to-back W-Beam design, the box-beam design, and the cable design.
- *Development of the Highway-Vehicle-Object-Simulation-Model (HVOSM)* - HVOSM, which was originally known as the Cornell Aeronautical Laboratory Single Vehicle Accident model(CALSVA) was developed during the 60's by Ray McHenry and other researchers at CAL (later to become Calspan Corporation)[7]. It was used initially in the development of longitudinal barriers for the New York Department of Transportation. TTI researchers have made wide use of HVOSM in numerous studies involving vehicle-roadway and vehicle-barrier interactions. It has also been used by researchers at Southwest Research Institute and the University of Nebraska. When used properly and within its limits HVOSM provides valuable insight into these types of events, and has been used in the design and analysis of various safety features.

1970's

The decade in which the Federal government and FHWA emerged as a leading force in promoting and supporting highway and roadside safety.

- *Highway Safety Act of 1970* - This act established the National Highway Traffic Safety Administration (NHTSA) and separated the functions of the National Highway Safety Board between NHTSA and FHWA.
- *U.S. congressional hearings* - Comprehensive hearings were held early in the 1970's on highway safety issues. It was concluded that substantial improvements could be made if the Federal Highway Administration took a more active role in highway safety. These hearings led to the advancements made in the Highway Safety Act of 1973.
- *"Location, Selection, and Maintenance of Highway Traffic Barriers,"*[8] This report updated and superseded NCHRP Report 54. It presented a synthesis of existing information on warrants, service requirements, and performance criteria for all traffic barrier systems, including longitudinal barriers and crash cushions.
- *"Evaluation of New Guardrail Terminal,"*[9] This paper described development of the breakaway cable terminal (BCT) for W-beam guardrail. The BCT design, with subsequent modifications, became the most widely used end treatment for W-beam guardrail in the U.S. Other end treatment designs developed since, such as the eccentric loader terminal, the modified eccentric loader terminal, and the ET-2000® have utilized the breakaway cable feature of the BCT.
- *Highway Safety Act of 1973* - For the first time, this act required that a portion of the Highway Trust Fund be used for highway safety improvement programs (Highway Safety Act of 1966 provided no funding and was therefore ineffective). This act also created various funded safety improvement programs including rail-highway crossings, pavement markings, corrections to hazardous locations, removal of roadside hazards, and improvements on non-Federal aid highways.
- *"Highway Design and Operational Practices Related to Highway Safety,"*[10] This was a second edition of the "yellow book" report originally issued in 1967. This new edition represented both new knowledge and new priorities for highway safety efforts by highway and traffic departments. It incorporated results of research and field experience in the areas of design and operations.
- *"Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances,"*[11] This report updated the one-page guidelines provided in HRB Circular 482 and provided recommendations relative to the testing and evaluation of longitudinal barriers, crash cushions, and breakaway features.
- *"Guide for Selecting, Locating, and Designing Traffic Barriers,"*[12] This was the first publication by AASHTO that comprehensively addressed the subject of traffic barriers. Its purpose was to summarize the current state of knowledge and to present specific design guidelines that established conditions which warrant barrier protection, the type of barriers available, their strength, safety, and maintenance characteristics, selection procedures, and how the barrier should be installed dimensionally or geometrically. Also presented were a cost effectiveness analysis procedure and barrier design methodologies.
- *Further development of new crash cushion designs* - The 1970's saw the development and implementation of

several new and innovative crash cushion systems. Some of these systems employed sacrificial, energy-absorbing cartridges made of lightweight concrete, foam, and honeycomb type materials. Others made use of reinforced, large-diameter steel pipe. Specific designs included the Guardrail Energy Absorbing Terminal (GREAT®), the HEX-FOAM® Sandwich System, and the Connecticut Impact Attenuating System (CIAS).

● *Development of truck mounted attenuators (TMA)* - Initial efforts to develop a TMA were made at TTI and the design consisted of an array of steel drums mounted on a wheeled trailer. Subsequent efforts involved the use of reinforced steel pipe, vermiculite concrete cells, HEX-FOAM®, and aluminum honeycomb.

● *Development of bridge rails for heavy vehicles* - Multi-fatality accidents involving a school bus in Martinez, California in 1976 and an anhydrous ammonia truck in Houston, Texas in 1977 brought national attention to bridge rail designs. Subsequently, major efforts have been made to (a) develop railing designs capable of containing heavy vehicles, (b) develop impact performance guidelines for railings to contain heavy vehicles, and (c) develop warrants for railings that have heavy vehicle containment capabilities. However, to date, wide use of high containment railings has not occurred.

● *"General Computer Program for Analysis of Automobile Barriers,"*[13] This paper describes the BARRIER VII program. Wide use has been made, and continues to be made, of BARRIER VII in the design and analysis of numerous longitudinal barrier systems. It has proven to be a valuable tool when used properly and within its limits.

1980's

The decade which focused on development of safer features for mailboxes, drainage structures, guardrail ends, and utility poles.

● *"The Rural Mailbox: A Little-Known Roadside Hazard,"*[14] This paper focused national attention on the problem of hazardous mailbox installations and presented safe designs. Subsequent research sponsored by FHWA, the Texas Department of Transportation, Minnesota Department of Transportation, and others has resulted in vastly improved mailbox installations across the country.

● *"Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances,"*[15] This report updated and superseded NCHRP Report 153[11] and TRB Circular 191[16]. It incorporated new procedures, updated the evaluation criteria (introduced the "flail-space" model), and brought the procedures up to date with available technology and practices.

● *"Safety Treatment of Roadside Drainage Structures,"*[17] This report described results of a study in which safety treatments for transverse and parallel drainage structures were developed. Results of this study have been applied across the U.S.

● *"Timber Pole Safety by Design,"*[18] This paper described a slip-base breakaway system for timber utility poles. Designs of this type are now being implemented on a select basis in various states.

● *"Roadside Design Guide,"*[19] This guide updated and superseded the 1977 AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers. New items addressed included "Roadside Safety and Economics," "Roadside Topography and Drainage Structures," "Sign and Luminaire Supports and Similar Roadside Features," and "Safety Appurtenances for Work Zones."

● *Development of new end treatments* - A number of new and innovative end treatments for roadside and median barriers were developed in the 80's, most of which are proprietary designs. These included the Safety End Treatment (SENTRE®), modifications to the turned down W-beam guardrail, the Transition End Treatment (TREND®), the Vehicle Attenuating Terminal (VAT), now referred to as the Crash-Cushion/Attenuating Terminal (CAT®), and the guardrail extruder terminal (GET), now referred to as the ET-2000®.

● *"Guide Specifications for Bridge Railings,"*[20] This document, which may be used in lieu of the AASHTO "Standard Specifications for Highway Bridges," required full-scale crash testing of all railings used on new construction. It also provided guidelines identifying roadway conditions for which railings of differing performance levels have application.

1990's

The decade of changing design vehicles, major advancements in computer simulation of vehicle/roadway/occupant interaction in crashes, and international cooperation and harmonization.

● *Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA)* - Among other things, this act "...requires that the Secretary of Transportation shall ... issue a final rule regarding the implementation of revised guidelines and standards for acceptable roadside barriers and other appurtenances, including longitudinal barriers, end terminals, and crash cushions. Such revised standards shall accommodate vans, mini-vans, pickup trucks, and 4-wheel drive vehicles and shall be applicable to the refurbishment and replacement of existing roadside barriers and safety appurtenances as well as to the installation of new roadside barriers and safety appurtenances..." (Section 1073, Public Law, 12/18/91). In response to this section of the act, FHWA has officially adopted NCHRP Report 350 for the testing and evaluation of safety features to be used on highways receiving federal aid. In consideration of the act, a 3/4-ton pickup was selected as one of the test vehicles in Report 350 for evaluating safety features. Also, NCHRP Study 22-11 is now underway at TTI for the "Evaluation of Roadside Features to Accommodate Vans, Mini-Vans, Pick-Up Trucks and 4-Wheel Drive Vehicles."

- *"Single-Slope Concrete Median Barrier,"*[21] This paper describes the development of a new type of concrete median barrier, incorporating a single sloped face. The barrier is thought to have improved impact performance, especially for small vehicles, in comparison to the New Jersey shape. Also, another advantage is that it will not be necessary to reset the barrier each time the adjoining pavement is overlaid. Use of the barrier is increasing across the U.S.
- *"Recommended Procedures for the Safety Performance Evaluation of Highway Features,"*[22] This report updated and superseded NCHRP Report 230. Key changes included guidelines for evaluating a wider range of features, adoption of the pickup truck to represent the upper end of the passenger vehicle spectrum, provisions for testing to a wider range of levels from which different service level systems can be developed, provisions for optional test methods for side impact testing, and adoption in total of the SI units of measure.

FORGIVING ROADSIDE CONCEPT

While the person who coined the term "forgiving roadside" is unknown, the concept or philosophy is thought to have originated in the 60's. K. A. Stonex, Paul Skeels, and others at the General Motors Proving must be given considerable credit for recognizing the need for such a concept, and for conveying that need to highway engineers across the U.S. There were many other roadside safety pioneers of that era who also fostered the concept, some of which were: John Beaton, Eric Nordlin, and others at the California Department of Transportation, Malcolm Graham, William Burnett, and others at the New York Department of Transportation, T. J. Hirsch, Thomas Edwards, and others at the Texas Transportation Institute, Jarvis Michie, Maurice Bronstad and others at the Southwest Research Institute, Leon Hawkins, Paul Tutt, and others at the Texas Highway Department, and Flory Tamanini, John Eicher, W. J. (Red) Lindsay, and others at the Bureau of Public Roads.

Basically, a forgiving roadside is one free of obstacles that could cause serious injuries to occupants of an errant vehicle. To the extent possible, a relatively flat, unobstructed roadside recovery area is desirable, and when these conditions cannot be provided, hazardous features in the recovery area should be made breakaway or shielded with an appropriate barrier. The key question highway engineers have grappled with for years is the lateral extent to which the recovery area or "clear zone" should extend.

A clear zone width of 30 ft. was first recommended in the 1967 AASHO Yellow Book[4]. This was based primarily on studies of the lateral extent of movement of vehicles inadvertently leaving the General Motors Proving Ground test track. The 30 ft. zone became the unofficial standard, and highway agencies attempted to meet this width, especially for high-speed facilities, regardless of operating conditions, roadside conditions, or roadway alignment. Publication of the 1977 AASHTO "Guide for Selecting, Locating, and Designing Traffic Barriers"[12] brought major changes in recommended clear zone widths. Factors such as side slope, operating speed, traffic volume, and horizontal curvature of the road influenced the clear zone width. Depending on these factors the width could be greater or less than 30 ft. Current clear zone criteria, as given in the 1989 AASHTO "Roadside Design Guide," are based on information in the 1977 Barrier Guide[19].

Clear zone criteria have been based on limited empirical data and the collective judgement of researchers and highway engineers. Little is known as to the relation between clear zones and benefits derived therefrom. AASHTO will seek to address these shortcomings through NCHRP Project 17-11 entitled "Recovery-Area Distance Relationships for Highway Roadsides." As stated in the 17-11 project statement, "Updated guidelines are needed to aid designers in determining safe and cost-effective recovery areas, while recognizing the constraints associated with building or improving the highway system." A primary element which has not been given adequate attention in selecting clear zone criteria is the cost-effectiveness factor. What are we buying in terms of benefits (reduction in number and severity of accidents) for increased recovery areas, when considering factors such as service level of facility, traffic operating conditions, roadway alignment, roadside conditions, cost of right-of-way, and hazards beyond the recovery area?

DESIGN

Design of a roadside safety feature is typically fraught with difficulties and pitfalls, and often involves a long arduous process. This should be expected when one realizes that most safety features are highly non-linear structural systems, usually supported by highly non-linear soils, being struck by speeding, highly non-linear vehicles. Both material and geometrical non-linearities usually exist. Furthermore, the design desirably should be aesthetically pleasing, meet environmental requisites, have a long design life, require minimal maintenance, and not cost too much. Despite the many obstacles, numerous advancements have been made in roadside safety design over the past 30 years.

Figure 1, taken from NCHRP Report 350, illustrates the design process required from initiation to completion of a safety feature. A summary of the methodologies used in the design process and key hardware developed follows.

Methodologies

Early designs were generally conceptualized through application of basic principles of mechanics coupled with retrospective data, and the experience and judgement of the designer. Then the design was hopefully finalized through an iterative crash testing program. In fact, this methodology is still widely used.

Up to the 1980's, bridge railings were designed to support a set of static loads, and it was not necessary to evaluate designs via crash testing. Following several multi-fatality accidents in which vehicles breached bridge railings, national pressure resulted in the adoption of impact performance specifications for bridge railings.

Although computer simulation programs have provided insight and served as design tools in recent years, they often lack the sophistication needed to accurately predict behavior and failure modes observed in crash tests. As a consequence, crash testing, with all its limitations, remains the ultimate proof of a features' acceptability.

Appendix D of NCHRP Report 350 summarizes useful techniques, methodologies, and sources of information for designing a safety appurtenance. It also summarizes computer simulation models that can be used in design of selected features. Table 1, taken from Appendix D of NCHRP Report 350, summarizes available techniques, area of their application, and their limitations.

Hardware

As illustrated in the "MILESTONES" section of this paper, major accomplishments have been made in roadside safety design over the past 30 years. Much of this can be attributed to new and improved "roadside furniture," including traffic barriers, breakaway/yielding supports, drainage structures, and traffic control devices used in work zones. A summary of principal contributions in hardware development during the past 30 years follows Items are not necessarily listed in any chronological or prioritized order.

Longitudinal Barriers - Roadside and Median Barriers and Bridge Railings

- Strong-post (wood or steel), W-beam, 6 ft-3 in. post spacing, 27 in. high rail for roadside applications - This is the most widely used roadside barrier and it replaced a similar system with 12 ft.-6 in. post spacing with a 24 in high rail. A 30 in. high version of the same barrier with back-to-back W-beams, and a rub rail has been used for median barriers.
- Concrete safety shaped barrier (CSSB) (often called the New Jersey barrier) - The CSSB is now the most widely used median barrier in the country, and is widely used as a bridge railing. Precast, segmental CSSB's are also widely used in work zones.
- Single slope concrete barrier (SSCB) - The SSCB was recently developed but it is gaining in popularity and use as a median barrier. Impact performance is as good or better than the CSSB and it has operational advantages over the CSSB.
- Thrie beam roadside and median barriers - Thrie beam barriers are widely used by some states, both on the roadside and in the median. Depending on their performance in comparison to W-beam barriers for Report 350 criteria, and for light trucks in general, thrie beam barriers may be in greater demand in the near future.
- Bridge railings in general - Since adoption of impact performance specifications for bridge railings by AASHTO, considerable efforts have been made to ascertain the adequacy of existing railings and to develop new railings to meet the AASHTO multi-performance level specifications. This process has eliminated some substandard systems and has resulted in a set of good performers. It has also resulted in railings capable of containing moderate size trucks. Many feel however that there are still too many designs and that only a few, standard, good performing designs are needed.

Longitudinal Barriers - End Treatments

- Turned down guardrail - Following recommendations of engineers at the General Motors Proving Grounds, highway engineers developed the turned down W-beam end treatment for guardrail to reduce the severe hazard of the blunt guardrail. Although later designs proved to be superior, the turned down treatment advanced roadside safety.
- Breakaway cable terminal (BCT) - The BCT was developed as an alternative to the turned down treatment, and its use grew dramatically during the 70's and 80's. Its performance has generally been good when

installed properly. However, its performance with small vehicles has been a problem, and for this reason other designs have been developed, including the "eccentric loader terminal" (ELT), and more recently the modified eccentric loader terminal (MELT).

- Proprietary systems - Several new and innovative proprietary end treatments have been developed and implemented, including the Safety End Treatment (SENTRE®), the Transition End Treatment (TREND®), the Vehicle Attenuating Terminal (VAT), now referred to as the Crash-Cushion/Attenuating Terminal (CAT®), and the guardrail extruder terminal (GET), now referred to as the ET-2000®.

Crash Cushions

- Steel drum crash cushion - The steel drum crash cushion is believed to be the first operational cushion. It has performed well and is still in wide use in Texas. Its use in other states has diminished, due primarily to maintenance difficulties.
- Proprietary systems - Several innovative proprietary crash cushions have been developed and implemented over the past 30 years, including the Fitch sand filled plastic barrels, the water filled tubes, Guardrail Energy Absorbing Terminal (GREAT®), the HEX-FOAM® Sandwich System, and the Connecticut Impact Attenuating System (CIAS).

Breakaway Supports

- The breakaway feature was a key factor in making the forgiving roadside concept a reality. It has been widely used on sign and luminaire supports, barrier end treatments, and utility poles.

Drainage Structures

- Safety treatment of transverse and parallel drainage structures - Improvements in the safety of blunt culvert ends and large culvert openings have been successfully treated with sloped ends and safety grates, without significantly compromising the hydraulic efficiency of the culverts. These designs are now widely used across the country.

Traffic Control Devices

- Construction of new highways has rapidly declined, whereas reconstruction and rehabilitation of existing facilities has dramatically increased. Safety of motorists and workers in work zones has become a leading concern. Consequently, development of safe traffic control devices has evolved, especially during the past 15 years. Traffic safe signs and channelizing devices, including barricades, cones and tubular markers, drums, and vertical panels have been developed and are now being widely used. Research is continuing in this area.

Truck Mounted Attenuators (TMA)

- With expanding maintenance and work zone activities, development and use of TMA's have increased. Several commercially available systems are in use, including the HEXFOAM TMA, the HEXCEL TMA, and the Connecticut Impact Attenuation System TMA.

Geometric Features

- Embankments, ditches, driveways, and crossovers - Research using computer simulation models, coupled with limited crash testing has led to recommended guidelines for these features.
- Curbs - Curbs along the edges of high-speed roadways have been in disfavor for a number of years. Analysis and field experience have show that a curb can be detrimental to safety since it may trip and overturn an errant vehicle, or it can cause the vehicle to become airborne, adding to vehicular instability and to the possibility of adverse behavior of a barrier or breakaway support behind the curb.

Other Features

- Mailbox supports - Noteworthy advancements in the safety of mailbox supports have been made in the past 15 years. Traffic safe supports are now available and being used for single and multiple mailbox installations.

- Emergency call box supports - Traffic safe supports for emergency call boxes are now widely used.

EVALUATION

Evaluation procedures for safety features have evolved over the past 30 years. However, full scale vehicular crash testing has been, and continues to be, the primary methodology by which impact performance of a safety feature is assessed. Bogie vehicles and pendulums have also been used to evaluate breakaway supports. Once proven acceptable via crash testing the feature is treated as an experimental device and is usually installed in the field on a limited basis, and its performance monitored for a period of time. If it performs as intended in the field, it normally will be treated as an operational system, and is ready for widespread use. However, some degree of ongoing monitoring is desirable. This process is illustrated in Figure 1.

Initial test guidelines applied only to longitudinal barriers, and results of the tests were evaluated primarily by subjective means. It was realized that vehicular accelerations were indicators of occupant risks, and effort were made to minimize accelerations. In early breakaway support development, change in vehicular momentum was used as an indicator of occupant risks. It was subsequently realized that change in vehicular velocity was a better indicator of occupant risk since it was not dependent on the vehicle's mass.

In the late 60's and early 70's, an acceleration severity index (ASI) was adopted for use in evaluating vehicular response to encroachments onto roadside geometric features such as ditches, embankments, and median crossovers. It was an interaction relationship involving the ratios of average vehicular accelerations in the x, y, and z directions, to tolerable accelerations in those directions. Although this approach was abandoned by U. S. A. researchers many years ago, some European countries still use it to evaluate tests of various roadside features. In fact, the ASI will be included in test standards for "road restraint systems" by the Committee on European Normalization (CEN).

NCHRP Report 153, published in 1974, contained state of the art test and evaluation guidelines for longitudinal barriers, crash cushions, and breakaway features.[11] Impact severity of longitudinal barriers was evaluated by limiting values of vehicular acceleration in the longitudinal and lateral directions. Direct, head-on impacts with crash cushions were evaluated by limiting acceleration in the longitudinal direction computed over the stopping distance.

NCHRP Report 230, published in 1980, updated Report 153[15]. Among other things, it completely revised the occupant risk evaluation criteria by introducing the "flail space model." It represented the occupant as an unrestrained lumped mass, free to flail in the vehicular x-y plane, within a given "occupant compartment." The velocity at which the occupant struck the compartment, and the ridedown accelerations subsequent to contact, were measures of occupant risk.

NCHRP Report 350, published in 1993, updated Report 230[15]. Although some changes were made in the "structural adequacy" and the "vehicle trajectory" evaluation criteria, only minor changes were made to the occupant risk criteria, and the basic flail space model was retained. Other changes in Report 350 relative to Report 230 included changes to test vehicles, changes to the number and impact conditions of tests required to evaluate a feature, adoption of the concept of "test levels" as opposed to "service levels," inclusion of test guidelines for additional features, and adoption of the International System (SI) of units.

Both Reports 230 and 350 pointed out that field evaluation was the final and perhaps the most important step in the evaluation of a feature. Both reports provided guidelines by which a feature could be field evaluated. However, to a large extent, field evaluation remains the weak link in the assessment of a feature's performance and suitability for use. Notable exceptions to this are the field studies the New York DOT conducted on many of its barrier systems, studies by the Kentucky DOT on end treatments, studies by California DOT on median barrier performance, studies by Texas DOT on end treatments, and studies by FHWA on selected safety features. Proprietary systems are often closely monitored by their suppliers/manufacturers, especially during the period of their initial use. Problems that arise in proprietary systems are usually quickly corrected; also, changes that will improve performance and reduce costs are also incorporated.

The FHWA has also played a key role in the evaluation and implementation of new safety features. The FHWA has served as an arbiter in establishing acceptability and operational status of new features to be used on federal-aid highways. An assessment is made based on design details, specifications, and crash test results. State highway agencies typically rely heavily on this assessment in their review and possible use of the approved feature on *all* highways in their system.

INSTALLATION AND MAINTENANCE

Proper installation and maintenance of a safety feature is usually critical to its proper performance. The BCT has been one of the most widely used safety features, and one that has often been improperly installed. Frequently it has been installed without the recommended flare and end offset, and the consequences have been alarmingly injurious. Another example concerns sloping culvert ends for parallel drainage structures. Typically, the culvert end has a 6 to 1 slope and it is intended that the slope of the driveway, entrance ramp, or crossover under which the culvert traverses, match the sloping culvert end. In many cases the sloping end has been either left exposed due to improper fill slopes for the driveway, entrance ramp, or

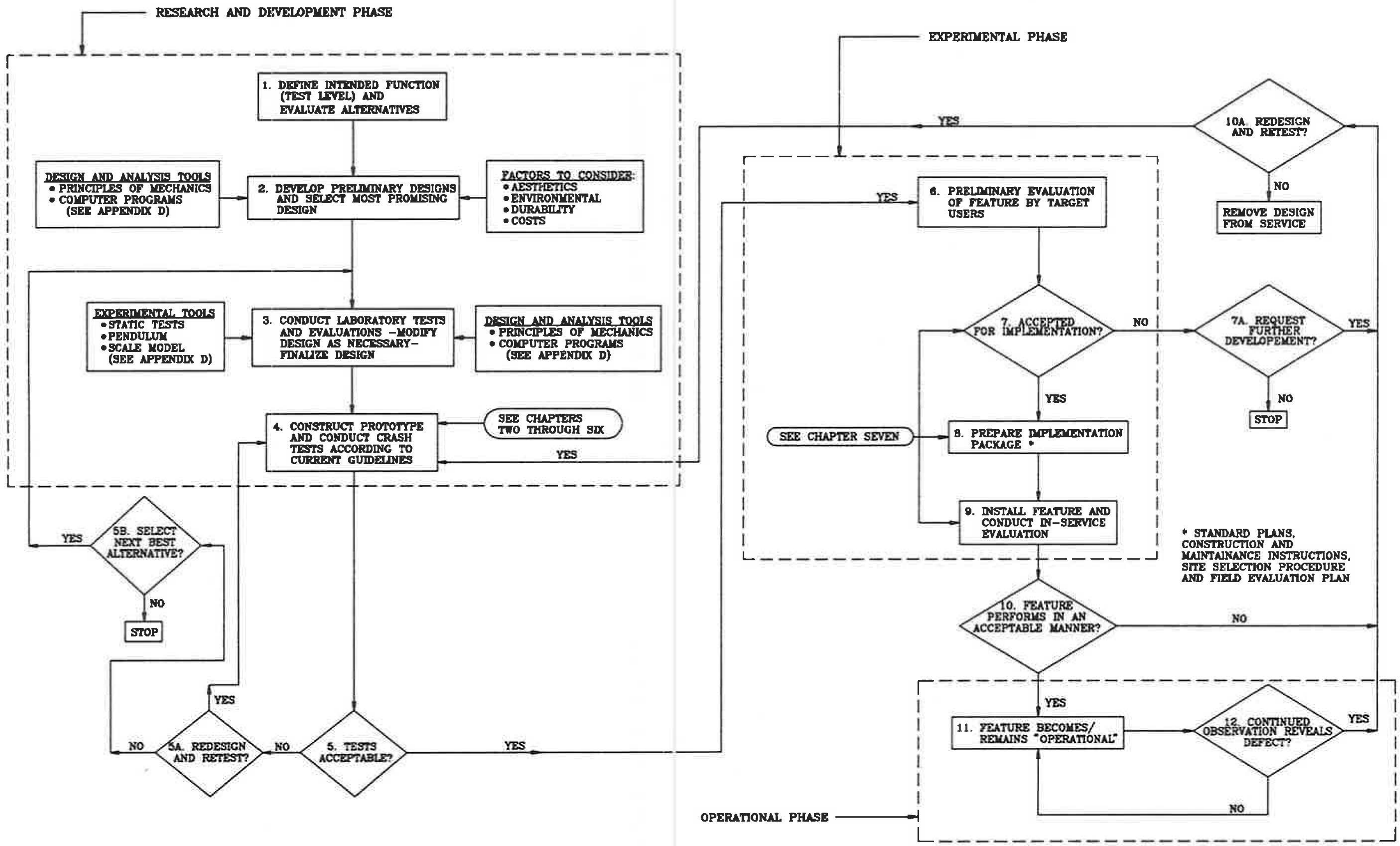

FIGURE 1 Flow chart for development of a safety feature.

TABLE 1 APPLICATION AND LIMITATIONS OF SAFETY FEATURE DEVELOPMENT TECHNIQUES

Development Technique	Principal Areas of Application	Possible Limitations
1. Structural Design Methods	• Preliminary and final design of feature for environment and non-collision performance • Preliminary design of feature for vehicle collision performance • Analysis of connections, material properties requirement and foundation design	• Dynamics and kinematics of feature and collision vehicle are not addressed • Collision severity in terms of occupant injuries and fatalities is not addressed
2. Static Tests (quasi-static)	• Mechanical properties of unique shapes, connections, new materials • Validation of structural design features • Quality control of critical material properties • Develop input values for computer programs	• Dynamic properties not examined • Generally applicable to samples, connections, and small subassemblies; entire system is not accommodated
3. Computer Simulations	• Study interrelations of feature and vehicle dynamics and kinematics • Study interrelations of vehicle dynamics and occupant dynamics • Study sensitivity of feature, vehicle and site conditions on vehicle/feature dynamic interactions	• Program should be validated by full-scale crash tests for specific conditions that bracket the conditions under study • Input parameters are sometimes not available and must be estimated • For practical and economic reasons, programs model only major feature/vehicle properties • Sometimes minor features decide the performance
4. Laboratory Dynamic Tests A. Gravitational Pendulum	• Compliance test for luminaire and single-leg sign breakaway supports • Evaluation of breakaway mechanisms • Force/deformation properties of guardrail post/soil interaction • Dynamic strength of anchor systems • Dynamic properties of barrier subsystems	• Impact speed 40 km/h or less • For dual-leg supports, upper-hinge mechanism are not examined • Does not simulate off-center impacts • Trajectory of article not reproduced • Base-bending support not applicable • Crushable nose must be tuned for type and width of specimen and recalibrated periodically • Cannot properly evaluate criterion D, Table 5.1
B. Drop Mass	• Quality control test of breakaway component • Test can be performed in a confined, indoor space	• Same limitations as for pendulum • For breakaway base, attached pole introduces artifact moment into base due to gravity
C. Scale Model	• Development testing of feature	• Difficulties and uncertainties in modeling vehicle and safety feature components
C. Bogie Vehicle Test	• Compliance test for single or multi-leg breakaway support • Repeatable test vehicle suspension, nose crash, and other dynamic properties • Low-cost, high-speed (0-60 mph) experiments	• Must be carefully designed and calibrated to represent vehicle characteristic of interest, which is often a long and expensive process • Designs have been appropriate for testing only limited variations in feature • Must be updated and recalibrated periodically.
D. Vehicle Crash Test	• Compliance test for all features • Investigation of unusual conditions • Most direct tie to actual highway collisions • Final proof test	• Relatively expensive to perform • Requires extensive capital facilities • Deliberate and slow to perform • Test results pertain to the specific vehicle model tested and may not be applicable to other vehicles

crossover, or fill has been added only in the immediate area adjacent to the sloped end.

Another common problem transportation agencies face is the expertise and attention to detail required in proper maintenance of many safety features. The initial installation may be by well trained and experienced contractors, while maintenance and restoration may be the responsibility of agency personnel. Both contractors and maintenance personnel must know the importance of proper installation and maintenance procedures, and the consequences if these procedures are not followed.

FUTURE CONCERNS

While major advancements have been made in roadside safety design, challenges and opportunities for further advancements remain. Following are selected issues relative to the design, evaluation, and maintenance of safety features for future consideration.

- *Multi-Performance Level Features and Warrants for Their Use* - NCHRP Report 350 provides guidelines for evaluation of safety features/hardware for up to six test levels (note that test levels imply performance levels). However, Report 350 provides no warrants or guidelines that establish highway conditions for which a specific "test level feature" would have application. Many of the operational safety features developed to date were designed to meet test level 3 requirements of Report 350. Thus, there is a need to (a) develop other features meeting the array of test levels in Report 350, and (b) to develop guidelines for their use. NCHRP Project 22-12, soon to be awarded, will address part b. In the absence of a wide array of operational, multi-performance level safety features/hardware, the study may have to approach the problem from another perspective. In this case, the project may have to develop guidelines for a family of "hypothetical, multi-performance level features," having assumed characteristics such as impact performance parameters and costs associated with purchase, installation, and maintenance. It would then remain to be determined if such features could be feasibly produced.
- *Vehicle mix* - There is a clear trend toward increased use of pickups, vans, and sport/utility motor vehicles. The ISTEA of 1991 recognized this trend, and mandated that highway safety features be designed to accommodate these vehicles. Project 22-11, which began June 1, 1994, will address many concerns relative to roadside safety design for light trucks. An FHWA study soon to be awarded will also address the light truck problem by estimating future trends in vehicular design and by developing a limited number of vehicular platforms representative of a group or class of vehicle types. Are there areas not covered in either of the above mentioned studies that need attention?
- *Performance guidelines/standards* - Future updates to NCHRP Report 350 need to consider:

  a) *Impact conditions* - In a significant percentage of accidents with safety features the vehicle is yawing and not in a tracking mode. All compliance test guidelines to date use a tracking vehicle. Should non-tracking tests, including full side impacts, be included in future test guidelines? How would identification of standardized non-tracking tests be made? Can such tests be conducted with a high degree of control and repeatability? Can hardware be cost effectively developed to accommodate these types of impacts.

  b) *Test vehicles* - For test levels 1 through 3 of Report 350, two passenger vehicles are used to evaluate safety features. For test levels 4 through 6 the small car and three different size trucks are used. The two passenger vehicles and three trucks used in these tests are intended to bracket the wide spectrum of vehicle types on the road, and as such it is assumed that they reflect the extremes in vehicle/feature performance expected in the field. Are safety features being properly designed to accommodate the wide range of vehicles in the mix? Do the design vehicles of Report 350 adequately represent the mix? What about motorcycles? What is a realistic tradeoff between the cost of requiring additional tests to represent a wider vehicular mix and added safety benefits which may result therefrom?

  c) *Occupant compartment deformation/ intrusion criteria* - Criterion D, Table 5.1, of Report 350 addresses occupant compartment integrity, but assessment thereof must of necessity be subjective. An occupant compartment deformation index (OCDI) is to be computed and reported, which gives a quantitative measure of the change in occupant compartment dimensions. However, limiting values for the OCDI are not given, and it is used for information only. Should limiting, quantitative values be established for this criterion? If so, how can this be accomplished?

  d) *Occupant risk criteria* - Surrogate measures such as the flail space approach of the U.S.A, the THIV and PHD approach employed by CEN (which is very similar to the flail space approach), and the ASI approach also used by CEN, are at best only indicators of occupant risks. Furthermore, they cannot account for factors such as occupant restraint systems, air bags, crashworthiness of the occupant compartment, effects of driver/passenger size, etc. Advances in computer technology and in the development of sophisticated dummies and collision victim simulation models are such that quick and accurate determination of occupant response in a crash test or simulation is feasible. Should future occupant risk indices include application of these technologies?

e) *Use of surrogate test vehicles* - Bogie vehicles and pendulums have frequently been used for development and compliance testing of breakaway supports, especially luminaire supports. Efforts are being made to extend the range of application to other features such as crash cushions, yielding signs, and longitudinal barriers. Have these devices performed in an acceptable manner? What efforts and costs are involved in development of a validated surrogate? Heavy roof damage was observed in recent tests of light poles with production model vehicles. Bogies and pendulums generally cannot assess roof crush. Should a compliant roof be required in these surrogate devices?

- *Work zone safety features* - Are there still problems with work zone safety features and traffic control devices? Are new designs needed? Potential candidates include highly portable barriers that can be quickly deployed and retrieved, truck mounted attenuators for high speed impacts (100 km/h), and safe changeable message sign systems.

- *New Materials* - Advanced and recycled materials are being used in various transportation areas, including composites, high-strength concrete, and recycled rubber and plastics. Which new materials and recycled materials are candidates for use in roadside safety features? What is the current state of knowledge relative to the use of these types of materials in roadside safety design? Can these types of materials be cost-effectively used in roadside safety design, and if so how? Do we need basic studies to better define the properties and characteristics of these materials necessary for their use in roadside safety design?

- *Railing design* - The W-beam rail, and to a lesser extent the thrie-beam rail, have been widely used as basic elements in longitudinal barrier systems in the U.S.A. and other countries for many years. How did this come to be? Are these shapes optimum? Can we do better considering factors such as performance, cost, design flexibility, cost effectiveness?

- *Safety feature installation and maintenance procedures* - Proper installation and maintenance of safety features remains a concern. Installation and maintenance problems are generally proportional to the degree of design complexity. Keeping designs simple, and use of readily available, standard parts is highly desirable. What, if anything, can and should be done to improve the quality of installation and maintenance of safety features?

- *International cooperation and harmonization* - Considerable progress has been made in international cooperation and harmonization relative to roadside safety. The European community was represented on the advisory panel for NCHRP Project 22-7, in which Report 350 was prepared. U.S.A. representatives attend and participate, as observers, in CEN technical working groups responsible for writing test standards for road restraint systems. Further, subcommittee A2A04(2), International Research Activities, has been very active and successful in promoting technology exchange in the roadside safety area and in promoting harmonization of impact performance guidelines/standards internationally. It is certainly desirable to continue and expand these efforts.

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