Proceedings of STRATEGIC HIGHWAY RESEARCH PROGRAM AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden, 27-29 September, 1989

- Opening

- International Harmonization of Test Procedures and Requirements for Roadside Safety Features, Workshop
Proceedings of STRATEGIC HIGHWAY RESEARCH PROGRAM AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden, 27-29 September, 1989

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The Swedish Road and Traffic Research Institute (VTI) and the US Transportation Research Board (TRB) of the National Research Council were jointly organising this international conference. The objective was to cover the present and future road research with special emphasis on the Strategic Highway Research Program (SHRP), as well as the research concerning drivers and vehicles as related to highway safety.

Under development for 2-3 years, SHRP is a fully funded, $ 150 million (US), five year program of research directed at asphalt, concrete and structures, highway operations, and long term pavement performance.

In the sessions on roads there were presentations which highlighted differences between European and US practices and needs, and the discussions were concentrated on how to promote international involvement in SHRP and application of its research, within the areas of Asphalt, Long Term Pavement Performance (LTPP), Highway Operations and Concrete and Structures.

In the different road safety sessions there were presentations of actual research in different countries and discussions of the differences that exist between Europe and the USA, trying to explain the reasons for them and examine whether they are reasonable and acceptable.

Linköping October 1989

Kenneth Asp

Proceedings of STRATEGIC HIGHWAY RESEARCH PROGRAM AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden, 27-29 September 1989:

VTI RAPPORT 349A
- Opening
- International Harmonization of Test Procedures and Requirements for Roadside Safety Features, Workshop

VTI RAPPORT 350A
- Asphalt
- Long Term Pavement Performance

VTI RAPPORT 351A
- Work Zone Safety
- Heavy Truck Safety
- Highway Safety

VTI RAPPORT 352A
- Highway Operations
- Concrete and Structures
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## OPENING

### Overview of Traffic Safety in the United States
Marshall Jacks Jr, U S Department of Transportation, USA

### European Trends in Road Safety Research
David F Cornelius, Transport and Road Research Laboratory (TRRL), United Kingdom

### Need for Road Maintenance Research in the Nordic Countries
Tord Lindahl, VTI, Sweden

## INTERNATIONAL HARMONIZATION OF TEST PROCEDURES AND REQUIREMENTS FOR ROADSIDE SAFETY FEATURES, WORKSHOP

### Installation Requirements and Test Procedures of Safety Features on Australian Road
Rod J Troutbeck, Queensland University of Technology, Australia

### Roadside Safety Activities in Canada
Randy W Sanderson, Transport Canada, Canada

### Roadside Safety Barriers
Robert Quincy, INRETS, France
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<td>Malcolm H Ray, Vanderbilt University, USA</td>
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ABSTRACT

Papers presented at the seminar were as follows: Overview of Traffic Safety in the United States (Jacks, M Jr); European Trends in Road Safety Research (Cornelius, D F); Need for Road Maintenance Research in the Nordic Countries (Lindahl, T); Installation Requirements and Test Procedures for Safety Features on Australian Roads (Troutbeck, R J); Roadside Safety Activities in Canada (Sanderson, R W); Roadside Safety Barriers (Quincy, R); Rational Approach to the Problem of the Choice of the Safety Road Barriers, through Valuation of the Total Costs on Remarks of Statistic and Probabilistic Type (Colonna, P and Piccinni, I); Current Standards Regarding Roadside Safety Barriers in the Netherlands (Heijer, T); Status Report on Current Regulations in United States (Michie, J D); NCHRP Report 230 Update (Ross, H E Jr and Michie, J D); Current Issues in Work Zone Safety (Hunter, W W); Traffic Environment and Vehicle Accidents (Norin, H); Proposal for European Harmonization of Crash Cushions (Dreznes, M G); Overrepresentation of Non-belt Users in Traffic Crashes (Hunter, W W and Stutts, J C); Side Impact Accidents with Fixed Roadside Objects (Ray, M H).
STRATEGIC HIGHWAY RESEARCH PROGRAM AND TRAFFIC SAFETY ON TWO CONTINENTS

Gothenburg, Sweden

September 27-29, 1989

WEDNESDAY SEPTEMBER 27

OPENING

9.00 - 11.30

Chairman: Mrs Monica Sundström, Director General, Swedish Road and Traffic Research Institute (VTI), Sweden

Opening Speeches
Mr Åke Norling, County Governor, Gothenburg, Sweden

Mr Thomas B Deen, Executive Director, Transportation Research Board (TRB), USA
Mrs Monica Sundström, Director General, Swedish Road and Traffic Research Institute (VTI), Sweden

Overview of Traffic Safety in the United States
Mr Marshall Jacks Jr (Mr R Clarke Bennett, Director, Office of Highway Safety (FHWA), USA)

European Trends in Road Safety Research
Mr David Cornelius, Executive Director, Transport and Road Research Laboratory (TRRL), United Kingdom

Highways for the Future: The Strategic Highway Research Program (SHRP)
Dr Damian J Kulash, Executive Director, Strategic Highway Research Program, USA

Need for Road Maintenance Research in the Nordic Countries
Mr Tord Lindahl, Research director, VTI, Sweden
WEDNESDAY SEPTEMBER 27

INTERNATIONAL HARMONIZATION OF TEST PROCEDURES AND REQUIREMENTS FOR ROADSIDE SAFETY FEATURES, WORKSHOP

11.30 - 17.00

Chairman: Mr Thomas Turbell, VTI, Sweden

Status Reports on Current Regulations
Australia Mr Rod Troutbeck, ARRB
Canada Mr Randy Sanderson, Transport Canada
Mr Frank DeVisser, Ministry of Transport
France Mr Robert Quincy, INRETS
Italy Mr Francesco La Camera, La Sapienza
Mr Pasquale Colonna (written presentation only)
Netherlands Mr Tom Heijer, SWOV (including presentation of VEDYAC)
Sweden Mr Thomas Turbell, VTI
United States Mr Jarvis Michie, Dynatech

12.30 LUNCHEON

14.00

NCHRP Report 230 Update
Dr Hayes Ross, Texas Transportation Institute (TTI), USA

Current Issues in Work Zone Safety
Mr William Hunter, Highway Safety Research (HSRC), USA

Harmonization Within the European Common Market
Mr Thomas Turbell, VTI, Sweden

Manufacturers Views on Harmonization
Mr Hans Norin, Volvo Car Corporation, Sweden
Mr Mike Dreznes, Energy Absorption Systems, USA

Panel Discussion
Subjects:
Requirements, Severity Index, Flail space, Theoretical Head Impact Velocity
Belted car occupants
Side impacts

Introduction by: Mr Gordon Bacon, MIRA
Introduction by: Mr William Hunter, HSRC
Introduction by: Mr Malcolm Ray, Vanderbilt University

Summary
Mr Thomas Turbell, VTI, Sweden

VTI RAPPORT 349A
WEDNESDAY SEPTEMBER 27

ASPHALT

11.30 - 17.00

Chairman: Mr Bo Liljedahl, The Swedish Asphalt Pavement Association, Sweden

SHRP's Asphalt Research: Progress and Products
Dr Edward T Harrigan, Strategic Highway Research Program, USA

Asphalt Research in the Finnish ASTO-project
Dr Asko Saarela, Technical Research Centre, Finland

Data Distributions for Asphalt Concrete Resilient Modulus and Indirect Modulus
Ms Mary Stroup-Gardiner (Prof David Newcomb, University of Minnesota, USA)

Bitumen and Asphalt Mixes in USA, how do they look like?
Mr Andre Gastmans, Nynas NV, Belgium

What can Europe Learn from SHRP Asphalt Research?
Panel discussion

THURSDAY SEPTEMBER 28

WORK ZONE SAFETY

9.30 - 13.00

Chairman: Mr R Clarke Bennett, Director, Office of Highway Safety (FHWA), USA

Work Zone Safety
Mr Rudolph M Umbs, Federal Highway Administration, USA (Mr R Clarke Bennett)

Analysis of Driver Behaviour and Accidents at Work Sites on German Motorways
Priv Doz Dr-Ing Wilhelm Kockelke, Bundesanstalt für Strassenwesen (BAST), Federal Republic of Germany

A Coordinated Approach to Traffic Control Management Through Multiple Highway Construction Contracts
Mr Hermann Guenther, Project manager, Daniel, Mann, Johnson and Mendenhall, USA

Safety at Roadworks
Mr Michael Marlow, Transport and Road Research Laboratory (TRRL), United Kingdom

Service Vehicle Warning Light Systems for Work Zones
Dr Richard F Pain, Transportation Research Board, USA
THURSDAY SEPTEMBER 28

HEAVY TRUCK SAFETY

14.00 - 17.30

Chairman: Mr Robert E Spicher, Director, Technical Activities, TRB, USA

Analysis of Statistical Data on HFV-Accidents and Vehicle Measures to Improve Safety
Dr-Ing Ulrich Stöcker, Bundesanstalt für Strassenwesen (BASt), Federal Republic of Germany

Vehicle and Driver Factors in Relation to Crash Involvement of Heavy Trucks
Dr Ian Jones, Forensic Technologies International, USA

Evaluation of Handling and Braking Characteristics of Heavy Vehicles
Prof Dr-Ing Klaus Rompe, Director, and Dipl.-Ing. Andreas Schindler, TÜV, Federal Republic of Germany

Heavy Vehicle Braking Characteristics - US and Europe
Mr Richard W Radlinski, Vehicle Research and Test Center (NHTSA), USA (Mr Robert E Spicher)

Braking Safety of Heavy Vehicle Combinations in the Nordic Countries
Prof Lennart Strandberg, VTI, Sweden

Safety Aspects of Heavy Goods Vehicle Design
Dr P H Bly, Transport and Road Research Laboratory (TRRL), United Kingdom
THURSDAY SEPTEMBER 28

LONG TERM PAVEMENT PERFORMANCE

9.30 - 17.30

Chairman: Dir Ivar Schacke, Head of the Danish Road Research Laboratory, Denmark

Long Term Pavement Performance: Progress and Products
Mr Neil F Hawks, Strategic Highway Research Program, USA
(Dr W R Hudson, Texas Research & Development Foundation)

Performance Monitoring and Data Acquisition for Pavement Performance Evaluation
Ms Cheryl A Richter, Strategic Highway Research Program, USA

Trends in Pavement Performance Based on the National Road Maintenance Condition Survey
Mr Peter Scott, Department of Transportation, United Kingdom

Canadian Long Term Pavement Performance Study: Recent Developments
Mr Greg Williams, Roads and Transportation Association of Canada, Canada

13.00 Luncheon

14.00

Future Pavement Performance Research Data Needs for Texas
Mr James L Brown, Texas Department of Highways and Public Transportation, USA

Means of Creating Links between US LTPP and European Monitoring Programs
Panel discussion

HIGHWAY OPERATIONS

15.00 - 17.30

Chairman: Mr Bo Simonsson, Swedish Road and Traffic Research Institute (VTI), Sweden

An overview of SHRP’s Highway Operations Research
Mr Don M Harriott, Strategic Highway Research Program, USA

Evaluation of Effectiveness of Pavements’ Preventive Maintenance Treatments
Dr Roger E Smith, Texas A & M University, USA (Mr Don Harriott)

ERASME - French Expert System for Pavement Maintenance
Mr Pierre Joubert, SETRA, France

Use of Rubber Modified Asphalt for Snow and Ice Control
Mr Hossein B Takallou, CTAK Associates, USA

VTI RAPPORT 349A
FRIDAY SEPTEMBER 29

HIGHWAY SAFETY

8.30 - 12.30

Chairman: Prof Kåre Rumar, Swedish Road and Traffic Research Institute (VTI), Sweden

Risk Analyses in Highway Engineering
Prof Dr-Ing Walter Durth, Techn University of Darmstadt, Federal Republic of Germany

New Methods for Evaluating Safety Measures Using Accident Data
Dr Olga J Pendleton, Texas Transportation Institute, USA

Evaluation and Comparison of Traffic Safety on High Standard Rural Roads
Dr-Ing Ulrich Brannolte, University of Karlsruhe, Federal Republic of Germany

Road Design and Safety
Dr Karl-Olov Hedman, VTI, Sweden

A Strategic Transportation Research Study for Highway Safety
Mr Jerry A Reagan, Turner Fairbank Highway Research Center (FHWA), USA
(Mr R Clarke Bennett)

CONCRETE AND STRUCTURES

8.30 - 12.30

Chairman: Dr Damian J Kulash, Strategic Highway Research Program, USA

SHRP's Concrete and Structures Research: Goals and Recent Developments
Dr Damian J Kulash, Strategic Highway Research Program, USA

Concrete Microstructure Research and Its Applications in Highway Pavements
Dr G M Idorn, G M Idorn Consult, Denmark

Chloride Removal and Corrosion Protection of Reinforced Concrete
Mr John Miller, N O T, Norway

Chloride Binding in Cement and the CL/OH-Ratio of the Pore Solution
Univ Doz Dr Josef Tritthart, Graz University of Technology, Austria

Corrosion Protection of Reinforcement Against Chloride Impact
Univ Doz Dipl-Ing Dr Gerhard Hartl, Austrian Concrete Research Institute, Austria

Protecting Concrete by Flexible Waterproofing Slurries
Dipl Ing Andreas Volkwein, Technical University of Munich, Federal Republic of Germany

VTI RAPPORT 349A
Participants in international conference in Gothenburg 27–29 SEPT 1989
"Strategic Highway Research Program and Traffic Safety on Two Continents"

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Participants in international conference in Gothenburg 27-29 SEPT 1989
"Strategic Highway Research Program and Traffic Safety on Two Continents"

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Overview of Traffic Safety in the United States

Marshall Jacks, Jr
Associate Administrator for Safety and Operations
U S Department of Transportation, Federal Highway Administration
U S A

presented by

R Clarke Bennett
Director
Office of Highway Safety (FHWA)
U S A
Distinguished Guests, Ladies and Gentlemen. It is a pleasure to visit Gothenburg and an honor to be invited to represent the United States government during this international conference. I commend the Swedish Road and Traffic Safety Research Institute and the Transportation Research Board from the United States for your outstanding work in supporting highway research and traffic safety throughout the international community and for your efforts in providing this opportunity for further dialogue and exchange of information among the various countries.

I would like to begin my remarks by saying that 1988 was a year of significant gains in highway safety in the United States, and that highway travel in our country is safer than at anytime in modern history. There is good news in virtually every part of the highway safety picture.

Although approximately 47,000 people were killed in motor vehicle crashes in the United States in 1988, this figure represents an 8,000 decrease from the peak year, 1972. In addition, the mileage fatality rate per 100 million vehicle miles (100 mvm) has declined over the last 40 years to a low of 2.4 per 100 mvm in 1988. This is one of the lowest motor vehicle fatality rates of any country in the world. The decline of the fatality rate is encouraging, however, we must continue to look for ways to further reduce the fatality rate and the number of people killed and injured. For example, if the rate had remained at the 1979 and 1980 levels of 3.3 fatalities per 100 mvm, we estimate about 18,000 more people would have died in motor vehicle crashes in 1988.

We do not know which traffic safety programs have contributed most to the reductions over the years. However, we do know that a mix of programs involving the driver, the vehicle, and the roadway has helped to hold the totals down.

The 42,800 mile system of Interstate highways constructed according to the latest and safest design standards is more than two times safer than non-Interstate routes in terms of fatalities, and almost four times safer in terms of injury-producing accidents.

Roadway, roadside and operational improvements such as wider lanes and shoulders, extension of culverts and removal of hazards and signs, and the use of standard pavement markings and traffic signals have helped reduce the number of accidents by providing consistent and uniform conditions and improved driver comfort.

Arrests, convictions and sanctions for alcohol-related offenses, and the public's increased awareness of the dangers of drunk and impaired driving have resulted in an 11 percent reduction in alcohol-related fatalities since 1982.
The increased use of safety belts and child safety seats saved an estimated 4,300 lives in 1988. In addition, significant improvements in the crashworthiness of new cars to comply with the Federal Motor Vehicle Safety Standards have saved numerous lives and prevented or reduced thousands of serious injuries since 1966.

As you can see, highway safety involves a wide range of problems, remedies, and disciplines among and between the various levels of government and the private sector.

Historically, States and local jurisdictions have been responsible for funding and implementing highway safety programs in the United States. During the more than 85 years since the development of the automobile, the States and communities have had programs to regulate the use of the motor vehicle in the interest of public safety. For example, they register vehicles, license drivers, educate children, regulate traffic, enforce the laws, and construct and maintain the streets and highways.

In 1966, increased concern over the loss of life and the growing drain on our public and private resources resulted in the enactment of two landmark safety laws.

One Act (The National Traffic and Motor Vehicle Safety Act of 1966) requires the Secretary of Transportation to establish standards setting a minimum level of safety for motor vehicles and motor vehicle equipment. The purpose of these standards is to protect the public against accidents caused by mechanical failure, and to reduce the risk of death or injury in the event of a crash.

The second Act (The Highway Safety Act of 1966) provides for a cooperative highway safety effort among the Federal, State, and local governments. The States continue to have a predominant role with the Federal government providing research, technical guidance and limited financial aid to initiate new highway safety activities and improve on-going activities.

These Acts were followed by legislation in 1973 and subsequent years providing Federal funds for specific highway safety construction programs to reduce the number and severity of highway accidents through engineering improvements. There are currently two special safety construction programs, the Hazard Elimination Program and the Rail-Highway Crossings Program. Congress later established the Motor Carrier Assistance Program in 1982 and the Commercial Driver License Program in 1986 to strengthen State motor carrier safety programs.

The Hazard Elimination Program provides $170 million each year for Federal funding of 90 percent of the cost to provide safety improvements on all public highways except the Interstate System. Projects are selected from a priority list of identified hazardous locations or elements developed by the State. Typical projects include intersection improvements (channelization, traffic signals, and sight distance); pavement and shoulder widening; guardrail and barrier improvements; modification of roadway alignment, signing, pavement marking and delineation; and breakaway sign supports. These improvements have resulted in substantial reductions in accidents, particularly fatal accidents.
In addition to regular Federal-aid construction funds, $160 million is made available annually for safety improvements at rail-highway crossings on any public road. There are approximately 200,000 public crossings in the United States. Typical projects carried out under this program with 90 percent Federal funding include new grade separations and reconstruction of existing grade separations; installation of standard signs and pavement markings; installation or upgrading of active warning devices (flashing lights and/or gates); relocation of the railroad or highway to eliminate crossings; removing or closing grade crossings; crossing surface improvements; illuminating crossings; and sight distance improvements. Since the beginning of the program in 1974, crossing fatalities have declined from 1,200 to 598 in 1987—a 50 percent reduction.

In addition to these categorical highway safety funds, States use a significant portion of other Federal-aid funds for highway safety improvements which are normally accomplished as part of other construction or reconstruction work. In 1988, $243 million of Interstate funds were used for highway safety improvements in conjunction with other improvements.

Federal-aid highway construction funds are available for reconstruction, resurfacing, restoration, and rehabilitation (4R) work to extend the service life and enhance safety on existing Federal-aid highways. Typical safety enhancements included with 4R work are safer pavement features such as improvements to rideability, cross slopes, surface drainage, skid resistant pavements and pavement markings; upgrading bridge rails, approach rails, connections and terminals; wider lanes, wider shoulders, improved shoulder surfaces (particularly along the pavement edge) and installation and upgrading of guardrail; improved railroad grade crossing surfaces; improved clear zones; more traversable ditches and side slopes; replacement of deteriorated signs; addition of left and right turn lanes; culvert extensions and headwall modifications and new or improved intersection channelization; upgraded pavement markings; construction of climbing lanes for slow-moving vehicles; passing lanes; brush and tree trimming to improve sight distance; upgraded traffic signals; and new facilities for pedestrians and bicycles.

The Federal role in aiding pedestrian traffic includes promoting pedestrian safety in key areas such as improving streets and sidewalks to better accommodate the elderly or physically handicapped; providing better accommodations for pedestrians in construction and maintenance zones; and the use and location of special signal systems and structures to better separate vehicles and pedestrians. Public information and education programs are directed toward the prevention of pedestrian accidents with special emphasis on school-age youths, the elderly, and the alcohol-impaired pedestrian. A pedestrian impact protection program also is underway to examine various vehicle modifications to reduce head, thorax, and lower leg injuries.

State and local governments have a major role in implementing pedestrian safety programs. Comprehensive programs, including the application of engineering, enforcement and education principles, have been established in several States. A key to the effectiveness of these programs is an advisory committee of professionals and volunteers working together to
promote pedestrian safety. For students, local programs include identifying safe routes to school, providing and training crossing guards, and educating students on the safe way to cross the street. Where particular pedestrian problems exist, selective enforcement programs may be implemented, or crossing devices such as signals, crosswalks, or special signs may be installed. Programs are also implemented to increase driver awareness of the needs and problems of pedestrians.

In addition to the construction funds, approximately $185 million is authorized for other national special purpose Federal programs to help State and local jurisdictions improve safety on their streets and highways. These programs involve alcohol and other drug countermeasures, police traffic services, occupant protection, traffic records, emergency medical services, motorcycle safety, roadway safety, and commercial vehicle safety.

Special programs are underway at the Federal and State levels and in the private sector to address some of the more critical highway safety problems.

One issue involves the growing number of aging drivers. By 1995 one-third of the drivers will be age 65 and over. This will require that we keep the driving task as simple as possible and provide good visibility of signs and markings.

The Highway Safety Act of 1987 provided for the National Academy of Sciences to study problems which may inhibit safety and mobility of older drivers and means of addressing these problems, and required that we develop a pilot program of highway safety improvements to enhance the safety and mobility of older drivers.

Four States (Arizona, Florida, Nebraska and Nevada) are carrying out nine pilot projects to test the effectiveness of selected roadway safety improvements for older drivers. A report on the effectiveness of the pilot programs is due April 1990.

Work zone traffic safety continues to grow in importance as more and more streets and highways are maintained and constructed under traffic. Fatalities in work zones increased from about 500 in 1982 to more than 700 in 1988 with over 30 percent occurring on freeways. Special programs are underway to advise motorists and workers of work zone dangers and to assure that traffic control plans are approved and working properly.

In the area of commercial vehicle safety, increased activity is underway in driver training and licensing, operation and equipment standards, and compliance inspections to strengthen the driver-vehicle interface with the highway.

The Federal government establishes and enforces safety regulations based on the principle that safe operation requires a properly maintained vehicle, a qualified driver, and securely contained cargo. They cover such activities as minimum qualifications of truck and bus drivers, maximum hours of service for drivers, employee health and safety, installation and use of vehicle safety equipment, vehicle inspection and
maintenance practices, reporting and recording of accidents, commercial driver licenses, and insurance levels for financial liability.

Under the Federal Motor Carrier Safety Assistance Program, States receive limited Federal funds to adopt and enforce the Federal regulations or compatible State safety requirements. During 1988 State officials conducted approximately 1.2 million inspections and removed more than 470,000 vehicles and 83,000 drivers from service for violations of Federal safety regulations.

The Commercial Driver License Program requires that each State test and license all commercial drivers by April 1, 1992. In addition, we are testing 200 vehicles to monitor the reliability and maintenance of a new generation of antilock brakes for use on air-brake equipped trucks in the mid-1990's.

Beginning on September 1, all new passenger cars will be equipped with automatic crash protection in the front seat. To complement the effects of the new occupant protection systems, we are reinforcing our campaign to raise safety belt use. A total of 33 States and the District of Columbia now have safety belt use laws. Our survey of safety belt use in 19 cities showed that drivers have increased their use of belts to 47 percent, an increase of 4 percent over 1987. In the related area of child passenger protection, we are conducting research to improve child seating systems.

Other measures to protect vehicle occupants include proposed requirements for upgraded side impact protection for passenger cars, head restraint requirements for light trucks, and 3-point belts in the rear seats of passenger cars and light trucks.

The national movement to curtail drinking and driving has reduced the incidence of alcohol-related crashes to 40 percent and increased the general awareness of the other dangers of drunk and impaired driving. All the States now have age 21 minimum drinking laws which are estimated to have saved over 1,000 lives in 1987. In 1988, national public service campaigns valued at over $1.5 million were conducted by the private sector to encourage responsible drinking and the use of designated drivers. Much of the success of the drunk driving movement is due to the work of concerned citizen groups at the State and local levels.

In addition, research is underway to assess the highway-related safety problems in five high priority national program areas and to develop products which can be used to improve the safety of the highway. This work is essential to meet current needs and the changes now occurring in the driver, vehicle, and roadway areas. The five program areas involve: visibility of traffic control devices, highway safety design practices and criteria, truck-highway safety, information resources, and work zone traffic control.

In order to improve the nighttime visibility of traffic control devices, a concentrated effort is being made to establish minimum requirements for retroreflectivity of signs and markings and develop practical methods of measuring retroreflectivity in the field.
Since single vehicle crashes amount to over 50 percent of the total fatal accidents, an in-depth analysis is underway to determine the causes of these accidents and the roadway and roadside design practices, procedures, and criteria needed to prevent these accidents and reduce their severity.

A special effort is being undertaken to determine the geometric and operational needs of large trucks and to develop revised geometric design criteria and operational guidelines for their safety on existing and future highways. The safety implications of lower speed limits for trucks is also being examined.

Another effort is underway (using accident data from several States) to create an improved, broad based, technological approach for gathering and using accident, geometric, and traffic data to analyze highway safety problems. Improvements in data quality, timeliness, and reduced cost will provide access to the data necessary to identify safety problems, analyze new safety issues, and evaluate safety program effectiveness.

As a final step in the program to disseminate, teach, and implement technology on work zone traffic control, we are planning a second national symposium to summarize research findings on effective signs and markings and on methods and practices for proper planning and management of work zones.

Since 1983, 44 States have established Technology Transfer Centers as part of a national effort to provide city and county highway and transportation employees with the latest technology on streets, roads, and bridges. This mini-transportation extension service, operated through university continuing education offices or special units designed to provide technical assistance to local jurisdictions, has been very successful in raising the safety awareness and knowledge of local personnel. This program serves the needs of approximately 37,000 local highway agencies in the United States.

In addition to the above-mentioned programs and activities of Federal, State, and local governments, elements of the private sector, such as the National Safety Council, automobile industry, auto insurance industry, and other local and national groups, are responsible for continuing efforts devoted to promoting highway traffic safety. These efforts, most of which are educational or informative in nature, serve an important role in the overall traffic safety picture in the United States.

Traffic safety is considered to be a serious issue in the United States of America. We are very much aware that continued diligence must be maintained, and every opportunity for enhancement must be utilized if we are to retain an acceptable level of safety on our streets and highways. You can be assured that this we intend to do.

I hope you have found these remarks informative. It has been my pleasure to share them with you. Thank you for this opportunity.
European Trends in Road Safety Research

David F Cornelius
Director
Transport and Road Research Laboratory (TRRL)
United Kingdom
EUROPEAN TRENDS IN ROAD SAFETY RESEARCH

D F CORNELIUS
Director
Transport and Road Research Laboratory

1. INTRODUCTION

1.1 It is a great honour to have been invited to give a keynote address here in Gothenburg. I have chosen for its title "European Trends in Road Safety Research" - an all embracing and fearsome title to which I shall attempt to do justice. However it is inevitable that I shall fail to recognise fully the seminal ideas and original work of many highly regarded researchers in European countries; to them I apologise without reservation.

1.2 Whilst our main interest must be where we are, and where we are going, it is helpful to understand how we got here, and how effective have been our past research initiatives. Their successful implementation depends crucially upon a receptive policy response; and research in its turn must pay due regard to what is legislatively and socially possible, and what is cost-effective. The reduction of road casualties and their severities must always be the ultimate aim of safety research; intermediate objectives are only worthy if they contribute to this.

1.3 Indeed there is a more general point here. Road safety measures should not be selected just because intuitively they seem likely to reduce accidents - no country has enough money for that - but because they produce measurable benefits in reduced accidents. In the UK we have moved firmly to that principle over past years. It does not always lead to easy judgements; but as a guiding principle it is very powerful. Ask always: how many casualties can we save?

1.4 Despite the ever increasing volume and speed of traffic most European countries have achieved a downward trend in casualties per kilometre of travel in recent years. Such reductions represent the application of effective road safety policies in engineering, education, and enforcement - in nearly every case based on
findings from research. They also reflect: cultural acceptance of restraints such as speed limits, seat belt wearing, blood alcohol limits, vehicle testing and the associated enforcement policies; increased investment in safer roads; improved highway design and traffic control systems; safer vehicles and, above all, political will. It is not possible to identify unambiguously the causal link between remedial measure and accident reduction, because the mechanisms by which accident reductions are achieved often contain a large element of adjustment in societal risk acceptance levels. But with 60,000 deaths and 1,500,000 injuries on European roads each year, the need for research is as great as ever.

1.5 In the UK, a careful assessment has been made of the potential for reducing road accidents in terms of the increased application of accident countermeasures already in existence, and development and application of new ones. This analysis showed that the former might contribute 20% reduction in relevant accidents and the latter some 40%. These estimates have been the basis of the UK target of reducing accidents by one third by the year 2000. Many other countries have set similar targets: The Netherlands aim for 25% reduction over the same period; Austria has its minus 10% campaign; France has a goal of 10% reduction; and Finland and other countries have stated their targets.

1.6 To achieve such accident reductions road safety measures have to advance on a wide front. It is useful to classify road safety measures into those relating to the road surface, the vehicle, traffic engineering and the road user. For convenience I will consider the achievements and likely developments in these four areas as though they were independent and then consider interactions between them when discussing the future direction of research.

2. THE ROAD SURFACE

2.1 Considering first the road surface, the Permanent International Association of Road Congresses (PIARC) set up a Technical Committee on Slipperiness forty years ago and through the years, requirements for skidding resistance to reduce accidents have been discussed in the
context also of emerging concerns about ride quality, energy conservation and noise.

2.2 Early research focused mainly on the development of methods to measure statically the skid resistance of road surfaces, the identification and development of aggregates with high resistance to polishing, and the study of tyre-road interaction. This has led to the production, by several countries, of sophisticated equipment to monitor, at traffic compatible speeds, the surface condition of the road network. The properties of materials that can be used in the surface have been established and countries are considering the best way to apply this knowledge. The legal implications of setting standards of skid resistance are very complex but these have to be addressed if the benefits of the developments in this area are to accrue to all road users. Recently the UK has adopted standards for investigating skid resistance on highways that are appropriate to the volume and type of traffic carried - a measure that should save 1800 casualties each year.

2.3 During the past two decades, various countries have given attention to the development of pervious surfacings as a means of reducing spray, surface water and aquaplaning, thereby improving wet skid resistance and safety. Recent advances in bituminous binders have improved the durability of pervious surfacings which can reduce spray by 90% with consequent savings in accidents.

2.4 Pervious surfacings are already being used in Holland on heavily trafficked roads, and in France and Holland in noise-sensitive urban locations where the reduced noise from interaction between tyres and pervious surfaces provides environmental benefit. Pervious surfacings will be approved for use in UK during the next year following the successful completion of long-term trials. Trials are also being carried out in Austria, Belgium, Switzerland and FR Germany; and research studies are proceeding in Sweden and Norway. Countries which have asphaltic concrete road surfaces need pervious surfacings although many of the qualities of a pervious surfacing can be achieved by using hot rolled asphalt with pre-coated chippings - as used in the UK on high speed roads.
2.5 So far most applications of pervious surfacings have used bituminous materials but the concept is now being extended to concrete roads. Future research will enable bituminous or concrete surfacings to be designed for different types of road to give the optimum balance between skid resistance, noise reduction and maintenance requirements.

3. THE VEHICLE

3.1 Let us now consider vehicles. A road accident may be the result of many contributory factors but it is the vehicle which causes death and injury to persons and damage to property.

3.2 Since the earliest days of motoring, most motor manufacturers, (Volvo of Sweden is a notable exception), have consistently argued that safety does not sell cars. As a consequence they have concentrated on improving those aspects that do, such as performance and reliability and they have been enormously successful. Some safety improvements have followed, for example, improved brakes, lights, tyres and handling, but probably because they were necessary parallel developments so that drivers could use fully the improved engine performance, rather than to improve safety for its own sake.

3.3 Historically vehicle safety has been imposed on manufacturers by the concern of society at the unacceptably high rate of road casualties; it has been realised mainly through Government and, increasingly for Europe, EC regulations. A situation which still holds true today.

3.4 Early Government sponsored research in the field of vehicle safety recognised the manufacturers preoccupation with performance related features and took advantage of it. Work started in the 1950s, mainly by NHTSA in the USA, TRRL in the UK and ONSER in France, and concentrated on, for example, improved tyres, brakes, lighting and visibility thereby improving the accident avoidance capability of vehicles - an area we now know as Primary Safety.

3.5 In the 1960s research intensified in line with the rapid growth in vehicle ownership and
accidents. High hysteresis rubber was shown to improve tyre performance and the first anti-lock brake systems were developed - though only today are they becoming widely available. By the end of the decade it seemed that most of the potential from improvements in primary safety had been realised. However, it was recognised that vehicles which were not properly maintained became increasingly unsafe with age so Governments set regulations concerning vehicle roadworthiness and enforced these through the introduction of annual vehicle testing.

3.6 During this period researchers turned their attention to the design of the vehicle to see how to reduce the level of injury sustained by persons involved in road accidents. Early work on injury prevention (secondary safety) compared the injuries caused by toughened and laminated windscreens in accidents, investigated the potential for injury reduction by padding and altering the layout of the interiors of cars, and studied the feasibility of restraint systems such as seat belts.

3.7 In the mid-1960s work started in the USA on producing the first Experimental Safety Vehicles (ESV). These were mostly very heavy, and costly, being specifically designed to provide high levels of protection for unrestrained occupants in impacts. In contrast motor manufacturers in Europe and Japan who produced smaller vehicles aimed to achieve secondary safety without an unacceptable increase in weight. A scientific study of injury mechanisms provided the rationale to their engineering solutions.

3.8 In 1972 the European Experimental Vehicles Committee (EEVC) was founded with representatives from the Governments of the car manufacturing countries: France, FR Germany, UK, Italy and Sweden, with The Netherlands and the EEC as observers.

3.9 At the London ESV Conference in 1974, the EEVC presented a paper 'The future for car safety in Europe' which proposed a co-ordinated European programme of research and identified the need to concentrate on Secondary safety and protection issues such as accident investigations, improved designs to protect pedestrians and occupants in front and side impacts, and occupant restraint.
systems. The paper was a major landmark in the evolution of car safety in Europe, and the EEVC became the main co-ordinating body for research planning by the European Governments.

3.10 Also at the 1974 Conference, the first European Experimental Safety Cars were shown: by Ford and British Leyland from the UK, Fiat from Italy, Renault from France, Opel, Volkswagen and Daimler Benz from Germany, and by Toyota, Nissan and Honda from Japan. These cars demonstrated a wide range of safety features including early attempts to provide occupant protection in roll-over, as well as front, rear and side impacts, and developing padding and soft steering wheels for head impact protection, passive restraint systems, and pedestrian protection.

3.11 Early European research on injury protection concentrated on protecting unrestrained occupants in front impacts. This led to the development of collapsible and tilting steering columns and crumple zones in order to meet developing EC and ECE regulations, though subsequent research has shown that angled or offset impacts can be more severe in terms of intrusion than head-on impacts. However, by this time EC directives were in force in Europe and, together with the voluntary wearing of seat belts, they provided an adequate degree of protection in front impacts. Additional directives were introduced for manufacturers to fit seat belts in the fronts of cars, and publicity campaigns mounted to persuade car occupants to wear them.

3.12 European countries began to introduce legislation to make seat belt wearing mandatory for the front seat occupants of cars in the late '70s. Research into vehicle safety then turned to providing protection in side impacts - the second most serious cause of deaths and injuries to car occupants. The lead for Europe was taken by the EEVC who were supported by the EC with the aim of avoiding the creation of barriers to trade and developing a draft directive.

3.13 The EEVC proposed a standard for European side impact test procedure in 1982 which led to an extensive European collaborative research programme on the biokinetics of impacts. This in turn led to the development of a European Side Impact Dummy (EUROSID) and the specification of a
Mobile Deformable Barrier (MDB) for use in the test procedure. Final recommendations for a European side impact test procedure were made to the 12th ESV Conference here in Gothenburg last May. These recommendations offer significant potential for reducing the injuries experienced by those involved in side impacts and, it is hoped, will be accepted by the EC as a basis for a new directive.

3.14 The EEVC was also active in other areas such as the development of improved accident avoidance and injury reducing measures for heavy goods vehicles; the feasibility of developing a test procedure to ensure adequate levels of protection for pedestrians who are struck by cars; and revising the EC directive for the level of protection afforded by steering wheels. This last area of concern has arisen because the pattern of injuries has changed following the introduction of seat belt laws. Seat belts protect the driver's chest and prevent ejection but at the expense of the head and face which now swing down to collide with the steering wheel.

3.15 This is a classic example of how an improvement in one area can lead to new problems, and shows clearly the continuing need for research into accident investigation as a precursor to developing injury prevention measures.

3.16 For the future, attention is turning again to frontal impacts, which is still the major cause of deaths and injuries to car occupants. Further work is needed to ensure the protection of pedestrians struck by cars, HGVs and buses; and standards for the protection of motorcyclists need to be developed. Injuries to motorcyclists could be significantly reduced if their machines were equipped with devices such as anti-lock brakes, leg protectors and air bags.

3.17 In such areas vehicle manufacturers are reluctant to take the lead lest they incur cost disadvantages relative to their competitors or expose themselves to public liability. Regulations and directives remain the only sure way of providing improvements for the consumer. Increasing effort is being made by NHTSA and the EEVC to harmonise regulations on both sides of the Atlantic.
The advice and collaboration of European motor manufacturers is sought by Governments in developing proposed legislation. And in view of the long lead times involved in bringing new vehicles to the market place, manufacturers see advantage in taking part in safety-related research which prepares them for new legislation. Since 1987 they have been collaborating in two programmes: PROMETHEUS and DRIVE, both of which are looking at the potential of the new Informatics Technologies for providing improved safety. These programmes offer a new approach. They depart from the tradition of considering the vehicle in isolation, and consider it as part of a complete traffic control system.

4. TRAFFIC SAFETY ENGINEERING

4.1 The road and vehicle are the first two major elements in safety. Now let us turn to the problems of design and control of the road network and how they affect safety. The risks run by road users are influenced greatly by the design and layout of the roads they use, and the management of traffic and pedestrians. In Western European Countries accidents are mostly concentrated on urban and suburban roads, where the major traffic delays also occur. The design and control of urban road systems is thus of key importance.

4.2 Accident numbers and severity can be reduced overall by better design of roads and junctions and encouraging traffic and pedestrians to use safer routes. But as soon as we start looking at the infrastructure we begin to see a rather close relationship between research and policy, both national and local. In most countries local authorities have the direct responsibility for safety engineering measures, supported by the central Governments, and recently reinforced in France and Holland by financial incentive schemes directly linked to casualty reduction achievements. These can take the form, singly or in combination, of area-wide traffic routing strategies, localised traffic engineering improvements and devices for discouraging traffic access and reducing traffic speeds.

4.3 The classical research structure of hypothesis, experiment, and conclusion, followed by policy decision and large scale implementation
is often not possible politically. Many initiatives are put in place and their effects monitored later. Many set out with multiple objectives, of which safety is only one. Moreover, they frequently pose difficult statistical problems, since drivers are almost infinitely resourceful and any measure to change one part of a road network inevitably produces widespread and subtle changes in the traffic patterns elsewhere, with all the accident consequences which follow. Nonetheless there have been some very significant experimental trials of safety schemes over the past decade or so; they have told us much.

4.4 About ten years ago an OECD report set out the principles then thought important and distinguished between: full segregation of pedestrians, traffic, and cyclists; the establishment of road 'hierarchies' (keeping through-traffic to arterial roads, and out of residential areas); and shared areas for vehicles and pedestrians.

4.5 Full segregation was used as far as possible in New Towns in UK in the 1950s and 1960s, and has resulted in low overall accident rates. In the 1970s the emphasis swung towards General Improvement Areas where environmental and safety improvements were combined in existing road systems and some schemes in London showed safety benefits of up to 30%.

4.6 Shared pedestrian - vehicle areas (Woonerven) have been successfully introduced in Holland following experiments in the 1970s and 1980s. Vehicle speeds have been reduced to walking pace by a combination of road design - including raised 'sidewalk-style' pavements across access roads to the shared vehicle-pedestrian areas - and an environment designed to give more emphasis to pedestrian movement. Preferred schemes now use 30 km/h zones, which have also proved successful in FR Germany.

4.7 Schemes implemented in Holland (Eindhoven and Rijswijk), including Woonerven, in the early 80s have successfully changed the balance between vehicles, pedestrians and cyclists in residential areas and have reduced accidents by some 50%; and improvements to the main roads to which traffic was displaced resulted in net accident reductions of 15% on those roads.
4.8 In the UK a major research project was undertaken in the mid '80s in five large towns and cities using low-cost safety engineering to strengthen existing hierarchical systems and to keep traffic out of residential areas. Accidents reduced by about 14% overall, without significant increases in traffic delays. These schemes concentrated on safety. Other countries - France, and Denmark for example - have concentrated on schemes with broader objectives, to improve the environment at the same time as reduce accidents.

4.9 Danish experiments in the 1970s reduced urban accident risks by a range of low cost road and traffic engineering measures (road closures, turning bands, improved pedestrian refuges, and so on) and produced net savings in accidents and casualties. They were followed by another successful initiative in 1985 to reduce the speed and pace of traffic in three Danish towns; the figures so far available are showing a halving of reported accidents. The results of major trials in six towns and cities in FR Germany have reduced accidents by 12% with considerable benefits to pedestrians and cyclists, for whom the risk dropped by 30-40%.

4.10 The OECD is currently drawing together experience on some 37 schemes in nine European countries, Canada and Japan. The general pattern is that with sufficient incentives for cooperation between authorities and local groups, schemes can be achieved which swing the balance more in favour of vulnerable road users - pedestrians and cyclists - and that as this balance is changed so the accident benefits increase.

4.11 A key feature emerging in all of these schemes has been the importance of the views of local people - politicians, residents, and businessmen - and the will to tackle what is often an entrenched balance between mobility and safety. Changes in mobility are seen immediately after schemes are installed, safety benefits take time to accrue.

4.12 Despite the scale of the problem the trend over the past decade has been generally towards greater quantification. Research has begun to build up a picture of the effectiveness of
different measures - an essential output if we are to help policy makers to invest money to the greatest effect.

4.13 One emerging area of importance is the measurement of accident risk and how good road design can change it. Since the early 1980s there has been notable progress in determining relations between accident frequencies, traffic and pedestrian flows, and the road design for some particular components of the road network. In 1988 an International Group on Road Accident Risk was set up between 14 countries, 8 of them European, to develop accident risk relations more widely.

4.14 Substantial studies of accident risk and its relation to road and junction features have been conducted in a number of countries, including Canada, Finland, France, Israel, Sweden, FR Germany and UK. Such studies allow general design improvements to be identified for use with traffic assignment models to predict area-wide accident frequencies. This will become more important as congestion increases with traffic growth in towns; and casualty savings will have to be achieved against increasingly difficult operational requirements. The inclusion of accident risk into traffic appraisal methods for urban roads is a major challenge for coming years and will in the longer term prove very formative.

4.15 Research has a vital role to play in the two other major themes that are likely to shape the future in this area. The first is traffic 'calming' by which the speed and tempo of traffic within city centres, suburbs, and residential areas are reduced, so as to save accidents and to make living and working areas more pleasant. Studies in a number of countries - Holland, France, FR Germany and UK, among others - will lay the basis for the types of road environment we shall see in the longer term. Careful monitoring and experimentation will be essential.

4.16 The second theme is that interactions between the vehicle, the road and the driver made possible by rapidly advancing technology will enable traffic to move more efficiently through existing and new roads; and can be used creatively to reduce accidents. By routing vehicles away from areas of greatest risk - such as shopping areas during times of greatest pedestrian activity -
significant safety benefits should be achievable. Similarly route guidance systems which reduce wasted travel should also save accidents. This is all very dependent on the development of technology, which is proceeding rapidly, and the political will to make safety an objective in these new and promising systems. Research should seize the opportunity to provide the essential link in this challenging area.

5. THE ROAD USER

5.1 I now wish to move on to the role of the road user in accidents. No matter how well we design the road surface or improve the primary safety features of our vehicles, no matter how effectively we manage traffic for safety, individual road users will still make mistakes whilst driving, riding or walking which will result in an accident. As a number of studies have suggested, the contribution of human error to road accidents is considerable so I now offer a few thoughts on the 'human factors' component.

5.2 Road accidents are a major public health problem. But unlike cholera or heart disease, the road safety 'epidemic' consists of the aggregation of hundreds of thousands of separate 'accidental events' which are not seen to have a common diagnosable 'cause'. Because of this road accidents form a health problem which is too often regarded by members of the public as being unavoidable - a fact of life which they have to live (or die) with. We need to raise awareness of road safety issues and help the public realise that by modifying their individual behaviour they can help to cure what has been called 'the greatest epidemic of our time'.

5.3 Public awareness is a useful barometer of how effectively the road safety message is getting across. For example, a recent UK survey - a repeat of one commissioned in the late 70's by the International Driver Behaviour Research Association (IDBRA) - showed that the public's view of some road safety issues has changed markedly for the better over the last 10 years. Public perceptions of the driving environment, and behaviours such as close following, speeding, drinking and driving, reflect increased concern for road safety - a concern which in relation to
drink/drive is reflected in the falling proportion of fatalities with blood alcohol concentrations above the legal limit.

5.4 How then should governments aim to influence people on road safety matters, and what is the role of research? Perhaps I can best illustrate this by considering three specific measures - road safety education, driver training, and reducing drinking and driving.

5.5 In 1974 an ECMT report showed that road safety education in primary schools was compulsory in ten of the European countries reviewed; but that does not mean that its delivery is guaranteed. There are both technical and institutional difficulties in providing adequate road safety education in schools and plenty of scope for improving our performance in this respect.

5.6 In the UK where safety education is not compulsory, recent research has demonstrated the urgent need to improve the arrangements for road safety education in schools. My Laboratory is now working with teachers, education advisers, road safety officers, the Police and health education officers to devise guidelines for good practice which will be assessed in the next three years in trials in the city of Sheffield and in parts of the county of Hertfordshire.

5.7 Within the EEC, road safety education is seen as part of health education. Last year the Council and Education Ministers called for an initial report - due in 1991 - on policies in member states and at Community level. The EEC resolution emphasised that health education (and therefore road safety education) should first be delivered in the family setting. For some years already traffic clubs for pre-school children have been operating in Norway, Denmark and Sweden. A similar traffic club - sponsored by an insurance company - is soon to be launched in one region of the UK and my Laboratory will be monitoring its effectiveness.

5.8 In their middle to late teens youngsters usually progress to becoming a moped or motorcycle rider or a car driver, and the starting point for this crucial transition should be driver/rider training. Driver training and testing
requirements vary considerably within Europe so this year the EEC has proposed a detailed specification for a learner driver syllabus and minimum requirements for the content and length of the driving test. This will affect what individual countries provide by way of training, and research will be needed to assess the effectiveness of such changes.

5.9 Some European countries already have research programmes on driver training and testing. In France for example, research has focused on a special 'apprentice' driver training scheme for 16-18 year olds. This scheme has - at least in the short term - produced promising results reflected in higher pass rates in driving tests and lower accident rates in the first two years of driving.

5.10 In Britain a large longitudinal cohort study involving 30,000 drivers is investigating the relationships between the methods used to learn to drive, performance in the driving test, the development of driving skills and subsequent accident involvement rates. This type of research supplemented by studies of the training methods used by instructors in driving schools should provide a sound basis for improving the standard of driver training in the UK.

5.11 Driver training is a crucial part of achieving the skills which are needed to avoid making errors on the road. However, the risks associated with driving are enormously increased if the driver is under the influence of alcohol as pioneering studies in Sweden and the USA clearly showed. Despite the extensive legislative measures that have been introduced in European countries over the last few decades - led by Scandinavian countries - drinking and driving as a major road accident problem is still very much with us.

5.12 The limitations of the present drink/drive countermeasures are revealed in the number of convicted drinking drivers who are re-convicted. In England about 10% of convicted drivers are re-convicted within a three year period. Some 20 years ago the problem of re-conviction offences was tackled in FR Germany and the USA by the establishment of driver rehabilitation courses; Australia and Holland followed a little later. The experience in FR Germany and the USA suggests
that rehabilitation produces substantial reductions in reconvictions both for first offenders and multiple offenders.

5.13 A recent review of road traffic law in the UK recommended that courses to rehabilitate drink drive offenders should be tried experimentally. Some rehabilitation work among repeat offenders is already undertaken on a relatively small scale by the probation services and charities concerned with alcohol abuse. In its response to the traffic law review, the UK government accepted that a large scale trial was essential, though to implement such a proposal in England will require the law to be changed - and this will obviously take time. Meantime it is intended to study the effectiveness of existing courses, and to explore the possibilities for conducting preliminary trials in Scotland where the law is more flexible. Again, the emphasis for the research community in this kind of work is to demonstrate as unambiguously as possible that such road safety remedial measures - which are obviously very costly - do in practice reduce accidents.

6. THE FUTURE DIRECTION OF RESEARCH

6.1 Now we need to look to the future. In doing so I would like to draw attention to the need for all research to be underpinned by more fundamental research aimed at improving our understanding of the mechanisms involved in accident causation. There are four steps to the successful implementation of an accident countermeasure: (i) identifying the problem, (ii) understanding the mechanisms involved, (iii) designing and piloting the countermeasure, and finally, (iv) measuring its effectiveness in large scale trials. Although often in the past it was thought possible to move straight from problem identification to treatment, more and more - as the obvious countermeasures are implemented - it is becoming necessary to understand the basic mechanisms involved.

6.2 Such understanding can only be obtained by means of studies of the interactions between the road, the vehicle, the physical and psychological characteristics of road users and the social context in which the accident occurs.
6.3 Up to the present time, each individual vehicle is driven on the roadnetwork by an individual driver who is responsible for his or her own decisions, actions and behaviour such as time of departure, route choice, and conforming with speed limits. Traffic control authorities have little feedback on the consequences of such individual decisions and what might be done about the problems that they cause.

6.4 But traffic and congestion are increasing rapidly, and technology has advanced to the stage where traffic responsive route guidance systems are considered viable in many European countries. Two closed loop control systems are under test, in FR Germany and the UK, and an agreement between these countries has been reached to ensure that they are compatible. These systems provide guidance advice to individual vehicles, continuously and automatically monitor the consequences of that advice to detect congestion areas, and change the advice as necessary so as to distribute traffic on the available roads as efficiently as possible.

6.5 These systems require two way communication between an infrastructure of roadside equipment and individual vehicles. This communication link could be used for other purposes also, such as auto-tolling, providing drivers with road condition, weather, other hazard and speed limit information, as well as enabling the driver to communicate with others directly from his vehicle.

6.6 Moreover, the advances in technology which make these systems feasible, also provide opportunities for increasing the level of intelligence contained within the vehicle itself. Some examples include: intelligent cruise control systems that could automatically follow the vehicle in front at a safe distance, accelerating and braking automatically as necessary; systems for monitoring road conditions and tyre-road adhesion, and automatically limiting the vehicle performance to within safe limits; systems for electronic communication directly with neighbouring vehicles so that drivers could be advised when the proximity of other vehicles would prevent overtaking or junction turning manoeuvres from being conducted in safety; driver tutoring aids that would monitor the drivers performance and both advise him of any deficiencies and
constrain the vehicle's performance within his capabilities to drive; self policing systems that would disable, or even report, a vehicle that was not functioning correctly, or whose driver had not fastened his seat belt, or who was 'over the limit' for alcohol.

6.7 All of these, and many other promising and exciting possibilities, have been recognised within Europe, and two main programmes have been established to pursue them further. They are called PROMETHEUS and DRIVE.

6.8 PROMETHEUS (Programme for European Traffic with High Efficiency and Unprecedented Safety) is a 7 year programme of pre-competitive research with total costs in the region of 650MECU. It was started in 1987 under the EUREKA framework for collaboration by European industries. PROMETHEUS was initiated by the major European motor manufacturers and aims to exploit recent advances in the Informatics technologies for use in the next generation of motor vehicles. Improved Primary safety systems are a major target, including obstacle detectors, car following aids, enhanced vision systems, methods for communication between vehicles as well as between vehicles and the infrastructure, and co-operative driving systems.

6.9 DRIVE (Dedicated Road Infrastructure for safe Vehicles in Europe) is a parallel activity initiated in 1988 by DG XIII (Telecommunications, Information Industries and Innovation) of the EC. This programme, extends over a period of 3 years and will cost about 120MECU. It is essentially collaborative and pre-competitive research to exploit the Informatics technologies for improving traffic and safety - but with more emphasis on the infrastructure, the requirements of governments, and community benefits.

6.10 PROMETHEUS and DRIVE will continue into the 1990s and are likely to lead to developments in Primary safety such as obstacle detection and collision avoidance, and to new driver information and traffic control systems. The potential benefits from the primary safety aspects alone could be very large. Various attempts have been made to evaluate them, perhaps the most conservative from my own Laboratory which suggests that major benefits can be expected from aids for
speed keeping, driver condition monitoring, carriageway keeping, tutoring, enhanced vision and overtaking - each of which would on its own be capable of reducing accidents and casualties by at least 5 per cent. Estimates from elsewhere are more optimistic so the potential is significant, although careful monitoring will be needed to see how the devices are used and if they are indeed an aid and not a liability to the driver.

6.11 Substantial safety benefits might also result from the reduced anxiety and frustration that can be expected amongst drivers using improved information and guidance systems. Also from the reduced risk that these systems can provide by selecting routes with low risk of accidents, and by reducing exposure by saving wasted time and distance driven. In tandem with traffic calming techniques much could be achieved.

6.12 I have drawn attention to activities and trends in safety research on roads, vehicles, traffic and road users. Together they form the "system" which should ensure the movement of people and goods efficiently, effectively, economically and safely.

6.13 The fields of research that I have discussed are coming together in European research activity, notably DRIVE and PROMETHEUS. Developments in informatics technology over the next decade or two will lead to a fusion between vehicle safety techniques, the road infrastructure (links and control systems) and the user. European countries are becoming more involved in international research programmes, and moving from competition to collaboration in a synergistic process. The application of scientific research to road safety is expanding almost explosively and has the potential to lead to advances in the road transport system, road safety and road safety research beyond our most adventurous expectations.

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Need for Road Maintenance Research in the Nordic Countries

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ABSTRACT

Government allocations for road maintenance in the Nordic countries are insufficient, at the same time as demands on roads are growing steadily. Traffic has increased heavily in recent years. Adaptation to the European Community's weight regulations at the beginning of the 90s will further increase wear and tear on roads.

Increased loads and an ageing road system, together with inadequate funds for road maintenance, impose far-reaching demands on research. More durable pavements need to be developed. Methods must be found for correct dimensioning of strengthening and overlays. Determined efforts are also required in building up know-how of the degradation of roads. A great deal of research is needed regarding the qualities of roadbuilding materials, both old and new. The effects of frost on roads and maintenance requirements is a further topic requiring study.

In general, major research efforts are needed before we achieve economically optimal road maintenance in the Nordic countries.
Need for Road Maintenance Research in the Nordic Countries

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1. INTRODUCTION

Government allocations for road maintenance in Sweden have been inadequate for a number of years. The same situation prevails in other Nordic countries. Yet demands on the road network are steadily growing. In Sweden the volume of traffic has increased by about 6% annually in recent years. Adaptation to the European Community’s weight regulations in the early 1990s will increase wear and tear on our roads still further.

Many of the roads in Scandinavia were built in the 1950s and 1960s. Government allocations for the construction of new roads have therefore become smaller and in Sweden they are now less than half of what they were at the end of the 1960s. As a result, large parts of the road network are now beginning to show signs of age and therefore require more maintenance.

Increased loads and an ageing road system, combined with inadequate funds over a succession of years, call for major efforts in research. Wearing courses that are more resistant to wear must be developed. Methods must be found for correct dimensioning of strengthening and overlays. Major resources must also be allocated to research about the causes of road deterioration. In general, major research efforts are required to attain the goal of economically optimal road maintenance in the Nordic Countries.

2. WEARING COURSES

Studded tyres are widely used in all the Nordic countries except Denmark, where the proportion of studded tyres is low. In southern Sweden the frequency of studded tyres is 50-70% while in northern Sweden, Norway and Finland it is as much as 90%. This means that major efforts are required to develop durable wearing courses, particularly for roads with high traffic volumes.

2.1 Asphalt concrete

Research is needed to develop a new mix design technique which describes the functional properties of the asphalt layer better than the present method. Research on mineral aggregates with good abrasion resistance must be continued. Research into the effect on bitumen of different additives such as polymers, rubber and fibres is also required.
2.2 Surface treatment

Surface treatment is carried out to a large extent on roads with a low traffic volume. The technique of proportioning binder and mineral aggregate needs to be developed so that problems of stripping and bleeding are reduced. Research is also required on suitable binders with different additives.

One of the problems associated with surface treatment is the way it is applied to the road. Many road users complain about dust and stone chippings thrown around by the wheels of other vehicles. The technique of applying surface treatment requires development to minimize inconvenience for road users.

2.3 Recycling

Knowledge about methods of recycling asphalt pavements needs to be improved in Sweden. The use of cold recycling is fairly limited, while hot recycling is utilized to a greater extent. Research efforts are especially needed in regard to methods of analyzing old recycled materials.

2.4 Concrete pavements

In Sweden, as in the other Nordic countries, concrete pavements have not been constructed to any great extent in recent years. Owing to maintenance problems involving serious unevenness and joint erosion, ten years have passed since the last concrete pavement was built in Sweden. Following the development of high-strength concrete, coupled with the increased use of studded tyres and higher loads, fresh experiments are now being carried out with concrete pavements. Most progress has been made in Norway, where concrete pavements have been used for several years on roads with a high volume of traffic. A decision has been reached in Sweden to conduct two major experiments with concrete pavements. Research into bases for concrete pavements is necessary in order to avoid uneven settlement. Much research and development work is also called for in regard to maintenance so that the new concrete pavements do not become as uneven as the older concrete roads we have in Sweden.

3. OVERLAYS AND REHABILITATION

Many of the roads built in the 1950s and 1960s are now in such a state of deterioration that they are in need of rehabilitation. Inadequate funds for road maintenance and increasing traffic loads accentuate the need for strengthening measures. The necessary research concerns the dimensioning of overlays and reinforcement measures, as well as evaluating the effects of different methods for strengthening roads.

3.1 Dimensioning of overlays and reinforcement

Research is required concerning the study of existing roads, traffic forecasts and design models for dimensioning purposes.
Included in the study of existing roads are bearing capacity measurements with FWD (Falling Weight Deflectometer), sampling and inspection, as well as a study of the need for measures concerning drainage of the road structure. Input data for the sizing design model requires research into the fatigue and deformation properties of different materials.

Long term pavement performance are being followed up on a large number of observation stretches in Scandinavia. Methods of measurement used for this include the Laser RST (Road Surface Tester) vehicle. In a recently developed version, the RST vehicle can also be used for measuring texture and cracks, in addition to ruts and unevenness of the road surface. Data obtained by these measurements can subsequently be used for dimensioning of overlays and strengthening.

3.2 Effect of strengthening measures

Several different methods of strengthening roads have been developed, including the application of overlays on existing roads, increasing basecourse thickness, mixing crushed aggregate into existing basecourses, and stabilizing old pavement structures with cement and bitumen. It is extremely important for more research to be done into the long-term effects of these strengthening measures. Questions requiring study include "How far do the different measures increase the bearing capacity of the road structure?" Even more important is "How long does the effect last?" In regard to cement stabilization, for example, we know that the higher bearing capacity of the road may diminish within five years or less.

4. OPTIMAL ROAD MAINTENANCE

Through more research on how roads deteriorate due to the effects of traffic and the weather, it should be possible in the future to develop a system of optimal road maintenance. The first step in this direction has been taken with the observations of long term pavement performance on a large number of stretches in the Scandinavian countries that are being carried out in cooperation with the LTPP programme initiated by SHRP. Much research is also required in regard to the properties of both old and new roadbuilding materials. In the Scandinavian countries with their cold climate and (as a result of the Ice Ages) widely varying types of soil in the subgrade, major research efforts are also needed to ascertain how frozen ground affects the roads and their maintenance requirements.

To sum up, a great deal of research will be necessary before we reach an economically optimal system of road maintenance in the Nordic Countries.
The Installation Requirements and Test Procedures for Safety Features on Australian Roads

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THE INSTALLATION REQUIREMENTS AND TEST PROCEDURES OF SAFETY FEATURES ON AUSTRALIAN ROAD

SHORT ABSTRACT

Australia installation and testing requirements closely follow the current American standards. However our vehicle fleet is more closely aligned to the European scene. This paper discusses Australia's present guard fence installation standards and outlines recent Australian testing of guard fences, light standards and so on. Subtle differences in the design standard used by the various states are also discussed. Using details of our vehicle fleet, suggested vehicle masses for testing are proposed.
1. INTRODUCTION

The proper design of safety barrier systems should incorporate characteristics of the vehicle fleet as well as attributes of the driving population. This paper describes the Australian road network and the demographic characteristics so that the reader can compare the road safety engineering task with that in other countries. The dimensions of the vehicle fleet and the likely vehicle speeds are then used to suggest suitable impact conditions for Australia. Aspects of current and future hardware designs are also discussed here.

2. THE AUSTRALIAN ROAD NETWORK

The Australian roadways system and demographic conditions are unique. Australia has a population of about 16 million people and an area of $7.6 \times 10^6$ km$^2$. The overall population density is about 2.1 persons/km$^2$ and is much less than the densities in other developed countries (refer to Table I). Australians are becoming progressively more suburbanised; some 62 per cent of the population reside in capital cities. The population density of the great part of rural areas is less than 0.04 persons/km$^2$.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>DEMOGRAPHIC DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>U.K.</td>
</tr>
<tr>
<td>Area ($10^3$ km$^2$)</td>
<td>224</td>
</tr>
<tr>
<td>Population ($10^6$ persons)</td>
<td>56.7</td>
</tr>
<tr>
<td>Population density (persons/km$^2$)</td>
<td>233</td>
</tr>
<tr>
<td>Road length ($10^3$ km)</td>
<td>351</td>
</tr>
<tr>
<td>Motorway ($10^3$ km)</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Australians are very mobile. Vehicle ownership in Australia is about 42 passenger cars per 100 persons. This is similar to the value of 50...
passenger cars per 100 persons in the U.S.A. The average distance traveled in both countries is about 16,500 km per annum.

Australia's road network is about 760,000 km in length giving a road network density of about 0.1 km/km² compared with 0.7 km/km² in the U.S.A., 1.5 km/km² in the U.K. and 0.3 km/km² in Sweden. In 1975 about 115,000 km of the rural road network was used to provide access to major cities and towns (Fry et al 1976). About 0.3 per cent of this rural network had separate carriageways for each direction (i.e. divided roads).

In 1983 there was about 1086 km of divided rural road and about 1765 km of divided urban road with a further 177 km of Freeway or motorway. Much of the urban divided road system has an arterial road function with considerable access to and from abutting properties and roads. These urban arterial roads cannot be conveniently protected with a median barrier. The divided rural road system and the urban freeway system are high speed facilities and constitute about 0.12 per cent of the road network (NAASRA 1984a). Hence, the Australian high speed road system consists predominantly of two-lane rural road with only short lengths of divided road or freeway.

Since 1983, there has been a reduction in Australian Federal Government funding and even if this funding remains static at 1987/88 levels, there will still be a reduction in the amount of effort in new road works (NAASRA 1987a). Therefore, Australia's road network is not expected to be extended significantly in the foreseeable future. There is expected to be continued duplication of rural roads which may require median barrier protection. It is estimated that between 45 and 150 km per year will be duplicated depending on road funding policies.

The traffic carried on these divided roads is expected to increase dramatically. In 1981 the 4 per cent of the duplicated national highway carried 26 per cent of the traffic. This trend is expected to continue with the divided road system carrying about 9600 million vehicle kilometres in 1991 (NAASRA 1984b). The road system will continue to have more traffic as the number of vehicles on register and the total distance travelled continue to increase (NAASRA 1987a).

A consequence of this increased traffic is the growing need to make the road system safer. The lack of construction of new roads puts ever more pressure on the existing system. There will be a continuing and increasing need for improved safety standards on both rural divided and undivided roads. This will result in more safety barrier protection on the outer verge, and on the median for divided roads. The increase in traffic will also require more traffic lanes. Verges and medians will be narrowed to allow for these additional lanes. Again this will put
pressure on the road safety system and require the use of safety systems that operate in these locations.

3. THE AUSTRALIAN VEHICLE FLEET

The Australian passenger car vehicle fleet has been changing over recent years. The fuel crisis in the 70's lead to increased sales of smaller vehicles. Since this time, the mass of the vehicle fleet has been increasing. Australians are now preferring to buy larger cars than they did in the 70's.

The Australian vehicle manufacturers are now producing "world cars." These vehicles are essentially the same as others available in Japan, Europe or America. This "world car" concept has caused vehicle fleets to be similar in many parts of the world. Figure 1. gives the proportion of new cars with tare masses less than the values indicated. Whilst, the data is only available for the last 7 years it does indicate that there has been a marginal trend to larger vehicles during this time. Table II lists the approximate median and 85th percentile passenger car vehicle masses. Whilst there has been an increase in mass, over the 5 year period the median vehicle mass has increased by 140 kg and the 85th percentile by 100 kg. In comparison to the loadings that can be expected in these vehicles these differences are slight. The 95th percentile value is close to 1.5 t throughout the period. Thorensen and Wigan (1988) have demonstrated that an analysis of the mass of vehicles on register was not able to establish "a significant downsizing effect". This is contrary to the U.S. scene where Wood (1983) indicated that there has been significant downsizing.

![Figure 1. Distribution of the tare masses of new vehicles](image-url)
TABLE II

<table>
<thead>
<tr>
<th>Year</th>
<th>50th percentile tare mass</th>
<th>85th percentile tare mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>83-84</td>
<td>1.07</td>
<td>1.34</td>
</tr>
<tr>
<td>84-85</td>
<td>1.09</td>
<td>1.36</td>
</tr>
<tr>
<td>85-86</td>
<td>1.12</td>
<td>1.36</td>
</tr>
<tr>
<td>86-87</td>
<td>1.16</td>
<td>1.39</td>
</tr>
<tr>
<td>87-88</td>
<td>1.18</td>
<td>1.40</td>
</tr>
<tr>
<td>88-89</td>
<td>1.21</td>
<td>1.41</td>
</tr>
</tbody>
</table>

The passenger car vehicle fleet in Australia is similar to the sub-compact sedan outlined in Michie (1981). The effect of a smaller vehicle fleet is discussed by Viner (1984) and Bryden and Fortuniewicz (1986). They independently concluded that the smaller (lighter) vehicles may be more frequently involved in overturning accidents. Viner indicates that this increased frequency implies a greater use of safety barriers. Improved guard fence designs may also be required to better redirect these smaller vehicles. Bryden and Fortuniewicz indicated that the current U.S. barriers performed better with the mid-sized vehicles.

4. VEHICLE SPEEDS

Vehicle speeds on rural roads are generally high. Fry and Thompson (1980) reported that the mean speed of cars on rural roads in Victoria was 98 km/h when the speed limit was 100 km/h. The 85th percentile speed was 109 km/h. On urban roads the mean speed is less than the statutory speed at the higher legal speeds but significantly greater than the legal speeds for lower speed areas. Refer to Table III

A design impact speed for urban freeways and for rural roads should be greater than the 85th percentile speed. A value of 110 km/h to 113 km/h (or 70 mph) are suggested values.

5. SAFETY BARRIERS USED IN AUSTRALIA

Australian road authorities have tended to use American safety products in the past. There are some moves now to use of techniques from other continents. The different types of safety barriers used in Australia are discussed below.

5.1 Semi-rigid steel barriers

These barriers consist of a steel beam attached to steel or wooden posts. The most common beam type is the standard "Armco" steel in section.
mounted at a height of 680 mm to 730 mm above the ground, as shown in Figure 2 from NAASRA (1987b). The Road Construction Authority in Victoria still recommends the use of a W beam mounted on blocks at a height of 750 mm and with a rolled steel rubbing rail under the main rail. This guard fence would be used in high speed, high flow situation where the maintenance is not considered to be a problem (Troutbeck 1977).

The choice of timber or steel post is made on economic grounds. Although, it is recognised that a steel post in a concrete footing increases the bending moment at grade and increases the possibility that the post will develop a plastic hinge and allow the barrier to be forced to the ground. The steel post dimensions are usually a channel 178x76x4.5 mm or 178x76x6.0 mm posts.

TABLE III

FREE SPEED DATA
from Thompson and Fry (1980)

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Number of sample sites</th>
<th>Mean speed (km/h)</th>
<th>85th percentile speeds (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cars</td>
<td>Rigid Trucks</td>
</tr>
<tr>
<td>Rural Victoria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed limits:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cars = 100 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCVs = 65 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>98</td>
<td>78</td>
</tr>
<tr>
<td>Urban Victoria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed limits:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cars = 100 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCVs = 65 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>92</td>
<td>73</td>
</tr>
<tr>
<td>Urban Victoria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed limits:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cars = 75 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCVs = 65 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>72</td>
<td>59</td>
</tr>
<tr>
<td>Urban Victoria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed limits:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cars = 60 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCVs = 50 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>66</td>
<td>59</td>
</tr>
<tr>
<td>Rural New South Wales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed limits:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cars = 100 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCVs = 80 km/h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>102</td>
<td>77</td>
</tr>
</tbody>
</table>

HCVs = Heavy Commercial Vehicles
Figure 2. Semi-rigid guard fence recommended by NAASRA (1987b).

Although, the steel W beam on strong posts is the most common, there are some installations that have used either a steel box beam (system G3 in AASHTO, 1977) or have used the 'tensioned' guard fence as designed and tested by Jehu and Pearson (1972). Neither of these systems have been used extensively. The tensioned beam is slightly more difficult or involved to install and current practices tend not to include this type of installation (NAASRA 1987b).

There are slight differences between the hardware standards used by the various Australian State Road Authorities. In Victoria, the beams are 5.0 m long with posts every 2.5 m. In other states, 3.81 and 4.0 m lengths are used. There are also some differences between the main fixing bolts and the degree and type of galvanising. From field experience, these changes have had only minimal effect on the barrier's performance.

5.2 Rigid barriers

The New Jersey shape concrete (median) barrier is certainly the most common rigid barriers. It is now commonly used in the narrower medians. The ease of maintenance and zero deflection are seen as its major advantages.

The New Jersey barrier is usually cast in-situ or precast. There has been some slip forming of the barrier but this is usually considered to be more difficult to obtain a satisfactory finish and profile. Slip forming is now no longer a common technique.
5.3 Moveable Rigid Barriers

With the development of pre-cast rigid barrier, there are now designs of moveable barriers which rest on the pavement and move laterally when impacted. The usual design is to attach one barrier to its neighbour. When a vehicle hits a length of this barrier it remains intact and the impact area allows for other errant vehicles to slide along an essentially continuous face without any one block protruding in front of others. Consequently, the block to block connections are important elements.

The Tric Bloc system (Troutbeck 1988, Turbell 1981 and Figure 3.) have been successfully used in Australia. Some road authorities are continuing to use pre-cast blocks with connections similar to those described in Beason and Ivey (1985). Moveable barriers are likely to be used more frequently in Australia.

![Figure 3. Tric Bloc and New Jersey Barriers.](image)

5.4 Flexible Barriers

Simple post and cable barriers have been used on Australian roads. However in the last 15 to 20 years their use has been discouraged. There
is now a need for an acceptable flexible barrier design to be re-introduced into Australian practice.

5.5 Guard fence terminals and transitions

The AASHTO (1977) recommended guard fence terminals and transitions are used in Australia. The Breakaway Cable Terminal (designs GET 1 and GET 2 in AASHTO, 1977) are the most commonly used transitions. For some major W beam or concrete median barrier installations an acceptable energy attenuator may be used.

5.6 Attenuators

Although, energy attenuators have not been used extensively, many road authorities have installed the Hi-Dri cell system (C5 in AASHTO, 1977)
(a) at isolated freeway exit points
(b) to protect an exposed median barriers end or
(c) at a bridge pier and the like.
There have also been installations of the AASHTO C4 sand filled plastic barrels.

6. FUTURE AUSTRALIAN TRAFFIC BARRIER REQUIREMENTS

6.1 Flexible Barriers

There is a growing perceived need for a flexible barrier which would offer greater occupant protection through decreased decelerations. A cable barrier is considered appropriate as it offers the flexibility and is less visually obtrusive. There is concern about the possible excessive loading of cables on the 'A' pillar of a car. There is also a greater possibility of vehicles overturning. Viner (1984) indicated that 3.9 per cent of the collisions with a Californian metal beam (MB4W) median barrier in 1979 resulted in vehicles overturning. The rate of overturnings from collisions with the median barrier cable type were some 60 per cent greater in the same year. Viner (1984) also points out that the median cable barrier is no longer used on new construction. Nevertheless, it would be suitable to use of a more flexible barrier with greater deflections on some freeways with moderate to light traffic volumes and wide medians.

6.2 Semi-Rigid Barriers

The Australian passenger car fleet closely resembles the European fleet although our heavy commercial vehicle fleet can be very large. In the greater part of Australia, the north-western region, it is not uncommon
for truck trailer combinations to be 50 m long and have a gross combination mass of 120 t. It is considered almost impossible to stop or redirect these vehicles. Fortunately, these vehicles operate on roads where safety barriers would not normally be required. For the eastern seaboard heavy commercial vehicles are generally less than 38 t with the median truck size on register about 4 t. Vehicles of about this mass can be redirected using the bridge parapet designs in AASHTO (1977). However there is also be a need for a more substantial road-side and median barrier in some critical locations. The "Thrie Beam" section is considered to be a viable alternative (NAASRA, 1987b) as Ivey et al (1982) have demonstrated its suitability for re-directing a range of vehicle types.

6.3 Temporary Barriers

Some Australian road and local government authorities are now requesting that temporary site works be protected with a suitable traffic barrier. Thus there will be a growing demand for temporary barriers. The requirements will be for barriers which are able to redirect errant vehicles with the standard tests (Michie, 1981) and yet will not be too hazardous if impacted by a slow moving vehicle head-on. Of course their prime attribute will be their relocation potential. Barriers which can be conveniently placed around curves are preferred. Their lateral movement on impact should not be excessive (say less than 1 m) this should allow an effective pedestrian walk-way behind the barrier. The Tric Bloc system is considered to be one of the satisfactory designs.

7. GUIDELINES FOR THE INSTALLATION OF SAFETY BARRIERS

As in AASHTO (1977), the Australian guide (NAASRA, 1987b) uses a cost effective considerations to establish whether guard fences should be located at a particular location (Troutbeck, 1983). The decision to install a guard fence is affected by the frequency of collisions, which is in-turn related to traffic volumes, and to likely accident severity. The decision to install a barrier is not made on the likely accident severity alone. If a consequences of a single driver colliding with a object would be more be more hazardous than if he collided with a guard fence, then this fact alone would not warrant the installation of the guard fence.

NAASRA (1981) is a consensus document which attempts to outline principles and not to be too restrictive on individual state practices. Consequently, it tends not to give as much guidance as does the AASHTO guide. Similarly, the individual state practices may be quite different to the NAASRA guidelines. Generally the Australian guidelines have been based on U.S. practices and research.
8. FULL SCALE TESTING OF BARRIERS AND LIGHT STANDARDS

There has been few full scale tests of safety barriers in Australia. A road authority may embark on a short testing program to confirm that a slight modification to an approved U.S. design is acceptable but this uncommon. Australian Road Authorities have generally accepted U.S. guard fence designs as being suitable for Australian conditions.

An exception has been the preliminary full scale testing of a mechanically transportable concrete barrier shown in Figure 4. Rourke (1988) described these full scale tests and results produced the test results shown in Table IV. These tests could only be described as qualitative and demonstrated that the design was suitable and should be tested further. The intention of the Australian tests was to establish the potential for this barrier. However, the NCHRP 230 test conditions (Michie, 1981) were seen as suitable test conditions. Further tests on this barrier were conducted in California during 1986 and reported by Nordlin (1987).

Davis (1981, 1983) and Barton and Freeman (1988) describe two series of full scale on lighting standards. In both cases a 1200 kg vehicle was used and the impact speeds ranged from 17 to 58 km/h for frontal impacts and about 35 km/h for side impacts. Although, it was recognised that these were low energy collisions, the appraisal of the results were examined using the NCHRP 230 requirements. Unfortunately, the accelerations were averaged over 50 ms instead of the now preferred 10 ms period (Michie, 1981). Nevertheless the intention has been to conform to the U.S. safety barrier test procedures.

![Figure 4. Profile of the moveable concrete median barrier used in the Australian tests. (from Rourke, 1988)
TABLE IV

TEST RESULTS FROM PRELIMINARY FULL SCALE TESTS
ON A MOVEABLE BARRIER.
from Rourke (1988)

<table>
<thead>
<tr>
<th>Car mass (t)</th>
<th>Angle of impact (°)</th>
<th>Speed (km/h)</th>
<th>Barrier deformation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>7.5</td>
<td>56</td>
<td>50</td>
</tr>
<tr>
<td>1.0</td>
<td>7.5</td>
<td>72</td>
<td>75</td>
</tr>
<tr>
<td>1.0</td>
<td>7.5</td>
<td>88</td>
<td>178</td>
</tr>
<tr>
<td>1.0</td>
<td>15</td>
<td>56</td>
<td>203</td>
</tr>
<tr>
<td>1.0</td>
<td>15</td>
<td>72</td>
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<tr>
<td>2.0</td>
<td>15</td>
<td>88</td>
<td>305</td>
</tr>
</tbody>
</table>

9. CONCLUDING REMARKS

Australia has a large country with long road lengths for each head of population and for each registered vehicle. The protection of all errant vehicles under these conditions is costly. The long distances also affect travel speeds. The 85th percentile speed on important highways on the eastern sea-board is around 110 km/h. On other roads in the north-western areas speeds can be much higher. There has not been a significant down sizing of the passenger car vehicle fleet; the 85th percentile mass is currently about 1.4 t. The sub-compact vehicle type described by Michie (1981) is considered to be suitable for Australian conditions. The gross combination masses of commercial vehicles are varied. Some vehicles have a gross combination mass of 120 t whereas the median mass is less than 4 t.

The structural requirements for Australian safety appurtenances have generally been based on the standards set out in NCHRP 230 (Michie, 1981). This is historically because the Australian Road Authorities have based safety barrier research on the American practice. There has been few full scale tests on safety barriers in Australia and those that have been done have generally been of a preliminary nature. Nevertheless, the NCHRP 230 testing requirements have been used in, or have been the basis of, the Australian tests.
REFERENCES.


TROUTBECK, R.J. (1983). Background to proposed NAASRA Guidelines for the provision of Safety Barriers. Australian Road Research Board Internal Report AIR 833-1


Roadside Safety Activities in Canada

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Canada
Workshop on International Harmonization of Test Procedures and Requirements For Roadside Safety Features

Gothenburg, Sweden - September 27-29, 1989

Abstract

R.W. Sanderson, Transport Canada

Although close neighbours to the United States, the ten provinces and two territories in Canada do not have the same requirements for roadside safety hardware such as contained in NCHRP 230. Although design requirements are specified in the various manuals, no physical testing of roadside safety hardware has been carried out in Canada since the early 1970's. Performance criteria is based primarily on U.S. testing and experience.

This paper will outline the current status in Canada with respect to requirements for roadside safety hardware and the efforts being taken in trying to increase the level of activity in this most important area, since approximately 30% of all Canadian road fatalities are related to single vehicle run off the road accidents.

This paper will also describe the Federal Governments interests through the Motor Vehicle Safety Act, in the requirements for vehicle standards such as side impact strength, roof crush, passenger compartment intrusion and occupant restraint.
ROADSIDE SAFETY ACTIVITIES IN CANADA

Prepared for the Workshop on the International Harmonization of Test Procedures and Requirements for Roadside Features
Linkoping, Sweden, September 27, 1989

by:
R.W. Sanderson, P. Eng.
Transport Canada
ROADSIDE SAFETY ACTIVITIES IN CANADA

Introduction

The fact that approximately 30% of the 4,285 traffic fatalities in Canada, result from vehicles leaving the roadway and either striking an object or rolling over highlights the importance of roadside safety research. Although there has been no full scale testing of roadside barriers in Canada since the early 1970's, there has been considerable research in Canada over the years addressing the larger subject area of roadside safety, of which roadside barriers are a component. This paper will summarize those research efforts, and the insights gained, particularly as they relate to the test procedures for roadside barriers, and the requirements for roadside safety features.

Previous Research

Starting with an in-house study in 1973, and extending over an eight year period, Transport Canada has undertaken several research studies to identify the factors associated with single vehicle run-off accidents and collisions with roadside objects. These studies have included the analysis of available accident report forms, use of infrared false colour photography to identify both reported and unreported run-offs, and a more in-depth long term surveillance of 4,300 km of roadways in 5 Canadian provinces by specially trained teams. Details of these research efforts have been presented previously, and described in Transportation Research Circular 3411.

The provincial highway agencies were also developing and implementing roadside hazard elimination programs during this same time period. As a result of these activities at both the national and provincial levels, it was recognized that the knowledge being gained was at the research/design level, and was not available to the field personnel who regularly patrolled the roadways, and who were ultimately responsible for identifying and correcting the hazards. In a co-operative effort, a committee of the Roads and Transportation Association of Canada (RTAC) was formed to consider this problem, and as a result, developed and published a Handbook entitled the "Treatment of Roadside Hazards". The Handbook, using before and after diagrams as well as text, identified typical roadside safety problems and their potential solutions.

Shortly after the publication of the Handbook in 1979, Transport Canada then undertook a study to investigate the state of the art of highway barrier practice in Canada. The report reviewed the state of the art with respect to barrier performance criteria, the types of guiderail systems in use and their warrants, and an assessment of need within the Canadian environment. This report was viewed as a very comprehensive document, and served as a
catalyst in generating renewed interest in the area of roadside safety, this time focussing on traffic safety barriers. In association with the research carried out in this project, Transport Canada was also investigating the feasibility of using its Test Centre in Blainville Quebec for highway barrier testing, and through the questionnaire portion of the study, asked the provinces if they would support such an undertaking. The opportunity to extend the feasibility study to the implementation level presented itself when a private firm, the International Barrier Corporation, approached Transport Canada to use their facilities to crash test their proposed new barrier. Several full-scale tests, which led to modifications of their prototype barrier, were carried out, giving Transport Canada considerable first hand experience in this area. Despite the practical experience gained, and the fact that most provincial responses to the questionnaire were positive, no further testing has been carried out since that time.

One of the main activities that did result from the study was the development and publication of a new chapter in the Canadian Geometric Design Manual4, in 1986, which although paralleling the 1977 AASHTO Guide5, did bring the subject matter into national focus. This new chapter was a major step in standardizing the varying specifications and practices which had been identified in the state of the art review. The Canadian Manual, while not a legal document, does serve as an example of nationally recognized good practice, with each province maintaining their own design manuals which are referenced in their provincial legislation.

Current Activities

While the members of the committee who participated in the development of the new chapter for the Canadian Manual recognized that there was still more work to be done in the area of highway barriers, it was also recognized that it was a significant step towards more uniform practice in Canada. Being a relatively new document, most of the activity to date has been to review existing provincial standards and guidelines in the context of these new recommendations, and making the necessary revisions. As mentioned, based on the responses to the questionnaire contained in the 1980 study, there was considerable interest expressed in carrying out full scale crash testing in Canada on a limited scale which has not of yet been realized. This perhaps is due in part to the proximity of the United States and the relatively easy access to their extensive program of barrier development and testing. Another reason is the significant amount of capital, maintenance and operational costs associated with full scale testing, which is difficult to obtain in these days of reduced road spending. As a result, most provincial agencies have therefore tended to adopt a program of monitoring the literature, reviewing their accident data, and modifying
their design standards where applicable in lieu of full scale testing.
The Federal Government, and in particular, the Road Safety and Motor Vehicle Regulation Directorate which is responsible for motor vehicle safety standards in Canada, has also been researching several areas of vehicle safety which are important considerations to roadside safety. Current efforts include: promoting the use of active seat belts (currently at a 75.8% national average wearing rate); investigating the benefits/disbenefits of active versus passive restraints; and developing new dynamic side impact criteria for motor vehicles under the Federal Motor Vehicle Safety Act. Although primarily intended for the motor vehicle, the characteristics of the vehicles as defined by these standards, are important considerations when evaluating the collision performance and injury potential of traffic barriers.
Another important activity has been through participation in the International Roadside Safety Committee of the Transportation Research Board, which was formed to act as a forum for the exchange of information on the roadside safety research activities of the member nations. The activities of this Committee to date have confirmed the benefits of this international exchange of ideas/findings, assisting researchers in the conduct of ongoing studies and the planning of new research studies. As a result of the experience gained through this international activity, a similar Committee has been struck at the national level within RTAC to re-evaluate the Canadian position with respect to roadside safety, and address the common problems/solutions experienced by most jurisdictions. This newly formed Committee will have its first meeting this year.
Barrier Performance Criteria

As mentioned, the state of the art review of traffic barrier requirements is perhaps the most comprehensive Canadian document relative to traffic barrier testing. In the report, three major areas were identified that should be considered when evaluating the performances of safety barriers: vehicle dynamics; the damage sustained by the barrier and vehicle occupant injury potential.

In relation to vehicle dynamics, based on a review of the literature of accident experience with traffic barriers, it was found that there was consistency in the fact that high impact speeds were associated with small impact angles, and vice versa. The envelope as shown in Figure 1, suggests that the most critical combinations might be at 90 km/h and 25° (similar to current standards), or else at higher angles and lower speeds. A review of approximately 400 full scale barrier tests also indicated that impact speed had very little influence on the safety performance of the barriers in the 70-105 km/h range. Since the majority of barrier impact speeds fall in this range, it becomes evident then that impact angle is the more critical criteria. An analysis of the effect of impact angle was carried out for the three major safety barriers used in Canada, the results of which are shown in Figure 2.

Further analysis of full scale crash tests and HVOSM (Highway Vehicle Object Simulation Model) computer simulations also led to the establishment of a maximum acceptable exit angle of 15° away from the barrier, and a maximum roll of plus or minus 30° from the horizontal.

While repair costs to the barrier are very real consequences, as is the maintenance of barrier integrity against subsequent impacts, these factors should not outweigh the primary function of safety barriers - which is to save lives and reduce injuries in any given accident configuration. The dynamic reaction of the barrier should be to minimize the decelerative forces acting on the vehicles occupants, while assuring that the vehicle does not subsequently interact with other vehicles on the travelled way. Several concepts have been used in the past in order to relate occupant injury potential to the extent of measurable crash severity. The best known relationships of these are probably: velocity change; vehicle crush; and net deceleration.

Velocity change is simple to use when deceleration is totally dependant on impact speed and vehicle crush, such as with frontal rigid barrier tests used to evaluate Canadian Motor Vehicle Safety Standards. It cannot however, explain the consequences experienced with flexible or semi-rigid barriers due to the energy absorption characteristics of these barriers.

The measure of vehicle damage, such as the Vehicle Deformation Index of the Collision Deformation Classification rating system is also useful since data from actual accidents can be merged with that obtained through crash tests. The wide variation in
crush characteristics over the vehicle population however, does not lend itself well to relate it to establishing injury potential.

Since actual accidents do not involve instrumented vehicles, it is felt that it would however be useful to retain a criterion based on vehicle damage. From an evaluation of full scale crash tests, and MDAI (multi-disciplinary accident investigation) reports, the relationship in Figure 3 was developed. From this figure it can be seen that for angle impacts up to 30°, a VDI of less than 3 would be required to ensure that the probability of death or injury would be less than 0.5 for unrestrained occupants, and a VDI of less than 5 for restrained occupants. Net vehicle deceleration or occupant acceleration has been used widely to measure injury potential, with separate components of the X, Y and Z accelerations being used as the measurable criteria. The review of available literature determined that, for the most part, the effect of the vertical acceleration component was negligible. It is suggested however, that due to the smaller number of cases where it was found to be quite significant, it should be retained in future test results. Many injuries result however from contact with the interior of the vehicle rather than the acceleration forces acting on the body, pointing out the disadvantages of this measure. This criteria may however become more feasible to use in the future as seat belt wearing rates increase.

Based on an evaluation of the above factors, the study concluded that the newer concept of occupant terminal velocity suggested by Chi, combining the principles of velocity change and acceleration, more readily explains the injury causation mechanism. This criteria, which is based on the average occupant compartment acceleration and a final striking velocity of the occupant, assuming an average travel distance of 0.6 metres (2 ft), was found to be more relatable to the medical literature on injury criteria for various body components. A summary of injury criteria reported in the literature is shown in Table 1. From the evaluation of several research studies, this value of 9 metres/second suggested by Chi appears to be the threshold level
for moderate injuries to head and chest areas for unrestrained occupants. Since the 9 m/s criteria was derived from commonly accepted deceleration tolerance limits for unbelted occupants, an equivalent criteria of 17 m/s can also be derived for restrained occupants, equivalent to approximately 8 KN strap loads.

In summary, the following conclusions were developed:
- barrier test conditions should be at 100 km/h impact speed and 25° impact angle;
- exit trajectories should not exceed 15° away from the barrier;
- roll angle measured from the horizontal should not exceed plus or minus 30°;
- an acceptable injury criteria based on occupant terminal velocity is 9 m/s for unrestrained occupants, and 17 m/s for restrained occupants;
- another injury potential criteria based on vehicle damage would be VDI < 3 for unrestrained occupants, and VDI < 5 for restrained occupants, for impact angles greater the 15°.

Discussion

The results above suggest that the acceptable injury criteria (such as 9 m/s for occupant terminal velocity) for barriers could be increased given a higher seat belt wearing rate, which is now at a national average of 75.8% (1988) in Canada, and approaching the 90% mark in many other countries. As with many other design considerations however, it remains to be decided as to what should be adopted as acceptable. If in fact we maintain the 50% probability level of serious injury (which was the criteria used in this study), and raise the associated injury criteria levels (i.e. to 17 m/s rather than 9 m/s), we would in effect be penalizing the unrestrained occupant, since it would increase their probability of serious injury. On the other hand, since traffic barriers are also roadside objects, it may be more appropriate to leave the injury criteria as it is for unrestrained occupants, thus reducing the probability of a restrained vehicle occupant being killed or seriously injured. Vehicle characteristics are also important factors to be considered when evaluating traffic barrier performance. For example, although new vehicles, as a requirement of motor vehicle safety standards, must pass the same pass/fail criteria for deformation of bumper, roof crush, etc., examination of the data from barrier crashes has shown there to be a wide variation in the dynamic crush behaviour across the vehicle fleet. Similarly, field experience in some jurisdictions has indicated problems with barrier under-ride because of the sloped nose aerodynamic shape of newer, smaller vehicles, indicating a potential problem with vehicle profile. Evidence such as this seems to indicate that there may be other components of vehicle design which could greatly influence the response characteristics...
of traffic barriers, other than those which are currently specified in NCHRP 230.
For the optimum safety benefits to be realized, the compatibility of the vehicle and the barrier must be maintained. Historically however, modifications to barrier designs have been predicated by changes in vehicle design which have been based on factors other than the roadway environment. Similarly, in Canada, as in many other countries, the two critical factors of barrier and vehicle design are dealt with almost independently - barriers at the provincial highway agency level, and vehicles at the federal motor vehicle regulatory level. More cooperative research is required in the future to ensure that the vehicle and highway standards are harmonious as well.

While most research efforts usually focus on the automobile, the increasing number of trucks on our highways is presenting new problems to researchers and designers. Highway agencies are coming to realize that, due to this increasing truck traffic, it is simply not feasible any more to disregard the truck population in its design practices. For example, design standards for passing sight distance, which were developed in the 1940's, are based solely on the operation of one car passing another, assuming that the then small truck population could compensate for this automobile related design standard due to their higher height of eye. Many recent research studies, including a Transport Canada evaluation of the safety benefits of passing lanes, have questioned the effectiveness of these assumptions, primarily due to the increased percentage of trucks on our highways, and their subsequent effects on accident experience. Since traffic barriers are also part of the roadway design, it also raises the question of how adequate our traffic barriers are for the whole population of traffic, versus only the automobile traffic for which they are ultimately designed. Do we create a new generation of barriers for roadways experiencing heavy truck traffic (such as the Tall Wall barrier being tested in the U.S.)? Do we assume that they are professional drivers, and better able to handle the driving tasks, and therefore less likely to run off the road and impact a traffic barrier? These and many other questions remain as the percentage of trucks on our roadways continues to grow.

Transport Canada has also been researching the need for improving side impact protection through the Federal Motor Vehicle Safety Act. Accident data (Ontario, 1987) has shown that 33% of all right side passenger fatalities are due to right side impacts from other vehicles, as compared to 28% fatalities for full frontal impacts, indicating the possible need for improved side protection. Research is now underway to investigate new dynamic full scale testing procedures for side impacts (either the U.S. or European proposals), to replace the current static point load standard. It remains to be seen however, that in the case of an impact with a traffic barrier, if such a change in vehicle standards will have the effect of reducing injury severity due to
improved crush resistance of the passenger compartment (particularly in the case of the right hand side passenger), or a negative effect due to the increased rigidity of the vehicle structure. Only further testing, both of vehicles and barriers, will tell where the benefits will be realized. Fortunately, this dynamic testing will produce results which will be more comparable to those from current highway barrier tests.

Conclusions

Recent developments, such as the formation of the International Roadside Safety Committee, the proposed revisions to NCHRP 230, as well as this workshop on the international harmonization of test procedures and requirements for roadside safety features, present excellent opportunities for international cooperation in comparing research results, and presenting new barrier systems for consideration. These new systems can more readily be accepted and implemented in other countries if the criteria used to evaluate them are the same from country to country. Most highway agencies in Canada accept the procedures outlined in NCHRP 230 as acceptable criteria for their barrier systems. A review of these criteria made the following conclusions:
- barrier test conditions should be at 100 km/h impact speed and 25° impact angle;
- exit trajectories should not exceed 15° away from the barrier;
- roll angle measured from the horizontal should not exceed plus or minus 30°;
- an acceptable injury criteria based on occupant terminal velocity is 9 m/s for unrestrained occupants, and 17 m/s for restrained occupants;
- another injury potential criteria based on vehicle damage would be VDI < 3 for unrestrained occupants, and VDI < 5 for restrained occupants, for impact angles greater the 15°.

Changing economic and environmental criteria are also presenting the designer with newer types and mixes of vehicles. With more emphasis on fuel economy and emissions in most countries, designs of automobiles have been rapidly changing to meet these criteria, resulting in vehicle designs which may not be compatible with current barrier designs. Similarly, the economic advantage of truck transportation, and the popularity of just in time delivery, have also increased the percent of trucks on our highways. The influence of these vehicles on barrier design will also become more critical in the not too distant future. Historically, traffic barriers have been modified to respond to these independent vehicular changes. While some of these factors are out of the control of standard makers, there are others, which through the cooperation of motor vehicle and highway regulators, could result in mutually beneficial rather than independently responsive research efforts.
Although not carrying out full scale highway safety barrier testing, Canada has been continuing in its efforts to address the problems of roadside safety. The establishment of the new Canadian Roadside Safety Committee, standardization of Canadian practices, continued research in the area of vehicle standards and cooperation in the international harmonization of barrier test requirements will all, most certainly, contribute to the improvement of roadside safety and a reduction in the number of fatalities and injuries on Canadian roadways.

REFERENCES

FIGURE 1
Envelope of Impact Speed - Angle Relationship

Impact Speed (km/h)

Impact Angle (deg.)

FIGURE 2
Performance of Safety Barriers

Rigid unshaped barrier
Shaped concrete barrier
Metal beam guardrail
Cable guardrail

Probability of Injury or Death

Angle of Impact

Performance of Safety Barriers Envelope of Impact Speed - Angle Relationship
### Table 1: Summary Table of Occupant Injury Criteria in Motor Vehicle Crashes

<table>
<thead>
<tr>
<th>BODY COMPONENT</th>
<th>CSI</th>
<th>HIC</th>
<th>Loading</th>
<th>Belt Force</th>
<th>Torso Peak G*</th>
<th>Occupant Impact Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest &amp; Thorax</td>
<td>SI</td>
<td>500</td>
<td>8</td>
<td>8</td>
<td>60 (Net)*</td>
<td>9</td>
</tr>
<tr>
<td>Abdomen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip &amp; Pelvis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Extremities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck &amp; Spine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head &amp; Face</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>avg: 30 (Net)*, 36(2)</td>
</tr>
</tbody>
</table>

**Definitions**
- SI: Gadd Severity Index
- CSI: Chest Injury Severity Index
- HIC: Head Injury Criteria
- Loading: Force of Impact on Restraint
- VDI: Vehicle Deformation Index

\[
* \text{Net} = (G_x^2 + G_y^2 + G_z^2)\text{vert}
\]

\[
\text{XVI: longitudinal & lateral}
\]

### Figure 3

Relation Between Vehicle Damage and Occupant Injury Probability
The Roadside Safety Barriers

Robert Quincy
INRETS LCB
France
Research carried out on various countries showed the importance of roadside safety features for improving road safety.

These experiments led these countries to create usually their own regulations concerning these devices. Our intention is to deal with the French experience which leads at present to a revision of standards in force.

These new regulations rely on a great number of full-scale impact tests but also on a systematic analysis of accidents with run off the road. We shall only get on to the field of lateral barriers, our reflexion being less well on in the field of crash cushions.

Concerning lateral barriers, there are some categories of big problems (type of vehicles to be hold back, type of road network...) to which certain types of devices should match.

- safety of private cars passengers should be provided, our recent experience has showed the importance to create several service level dependent on the type of road to be equipped. There are three levels :
  
  . The level 1 which is the standard level of equipment.
  
  . The level 2 corresponding to the secondary roads network on difficult site on which, either specific devices are more fitted, or it is possible to reduce the cost with simplest devices.
  
  . The level 3 corresponding to the urban network.

- In some case, we have to hold back heavy vehicles, with two big levels, either a medium prevention, or in some extreme cases, a type a device maintaining the safety in some very severe accident conditions (bridges getting over occupied areas...).

. The development of motorway networks leads at prevent to consider specific barriers for the equipment of central reserves, in order to avoid the overstepping of vehicles, heavy vehicles included. The analysis of accident data, particularly our file covering about 1,000 kms of motorways, shows that with the present rigid barriers, there is on the one hand an advantage, owing to the absence of heavy trucks overstepping, on the other hand, an overall increasing of accident severity involving cars, the results depending on the local conditions.
A Rational Approach to the Problem of the Choice of the Safety Road Barriers, through Valuation of the Total Costs on Remarks of Statistic and Probabilistic Type

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A rational approach to the problem of the choice of the safety road barriers, through valuation of the total costs on remarks of statistic and probabilistic type

* University of Bari, Ways and Transport Departement - Italy

** Engineer and researcher

1. Introduction

The problems of safety road barriers choice are certainly complex, both for the variability of the local conditions which, according to the different typology, impose different safety levels, and for the heterogeneity of geometry and mass of circulating vehicles that can arrive to present needs of plan characteristics of restrain quite opposite.

In this position, above all in these last twenty years, many efforts have been done to attempt to provide more organic solutions to the planners.

The principal approaches have been essentially two, often pervaded between them in an harmonic symbiosis:

the former, of theoretical-speculative type, with the purpose of studying the dynamics of the impact and the relative consequences. Such seam of research has produced important results, even in the objective difficulty to schematize phenomena that are extremely complex and are dominated by an enormous numbers of variables.
the latter, of pragmatic-experimental type, with the purpose to value the effects of the impacts between vehicle and barrier by the direct analysis of crash tests. Such seam of research has brought out operative consequences of certain importance, even if the considerable costs of the tests determine inevitably limits of selection and difficulties of access to the knowledge of the experimental results for the great majority of the researchers.

At the moment the planners have access of a whole of information rich enough and qualitative indication which certainly facilitate their choices.

Yet the mentioned differences of behaviour between lighter vehicles and heavy vehicles, unitedly to the not complete knowledge of the total costs of accident, are certainly sources of perplexity and, excluding the cases for which the safety level requested is the highest (for example bridges, viaducts on other infrastructures or in town background, etc.), it runs the risk to operate a choice among most solutions, only in function of the lowest cost of realization and installation of the barriers (this above all in presence of limited funds).

The study is carried from these considerations, with the purpose to operate a rational approach to the problems of the choice of the safety road barriers, through valuation of the total costs of different alternative solutions.

2. Statement of the methodology

The methodology is founded on bases of statistic and probabilistic type, through which it is possible to value the total and capitalized social-economical cost \( C \) (relative to the period of usefhl life of the road) that it derives from the installation of the different types of barrier in a defined section of unitary length and of homogeneous characteristics.
If $v$ is the number of years of useful life of the road and $r$ the capitalization rate, such cost is the total of two addenda, the first relative to the cost $C_b$ for the realization and installation of the barriers, and the second connected with the social—economical cost $C_t$ of all accidents that shall involve the barrier in the considered section and in the generic year $t$:

$$
C = C_b (1 + r)^v + \sum_{t=1}^{v} ((1 + r)^t C_t)
$$

(1)

It is evident that the case of single carriageway will be studied differently from that of road with two separate carriageways. In the first occasion the barrier, necessary side, will be implicated in collisions connected both right and left out-of-control vehicle, while in the second eventuality it will be possible to have side barrier (interested by out-of-control vehicle on the right) or median barrier (out-of-control vehicle only on the left).

Anyway if $N_L$ and $N_p$ are the number of collisions against the barriers (relative to lighter vehicles and, respectively, heavy vehicles) that happen at the general social economical cost $C_{Lk}$ and $C_{Pk}$ in one year in the section of unitary length in the question, $C_t$ will be:

$$
C_t = (\sum_{k=1}^{N_L} C_{Lk}) + (\sum_{k=1}^{N_p} C_{Pk})
$$

(2)

The single costs $C_{Lk}$ and $C_{Pk}$ will be, obviously, influenced by the gravity of the accident, that it depends on the angle $\alpha$ of impact vehicle—barrier and on the velocity $V$ of the collision.

The angle $\alpha$, as it results from statistic survey of the Texas Trasportation Institute [7], is a casual variable that follows the Normal Gauss's law, and it yet depends on:
1) characteristics of cross section;
2) direction of the out-of-control vehicles (onright or left);
3) velocity.

The last one is also a causal variable and depends on characteristics of cross section.

So the probability that there is a collision with an angle of impact in a determinate range and with a velocity in another range it will be:

\[ P = P(\alpha) \times P(V) \]  \hspace{1cm} (3)

where \( P(\alpha) \) and \( P(V) \) are the probabilities that \( \alpha \) and, respectively, \( V \) are in the determinate range.

If the field of variability of the angles is divided in \( n \) intervals and the field of the velocities is divided in \( m \) intervals it will be:

\[ P_{ij} = P(\alpha)_{ij} \times P(V)_{j} \]  \hspace{1cm} (4)

\[ \sum_{i=1}^{n} \sum_{j=1}^{m} P(\alpha)_{ij} \times P(V)_{j} = 1 \]  \hspace{1cm} (5)

So, if \( C_{ij} \) and \( CP_{ij} \) are, respectively for lighter and heavy vehicles, the economic-social costs of an accident that has an angle of impact \( \alpha \) included in the angular interval \( i \) and velocity \( V \) included in the interval of velocity \( j \), it will be:

\[ \sum_{k=1}^{NL} \sum_{i=1}^{n} \sum_{j=1}^{m} P_{ij} C_{ij} N_{L} \]  \hspace{1cm} (6)
Therefore the (1) according to the (2), (6) and (7) becomes at last:

\[
V_{n_i} = n_m \sum_{k=1}^{N_p} \sum_{i=1}^{n} \sum_{j=1}^{m} P_{p_{ij}} C_{p_{ij}} N_p
\]

When the terms of the (8) are known for any type of barrier possible for planning, it's immediate to calculate the total costs and to operate the most convenient choices.

So, if the characteristics of the cross section and of the barrier (geometry, material, position, etc.) are defined, \( C \) will be the function of the only independent variable \( TGM \) (average daily traffic for every carriageway) and \( p \) (percentage of heavy vehicles).

Therefore, for confronting two types of barriers in a determinate road and for a determinate position (side or median), it will be possible to define, in a Cartesian plan that has in abscissa \( TGM \) and in ordinate \( p \), a curve (locus of the points of same cost) that is border between two plane fields in the which it's most convenient to utilize one barrier rather another. An example of this it will be shown in the application.

The process has been completely automathized, working out an apposite software for personal computer, so that, if same parameters change, it is immediate to re-calculate the cost function and to plot the curve of confront.

3. Determination of the necessary parameters

Successively it will shown as it's possible to proceed at the determination of necessary parameters. Such determination isn't the only
or the best because, as it will be clear forward, it is sensibly influenced by statistic data and surveies.

A remarkable contribution to the research can be given constituting a specific data bank through which the parameters can be improved and revised.

3.1. Cost of construction and installation of barrier

The cost $C_b$ of construction and installation of the barrier can easily be obtained from the List prices of the Administrations that menage roads, or effecting directly the analysys of cost.

3.2. Yearly number of collisions vehicle-barrier

The number of collisions vehicle-barrier $N_L$ and $N_p$ (related to lighter vehicle and respectively heavy vehicle) that happen in one year in a section of unitary length of the road in question, depends by following parameters:

1) roadway size;
2) average daily traffic;
3) percentage of heavy vehicle;
4) typical atmospheric conditions;
5) type of pavement;
6) type of edge of carriageway marking (nightly drive).

Therefore a right estimate can be effected, starting from data of roads of the same geographic area and with homogeneous characteristics respect to elements just mentioned.

If such statistic researchs there are not, at first approximation it is possible to utilize a criterion deduced starting from an american
research [1] that expresses the results of a systematic survey into accidents happened in 1978 on the Indiana Toll Road, which is a road with four lanes, two for every direction; it's 157 miles long and hasn't high gradients neither curves of short radius.

If the specific conditions of the road in examination are different from the last, it will be necessary to utilize suitable corrective coefficients to conclusive results that later shall be exposed.

The statistic analysis of the results of the Indiana Toll Road research defines the number \( L \) of the accidents estimated in one day through the:

\[
L = \beta_0 (VMTa)^{\beta_1} (VMTt)^{\beta_2} (1 + H\text{snow})^{\beta_3} (1 + H\text{rain})^{\beta_4} \quad (9)
\]

where:

\( VMTa, VMTt = \) number of miles gone daily for any direction by lighter vehicle and respectively heavy vehicle (in millions);

\( H\text{snow}, H\text{rain} = \) hours of snow and, respectively, of rain in the examined system;

\( \beta_0, \beta_1, \beta_2, \beta_3, \beta_4 = \) coefficients experimentally determinated for any type of accident and through Poisson's pattern of regression.

Disregarding, for simplicity and approximation, the influence of the atmospheric conditions, the values of \( \beta \) are:

<table>
<thead>
<tr>
<th>lighter vehicles</th>
<th>heavy vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta_0 )</td>
<td>0.572</td>
</tr>
<tr>
<td>( \beta_1 )</td>
<td>0.513</td>
</tr>
<tr>
<td>( \beta_2 )</td>
<td>-0.059</td>
</tr>
<tr>
<td></td>
<td>0.481</td>
</tr>
<tr>
<td></td>
<td>-0.066</td>
</tr>
<tr>
<td></td>
<td>0.674</td>
</tr>
</tbody>
</table>

Table 1
All this is true if the number of the accidents with barriers is the same relative at accidents with isolated vehicle; this condition is enough reliable because, even if in the accidents related at isolated vehicle there are also those regarding pedestrians and some accidents with barrier interest several vehicles, it's possible to think that two differences compensate one another.

Besides the percentage \( p \) of heavy vehicle is defined by:

\[
P = \frac{VMT_t}{VMT_a + VMT_t}
\]  

(10)

and average daily traffic \( TGM \) is connected with \( VMT \) through:

\[
VMT = TGM \times 157
\]  

(11)

In fact, if \( \Delta \) is the average distance gone on the road by one vehicle, it will be:

\[
\frac{VMT}{\Delta} = \text{number of vehicles that have interested the road in one day, in millions;}
\]

\[
\frac{\Delta}{157} = \text{probability that a certain vehicle passed through a determined section;}
\]

\[
TGM = (VMT/\Delta) \times (\Delta/157) = VMT/157 \text{ (millions of vehicles)}.
\]

So (9) becomes:

\[
L = \beta_0 (TGM \times 157)(\beta_1 \times \beta_2) (100 - p) \beta_1 \beta_2
\]  

(12)

For determining the number of accidents related to isolated vehicles in one year and for every kilometer of road, it will be necessary
multiply L by 365 and divide by \((157 \times 1,609)\), where 1,609 is the factor of equivalence between miles and kilometers. For individuating separately the number of right and left collisions, it can be used the simplified hypotesis that the probability of both events is the same, dividing therefore the total number of accidents by two. In conclusion it will be:

\[
NL = \frac{365}{157 \times 1,609 \times 2} B_0 (TGM \times 1,57)(\beta_1+\beta_2)(100-p)\beta_1 p\beta_2 \tag{13}
\]

\[
Np = \frac{365}{157 \times 1,609 \times 2} B_0 (TGM \times 1,57)(\beta_1+\beta_2)(100-p)\beta_1 p\beta_2 \tag{14}
\]

with the values of \(\beta\) indicated in previous table 1.

So, if the road and traffic conditions are like that of previous formulae, it is possible to value, in function of TGM (in million of vehicles) and of the percentage \(p\) of heavy vehicles, the probable number of collisions \(NL\) and \(Np\) (relative to lighter vehicles and, respectively, heavy vehicles) that happen in one year in a generic section of unitary length.

If the specific conditions of the road in examination are different from the last, it will be necessary to utilize suitable corrective coefficients to (13) and (14).

3.3. Probability of the different velocity ranges

Next objective is to find the value of the probability of a collision that happens in a determined velocity range.

Every road has its cumulative curve of the total probability of the velocity, that is univocally determined when the average value (Vmed) and the velocity (V95%) that has the probability of the 95% to be not exceeded are known.
So, through these two parameters it is possible to know the probability that a vehicle has a definite velocity in a determined road.

Such probabilities, such as these related to the impact angle of which to following 3.4 point, will can be calculated both for lighter vehicles and heavy vehicles (for example for every type of cross section of C.N.R. Italian Standards), assigning suitable values for (Vmed) and (V95%). So the planners have a matrix of probability from which to take necessary elements.

3.4. Probability of the different impact angles $\alpha$

The process is very similar to that previous 3.3. point, but for determining the cumulative curve of the total probability, it will be necessary to utilize the following two conditions:

1) for $\alpha = 0$, the cumulative function of the total probability is nought;

2) $\alpha_{95\%}$ is the angle corresponding to the trajectory of a vehicle with velocity $V$ when the steering velocity $\dot{\alpha}$ is to the limit of the side skid tire-road.

Such condition, that will be illustrated in the following 3.4.1. point, is justified by the consideration that $\alpha$ increases if $\dot{\alpha}$ grows, but it cannot have more increments in side skid limiting condition.

3.4.1. Limiting impact angle

The hypothesis is that the trajectory that the vehicle goes before impacting the barrier is a transition curve obtained if the vehicle goes with constant linear velocity while the steering angular velocity $\dot{\alpha}$ is constant.
For convenience of calculation it will be utilized the curve which is
defined by the equation of the cubic parabole, that well approaches, in the
forecast area of utilization, the starting hypothesis.

Such curve has equation, in the x-y plane (fig. 1):

\[ y = \frac{x^3}{6k} \]  \hspace{1cm} (15)

with \( k = \frac{PV}{\partial} \) \hspace{1cm} (16)

where \( P \) is the wheel-base of the vehicle.

The angle \( \alpha \) is the arctangent of the first derivative for the values
of \( y_d \) and \( y_s \) indicated in fig. 1 (where \( d \) is generally for right and \( s \),
respectively, for left collisions). Therefore it will be:

\[ \alpha = \arctg \left( \frac{6yPV}{2/3d} \right) \] \hspace{1cm} (17)

The maximum angle \( \alpha \) is that corresponding to the maximum
steering velocity \( \partial \); this last is defined by the side skid limiting condition:

\[ \frac{V^2}{r} = g f \] \hspace{1cm} (18)

when \( r \) is the radius of curvature and \( f \) is the transverse wheel grip
coefficient. Besides (fig. 1):

\[ r \theta = P \] \hspace{1cm} (19)

and, to the time \( t = \frac{x}{V} \) results \( \theta = \partial t = \partial \frac{x}{V} \), by which:

\[ r \partial \frac{x}{V} = P \] \hspace{1cm} (20)
By the (15), (16), (17), (18) and (20) it will be:

\[ \alpha_{\text{lim}} = \arctg \left( \frac{3 \gamma g f^{1/2}}{v^2} \right) \]  

(21)

The (21) is graphically expressed in the abacus of the fig. 2.

A test of the validity of the utilized methodology was done.

The different types of cross sections of the C.N.R. Italian Standards were considered and the related values \( y_d \) e \( y_s \) both for lighter and heavy vehicles were obtained; besides, chosen, for example, \( f = 1 \), it was possible to calculate \( \alpha_{\text{lim}} \) and \( \alpha_{\text{lim}} \) in function of \( V \), having the abaci shown in fig. 3,4,5 and 6. Choosing \( V \) equal to minimum value in the range of the project velocities (in fact the maximum value of \( \alpha_{\text{lim}} \) is in correspondence of the minimum value of \( V \)) it's possible to obtain the real values of \( \alpha_{\text{lim}} \) for any type of cross section.

Confronting these results with those obtained from [7] by H.V.O.S.M. (Highway Vehicle Object Simulation Model) utilizing the velocity of 97 km/h, there are, for the values of \( \alpha_{\text{lim}} \), differences never higher than 4°, and under 1° from the cross sections Ila and Iib C.N.R. for which \( V \) has been assumed equal to 90 km/h, that is the nearest value to that of the american research.

The validity of the choisen methodology has so an indirect confirmation.

3.5. Social economical cost of the accidents

It is important now to individualize the value \( C_{Lij} \) e \( C_{Pij} \) of the social and economical cost, for the two categories of vehicles, of an
FIG. 3 - RIGHT COLLISIONS FOR LIGHTER VEHICLES

FIG. 4 - LEFT COLLISIONS FOR LIGHTER VEHICLES

VTI RAPPORT 349A
FIG. 5 - RIGHT COLLISIONS FOR HEAVY VEHICLES

FIG. 6 - LEFT COLLISIONS FOR HEAVY VEHICLES
impact against a barrier that happens with a velocity and an impact angle included respectively in the i angular range and in the j velocity interval.

The cost $C_{ij}$ can be considered sum of three aliquots:

$$C_{ij} = C_B + C_U + C_V$$  \hspace{1cm} (22)

that are connected to the repairing cost of the barrier after the impact ($C_B$), to the human injury ($C_U$) and to the repairing cost of the vehicle ($C_V$).

Excluding the aliquot of cost related to the damage of the barrier (that is smaller than the other aliquots and therefore can, failing statistic data, be assumed constant if the type of barrier is defined) the other aliquots of cost were analyzed separately for the different type of vehicle.

3.5.1. Lighter vehicles

Utilizing experimental data of [7] and [2] researchs (cf. bibliography), it was possible, for the two barriers CBM (New Jersey) and MBGF (metallic) shown in fig. 7, to draw the abacus of fig. 8, in which the Severity index $S_i$ is expressed in function of the velocity and of the impact angle. As it's known, the Severity Index $S_i$ is defined, through the accelerations $G$ and the limiting accelerations $G'$, by:

$$S_i = \left( \frac{(G_{\text{long}}/G'_{\text{long}})^2 + (G_{\text{lat}}/G'_{\text{lat}})^2 + (G_{\text{vert}}/G'_{\text{vert}})^2}{1} \right)^{1/2}$$  \hspace{1cm} (23)

where the limiting accelerations $G'_{\text{long}} = 7g$, $G'_{\text{lat}} = 6g$ e $G'_{\text{vert}} = 5g$ are those in correspondence of the which an unrestrained occupant has the probability of the 70% to suffer serious injuries.

It's clear that, for different barriers, it will be necessary to utilize suitable corrective coefficients, or to effect experimental specific tests.
FIG. 7
3.5.1.1. Cost of the human injuries

The Post's research results published by T.R.B. [4] allow to connect the Severity Index with the probability that an user to suffer serious injury.

Besides, with the hypothesis that in every vehicle there is, on the average, 2.5 persons and that the social and economical costs of a slight injured man and of a serious injured man are 4.5 and, respectively, 30 millions of Italian Lires [3], it's possible to draw the abacus of fig. 9 that expresses the cost of the human injuries versus the Severity Index.

By the abaci of the fig. 8 and 9 it is possible to determine the cost of the human injuries for impacts of a lighter vehicle against CBM or MBGF barriers, for any velocity and impact angle. So it will be possible to define the matrix of cost for every range of velocity and of impact angle.

3.5.1.2. Costs of the damages of the vehicle

For determining the repairing cost of the vehicle in function of the Severity Index, it's possible to consider a curve like that of the fig. 9 and with absolute data of cost deduced from experimental evaluation (for example that the average damage for a vehicle that impacts with SI = 2.5 is 4.5 millions of Italian Lires).

3.5.2. Heavy vehicles

It's right to consider separately, according to A. Ranzo [5], the two heavy vehicles most representative that circulate on the european roads:

motor-bus of 56 + 58 seats, weight 21 t, $v_{\text{max}} = 118$ km/h, cost 300 millions of Italian Lires;
FIG. 8

FIG. 9

VTI RAPPORT 349A
tractor semitrailer, weight 43 t, $v_{max} = 118$ km/h, cost 130 millions of Italian Lires.

That all because the stresses of the barrier will be certainly different for the collision with one or the other type of vehicle, even if in the same kinematics conditions of impact, so as will be different the economical consequences for material damages and human injuries.

In the same research [5] are expressed, for the two mentioned vehicles, the impact strenghts $F_u$ in function of the velocity and of the impact angle. The different nature of the barrier is considered through the different deformation that the same suffers for the impact.

Besides, for every type of barrier, it's possible to determine the limiting value of the impact strenght ($F_{ur}$) beyond which it will verified the roll-over of the vehicle or the breaking through the barrier ($F_{us}$).

So it's possible, for each of two types of vehicle and for any value of the velocity and of the impact angle, to determine the correspondent impact strenght.

Now it's necessary to determine the percentage ($r$) of accidents of heavy vehicles in which are involved the motor-buses A and, respectively, that ($100 - r$) related to the tractorrs semitrailers T.

The cost $C_{pij}$ will be so expressed by:

$$C_{p ij} = \frac{r}{100} C_{Aij} + \frac{100 - r}{100} C_{Tij}$$

(24)

The parameter $r$ can be expressed as product of the percentage ($s$) of the motor-buses in circulation, related to the total of the heavy vehicles, by a coefficient of attention ($a$) that is connected to the better
maintenance of the safety systems for the vehicles that carry the persons and to the greater ability and responsibility of the driver. To the coefficient (a) it can be assigned, if there are not experimental data, the value 0.7.

3.5.2.1. Cost of the human injuries

It's possible to hypothesize that there are not costs for human injuries both for the motor-bus and for the tractor semitrailer if the impact is without roll-over of the vehicle or without breaking through the barrier.

Instead, in these latter eventualities it is possible to assume that all the occupants of the vehicle (1 for the tractor semitrailer and 50 for the motor-bus) suffer slight injuries.

So it is immediate to calculate the cost for every vehicle and for every range of velocity and of impact angle.

3.5.2.2. Cost of the damages of the vehicle

The hypothesis that the damages of the vehicles are proportional to \( F_u \) it's reliable enough.

As, besides, it was possible to check, through an effected market inquire, that a tractor semitrailer and a motor-bus suffer, after a roll-over, damages with a cost approximately equal to 48% and, respectively, 56% of the original value, it is possible to determine the coefficient of proportionality between \( F_u \) (in this case for the roll-over condition) and the damage of the vehicle, and so to calculate the cost of the damage for every vehicle and for all the ranges of velocity and of impact angle.
3.6. Years of useful life and capitalization rate

The evaluation of these parameters is subject to complex considerations of technical and economical type that are beyond the purpose of this research. However it is possible to suggest the values of 20 years for \( v \) and of 5\% for \( r \).

4. Limits of the methodology

The principal limit of the methodology is represented by the lack of experimental data that can confirm the choices done for the values of the parameters. A remarkable contribution to the research can be given constituting a specific data bank through which the parameters can be improved and revised.

In this research there is not the question of the special barriers for bridges, viaducts and side obstacles, because for these particular situations it is necessary to choose barriers with characteristics of maximum safety.

Besides was not considered the question of the use or not of the barriers, since it is previous to the problem at issue. However the methodology could be utilized, with light modifications, to this purpose.

Likewise were not taken in account the costs of the possible damages coming from the impact with other estates (manufactures, plants, animals, etc.) and, above all, with other vehicles. These latter costs have instead a notable probability to happen both when the vehicle is redirected by the barrier and, in special way, when there is breaking through the barrier. At the moment isn’t easy to keep in mind correctly these elements even if, fortunately, the related accidents are rare enough.

At last it is necessary to specify that in the calculation of the human injuries was not taken in account the death of the occupants. Such
omission, due to the known proportionality of the Severity Index with the probability of serious injuries (but not of the death of the occupants), is anyway fictitious for the statistic and economical (but not, unfortunately, human) correspondence between 1 dead man and k seriously injured men.

5. Application

It was done an application comparing, for the different cross section type of C.N.R. Italian Standards (fig. 10), the cls barrier CBM (New Jersey) and the metal barrier MBGF (fig. 7).

The comparison will be considered reliable in particular for the roads with two separate carriageways (since for this type of roads it was been possible to determine $N_L$ and $N_p$) and however it will be function of the reliability of the hypothesis of calculation.

The data utilized for the application, beyond these already expressed, were obtained from the List Prices of Italian Administrations in 1988.

Therefore it results:

**cost of construction and installation of the barrier:**

- side MBGF: £/m 50.000
- median MBGF (1/2): £/m 39.500
- side CBM: £/m 90.000
- median CBM (1/2): £/m 45.000

**reparing cost of the barrier after the impact:**

- MBGF: £ 250.000
- CBM: ===
<table>
<thead>
<tr>
<th>TIPO di STRADA</th>
<th>INTERVALLO DI VELOCITÀ (Km/h)</th>
<th>PIATTAFORMA (metri)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I°</td>
<td>110 ≤ Vp ≤ 140</td>
<td>a) 3,00 3,75 3,75 4,00 3,75 3,75 3,00 25,00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) 3,00 3,50 3,75 3,75 4,00 3,75 3,75 3,50 3,00 32,00</td>
</tr>
</tbody>
</table>

*Shrada a carreggiate separate*

| II°          | 90 ≤ Vp ≤ 120               | a) 3,00 3,75 3,75 3,75 3,75 3,00 23,00 |
|              |                             | b) 3,00 3,50 3,75 3,75 3,75 3,50 3,00 30,00 |

| III°         | 80 ≤ Vp ≤ 100               | 17,50 3,50 3,50 3,50 3,50 3,50 17,50 18,60 |

*FIG. 10*
percentage of motor-buses respect to the total of the heavy vehicles: 22.9%

transverse wheel grip coefficient: 0.8

velocity (km/h):

<table>
<thead>
<tr>
<th></th>
<th>lighter vehicles</th>
<th>heavy vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$V_{med}$</td>
<td>$V_{95%}$</td>
</tr>
<tr>
<td>I a</td>
<td>125</td>
<td>140</td>
</tr>
<tr>
<td>I b</td>
<td>125</td>
<td>140</td>
</tr>
<tr>
<td>II a</td>
<td>105</td>
<td>130</td>
</tr>
<tr>
<td>II b</td>
<td>105</td>
<td>130</td>
</tr>
<tr>
<td>III</td>
<td>100</td>
<td>120</td>
</tr>
</tbody>
</table>

In the fig. 11 + 18 there are the results of the elaborations; it is evident the better but not exclusive attitudes of the CBM to be utilized as median barrier and of the MBGF as side barrier.

The abscissa of the graphics is the homogenized average daily traffic, where the coefficient of homogenization between lighter and heavy vehicles is $\alpha_h = 5$.

6. Conclusions

A rational solution to the problem of the choice of the safety road barriers is possible through valuation of the total costs $C$ on remarks of statistic and probabilistic type.

In fact, if the characteristics of the cross section and of the barrier (geometry, material, position, etc.) are defined, $C$ will be the
FIG. 11 - Ia: RIGHT COLLISIONS

FIG. 12 - Ia: LEFT COLLISIONS
FIG. 13 - Ib: RIGHT COLLISIONS

FIG. 14 - Ib: LEFT COLLISIONS
FIG. 15 - IIa: LEFT COLLISIONS
FOR RIGHT COLLISIONS ALWAYS MBGF

FIG. 16 - III: LEFT COLLISIONS
FOR RIGHT COLLISIONS ALWAYS MBGF
FIG. 19
function of the only independent variable TGM (average daily traffic for every carriageway) and p (percentage of heavy vehicles).

Therefore, for confronting two types of barriers in a determinate road and for a determinate position (side or median), it will be possible to define, in a Cartesian plan that has in abscissa TGM and in ordinate p, a curve (locus of the points of same cost) that is border between two plane fields in which it's most convenient to utilize one barrier rather another. An example of this it will be shown in the application.

The process has been completely automathized, working out an apposite software for personal computer, so that, if same parameters change, it is immediate to re-calculate the cost function and to plot the curve of confront.

The methodology is conformable to the "General Catalogue of safety road barriers" elaborated by the Commission of study for the Standards of the road barriers, of the Italian Public Works Ministry. In fact, through the present process it's possible to resolve in rational way the element "Individuation of the most probable vehicles" of the flow-chart of the catalogue (fig. 19), adding to the usual technical criterion an economical criterion. This latter cannot be disregarded for public infrastructures for which is required to operate in a decisional context that must be satisfactory for the society.

7. Bibliography


Current Standards Regarding Roadside Safety Barriers in the Netherlands

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Abstract

Vedyac
a versatile tool for roadside design, applied to homologation

Vedyac is a powerful computermodel for the simulation and design of many kinds of movable and interacting (colliding) structures. It has primarily been used in design and improvement of roadside safety equipment as a cheap and reliable substitute for full scale testing. Some of its most prominent features, applications and limitations will be reviewed after which the possibilities and conditions for the use of this model in homologation will be discussed.

Tom Heijer,
S.W.O.V.

Institute for road safety research swov
1.1 General situation

Most of the current standards, are assembled in 1988 and therefore cover quite recent developments. There are two sets of standards, one for motorways and one for all other roads, not being a motorway; within the framework of this paper, the standards regarding motorways are considered most relevant.

The guidelines generally contain the following sections:

- definition of danger zones
  Here guidelines are provided to decide:
  * what road configurations require protective devices
  * which type of device should be applied
  * if applicable, general characteristics regarding the performance of the device

- description of standardized devices
  Five "generic" types of safety barriers are distinguished here:
  * transformable guardrail
  * non transformable barriers
  * impact attenuators for obstacle protection
  * (hand) railing
  * temporary provisions (removable barriers etc.)

For each of these devices, all permitted variants are described and details are provided concerning geometry and mechanical properties of all parts of the constructions.

Remarkably, dynamic behaviour of the constructions like energy absorption or reaction force, is only addressed generally if at all and certainly not standardized!

Although the guidelines are quite strict, they mostly apply to newly built or renovated roads; parts of the 2000 km length of motorways in Holland are therefore still equipped with non-standard (and sometimes sub-standard) devices.

The testing procedures, that underlie the guidelines, have not been formally standardized up to now, although physical testing conditions...
and criteria for approval have not changed substantially in the past 20 years and might be said to form an informal standard. The means, by which the testing is performed on the other hand, has switched from predominantly full scale testing to computer simulation, supported by a limited number of full scale tests.

1.2 Examples of standards:
A) Definition of danger zones
In appendix A1, several figures are shown which geometrically define danger zones and the general stiffness class of protection device (guardrail) required. In the figures, (a) denotes the escape zone (emergency lane, if any, included), (b) denotes the width of the guardrail, (c) the available deformation space and (D) the total distance between roadside and obstacle. The obstacle may be anything from a lighting pole, a concrete pillar to a up- or downgoing slope. Protective measures are only taken if (D) is less than 10 meters.

B) Transformable barriers
This type of barrier, in a variety of forms, is the most frequently used safety device along Dutch motorways. The fundamental form, as depicted in appendix A2, always includes two beams of two-wave-rail, blocked out to either one or both sides (the latter is preferred in most circumstances), depending on the area of application (roadside/median or on bridges). In earthen soil, which is predominant in Holland, these beams are mounted on posts that are driven to a depth of 1 m and are flattened to cut through the soil, thus providing dynamic resistance (damping) and relatively much deformation space. As the resisting force depends upon largely varying soil conditions (this variation may be in the order of 2), it is not formally included in the guidelines. Depending upon available deformation space, the overall stiffness of the construction is regulated by varying the distance between the posts or post resistance in the soil (by adding a "footplate"); there are 3 general categories:
- flexible, with a post distance of 4 m and a deformation space over 1 m
- intermediate, with a post distance of 2.76 or 1.33 m and an optional diagonal stiffener of the beam requiring a deformation space between .5 and 1 m
- stiff, with a post distance of 1.33 m and an additional resistor plate attached to the post to increase soil resistance; deformation space will be between .3 and .5 m.
On bridges and viaducts a type of post is applied which is welded to a footplate in such a way that the welds break at a (more or less) predetermined load. The same categories of stiffness can be realized using this post.

As stated before, the energy absorption characteristics of these barriers are only treated in a cursory way and are not standardized as an explicit design feature. However, as these particular standards for guardrail are relatively old (ca 20 years), they date back to times when traffic speeds and corresponding energy levels were relatively low. We may find that, with impending re-standardization and elevated energy levels in modern traffic, energy absorption will prove an important property in comparison and standardization of transformable structures.

C) non-transformable barriers
This type of barrier is still not very popular in Holland and is mostly applied on roads in the periphery of cities, where speeds are generally limited to ca 80 km/h. The only standardized form is the concrete New Jersey profile as shown in appendix A3, optionally heightened by adding a sort of railing. Variations for roadside and median and guidelines for the inclusion of the profile in walls of tunnels are provided.

D) Impact attenuators
The only formally approved device in Holland now is the so called RIMOB, a construction where energy absorption in frontal collisions is provided by aluminum crumpling tubes, contained in box-like elements. These same elements provide sufficient stiffness in side collisions. The device is programmable to a large extent by varying the number of segments, the number of crumpling tubes per segment, diameter of the tubes and the thickness of the tubes material.

Three configurations have been chosen as a standard (appendix A4):
- 7 segments, V shaped, total length 7.5 m, maximum width 2.7 m
- 6 segments, V shaped, total length 6.5 m, maximum width 1.85 m
- 4 segments, sides in parallel, total length 4.5 m, width 1.1 m

Most segments contain 3 tubes, only the last segment of each device has been strengthened (6 tubes) to handle vehicles with mass up to 2 tons. Furthermore, the first 2 segments of the V shaped attenuators contain somewhat weaker tubes than the other segments.
The weaker tubes are standardized to produce a crumpling force of ca 7.4 kN while crumpling for a minimum of 80% of their original length of 1 m; the stronger tubes yield a force of 13.6 kN. Thus, the approximated, energy absorption per element for each of the standardized attenuators is resp. 17.76 kN.m for the weakest, 32.64 kN.m for the stronger and 65.28 kN.m for the strengthened segment.

Currently, ca 200 of these devices have been installed along Dutch motorways. In some instances, Fitch barriers (sand filled barrels) can still be found, but these will be gradually replaced by RIMOBs; anyway they do not occur in the current standards any more.

E) Hand railing
Especially on bridges and viaducts, a situation can occur where, apart from lanes for motorized traffic, some space for pedestrians (maintenance crews) or bicyclists must be reserved. Appendix A5 depicts some of the standardized provisions for safeguarding these roadusers. In most cases the railing is designed in such a way that it may function as a secondary barrier system for the motorized traffic which is often stronger than the primary system, thus preventing even heavy vehicles from falling off the parapet.

F) Temporary provisions
Apart from the protection devices mentioned in the previous paragraphs, which can also be placed on a temporary basis, only one additional type of (re)movable barrier is included in the Dutch guidelines: the VECU-SEC (Appendix A6), a sheet-metal barrier. Concrete segments of double-faced New Jersey barrier, as used in several other countries, has not been standardized, probably because of their high weight and inherent transportation and handling costs.

1.3 Testing procedures
Initial conditions
In most test for protection devices for motorways, the following, pre-impact conditions have been used frequently: encroachment angles varying from 10 to 20 degrees and speeds between 80 and 110 km/h for passenger cars with a certain emphasis in full scale tests on the combination 20 deg-100km/h. For trucks and busses up to 10 tons, the encroachment angles were the same but speed conditions were chosen between 60 and 80 km/h,
with an emphasis on 20 deg-80km/h. During testing with computer simulations, encroachment angles were varied by 2.5 deg and speeds by steps of 5 km/h and often all possible combinations were tested.

Criteria for approval
In the early full scale testing, not many absolute criteria were formalized. The main objectives were to contain the vehicle, keep it on its wheels and prevent it from "bouncing back" too wildly. Also, snagging on posts and excessive bending of the beam were considered. The results were often primarily used for relative comparison of construction types.
Later, with the introduction of computer processing, the most explicitly used criterion for occupant safety during the impact has been the Acceleration Severity Index (ASI) on the place of the driver. This index only takes into account the linear accelerations in a certain place in the vehicle and is calculated as:

\[ \text{ASI} = \max \left[ \sqrt{\left( \frac{g_x}{7} \right)^2 + \left( \frac{g_y}{5} \right)^2 + \left( \frac{g_z}{6} \right)^2} \right] \]

with \( g \) denoting an average acceleration, averaged over a time interval of 50 msec. Criteria values of 1 and 1.6 for unbelted or belted occupants respectively, were used.

There also have been no formal criteria for post-impact conditions although a maximum value of ca 8 deg. for the redirection angle (the angle under which the vehicle leaves the construction after impact) seems to be accepted.
For tests or simulations with dummies as occupants, also the Head Injury Criterion, with its limit value of 1000, was used.
Other occasionally used criteria include a limit value for chest acceleration of 80 g and a maximum longitudinal femur load of ca 10000 KN.
2. Standardization
The current practice in the Netherlands and other countries, in which standardization primarily entails a definition of admissible shapes and geometrical details and much less a definition of function, is unsuitable as a procedure for international standardization.

Many countries employ more or less dissimilar protection devices that perform their intended duties well despite these dissimilarities. The basis for comparison therefore lies in international harmonization of testing procedures. The Dutch procedures so far, although not formalized, have been more or less successful, specifically for the protection of passenger cars on motorways. It is now felt that recent changes in automobile construction (heavier trucks, lighter and faster cars) and especially the increasing average speeds and multi-lane motorways require revision of these procedures, preferably on a more explicit theoretical basis and, if possible, in an international context. Also, increased speeds and increased traffic density on lower order roads call for better protection.

We must respecify the physical pre-impact conditions, probably not only speed and encroachment angle but also possible rotation (yaw) of the test vehicle prior to the impact. We must consider relevant, state of the art, safety criteria for occupants that are applicable both in full scale testing with dummies and in computer simulations. And finally we must define post impact criteria, whether and when the vehicle must be contained and stopped rather than being redirected and what conditions for redirection are acceptable.

Thus we may arrive at standards which essentially guarantee the road user a predetermined minimum of protection without necessarily abandoning local standards or impeding the development of new or better devices.

How to obtain quantitative standards?
Test conditions must correspond as closely as possible to realistic traffic conditions but not necessarily average conditions as these generally do not represent the most dangerous circumstances. Field observations and accident studies may be necessary to establish these conditions. Of course, already many research institutes have done this and defined their own set of test conditions although often only for motorways. We will probably need standardized conditions representing traffic on lower order roads as well.

Mechanics and biomechanics, but also in depth accident studies, may
provide the necessary safety criteria for vehicles and occupants; these also already exist to some extent. However, a significant lack of international coordination in biomechanical research has mostly precluded combination of results into new standards!

3. The use of mathematical simulations in standardization

3.1 VEDYAC: a brief description

VEDYAC, an acronym for VEhicle DYnamics And Crash, is a computer program that allows detailed simulation of manoeuvering vehicles and their interactions (crashes) with all sorts of obstacles. VEDYAC hardly utilizes pre-programmed structures but instead provides the user with an extensive "tool-kit" with which moving objects (e.g. vehicles) or fixed objects (road surfaces, concrete barriers etc.) can be designed. This toolkit enables the definition of an unlimited number of these movable or fixed objects, their shape, their mass and their inertial properties and allows interconnection of objects. These interconnections can be attributed a variety of mechanical properties; elasto-plasticity, frangibility and damping can be freely defined, both for translations and rotations. A connection can also be made an-isotropic, which means that it reacts differently in different directions.

By these means, the user can construct both simple, single mass, structures and intricate networks of interconnected masses representing flexible constructions like guard rail or a deflectable car body. The use of a library system facilitates the manipulation of large amounts of data; once defined, a structure is accessible under a simple name and can be manipulated by only using this name. Thus, the user can assign initial speeds and trajectories to complete structures but can also assign connections between complete structures, just as if they were single masses.

Model output can be in the form of tables or graphs (time histories) defining the place, speed and acceleration of selectable objects and also in the form of 3 dimensional drawings. If processed suitably, these drawings can easily be made into an animation picture of the simulated event.

Appendix B1 show some examples of results of simulations with flexible constructions.
3.2 Application of simulations in standardization

Essentially, mathematical simulations replace full scale tests to a certain extent. There are general limitations due to the fact that all models necessarily employ approximations and generalizations in order to limit the number of parameters describing details. Still in the relatively long experience of SWOV with the application of simulation techniques, we often find these simulations sufficiently accurate and very significantly cheaper than full scale tests. Especially in the comparison of the performance of different designs for safety devices, the simulations show certain advantages: the speed, the unconditional repeatability of impact conditions and the facility to investigate the influence of single parameters or components separately. Also, simulation allows to gauge the performance of a compound construction on the basis of separate characteristics of the components; these characteristics can usually be established by laboratory experiments without the need of large scale tests. Furthermore, the speed and relatively low costs per simulation generally allow the investigation of a much larger set of impact conditions than would be possible in full scale testing; the graph in appendix B2 illustrates this. It shows the value of the occupant safety criterion ASI as a function of both impact speed and encroachment angle. This function has been established with guardrail tests, by varying speed in increments of 5 km/h and the angle in increments of 2.5 deg. The remarkable shape indicates that at lower speeds but high encroachment angles (that have never been tested in full scale but can nevertheless occur in practice) the safety criterion allows a wider range of "safe" conditions than could have been extrapolated from full scale data. The simulations further indicate that the "Z" shape arises from what might be called the "rear end effect" : at angles below ca 30 deg the rear of the car always hits the barrier after the front end has collided, causing a distinct and high acceleration peak. Beyond 30 deg this effect does not occur.

In principle, all these properties make the simulation technique well suited for application in standardization procedures. There are of course, some "caveats"; putting together a sufficiently detailed, well working description of a protection device requires much time and, due to inevitable approximations, also extensive testing. Although this never increases the costs up to the same level as a comparable series of full scale tests, the costs of a single full scale test may well be equalled.
Moreover, the quality of the simulations of totally new constructions has to be calibrated against reality, which often takes the form of a small series of full scale tests. Fortunately, these calibration tests are often sufficient to validate a "generic" type of construction so that for instance most modifications (within a certain, not very well known limit) of guard rail will not require separate tests. In any case, some prudence must be exercised in attributing "reality" to simulation result, but, even if the results of a single test are not deemed completely realistic, comparison of the performance of different varieties of the same device in otherwise equal conditions can yield valid results.

Simulation techniques are not only useful in the standardization procedure itself, but may also play a role in the definition of standard impact conditions. Since VEDYAC also allows the simulation of vehicle maneuvers (steering, accelerating, braking), investigations can be made into several types of emergency manoeuvering and the resulting pre-impact conditions. As there is hardly a "fullscale test" equivalent for this type of investigation apart from field observations, simulations may even prove to be the most convenient way to establish a suitable set of test conditions.

4. Conclusions
Dutch standards are mostly geometrical in nature and define devices that have been proven successful in practice. The testing conditions that have been employed in the conception of these standards are less explicit and probably need revision.

The standardization of impact conditions and resulting vehicle behaviour, combined with more explicit standards for occupant protection, seems to be the only way to ensure an international "minimum of protection" for the road user.

This approach also permits the use of computer simulation techniques like VEDYAC to aid in the standardization process, thus providing access to a much larger set of initial conditions, improved comparability and a significant reduction of costs.
APPENDIX A5

VTI RAPPORT 349A
Status Report on Current Regulations in United States

Jarvis D Michie
President
Dynatech Engineering, Inc
USA
ABSTRACT OF PRESENTATION

STATUS REPORT ON CURRENT REGULATIONS IN UNITED STATES

Jarvis Michie, Dynatech Engineering
(7 to 10 min)

A brief historical review of U.S. crash testing procedures will be presented beginning with TRC Circular 492 in 1962, to NCHRP Report 153 and then to NCHRP Report 230. Evolution of the test vehicles, the types of roadside features evaluated and development of acceptance criteria will be discussed. Finally, the evolution of procedures that have been directed primarily to research and development efforts to those that are more specifically tailored for hardware acceptance testing will be briefly addressed.
NCHRP Report 230 Update

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ABSTRACT

"NCHRP Report 230 Update"
NCHRP Project 22-7

The objective of NCHRP Project 22-7 is to update the recommended procedures for the safety performance evaluation of both temporary and permanent highway safety features in such a manner as to reflect advances in technology and accommodate current and anticipated roadway and vehicle characteristics. Key topics to be addressed will include the text matrix, data acquisition systems, data evaluation procedures, performance criteria, test condition tolerances, the use of surrogate test vehicles, computer simulation programs and other alternative procedures, and in-service evaluation procedures. An overview and status report of the project will be presented, with a view toward areas of potential harmonization with the European community.
"NCHRP Report 230 Update"
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Research Engineer, Texas Transportation Institute
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and
Jarvis D. Michie
President
Dynatech Engineering, Inc.

INTRODUCTION

Since publication of the initial one-page guidelines for testing of guardrails (1) in 1962, a continuing effort has been made to develop improved, uniform, and consistent impact performance guidelines for roadside safety features. Results of these efforts are published in NCHRP Report 153 (2) in 1974, TRB Circular 191 (3) in 1978, and NCHRP Report 230 (4) in 1981. To a large extent these efforts have been successful in creating standardized test and evaluation procedures.

The efficacy of these documents has been clearly demonstrated in numerous research projects conducted by state and federal agencies and private industry as reflected in the steady improvement in roadside safety. These improvements notwithstanding, there is a growing concern and need for test procedures that are more discerning, that will reflect more than a simple pass-fail criterion, and that will be more indicative of real-world impact behavior during a broad spectrum of potential in-service situations. Potential benefits from improved test and evaluation procedures are most attractive in developing cost-effective alternatives. The capability of more thoroughly defining the impact performance of a feature prior to its introduction into service will minimize the use of a flawed system.

CHANGING NEEDS

The changing vehicle fleet is having an important effect on roadside impact conditions. Report 230 test matrices reflect a vehicle population that existed in the late 1970's and are not representative of the current vehicle fleet or that will operate on the U.S. highways in the 1990's and later. In particular, the downsized passenger sedan with its smaller mass, less rollover stability, less structural stiffness, smaller wheels, etc., has exhibited potential problems in exploratory crash tests with existing roadside features (5,6,7,8,9) and in preliminary analysis of accident data (2,10). Ross has just completed a National Cooperative Highway Research Program (NCHRP) study (5) to examine the performance of current safety features when impacted by sub-1,800 lb vehicles. The study also examined changes that would be necessary in current safety features to accommodate sub-1,800 lb vehicles. In that study it
was pointed out that there are at least four sub-1,800 lb cars now on the U.S. markets (as of 1988).

Accident data analysis indicates that as many as 45% of all impacts with roadside features may involve nontracking vehicles. Potential safety problems arising from nontracking impacts with some roadside safety devices, such as breakaway sign and luminaire supports, have been well documented. These problems arise from the lack of available vehicle crush distance and reduce crush stiffness along the sides of automobiles. Lack of crush distance allows hazards to penetrate the occupant compartment and occupants can come into direct contact with the hazard. Reduced vehicle stiffness can greatly increase vehicle velocity changes and attendant probabilities of injury associated with many point hazard impacts such as breakaway base sign and luminaire supports. Similar problems have been identified with other point hazards such as barrier end treatments and crash cushions.

Although some crash testing has been conducted to demonstrate the problems of side impacts with luminaire supports, there has never been a major effort to develop standard test procedures for these types of impacts. A Federal Highway Administration (FHWA) sponsored study (contract DTFH61-88-R-00092 with Vanderbilt University) has recently begun to develop standard test procedures for these types of impacts. The lack of a concentrated effort to solve this problem is attributed to the general belief that development of safety features to safely accommodate side impacts is beyond the state of the art.

The distribution of impact speed, angle, and attitude can only be determined from accident data bases where police officer estimates or accident reconstruction estimates of impact speed are available (11,28,31,32). More data of this type should soon be available since FHWA plans to fund a research project to reconstruct flexible barrier impacts in the NASS-LBSS accident data files. This project will be carefully monitored and relevant findings will be incorporated into the Report 230 update.

Council, et al. (10) recently completed a study in which small car accident data from a variety of studies were examined. It was found that small vehicles have an increased propensity to overturn in almost all types of accidents, including impacts with the concrete safety shaped barrier (CSSB). A recent study at the Texas Transportation Institute (TTI) also addressed rollover problems with the CSSB (11). Since simulations and crash tests of the CSSB, conducted in NCHRP Project 22-6 (5) in accordance with Report 230 recommendations, gave no indication of increased overturn propensity for minicars, an attempt was made to investigate the disparity between results of this project and evidence from accident studies. As reported in reference 7, a large percentage of single-vehicle accidents involve a skidding or nontracking vehicle. A series of computer runs were therefore made to study the impact behavior of minicars, as well as larger cars, for nontracking impacts with
the CSSB. Results of those runs, although somewhat tentative and subject to verification, clearly point to greater overturn propensity of the minicars for these impact conditions.

Computer simulations were also made to study tracking impacts at lower speeds and at higher impact angles than recommended in Report 230. For these conditions the minicars also had a greater propensity for overturn than did the larger cars.

These results offer some insight into possible reasons minicars have a greater overturn propensity in CSSB accidents. The results also raise interesting questions about the degree to which current impact performance tests reflect critical real-world accident conditions.

It was also shown in NCHRP Project 22-6 (5) that a minicar can easily traverse an AASHTO type B curb in a tracking mode. Studies by others (10) showed that overturn could be expected if the minicar struck the type B curb in a non-tracking skidding mode. Based on a first-order approximation, it was shown in reference 5 that the impulse at the tire-road interface necessary to overturn a 1,500 lb car was approximately one-third that required to overturn a 4,000 lb car. In terms of real-world conditions this means that a terrain irregularity such as a rut, mound of dirt, large rocks, etc., that would not overturn a nontracking large car could easily overturn a nontracking small car.

The current trend in the U.S. is toward smaller automobiles and the heretofore 4,500 lb sedan, widely used as a standard test vehicle, is no longer available except in a few luxury models. While the trend to smaller automobiles continues, the number of vehicle types weighing in excess of 4,500 lb have been increasing rather rapidly. These larger vehicles include pickups, vans, and light and heavy trucks. There is also a trend to longer, heavier, and multi-trailer articulated trucks. Highway safety features may have to accommodate these types of vehicles if the current level of safety is to be maintained. Reference 12 contains a good synopsis of issues related to the safe design of highways for trucks. Of special interest in reference 12 are the papers by Michie and Hirsch dealing with roadside safety design for trucks and the state-of-the-art reviews contained therein. TTI is currently conducting a pooled-fund study for FHWA involving bridge rail designs in which the question of performance levels is being addressed, including designs for large trucks (11).

Testing procedures were first applicable to only guardrails and median barriers (1). Later, bridge rails, breakaway supports, and crash cushions were added to the scope of the testing guidelines (4). It now appears that the scope should be expanded to include non-hardware features such as curbs, traffic islands, pavement dropoffs, embankment slopes, ditches, and driveway slopes. Such features, if not properly designed, can readily cause vehicles to roll over, especially a smaller car with a narrow wheel track and a short wheel base. Hardware
features not presently included in Report 230 that need to be addressed include mailboxes, call boxes, and drainage structures.

With the prospect of an increasing amount of maintenance and reconstruction of highways under traffic, the need for more carefully screened and tested temporary barriers has become more critical. An important design element of a temporary barrier not generally required for a permanent barrier is the protection of personnel in the work zone. This special requirement may take precedence over all other assessment guidelines and control the design of the devices. It may be desirable to develop guidelines dependent on the application of the safety feature. Some temporary barriers are in place for an extended period of time. Highly portable barriers such as the truck-mounted barrier developed at TTI (14) are in place for a very short period of time. It is noted that at least two research projects are underway to examine and develop improved work zone barriers (15,16). Ross is principal investigator of the project in reference 15 and, as part of the study, recommended performance levels will be developed for selected work zone barriers. One of the objectives is to develop a lower performance level end treatment for the concrete safety shaped barrier. In a study for FHWA, Ivey, et al., developed a set of tentative service or performance levels for temporary construction zone barriers (22).

Another changing need is to develop roadside features with a range of performance capabilities and associated test procedures to evaluate the features. The trends to the concept of multiple performance levels (MPL) for longitudinal barriers and increased use of benefit/cost analysis are in response to demands for more cost-effective safety features. In Report 230 the multiple performance level approach was introduced in a supplementary test matrix (Table 4). As a further step, the MPL should be revised to reflect current policy decisions by the American Association of State Highway and Transportation Officials (AASHTO) and FHWA. Furthermore, the MPL should also be extended to include the evaluation guidelines. For instance, evaluation factors for higher performance levels may need to be more restrictive and evaluation factors for lower performance devices may be less restrictive than the current values shown in Table 6 of Report 230.

Another point to considered is the fact that most of the safety funds in the U.S. have gone to the interstate road system. More emphasis may need to be placed on the development and implementation of safety features and programs for lower service level roadways. The update to Report 230 could play a major role in achieving this goal.

In updating Report 230 it may also be desirable to consider a "state-of-the-possible" criterion suggested by Ivey of TTI (17). The criterion is as follows:
"A new structural design for a highway auxiliary structure should be strongly considered for implementation if

1. The new design results in significant improvement in safety for the majority of drivers and passengers,

2. The new design does not result in a significant deterioration in safety for any group of vehicle occupants, and

3. There are no other proven designs of equal or better cost-effectiveness that produce a safer condition for a larger spectrum of vehicle occupants."

Ivey further states, "Although this safety criterion may appear to be self-evident, its acceptance could allow use of structures that vastly improve the safety of the traveling public while not meeting all requirements of NCHRP Report 230 or Transportation Research Circular 191."

Ivey applied the criterion to the design of a breakaway system for timber utility poles. Another feature for which this criterion may be applicable is the safety treatment of drainage structures. It has been well established through testing and computer simulation at TTI (18,19) and by other researchers (20) that safety end treatments for driveway culverts should be sloped at 10 to 1 or flatter in combination with the driveway slope to minimize overturn at encroachment speeds of 60 mph. Flattening driveways to a 10 to 1 slope is very costly due to added fill and longer culverts. Safety treatments of culvert ends are also expensive. Private property owners served by driveways are often responsible for the cost of culverts and necessary fill material.

Another emerging trend in evaluating impact performance is the increased use of surrogate vehicles such as a pendulum or a bogie. FHWA has developed a very reliable bogie at the Federal Outdoor Impact Laboratory (FOIL) in Mc Lean, Virginia for evaluation of sign and luminaire supports. Tests have shown that it has good repeatability. Questions that need to be addressed with respect to the Report 230 update are: (1) Should tests of certain safety features be standardized by recommending the use of a standardized bogie? (2) If so, how should it be configured (to model a specific car or to model a "typical" or "generic" car)? (3) What features can be evaluated most effectively by a bogie vehicle? (4) Should the update recommend procedures for validating bogies?

DEFICIENCIES OF REPORT 230

In the synthesis of Report 230, the general approach was to gather and review the best available research and technology pertaining to safety appurtenance performance and evaluation and then to update deficiencies and fill voids in the existing recommended guide (TRC 191). In the review phase it quickly
became apparent that, indeed, there were voids, inconsistencies, inadequate information, and obsolete procedures. However, it also became apparent that there was a lack of well documented research that addressed these deficiencies. Rather than overlook these deficiencies, NCHRP and the project staff decided to respond to them with the best available information backed up with sound engineering judgment. With the assistance of an expert ad hoc panel appointed by NCHRP, the project staff was encouraged to be bold in their recommended changes in the early drafts. As a consequence, a number of changes in the early draft were wisely deleted from the document.

Many of the deficiencies in Report 230 are documented in written comments and their responses that were prepared and circulated after each draft. Although numerous and quite extensive, these commentaries reflect only a portion of the questions and debate that relate to the evolving document. In addition the project staff accumulated a large file of correspondence, informally presented or incomplete findings from research contracts, annotated copies of drafts and taped proceedings from intensive review sessions with the ad hoc panel.

To address many of these deficiencies, FHWA originated and funded a special project at SWRI under the supervision of Michie (21). As a first step in the contract, Report 230 was extensively reviewed and 51 issues were identified. A number of the more important issues were investigated and solutions identified in the FHWA contract. Key issues studied included the flap space model, risks associated with a redirected vehicle (after impacting a longitudinal barrier), a replacement vehicle for the 4,500 lb automobile, and others.

APPROACH

The task of revising Report 230 will not be a typical research effort. It will require the blending and balancing of a broad range of engineering and scientific knowledge into a document that will be useful to a divergent highway safety community with sometimes conflicting needs. To illustrate, Report 230 has been used by:

- Testing agencies in examining the compliance of existing hardware,
- Researchers in the development of new hardware,
- Contract administrators who specify a crash test feature by reference to Report 230,
- Safety hardware suppliers that base performance design on the Report 230 test matrix and a pass/fail assessment criterion,
- Agencies to specify minimum acceptable performance standards for hardware procurement,
- Computer model developers who rely on vehicle crash test experiments for validation and modeling details, and
- International agencies in evaluating their safety features.

In addition to these possible conflicting needs there is a major concern with crash test costs. In the development and analysis of a new safety feature, cost of conducting a matrix of crash tests is usually the largest line item. The rationale and technique in reducing the innumerable real-world accident conditions to a few specific test conditions is most critical. The addition or deletion of a test for an item like a crash cushion or a guardrail terminal can have serious effects on the development cost and can possibly permit or eliminate implementation of a marginal hardware system. In revising Report 230 every test should be carefully examined to determine (a) is the test needed and if so, are the impact conditions appropriate for the changing times and (b) are other tests needed to examine hardware performance problems revealed by adverse accident experience.

Cost of a Report 230 crash test using passenger sedans is about ten thousand dollars and for trucks and buses, the cost may be five times greater. It is readily conceivable that cost for a typical sedan test could range from fifty thousand to one hundred thousand dollars each by adding complexity and specificity to the test design. Examples of sophistication include (a) using new vehicles, (b) using fully instrumented dummies in each seating position, (c) instrumenting the hardware with strain and displacement monitoring devices, (d) reducing tolerance range for impact conditions, etc. These factors have been carefully appraised by ad hoc advisory panels in preparing Reports 153 and 230 and should again be appraised in the proposed program. To emphasize, it is important to produce a testing procedure that is both technically and economically feasible.

It is also incumbent on those responsible for developing an update to Report 230 to carefully consider the overall effect the guidelines will have on the ultimate goal of improving highway safety and costs associated therewith. Test vehicles, test procedures, and evaluation criteria will have a major impact on future roadside safety. Examples to illustrate this point are:

1. Most frangible transformer bases, widely used as breakaway devices for luminaire supports, cannot meet the new safety specifications (for an 1,800 lb car) contained in the 1985 AASHTO sign and luminaire specification. This may result in a significant increase in the cost of breakaway luminaire supports and create economic hardships for several manufacturers. All available data suggests that the supports are performing in an acceptable manner. What is not known, however, is the degree to which small car
accidents are represented in the data and what the future holds in terms of the small car population. The 15 ft/sec limit on vehicular velocity change required in the AASHTO specifications (and in Report 230) is very conservative in terms of occupant risk, and only in rare instances will a 15 ft/sec impact produce serious injuries. When combined with the probability of an 1,800 lb car impact with unrestrained occupants, the actual risk is indeed very small. The question is: Is the limiting value too conservative?

(2) Report 230 identifies two soil types in which guardrail posts and breakaway devices can be tested. Performance of supports in the two soils can be significantly different, with poorer performance generally occurring in the weaker soil. Once tests of a support are conducted in both soils, an agency must then try to decide how to interpret and apply the results. In view of the extremely varying nature of soils both temporally and geographically, even within a relatively small region or jurisdiction, an agency may then have to conduct a costly and time consuming survey of practically every support site. How does an agency determine which of the two soils best fits the site conditions?

(3) The performance of a safety feature is obviously dependent on the characteristics of the impacting vehicle. For a given size and class of vehicle, significant variations exist in important properties such as C.G. height, mass distribution, structural stiffness, profile, and axle configuration. By selecting a vehicle with extreme properties, one can place very high and possibly unreasonable demands on a safety feature.

PROJECT OBJECTIVE

The objective of this project is to update the recommended procedures for the safety performance evaluation of both temporary and permanent highway appurtenances in such a manner as to reflect advances in technology and accommodate current and anticipated roadway and vehicle characteristics. In performing the project, it is anticipated that a number of important research needs will also be identified.

STATUS

The project to update Report 230 began June 1, 1989 and is scheduled for completion November 30, 1991. At the time of this writing (mid-June, 1989) there were no major developments to report. It will be conducted in two phases. Phase I will be concerned with the selection, synthesis and prioritization of issues. During this phase input from the project advisory panel and from selected highway safety experts will be solicited. A minimum of six "white papers" will be prepared covering the following topics: (1) Assess/Refine Purpose of Document, (2)
Examine and Revise Test Matrix, (3) Refine Assessment Procedures and Criteria, (4) Examine Test Conditions Control, (4) Use of Surrogate Test Vehicles, Computer Simulations, and Other Alternative Procedures, and (6) In-Service Evaluation of Safety Features. Phase II of the project will concentrate on the development of drafts and then a final report of the update. In this phase the project panel and representatives of various agencies in the highway safety community, both nationally and internationally, will be asked to critically review the drafts.

REFERENCES


11. "Rollover Caused by Concrete Safety Shaped Barrier,"


Texas Transportation Institute, Texas A&M University, Mar. 1983.


Current Issues in Work Zone Safety

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CURRENT ISSUES IN WORK ZONE SAFETY

Abstract

This paper will summarize the proceedings of a special summer meeting arranged by two separate committees of the Transportation Research Board -- the Roadside Safety Features Committee and the Traffic Safety in Maintenance and Construction Operations Committee. The joint meeting will be held at the Northwestern University Traffic Institute in Evanston, Illinois, on July 17-18, 1989. Planned topics of discussion include: (1) safety test conditions and evaluation procedures for work zone appurtenances (including the dynamic behavior of the appurtenance when impacted), (2) performance criteria and warrants for barriers, (3) criteria and warrants for truck mounted attenuators, (4) the relationship of traffic control plans and barrier warrants, and (4) temporary raised islands. Participants will be placed in breakout sessions to develop both recommendations for guidance in regard to these issues and ideas for research.
CURRENT ISSUES IN WORK ZONE SAFETY
William W. Hunter
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ABSTRACT

This paper summarizes the proceedings of a special summer meeting arranged by two separate committees of the Transportation Research Board -- the Roadside Safety Features Committee and the Traffic Safety in Maintenance and Construction Operations Committee. The joint meeting was held at the Northwestern University Traffic Institute in Evanston, Illinois, on July 17-18, 1989. Topics of discussion included: (1) requirements for work zone traffic control devices, (2) requirements for work zone barriers and crash cushions, (3) adjusting work zone barrier and crash cushion requirements by use of traffic control plans, and (4) warrants and safety requirements for truck-mounted attenuators.

1. INTRODUCTION - CHAPTER 1

A recent report by the American Association of State Highway and Transportation Officials (AASHTO, 1987) deals specifically with work site accident data. Chapter 9 of the Roadside Design Guide (AASHTO, 1989) offers a good summary of the AASHTO work zone report:

The recent AASHTO "Summary Report on Work Zone Accidents" contained several conclusions. It was noted that, in general, work zone fatal accidents concentrate in rural areas. However, the majority of all work zone accidents and injuries are concentrated in urban areas. For its mileage and traffic volumes, the Interstate highway system is over-represented in all types of accidents occurring in work zones and offers an excellent opportunity to enhance work zone safety. Accidents which occur in work zones are generally more severe, producing more injuries and fatalities than the national average for all accidents. Fixed-object accidents are more of a concern in rural areas; however fixed object accidents in both rural and urban areas more frequently result in injuries and fatalities than vehicle-to-vehicle collisions. About half of all work zone fixed object accidents occur in
darkness. The report finally concluded that although the data are limited, tractor-trailer injury and fatal accident involvement in work zones is considerably higher than the national average for these vehicles, particularly on the Interstate system.

Based on Fatal Accident Reporting System (FARS) data, annual fatalities in work zones and maintenance zones now exceed 700 in the United States.

Given this background, a special summer meeting on work zone safety was held at the Northwestern University Traffic Institute in Evanston, Illinois, on July 17-18, 1989. The meeting was planned and hosted by two Transportation Research Board (TRB) Committees:

- Committee A2A04 Roadside Safety Features
- Committee A3C04 Traffic Safety in Maintenance and Construction Operations

The meeting was divided into four major areas of discussions: (1) requirements for work zone traffic control devices, (2) requirements for work zone barriers and crash cushions, (3) adjusting work zone barrier and crash cushion requirements by use of traffic control plans, and (4) warrants and safety requirements for truck-mounted attenuators. Attendees first listened to background presentations about these subjects and were then split into break-out groups to discuss the most pressing issues. This paper will highlight the summary comments of the breakout groups.

1.1 Session 1 - Requirements for Work Zone Traffic Control Devices

The basic charge to this break-out group was the following:

In regard to work zone traffic control devices, what test procedures and performance standards should be used? What should be considered in developing performance standards?

As pertains to standard traffic control devices, the panel unanimously agreed that performance standards and test procedures should be developed. Performance standards should be the same for all devices when impacted by a vehicle. Product performance should also be uniform throughout the United States. The following recommended performance standards were presented:

- No passenger compartment intrusion;
- Minimum threat from debris for both workers and other road users;
No interference with vehicle control, especially as applies to loss of steering or braking, windshield visibility, and the chance of becoming a hazard to other drivers.

The following recommended test procedures were presented:

- Vehicles - need both large (3500 - 4500 pound passenger cars and 5400 pound pick-up) and small (1800 pound passenger car);
- Speeds - range of 30-60 miles per hour;
- Vehicle impact locations - need center front, wheel track front, and brushing impacts along the side of the vehicle;
- Test documentation - need two video or film cameras and high speed film or video (although regular speed film or videotape can be used for many tests).

These recommendations were based largely on the New York Department of Transportation's recent experience in traffic control device testing.

It was suggested that testing should begin with some national testing, perhaps an outgrowth of a pooled-fund study, and perhaps at some regional test centers. Test standards should be formulated, perhaps again from an NCHRP study, but this cycle could take five to six years to complete. An alternative is to add another task to the current NCHRP study that updates NCHRP Report 230, Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances (Michie, 1981).

The idea is to have a manufacturer obtain certification for a device by sending it to a test laboratory. Test results could then be compiled. Private companies and government agencies could perform subsequent testing based on established standards. Tests would be open to observers, and the manufacturer or supplier or government agency would need to prove that a product is certified.

It was felt that test standards and procedures are needed rapidly, to respond to the many new traffic control devices that are entering the market. Modification of an existing contract is probably the most efficient way to complete the process of developing, testing, and evaluating traffic control device performance standards and test procedures. Manufacturers of work zone traffic control devices should be involved in the process.

The response to these suggestions from other attendees was varied. One felt that the Federal Highway Administration (FHWA)
could help certify devices, while another felt that either AASHTO or TRB could become the clearinghouse for testing. It was recommended that requirements for passenger compartment intrusion and debris control be made specific.

1.2 Session 2 - Requirements for Work Zone Barriers and Crash Cushions

The basic charge to the second break-out group was the following:

In regard to work zone barriers and crash cushions, what test procedures and performance standards should be used? How should the warrants for use of barriers and crash cushions be established? What should be considered in developing the warrants? What should the warrants be?

A background presentation pointed out that a variety of issues are present in considerations involving work zone barriers and crash cushions. For example, the operational geometrics typically differ from the mainline, and traffic speed through the work zone tends to be reduced. Because of restricted shoulder area, impact angles tend to be shallower. Barriers and crash cushions not only have to protect the motorists from work zone hazards but also protect the workers from errant vehicles. Because of site geometrics, the barrier and attenuator systems used are frequently less protective than those which must satisfy permanent conditions. Determining appropriate crash test conditions is difficult.

The group felt that work zone safety features should be required to satisfy some minimum level of impact performance, especially barriers and crash cushions. The consensus was that the multiple performance level (MPL) concept for work zone safety features was a reasonable approach, although only one state representative was assigned to this group. The MPL concept would almost assuredly mean increased inventory and costs for state highway departments. If the MPL concept were adopted for work zones, probably two or three performance levels would be needed, as opposed to five or six levels for permanent devices.

A clear need is the availability of data that describe impact conditions in work zones, especially as related to site and traffic conditions and work zone activities. In determining the adequacy of barriers and attenuators for work zones, it would be desirable to try to limit the number of required crash tests. Tests for special tapers and flares would probably require larger impact angles, but little is known about how such tapers and flares should be treated.

Developing warrants or guidelines for the use of the devices would be difficult but necessary, and there should be as much overlap as possible between warrants for permanent and temporary devices. Little is known about current state agency criteria for
developing warrants or where to apply the performance levels. It was felt that using a benefit/cost concept would be a logical way to proceed in developing warrants, although more needs to be known about encroachment angles in work zones. The quality of the work zone also needs to be described, because this can affect both the number of accidents and the accident severity.

The audience discussion noted that test criteria for work zone barriers and crash cushions can perhaps come from the update of NCHRP Report 230, but development of warrants could take much longer. The process could linger for five to ten years if the typical NCHRP project funding cycle is followed, and AASHTO support would be needed. Due to the urgency of the need, it was suggested that ongoing or planned studies be amended or expanded to take the development of warrants into account.

1.3 Session 3 - Adjusting Work Zone Barrier and Crash Cushion Requirements by Use of Traffic Control Plans

The basic charge to this break-out group was the following:

How should warrants for use in restricted work zones be established? What should be considered in developing the warrants? What should the warrants be?

Two common types of restricted work zones are: (1) the upgrading of bridges with intersecting streets near the bridge end, and (2) the upgrading of urban arterials from two-lane, two-way facilities to divided, multi-lane facilities. Both create special problems with barrier use. In the first, large barrier flare rates are sometimes employed, and the second situation often creates exposure to many hazardous barrier ends through the provision of numerous business, apartment, home, etc. access openings. These situations were used as background to the group discussion.

The group consensus was that there is a clear need for a procedure to select traffic control devices or positive separation devices in restricted work zones. The procedure needs to be defendable and reproducible and should define a minimum device. Both the states of Florida and Virginia have developed such procedures in the past. The Virginia method takes into account such factors as encroachment rates; a hazard scale for the presence of fixed objects, dropoffs, and workers/equipment; duration of the activity; length of the work zone; traffic speeds; and lateral offset. The procedure covers devices ranging from traffic cones to positive barriers.

With such a procedure in place, the location or design engineer would use the criteria to determine what kind of traffic control device or barrier is needed. If a barrier were already in place, the engineer would try to manipulate traffic so as to
minimize the hazard by using supplemental taper, special channelizers or traffic signals, etc.

In regard to crash testing of work zone hardware, the consensus was that the multiple performance level approach was reasonable, but the group recommended caution in setting up the procedure. There was concern that a 30-foot barrier from one state could be judged acceptable from crash tests, while a similar 12-foot barrier from another state would not, and yet actual in-service performance of the shorter barrier could be excellent.

There was expressed a need for data about the distribution of impact speeds and angles when work zone hardware is struck. Such data is required to develop a recommended crash test matrix.

The audience response was again varied, especially in regard to the multiple performance level approach. On the one hand, there was concern about the cost of inventory for lower level systems, as well as the likelihood of some catastrophic failures. On the other hand, others felt that urban areas may have lower impact speeds and angles than rural or freeway areas, and that the urban areas should have the ability to use lower performance systems.

1.4 Session 4 - Warrants and Safety Requirements for Truck-Mounted Attenuators

This breakout group was to be concerned with the following issues:

How should the warrants for truck-mounted attenuators (TMA's) be established? What should be considered in developing the warrants? What should the warrants be? What testing procedures and performance standards should be used?

There is considerable experience with TMA's, as several thousand are now estimated to be in use nationwide. TMA's have shown to be effective in accident situations. Even with this exposure, the break-out group felt that not enough is currently known to develop "warrants" for TMA's -- the group was much more comfortable with the term "guidelines."

In terms of establishing guidelines, both short-term and long-term comments and suggestions were made. For the short-term, it was felt that highway agencies need guidelines in some form now, as the tendency is to use engineering judgment. There also seems to be a lack of clarity as to whether an individual state or the Federal Highway Administration is in charge of TMA policy. There is a need to survey the states to see what guidelines currently exist and how these affect the use of TMA's. It was suggested that the focus could be on states with high
usage of TMA's (such as California, New Jersey, New York, Ohio, Pennsylvania and Virginia) plus another ten or so states with somewhat less use. The survey could also ask for documented case studies.

For the long-term, it was suggested that a National Cooperative Highway Research Program (NCHRP) study be undertaken. This would help to provide data about how TMA's are used and the resulting accident circumstances.

The break-out group also offered comments on what factors should be considered in developing guidelines. Based primarily on the background speakers' presentations, these factors included:

- time of work zone performance (peak versus off-peak)
- distance of work site from the edge of pavement (e.g., within/beyond 15 feet)
- average daily traffic combined with number of lanes (e.g., 2000 ADT for a two-lane road and 5000 ADT for a four-lane road)
- highway operating speeds
- highway type or functional classification
- whether the work zone activity is a moving operation and, if so, the moving speed
- where a lane obstruction results from a continuous moving work zone situation
- visibility in the work zone, including considerations for roadway curvature, weather, etc.
- when a flagman is not anticipated to be totally effective
- when a warning sign is anticipated to be marginally effective
- when arrowboards create a sudden and dangerous reaction for the motorist
- when cone tapers are anticipated to be inadequate
- the number of workers to be protected
- the morale of the workers as affected by TMA placement
- the shielding of expensive equipment
Considering test procedures and the development of performance standards, it was not clear how TMA's would fit into the update of NCHRP 230. It was suggested that any test criteria developed should consider both the size and roll-ahead distance of the shadow vehicle, as well as the size, speed, and angle of the impacting vehicle.

In the ensuing discussion, it was noted that the State of Texas is about to develop standards for TMA's. Project activities may include surveying the states about their practices in using TMA's and testing all the devices on the market. An alternative would be for AASHTO to gather the state survey data.

2. SUMMARY AND DISCUSSION - CHAPTER 2

From this brief meeting on work zone safety, several needs have been identified:

1. There is an urgent need for the development of work zone performance standards for traffic control devices, barriers, and crash cushions.

2. There is a need for a thorough work zone accident study that can define impact conditions by vehicle type for a variety of work zone treatments.

3. There is a need for recommended crash test procedures for work zone hardware.

4. There is a need for warrants or guidelines concerning the use of all types of work zone hardware, including truck mounted attenuators.

In the United States, work zone fatalities have stabilized at around 700 per year, a high price to pay for construction and maintenance of our roadways. Besides the needs identified by this conference, other emphasis areas include traffic management strategies (such as shortening high volume construction time and better coordination and scheduling of projects), public awareness programs to help motorists understand the seriousness of work zone traffic control devices and the prevalent hazards, improved traffic control plans, and improved traffic management techniques and devices.
REFERENCES


The Traffic Environment and Vehicle Accidents

Hans Norin
Volvo Car Corporation
Sweden
THE TRAFFIC ENVIRONMENT AND VEHICLE ACCIDENTS
- Experience from Volvo Accident research in Sweden.


A high standard of road safety requires a good interaction between people, vehicles and traffic environment.

This presentation is devoted to experience gleaned from road accidents involving collisions with selected objects in the traffic environment. The report shows that a significant proportion of these collisions, which caused serious personal injury, were with objects off the actual road.

Trees and heavy lamp posts are the type of objects involved in most of these cases of personal injury. In addition, the report includes many accidents in which significant injury was caused by road rails/pedestrian pass rails, which from a traffic safety point of view were unfavourably designed.

In all new road constructions, as well as when revising traffic traffic systems, the objective should be to attain a high standard of safety with regard to road environment. Exclusive use of energy-absorbing posts and other safe types of road furniture would significantly increase the overall standard of road safety.
A Proposal for European Harmonization of Crash Cushions

Michael G Dreznes
Director of International Operations
Energy Absorption Systems, Inc
USA
A PROPOSAL FOR EUROPEAN HARMONIZATION OF CRASH CUSHIONS

By Michael G. Dreznes
Director of International Operations
Energy Absorption Systems, Inc., U.S.A.

I. INTRODUCTION

Highway engineers around the world today are faced with the challenge of providing many kilometers of safe highway condensed into limited space around a municipal area. As the luxury of ideal geometrics is replaced by practical flyovers, cloverleafs, and underpasses, the presence of blackspots, or hazardous sites, becomes more prevalent.

Design engineers will create more forgiving designs by:

1. redesigning the highway to eliminate the hazard;
2. moving the hazard further away from the road;
3. making the hazard breakaway;
4. shielding the hazard with a crash cushion, or impact attenuator.

As these designs become more sophisticated, many designers are relying on the fourth option, crash cushions, to provide a safe road. Crash cushions are a recent innovation in many countries, and it is necessary to develop a specific performance criteria for these systems to assure designers that the recommended crash cushions function properly.

This study traces the evolution of crash cushion performance criteria, and develops evaluation guidelines that take into consideration European vehicles and road conditions. These crash cushion guidelines are proposed for harmonization throughout Europe.

II. EVOLUTION OF UNITED STATES CRASH CUSHION GUIDELINES

Crash cushions, or impact attenuators, are called passive restraints because they are designed to reduce the consequences of an accident, rather than prevent the accident from happening. A crash cushion is designed to cushion or soften the impact of a vehicle hitting a rigid object, to eliminate fatalities, and to reduce injuries to occupants in the vehicle.

United States engineers began to develop crash cushions in the late 1960s. Extensive research and development by industry and federal and state governmental agencies produced some very basic systems, including Texas steel barrels, inertial barrels, telescoping cylindrical tubes, steel nets, and water filled crash cushions.
Approval to use these early crash cushion systems on U.S. roads was sought from the highway authorities. When it was discovered that some systems seemed to give acceptable results and some did not, the Transportation Research Board (TRB) cited the need for uniform and predictable performance. Research supported by the American Association of State Highway and Transportation Officials (AASHTO), and in cooperation with the Federal Highway Administration (FHWA), led the Transportation Research Board to issue the first guidelines for evaluating crash cushions in November, 1972, i.e., National Cooperative Highway Research Program Report 118 (NCHRP 118).

II.A. NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 118 (NCHRP 118)

NCHRP 118 was the first attempt to document evaluation guidelines required for crash cushion use on U.S. Federal-Aid highways. The performance criteria was somewhat vague and subjective in many respects.

TABLE 1: VEHICLE IMPACT TESTS

<table>
<thead>
<tr>
<th>Empty Weight</th>
<th>Speed</th>
<th>Angle</th>
<th>Barrier Impact Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 lb/907 kg</td>
<td>60 mph/97 kph</td>
<td>0°</td>
<td>Center nose of device</td>
</tr>
<tr>
<td>4500 lb/2040 kg</td>
<td>60 mph/97 kph</td>
<td>0°</td>
<td>Center nose of device</td>
</tr>
<tr>
<td>4500 lb/2040 kg</td>
<td>60 mph/97 kph</td>
<td>15°</td>
<td>Along barrier side</td>
</tr>
<tr>
<td>4500 lb/2040 kg</td>
<td>60 mph/97 kph</td>
<td>25°</td>
<td>Along barrier side</td>
</tr>
</tbody>
</table>

NCHRP 118 stated that occupant injuries and fatalities are usually related to:

1. accident severity, i.e., vehicle deceleration intensity and duration;
2. pre-crash physiological condition of passengers;
3. the passenger's degree of restraint;
4. the crashworthiness of the vehicle.

Crash cushion performance during the four tests shown in Table 1 was evaluated by the guidelines on the next page.

EVALUATION GUIDELINES:

1. Structural Adequacy: System must stop vehicle without allowing it to climb over, break through, or wedge under
the installation. The crash cushion should not endanger other vehicles with barrier fragments or barrier elements that could intrude into the passenger compartment or obstruct roadways.

2. **Impact Severity:** On impact, a crash cushion must redirect a vehicle so that occupants restrained by seat belts can survive with little or no injury. In a head-on impact, an average vehicle deceleration of 12g's, calculated from the vehicle impact speed and stopping distance, is allowed. When redirecting the vehicle, deceleration rates, based on the highest 50 millisecond (msec) average, are to be a maximum of 6g's for unrestrained passengers, 12g's for passengers restrained with lap belt, and 25g's for passengers restrained with lap and shoulder belts.

Average g rates are determined by the following formula:

\[ \text{Average } g = \frac{v^2}{2G(x)} \]

- \( g \) = deceleration rate
- \( v \) = the vehicle impact velocity (ft/sec or meter/sec)
- \( G \) = acceleration due to gravity (32.2 ft/sec\(^2\) or 9.8 m/sec\(^2\))
- \( x \) = vehicle penetration or stopping distance after striking the attenuator

3. **Vehicle Trajectory:** A crash cushion barrier should redirect or stop a vehicle so as to minimize the hazard to following or adjacent traffic. Ideally, the vehicle should remain close to the barrier installation and should not be directed back into traffic.

The 12g maximum deceleration rate for head-on impacts was based on evidence that some injuries could be expected at this deceleration level by restrained occupants, but most injuries would not be fatal.

During the analysis of crash test data, deceleration rates are evaluated each millisecond. A typical crash will last approximately 350 msec; therefore, 350 data points are considered. In calculating the average, all 350 measurements are summed and divided by 350.

This methodology does not give adequate consideration to "spikes" (abnormally high deceleration rates over short time periods that occur during the course of the impact, which can lead to a fatality). In other words, a spike of 50g's lasting 10 msec, which could cause a fatality, might be present in an impact that otherwise yielded a 10g average over the
entire event. The resulting overall average g would be 11.1, well below the tolerable limit of 12g; however, the occupants might not survive the impact.

\[
\frac{(10 \text{ [340 msec]} + 50 \text{ [10 msec]})}{350 \text{ msec}} = 11.1 \text{ g}
\]

A smaller vehicle will typically encounter a spike when it first impacts the crash cushion. The lighter mass of a smaller vehicle will result in a lower force against the crash cushion than a larger vehicle. The lower force will have less ability to overcome the resistance of the crash cushion during the initial impact. This inability caused by the lower mass will cause the occupants to experience higher deceleration rates and a more violent reaction during the initial phase of the impact.

A large vehicle gives lower deceleration rates when initially impacting the crash cushion, because the greater mass of the large car overcomes the initial resistance of the crash cushion. However, the larger vehicle can experience a spike if the vehicle reaches the obstacle at a high velocity and if the crash cushion's energy absorbing capability has been used. It is possible that the occupants of the vehicles can be seriously injured or killed during the high g spikes, yet the average deceleration rates for the entire event would be less than the 12g average limit.

The authors of NCHRP 118 understood the importance of occupant reactions, but did not have an adequate method to quantify occupant deceleration rates other than the vehicle average deceleration rate.

Continued analysis of the performance of existing crash cushions by researchers indicated that certain changes were necessary to consider the effect of high g spikes on the occupants. In 1974, NCHRP 118 was revised and issued as NCHRP 153.

II.B. NATIONAL COOPERATIVE RESEARCH PROGRAM REPORT (NCHRP 153)

TABLE 2: VEHICLE IMPACT TESTS

<table>
<thead>
<tr>
<th>Weight</th>
<th>Speed</th>
<th>Angle</th>
<th>Barrier Impact Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>2250 lb/1020 kg</td>
<td>60 mph/97 kph</td>
<td>0°</td>
<td>Center nose of device</td>
</tr>
<tr>
<td>4500 lb/2040 kg</td>
<td>60 mph/97 kph</td>
<td>0°</td>
<td>Center nose of device</td>
</tr>
</tbody>
</table>

(continued on next page)
Barrier Weight Speed Angle Impact Point

4500 lb/2040 kg 60 mph/97 kph 20° Along side, mid-length

4500 lb/2040 kg 60 mph/97 kph 10-15° 0-3 ft (0-1 m) offset from center of nose of device

EVALUATION GUIDELINES:

1. Structural Adequacy: The test article shall not pocket or snag the vehicle, causing abrupt deceleration or spinout, or shall not cause the vehicle to rollover. The vehicle shall remain upright during and after impact, although moderate rolling and pitching is acceptable. There shall be no loose elements, fragments or other debris that could penetrate the passenger compartment or present an undue hazard to other traffic.

Acceptable test article performance may be by redirection, containment, or controlled penetration by the vehicle.

2. Impact Severity: Where test article functions by redirecting vehicle, maximum vehicle deceleration (50 msec avg), measured near the center of mass, should be less than the following values:

<table>
<thead>
<tr>
<th>Maximum Vehicle Decelerations (g's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

These rigid body accelerations apply to impact tests at 15° or less.

For direct-on impacts of test article, where vehicle is decelerated to a stop and where lateral accelerations are minimal, the maximum average permissible vehicle deceleration is 12g’s, as calculated from vehicle impact speed and passenger compartment stopping distance.

3. Vehicle Trajectory: After impact, the vehicle trajectory and final stopping position shall intrude a minimum distance into adjacent traffic lanes.

This revised format increased the minimum small vehicle weight from 2000 lbs (907 kg) to 2250 lbs (1020 kg), and included more stringent requirements for the structural adequacy of the crash cushion. The 12g average was still
considered acceptable for vehicle deceleration in a head-on impact.

Experience showed that occupants in vehicles impacting some existing crash cushions still experienced serious injuries and fatalities. Researchers continued to evaluate the differences between reactions of occupants during an actual impact and the 12g event average deceleration rate to determine why the 12g theoretical accepted limit was not correlating with actual injuries and fatalities.

II.C. THE HARMONIZATION OF CONDITIONS FOR CRASH TESTS REGARDING PASSIVE SAFETY ON ROADS

The first European guideline was published while NCHRP 153 was in effect. Called "The Harmonization of Conditions for Crash Tests Regarding Passive Safety on Roads," it was a joint German-French document presented in Lyons on May 16, 1977. In this report, crash cushions were referred to as "Passive Safety Devices for Frontal Crashes."

### TABLE 3: VEHICLE IMPACT TESTS

<table>
<thead>
<tr>
<th>Weight*</th>
<th>Speed</th>
<th>Angle</th>
<th>Barrier Impact Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>1240-1300 kg</td>
<td>100 kph + 5 kph</td>
<td>0°</td>
<td>Enter point with .25 L to left or right (L is front width of crash cushion)</td>
</tr>
<tr>
<td>1250-1300 kg</td>
<td>80 kph + 5 kph</td>
<td>30°</td>
<td>Along side, mid-length</td>
</tr>
<tr>
<td>1250-1300 kg</td>
<td>100 kph + 5 kph</td>
<td>0° + 5°, vehicle axis to side of unit</td>
<td>+ 20 cm offset from side of device</td>
</tr>
</tbody>
</table>

*including dummy

These tests were designed for systems being installed at sites with maximum allowed speeds of 100 kph. As the site speed limits increased or decreased, so did the necessary test speeds.

EVALUATION GUIDELINES:

1. Structural Adequacy: The report must include if the vehicle, and under which circumstances, has or will have hit the obstacle isolated by the crash cushion. It must also include if parts of the test object or of the vehicle were catapulted. Which parts, and their position in
relation to the original location of test object, must be noted. Additional information is requested concerning the following:

a. The course of the vehicle, especially about the course before hitting in relation to the course after hitting; and general data for determination of the vehicle’s final position.

b. The behavior of vehicle on this course: rotating around the axis, rebounding, overturning.

c. The damages and deformations at the vehicle, caused by the impact. (It is especially noted that the vehicle’s doors be opened without tools, in order to see if it is possible for the passengers to leave the damaged vehicle.)

d. The damage and deformation of the test object, as well as quality aspects of the necessary repairs.

Two criteria for evaluating the vehicle’s damages are to be worked out. The first criterion, the economical factor, is the percentage of estimated costs for necessary repairs in relation to the estimated original value of vehicle at that very moment.

The second criterion considers the different deformations of the vehicle.

2. Impact Severity: Use the Acceleration Severity Index (ASI) Criteria:

\[
ASI = \sqrt{\left(\frac{g_x}{g_{x1}}\right)^2 + \left(\frac{g_y}{g_{y1}}\right)^2 + \left(\frac{g_z}{g_{z1}}\right)^2}
\]

where \(g_x\), \(g_y\), and \(g_z\) are average decelerations measured over a period of 50 msec and \(g_{x1} = 12\), \(g_{y1} = 9\), and \(g_{z1} = 10\).

Selected criteria for belted persons vary between .8 to 1.1, based on each country’s decision.

3. Vehicle Trajectory: Analyze the course of the vehicle, especially the angle before hitting in relation to the course after hitting; analyze general data for determination of the vehicle’s final position.

This report gave very general guidelines to evaluate crash cushion performance. The empty vehicle weight of 1000 to 1150 kg, used in the three tests in the Harmonization report were based on the weight of an average European vehicle. However, a large range of vehicle weights are on the highways.
around the world. Occupants in a heavy vehicle, average vehicle, and light vehicle react differently during an impact. A crash cushion system that is effective for a vehicle of one size may not be effective for a heavier or lighter vehicle. Similarly, the crash cushion designed and crash-tested for only the average vehicle may not be effective for a lighter or heavier vehicle.

This report used the "Acceleration Severity Index" (ASI) for impact severity evaluation. While the origin of ASI is unclear, it was first introduced to the highway safety community by the Texas Transportation Institute (TTI) in 1972. TTI used it to evaluate roadside geometric features such as ditches or sideslopes. It was never intended to be used as a crash cushion evaluation mode. The individual g components used in the ASI calculations are the highest 50 msec average during the deceleration event. These maximum 50 msec averages can include a spike and still meet the approved deceleration levels.

French and German officials decided to use the ASI criteria based on some earlier research done in The Netherlands. However, the ASI number selected for the criteria vary greatly, thereby allowing a system to be operational in one country, but not another. Table 4 illustrates this discrepancy by showing that a crash cushion using ASI specifications in The Netherlands is acceptable, but it will not meet the French or German requirements. This evaluation process compromises the credibility of the Acceleration Severity Index.

**TABLE 4: ASI ACCEPTABLE LEVELS**

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>RESTRAINED OCCUPANTS</th>
<th>UNRESTRAINED OCCUPANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>France and Federal Republic of Germany</td>
<td>≤ 1.0</td>
<td>Not specified</td>
</tr>
<tr>
<td>Netherlands</td>
<td>≤ 1.6</td>
<td>≤ 1.0</td>
</tr>
</tbody>
</table>

Evaluation criteria in the Harmonization report apparently are no longer being used in France or Germany for crash cushion evaluation. It is uncertain to what extent they were ever used in either country.

**II.D. TRANSPORTATION RESEARCH CIRCULAR 191 (TRC 191)**

In 1978, one year after the Harmonization report was issued, researchers in the United States were incorporating their findings on crash cushion performance in a second, revised guideline called Transportation Research Circular 191.
TRC 191 specifications included the following criteria:

**TABLE 5: VEHICLE IMPACT TESTS**

<table>
<thead>
<tr>
<th>Speed</th>
<th>Angle</th>
<th>Barrier Impact Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>eight</td>
<td></td>
<td>Same as shown in Table 2.</td>
</tr>
</tbody>
</table>

**EVALUATION GUIDELINES:**

1. **Structural Adequacy:** Same as shown in Table 2.

2. **Impact Severity:** Same as shown in Table 2, plus the following – for direct-on impacts of test article, where vehicle is decelerated to a stop and where lateral accelerations are minimal, the preferred maximum vehicle acceleration average is 6g's to 8g's. The maximum average permissible vehicle deceleration is 12g's, as calculated from vehicle impact speed and passenger compartment stopping distance.

3. **Vehicle Trajectory:** Same as shown in Table 2.

TRC 191 emphasized the importance of using crash cushions to protect the occupants in the vehicle, not just the vehicle. This circular also required the passenger compartment be intact after the crash for acceptable performance. In 1978, when TRC 191 was written, the method of evaluating the reaction of the occupants included only the vehicle’s average deceleration rate, not the actual reaction of the passengers. TRC 191 did reduce the preferred deceleration rate from 12g's to 6 to 8 average g's. However, 12g's was still acceptable.

Researchers confirmed that a vehicle crashing into a rigid object caused two subsequent and separate impacts. First, the vehicle impacted the object, and was brought to a stop. Second, the occupants in the vehicle, who were still travelling at the vehicle speed, impacted some component in the passenger compartment, i.e., the windshield, the front seat, the dashboard, the seat belt, or the steering wheel. This impact stopped the occupant relative to the interior of the vehicle. Third, the occupant’s internal organs were stopped by the chest cavity, which often resulted in internal injuries that were fatal if excessive g levels were experienced.

Highway experts and research authorities wanted crash cushions to safely control the effects of the final two impacts. They evaluated and monitored occupant reactions during accidents involving crash cushions. They learned that more serious injuries were being experienced by occupants of smaller vehicles, which had increased in number on the U.S. highways. The technical challenge the highway experts...
presented was to develop crash cushion standards that would ensure protection for occupants of both smaller and larger vehicles.

II.E. NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM (NCHRP 230)

In 1981, the most stringent, yet realistic, set of crash cushion specifications was issued under NCHRP 230. This was the third revision of specifications since NCHRP 118 was first issued in 1972.

**TABLE 6: VEHICLE IMPACT TESTS**

<table>
<thead>
<tr>
<th>Weight</th>
<th>Speed</th>
<th>Angle</th>
<th>Impact Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800 lb/820 kg</td>
<td>60 mph/97 kph</td>
<td>0°</td>
<td>Center nose of device</td>
</tr>
<tr>
<td>4500 lb/2040 kg</td>
<td>60 mph/97 kph</td>
<td>0°</td>
<td>Center nose of device</td>
</tr>
<tr>
<td>4500 lb/2040 kg</td>
<td>60 mph/97 kph</td>
<td>20°</td>
<td>Along side, mid-length</td>
</tr>
<tr>
<td>4500 lb/2040 kg</td>
<td>60 mph/97 kph</td>
<td>10-15°</td>
<td>0-3 ft (0-1 m) offset from center of nose of device</td>
</tr>
</tbody>
</table>

**EVALUATION GUIDELINES:**

1. **Structural Adequacy:** Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

2. **Occupant Risk (replaces "Impact Severity" category in previous guidelines):** Impact velocity of hypothetical unrestrained front seat passenger against vehicle interior, calculated from vehicle decelerations, 24 inches (0.61 m) forward displacement, and 12 inches (0.30 m) lateral displacement, shall be less than:

<table>
<thead>
<tr>
<th>Occupant Impact Velocity-ft per second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
</tr>
<tr>
<td>40 fps (12 mps)</td>
</tr>
</tbody>
</table>

and the vehicle highest 10 msec average accelerations
subsequent to instant of hypothetical passenger impact should be less than:

<table>
<thead>
<tr>
<th>Occupant Ridedown Accelerations - g's</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
</tr>
<tr>
<td>Lateral</td>
</tr>
<tr>
<td>20g's</td>
</tr>
<tr>
<td>20g's</td>
</tr>
</tbody>
</table>

3. Vehicle Trajectory: After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes. In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph (24 kph), and the exit angle from the test article should be less than 60% of test impact angle, both measured at time of vehicle loss of contact with test device. Vehicle trajectory behind the test article is acceptable.

The "Occupant Risk" section replaced the "Impact Severity" section, and considered the unrestrained occupant during an impact. Threshold occupant impact velocity change and occupant ridedown deceleration rates were derived from several sources including human volunteer testing, sled tests of animals, cadavers, dummies, and automotive accident statistics. An attempt was made to set the threshold values at a level equivalent to the American Association of Automotive Medicine Abbreviated Injury Scale (AIS) of 3 or less. AIS-3 classifies the resulting injury as severe, but not life threatening.

NCHRP 230 stated that during an impact, the occupant is set in motion once the vehicle starts its deceleration and the occupant's upper body begins to move forward. At some point, the upper body will be stopped due to an impact with the windshield, seat belt, passenger seat, dashboard, or steering wheel. The acceptable performance for crash cushions in NCHRP 230 requires the occupant impact the vehicle interior at a speed of 40 feet per second (12 meters per second) or less, measured over a theoretical 2 ft (60 cm) flail space.

Based principally on dummy head impacts into windshields with velocities ranging from 44 to 51 fps (13.4 to 15.5 meters per second) and with the resulting FMVSS 208 Head Injury Criteria less than 1000, the nominal 40 fps (12 meters per second) appeared to be a reasonable impact velocity threshold for unrestrained occupants striking the windshield or instrument panel. It was believed that the 40 fps (12 meters per second) value was consistent with compartment design and padding of the majority of the vehicle population. This criteria was used by NCHRP 230 to measure the effectiveness of the crash cushion during the initial phase of the
impact. The lighter the impacting vehicle, the more difficult it is for a crash cushion to meet this requirement.

The authors of NCHRP 230 realized that the crash cushion must also have the capability to stop the vehicle and to prevent the occupants from experiencing an unsafe deceleration spike at the end of the event. The highest g level for a larger vehicle would be expected at the end of the event if the crash cushion should "bottom out." This occurs when the crash cushion uses all of its remaining energy absorbing capabilities and becomes a rigid object.

For the unrestrained passenger considered in NCHRP 230, the occupant experienced essentially no "absolute" deceleration prior to impacting some part of the compartment surface, i.e., the vehicle was decelerated relative to the occupant. At occupant impact, the degree of injury sustained by the occupant was related to the occupant/compartment impact velocity. Subsequent to this impact, the occupant was assumed to remain in contact with the impacted surface and experiences the vehicle decelerations; the occupant may or may not sustain further injuries depending on the magnitude of these decelerations. For both lateral and longitudinal directions, it appeared that that threshold value of 20 g's was survivable (i.e, AIS-3), even for long durations.

NCHRP 230 established more stringent vehicle trajectory guidelines than previously required in TRC 191, NCHRP 153, or NCHRP 118. It required a side impact test in which the vehicle strikes the crash cushion at a 20° angle at the mid point of the crash cushion. The vehicle must be redirected safely back into the originally intended direction at an angle of less than 60% of the impact angle. For example, a vehicle impacting at a 20° angle must be redirected safely back into the originally intended direction at 12° or less. This new specification eliminated subjectivity when determining if a crash cushion met this requirement.

A crash cushion that satisfies NCHRP 230 will likely be approved for use on U.S. Federal-Aid highways as an experimental system. The ensuing impacts from actual use (as well as the effects of climate, maintenance, vandalism, and effects on traffic) are recorded during an experimental evaluation period. If the crash cushion performs successfully in actual use, it will likely receive official operational status by the U.S. Federal Highway Administration.

Highway researchers continue to strive for the best set of evaluation criteria for crash cushions. As of this writing, meetings are being held in the United States to discuss an update of the NCHRP 230 guidelines.

The ultimate goal is to assure the installation of proven crash cushions to make highways safer. This is indeed an
opportune time to discuss a standardized evaluation criteria for European crash cushions as well.

III. EUROPEAN HARMONIZATION OF CRASH CUSHION EVALUATION CRITERIA

Developing crash cushion guidelines is very time consuming and costly. As experience in the United States shows, tests over time are necessary to additionally evaluate the effectiveness of performance criteria. It is logical to use the most sophisticated crash cushion guidelines available as the basis for a European evaluation criteria.

Therefore, a modification of NCHRP 230 is being proposed as a starting point for the European guidelines. Three major differences between European and United States driving that must be taken into consideration when developing these guidelines are: speed limits, vehicle weight, and seatbelt use.

1. Speed Limits: The NCHRP 230 guidelines require tests to be run at 97 kph (60 mph). A more acceptable test speed for Europe would be 105 kph (65 mph).

   This is reasonable because maximum highway speed limits in France, England, Germany, and Italy are equal to or greater than 110 kph. However, during an impact, the driver will normally be able to use the brakes to slow down the vehicle prior to impacting the crash cushion. It is, therefore, proposed that the European crash cushion tests be run at 105 kph (65 mph).

2. Vehicle Weight: Impacting a crash cushion with an "average" weight car does not guarantee the proper performance for non-average weight vehicles. Furthermore, mathematical formulas or computer simulations without corresponding actual crash test data for each weight car cannot give an accurate analysis of occupant reaction during a high-speed impact. It is proposed that 820 kg (1800 lb) and 1600 kg (3528 lb) vehicle weights be used for the crash cushion tests to encompass the range of typical European vehicle weights.

3. Seatbelt Use: Considering the fact that shoulder and lap seatbelts are worn by the great majority of vehicle occupants in Europe, it is further recommended that the flail space requirement used to limit the forces during the initial impact for the NCHRP 230 guidelines be modified.

   Prior to the occupant being restrained by the seatbelt, he does not experience the vehicle deceleration rates; therefore, a higher limit for the vehicle's deceleration rate is acceptable. However, once the occupant has moved
forward and is being restrained by the seatbelt, he will experience the same deceleration rates as the vehicle.

NCHRP 230 states that an occupant may enter the ridedown phase by impacting the windshield or dashboard at a speed of 12 meters per second when measured at a 60 cm flail space. The use of the seatbelt reduces the flail space from 60 cm to about 25 cm. The accepted impact velocity threshold of 12 meters per second, based on a 25 cm flail space, allows for a very high, unrealistic force. This force could result in serious structural damage to the vehicle and injury to the occupants. The seatbelt mandates that a method of measuring acceptable criteria during the initial impact that is different from NCHRP 230 be developed.

It is proposed that a maximum average of 30g's be allowed prior to the ridedown phase. The average 30g limit will keep the vehicle damage within a tolerable, acceptable range. The 10 msec average ridedown limit will remain at less than 20 g's. This pre-ridedown phase will be a very short time period when measured against a 25 cm distance.

A summary of the proposed European harmonization of crash cushion guidelines would read as follows:

**TABLE 7: PROPOSED VEHICLE IMPACT TESTS**

<table>
<thead>
<tr>
<th>Weight</th>
<th>Speed</th>
<th>Angle</th>
<th>Barrier Impact Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>820 kg/1800 kg</td>
<td>105 kph/65 mph</td>
<td>0°</td>
<td>Center nose of device</td>
</tr>
<tr>
<td>1600 kg/3528 lb</td>
<td>105 kph/65 mph</td>
<td>0°</td>
<td>Center nose of device</td>
</tr>
<tr>
<td>1600 kg/3528 lb</td>
<td>105 kph/65 mph</td>
<td>20°</td>
<td>Along side, mid-length</td>
</tr>
<tr>
<td>1600 kg/3528 lb</td>
<td>105 kph/65 mph</td>
<td>10-15°</td>
<td>0-3 ft (0-1 m) offset from center of nose of device</td>
</tr>
</tbody>
</table>

**EVALUATION GUIDELINES:**

1. Structural Adequacy: Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.
2. **Occupant Risk:** The vehicle's average accelerations should be less than:

<table>
<thead>
<tr>
<th>Vehicle Impact Acceleration Limit - g's*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to Ridedown</td>
</tr>
<tr>
<td>30g's</td>
</tr>
</tbody>
</table>

*The average deceleration between point of vehicle impact and theoretical occupant impact point, based on 25 cm flail space.

<table>
<thead>
<tr>
<th>Occupant Ridedown Accelerations Limit - g's**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
</tr>
<tr>
<td>20g's</td>
</tr>
</tbody>
</table>

**Based on highest 10 millisecond average.

3. **Vehicle Trajectory:** After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 24 kph (15 mph), and the exit angle from the test article should be less than 60% of test impact angle, both measured at time of vehicle loss of contact with test device. Vehicle trajectory behind the test article is acceptable.

All other aspects of the NCHRP 230 report concerning crash cushion testing procedures and evaluation will be used for the "European Harmonization of Crash Cushions" evaluation criteria. A certification of compliance with these revised guidelines will be mandated for any crash cushions placed into operation in a country after January 1, 1990. However, authorities of each country will have the option of waiving the certification process and allowing the continued use in their country of any crash cushions installed in the subject country prior to January 1, 1990.

**IV. SUMMARY**

European drivers are using the highways more and more, and are creating additional transportation demands that can only be satisfied by sophisticated highway networks. These complex road systems will inevitably create some hazardous sites that should be shielded with crash cushions.

Crash cushions are relatively new in European countries, and today only a small number are being used. However, as
the interest and understanding of these systems increases, so will the demand for new installations.

To assure the safety of the motorists, guidelines outlining the criteria for acceptable crash cushion performance must be developed. By modifying the existing, proven United States crash cushion evaluation criteria to account for differences in European vehicles and driving habits, the road authorities in Europe can economically reach a consensus for the adoption of effective European crash cushion evaluation criteria.
Overrepresentation of Non-belt Users in Traffic Crashes

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U S A

and

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U S A
OVERREPRESENTATION OF NON-BELT USERS IN TRAFFIC CRASHES

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ABSTRACT

During the summer of 1987, color coded mailback questionnaires that identified belted and unbelted North Carolina drivers were handed out at the 72 sites that constitute the probability sample for determining the belt use rate in North Carolina. By obtaining identifying information ostensibly to determine the winner of a $500 prize from among the respondents, accident and violation records from the North Carolina driver history file were linked to the belted and unbelted respondents. Analyses found that non-belt users are overrepresented in accidents and violations.

Introduction

Seat belts are a proven countermeasure for reducing the injury morbidity and mortality associated with motor vehicle crashes. Recent studies estimate the effectiveness of seat belts at 40-50 percent (Hedlund, 1986; Evans, 1986). That is, for every 100 unbelted motor vehicle occupants seriously injured or killed in crashes, 40 to 50 would not have been seriously injured or killed if wearing a seat belt at the time of their crash.

Given the documented effectiveness of automotive seat belts, traffic safety researchers and health promotion practitioners alike have questioned why mandatory belt use laws have not resulted in as great a savings in lives as anticipated. Clearly part of the reason is that laws do not guarantee that everyone will buckle up; in the most recent U.S. 19 city survey conducted by the National Highway Traffic Safety Administration, belt use was observed at 50% in cities with belt laws in effect, compared to 34% for cities without belt laws (NHTSA, 1989). Nevertheless, the extent of injury reduction in states with laws has often been less than anticipated based on observed use rates. This has been noted in the U.S. and Canada as well as in a number of European countries (McCarthy, Taylor, et al., 1984; Robertson and Williams, 1978).

It has been speculated that this less than anticipated injury reduction results from non-use of seat belts by those at higher risk of crash involvement. That is, those who wear seat belts are less likely to be in crashes than those who
do not wear seat belts. This hypothesis is supported by Evans and Wasielewski (1983), Wasielewski (1984), Grant (1986), and Wilson (1986).

The goals of the research reported in this paper were (1) to examine the extent to which non-users of seat belts are overrepresented in crashes and violations, and (2) to determine whether these differ from the crashes and violations of belt users.

Previous studies of the crash experience of belt users and non-users have relied on police accident reports for data on belt use. However, in the presence of a mandatory use law there is a known and sizable bias in police-reported belt use. For example, in 1988 when observed belt use rates in North Carolina were in the 58-62% range (Reinfurt, Campbell, et al., 1988), reported belt use by drivers in crashes was 88% (NC DOT, 1989). Previous research has shown that belt use in crashes is lower, not higher, than use in the population at risk (Campbell, 1969).

Data utilized in the present investigation included a measure of both observed and self-reported belt use, along with information on previous crash involvement and violation experience from state driver history files and survey information covering a range of seat belt topics. The presence of both observed and self-reported belt use for a single sample of drivers is a unique feature of this study and yields insight into the validity and usefulness of both measures.

The research was carried out in the state of North Carolina, which implemented a mandatory belt use law for drivers and right front seat occupants of passenger motor vehicles in October, 1985. Between October 1, 1985 and December 31, 1986, only warning tickets were issued; thereafter, violators became subject to a fine of $25. While the results reported are specific to North Carolina, it is felt that they have implications to other states and beyond.

Method

Since the North Carolina seat belt law was enacted in October 1985, statewide belt use surveys have been conducted at regular intervals to provide data for evaluating the effectiveness of the law. Observed seat belt use for drivers and right front seat passengers is recorded at a probability sample of 72 intersection locations across the state. The 72 sites are stratified by region of the state (coast, piedmont, or mountain), rural/urban location, and time of day/day of week. (See Reinfurt, Campbell, et al. (1988) for a more complete description of the survey sample design.)

For the purposes of the present study, a one-page questionnaire was developed for distribution at the survey sites during the regularly scheduled June, 1987 belt observation survey. The survey forms were color coded, such that drivers who were observed wearing a seat belt were given a green color form and those observed not wearing a belt a yellow color (but otherwise identical) form.
Questions on the form asked about belt wearing frequency before and after implementation of the North Carolina seat belt law, opinion of the law, and primary reason for wearing or not wearing seat belts.

To encourage response, each survey was packaged in a clear plastic bag that also contained a self-addressed stamped envelope for returning the completed survey, a newly published North Carolina road map, and a pen for filling out the questionnaire imprinted with the message, "A pen for your thoughts." Recipients were also informed that participation in the survey would make them eligible for a $500 cash prize drawing, hence encouragement for them to include their name and address on the returned survey form.

Ten thousand survey forms were distributed. Although the belt use rate in North Carolina at the time of the survey was approximately 68%, half of the survey forms were given to belted drivers and half to unbelted. This was done in order to obtain a sufficient number of responses from non-belt wearers.

A total of 5,074 mailback surveys was returned, for an overall response rate of 51 percent. Using the name, address and date of birth information provided, the survey returns were linked with the North Carolina driver history file. 4,505 survey forms, or just over 90 percent of the returns, were successfully matched. From the driver history file, accident and violation counts for the most recent four years (1983-1986) were determined and appended to each mailback survey record. In addition, accident case numbers appearing on the driver history file were linked to the North Carolina crash data and additional information concerning the crash (crash severity, driver injury, rollover, crash type, violation charged, etc.) was accessed from this file and appended to the survey record. In North Carolina, accident reports are completed by law enforcement officials for all accidents exceeding a $500 damage criterion, regardless of injury occurrence.

The data were analyzed using contingency table analyses and multivariate categorical models. Models were constructed to determine whether belt use (both observed and self reported) is associated with prior crash and violation experience, and contingency table analyses were used to determine whether the crashes and violations of belt users differ from those of non-users.

Results

Mailback sample characteristics

Several comparisons were made to examine the representativeness of the sample of mailback survey respondents. These are summarized in Table 1. Since sex and race were both data items collected during the course of the seat belt observations, it was possible to compare these characteristics of our survey respondents with the sample of all drivers observed at the time the survey forms were distributed. Results show a lower percentage of returns from male drivers (54% vs. 61%), but about equal returns from whites and nonwhites.
Table 1. Characteristics of Mailback Survey Sample.

<table>
<thead>
<tr>
<th>Sample Characteristics</th>
<th>Mailback Survey Returns</th>
<th>Comparison Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>54.3</td>
<td>60.9 1</td>
</tr>
<tr>
<td>Female</td>
<td>45.7</td>
<td>39.1</td>
</tr>
<tr>
<td>White</td>
<td>88.4</td>
<td>86.2</td>
</tr>
<tr>
<td>Nonwhite</td>
<td>11.7</td>
<td>13.8</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;25</td>
<td>15.0</td>
<td>19.5 2</td>
</tr>
<tr>
<td>25-54</td>
<td>63.5</td>
<td>58.3</td>
</tr>
<tr>
<td>≥55</td>
<td>21.5</td>
<td>22.4</td>
</tr>
<tr>
<td>Accidents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>81.5</td>
<td>82.4</td>
</tr>
<tr>
<td>1</td>
<td>15.1</td>
<td>14.8</td>
</tr>
<tr>
<td>2 or more</td>
<td>3.4</td>
<td>2.9</td>
</tr>
<tr>
<td>Violations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>74.4</td>
<td>77.7</td>
</tr>
<tr>
<td>1</td>
<td>17.3</td>
<td>14.4</td>
</tr>
<tr>
<td>2</td>
<td>4.8</td>
<td>4.6</td>
</tr>
<tr>
<td>3 or more</td>
<td>3.3</td>
<td>3.3</td>
</tr>
</tbody>
</table>


Age data was not collected at the time of the survey; however, it was possible to compare the age distribution for our survey returns with the age distribution for all licensed North Carolina drivers. Results here show a slightly lower percentage of returns from drivers under age 25 and a higher percentage of returns from drivers aged 25-54. These results are not unexpected, since the survey was distributed to a sample of drivers "on the road," and middle-aged drivers tend to accumulate the highest annual mileages.

We also examined the accident and violation histories of our survey return sample compared with all North Carolina licensed drivers to see if persons with a history of accidents and/or violations were less likely to respond. These results showed that the survey sample had slightly higher accident and violation rates than did all licensed drivers. Again, these slightly higher rates might be anticipated since this was a sample of "on the road" drivers.

Finally, belt use for the mailback survey respondents (as determined by the color of form returned) was 61 percent, compared with 64 percent for the total sample of drivers observed at the time the forms were distributed. Given the results of these comparisons, the mailback survey respondents do appear representative of the population of all North Carolina drivers.
Comparison of observed and reported belt use

A unique feature of the mailback survey was the opportunity for comparing observed with self-reported belt use. Two questions on the survey form asked about seat belt use: (1) How often do you wear a seat belt now when driving? (never, rarely, sometimes, most of the time, or always); and (2) Were you wearing your seat belt at the time this survey was given to you? (no, yes, or no belt in vehicle).

Table 2 compares responses across these questions with observed belt use as determined by the color of the returned survey form. While there are some discrepancies among the various belt use measures, they are not extreme. Reasons for the discrepancies might include errors in distributing the coded survey forms, exaggerated reporting of belt use by the respondents, or simply the fact that many surveys were not filled out until some time after they were received. Regardless of the reasons, the results in Table 2 can be used to provide an interpretation of, and to lend some validity to, the self-reported belt use.

Table 2. Comparison of Observed and Self-Reported Belt Use.

<table>
<thead>
<tr>
<th>Self-Reported Belt Use</th>
<th>Observed Belt Use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Belted</td>
</tr>
<tr>
<td>How often wear belts now?</td>
<td></td>
</tr>
<tr>
<td>Always</td>
<td>87 %</td>
</tr>
<tr>
<td>Most of the time</td>
<td>48 %</td>
</tr>
<tr>
<td>Sometimes</td>
<td>17 %</td>
</tr>
<tr>
<td>Rarely</td>
<td>7 %</td>
</tr>
<tr>
<td>Never</td>
<td>6 %</td>
</tr>
<tr>
<td>Belt use at time of survey</td>
<td></td>
</tr>
<tr>
<td>Belted</td>
<td>87 %</td>
</tr>
<tr>
<td>Not belted</td>
<td>4 %</td>
</tr>
<tr>
<td>No belts in vehicle</td>
<td>7 %</td>
</tr>
</tbody>
</table>

Overrepresentation of non-belt users in crashes and violations

Table 3 shows the average number of crashes and violations for observed belted and unbelted drivers. Unbelted drivers had experienced an average 35% more crashes and 69% more violations over the previous four year period. The same trends hold when examined by self-reported as opposed to observed belt use (Table 4). Never/rarely wearers had, on average, 33% more crashes and twice as many violations as always wearers. The results for crashes are significant at p=.016, those for violations at p<.01.
Table 3. Average Number of Crashes and Violations per Observed Belted and Unbelted Driver, 1983-86.

<table>
<thead>
<tr>
<th>Observed Belt Status</th>
<th>Sample N</th>
<th>Average # Crashes</th>
<th>Average # Violations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belted</td>
<td>2759</td>
<td>0.20</td>
<td>0.32</td>
</tr>
<tr>
<td>Not Belted</td>
<td>1746</td>
<td>0.27</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Table 4. Average Number of Crashes and Violations per Self-Reported Belt Use Group, 1983-86.

<table>
<thead>
<tr>
<th>Self-Reported Belt Use Group</th>
<th>Sample N</th>
<th>Average # Crashes</th>
<th>Average # Violations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always</td>
<td>2507</td>
<td>0.21</td>
<td>0.31</td>
</tr>
<tr>
<td>Most-of-the-Time/Sometimes</td>
<td>1386</td>
<td>0.25</td>
<td>0.46</td>
</tr>
<tr>
<td>Rarely/Never</td>
<td>596</td>
<td>0.28</td>
<td>0.69</td>
</tr>
</tbody>
</table>

These results are reinforced when one examines the percentage of drivers with 0, 1 or 2 or more crashes/violations by observed belt status. For example, 83% of drivers observed wearing a seat belt had experienced no crashes, compared with 79% of those observed not belted. Similarly, 78% of belted drivers had had no violations during the previous four year period, compared with only 69% of unbelted drivers.

There are a number of factors known to be associated with both belt use and crash involvement. For example, young males experience two to three times the number of crashes of other age/sex groups. They are also the group least likely to wear seat belts. To determine whether differences in the demographic composition of the various belt use groups might account for their observed differences in crash and violation histories, higher dimensional tables were generated and categorical models developed to take into account these additional factors. Models were developed using both observed and self-reported belt use.
The model for crashes showed significant belt use effects (both observed and self-reported) in addition to effects due to age and sex. For the models concerned with violations, reported annual mileage, another factor related to both belt use and crash involvement, could also be taken into account. The analysis of variance results of this model for self-reported belt use are shown in Table 5. They show that all factors are highly significant and that the model fits well to the data. Similar results were obtained in a model that substituted observed for self-reported belt use. The models show that drivers who do not wear seat belts tend to have worse driving records than those who do, even after demographic differences and estimated mileage have been taken into account.

Table 5. Analysis of Variance from a Model with Violations as the Dependent Variable.

<table>
<thead>
<tr>
<th>Source</th>
<th>D.F.</th>
<th>Chi-Square</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>1179.35</td>
<td>0.0001</td>
</tr>
<tr>
<td>Age</td>
<td>1</td>
<td>95.21</td>
<td>0.0001</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>58.58</td>
<td>0.0001</td>
</tr>
<tr>
<td>Mileage</td>
<td>1</td>
<td>56.47</td>
<td>0.0001</td>
</tr>
<tr>
<td>Age*Sex</td>
<td>1</td>
<td>26.13</td>
<td>0.0001</td>
</tr>
<tr>
<td>Belt Use</td>
<td>2</td>
<td>38.21</td>
<td>0.0001</td>
</tr>
<tr>
<td>Residual</td>
<td>17</td>
<td>20.00</td>
<td>0.2744</td>
</tr>
</tbody>
</table>

Characteristics of crashes and violations of belt users and non-users

Additional analyses were carried out to determine whether the types of crashes and violations of current belt users differ from those of current non-users. Data for these analyses consisted of crash records from the 1,038 crashes involving mailback survey respondents in calendar years 1983-1986. The following variables were examined: crash severity, alcohol involvement, speed of accident, accident type, light condition, vehicle deformation, vehicle drivability, rollover, region of impact, driver charged, driver injury, and presence of a child. None of these factors produced significant results when the crashes of observed belted and unbelted drivers were compared. However, some differences were found based on self-reported belt use (never/rarely, sometimes/mostly, or always). Never/rarely users were more likely to have been involved in single vehicle crashes (p=.027), rollover crashes (p=.011), and crashes where they had been charged with a violation (p=.006).

To investigate whether these differences might be explained solely in terms of differing group demographic composition, categorical models were fit to the proportion of accidents in which drivers were charged with a violation. The analysis included the following factors: driver age (<25, >25), driver sex (male,
female), and self-reported belt use (rarely/never, sometimes/mostly/always). Driver age and belt use were both significant with p-values of .0001 and .026, respectively. Driver sex was not significant (p=.064).

In examining (serious) violation characteristics, no significant differences were found between either observed or self-reported belt users and non-users in their rate of serious violations defined by reckless driving and alcohol use.

**Implications for Roadway Design**

Given that more than 30 states in the United States now have mandatory seat belt laws, and that belt use in the population has been rising in recent years, should there be more of a movement to develop roadside design criteria based on belted occupants of motor vehicles? What would be the benefits of such a change? And what would be the safety tradeoffs?

From the benefit standpoint, designing for belted occupants could lead to the use of larger acceptable velocity changes when certain roadside objects are struck. One could argue that since the majority of the states have belt laws, designers should have the ability to use at least the upper limit of injury tolerances for unbelted occupants (40 fps as stated in Michie, 1981) for new or improved roadside devices like breakaway signs and poles and crash cushions. Another approach might be to develop velocity change criteria based on something like a weighted average approach. For example, if 65 percent of the states in the U.S. have belt laws, one might consider increasing current velocity change criteria by 65 percent of the difference between the current level (e.g., 15 fps for breakaway signs) and the level that could be tolerated by an unrestrained occupant (40 fps).

The effect of increasing velocity change criteria would have the benefit of allowing more new or improved roadside devices to pass crash test procedures, especially as related to longitudinal velocity change. This, in turn, would allow more devices on the market for use by the states and others, and this would theoretically lead to decreases in costs, especially for breakaway devices and crash cushions.

A negative side of this argument is that larger longitudinal velocity change criteria would be detrimental to the users of small cars. These vehicles are particularly vulnerable to off-center impacts.

A further counter argument is that the implications of the research reported in this paper indicate that it is the unrestrained drivers who are more often involved in crashes in general. And in particular, the unrestrained drivers are more involved in single-vehicle and rollover crashes, crashes that often involve roadside fixed objects. Thus, increasing current longitudinal velocity change criteria as applies to fixed objects would be indeed detrimental to this group of drivers.
In regard to other crash types, it could be argued that the injury outcome of many crashes into longitudinal barriers does not differ whether occupants are restrained or not. Recent research in the United States (Ray, Michie, Hunter and Stutts, 1987; Bryden and Fortuniewicz, 1986) shows that tracking vehicles at 15 degree angles or less and 60 mph speeds or less that are smoothly redirected from longitudinal barriers do not tend to yield serious injuries. Redirected vehicles that in turn strike fixed objects or other vehicles are much more likely to contain seriously injured drivers and/or occupants. These are crash situations where being restrained should certainly be beneficial. Belts might also be of significant benefit in crashes where non-tracking vehicles impact longitudinal barriers.

To conclude, it is difficult to argue for a relaxation of design criteria based on increased population belt use. There are some benefits that would ensue, but overall the positive gains that have resulted from seat belt legislation could be offset by such a relaxation of standards, especially given the fact that it is the non-belt wearers who are overrepresented in crashes.

References


Side Impact Accidents with Fixed Roadside Objects

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ABSTRACT

Side impact accidents account for approximately 8,000 fatalities in passenger cars each year in the United States. This represents more than one third of the approximately 25,000 passenger car fatalities that occur each year. Side impact is, therefore, a significant problem in transportation safety. Of the 8,000 side impact fatalities which occur each year, approximately 5,000 fatalities occur in multi-vehicle collisions. The problem of designing vehicles to better protect occupants in multi-vehicle side impact collisions has been an active area of discussion and research for the past decade.

Single vehicle side impacts with fixed roadside objects are also a significant safety problem, accounting for 2,200 of the 8,000 side impact fatalities each year. Approximately 225,000 occupants of motor vehicles are involved in a side impact with a fixed object each year yet very little is known about this type of collisions. Recommending effective corrective strategies has been impossible since knowledge about the mechanisms which cause such accidents and which ultimately cause injury to the vehicle occupants has not been developed.

The fixed objects most frequently struck by passenger cars in side impact accidents are trees and utility poles. Unfortunately, developing an effective strategy for reducing impacts of these devices is very difficult. Side impacts are also most common on state, county and other local roads making a centralized effort at improvement more difficult. Roadside safety appurtenances of various types account slightly more than 25 percent of the side impact accidents although they account for only 12 percent of the side impact, fixed roadside object fatalities.

Side impact accidents tend to result in serious injuries more often then some other types of accidents. Approximately 81 percent of redirectional longitudinal barrier collisions result in no injury and only two percent result in serious or severe injuries. Side impacts with roadside objects, in contrast, result in no injury in about 37 percent of accident cases and 11 percent result in serious or severe injuries. When a side impact occurs, it is more likely to result in a severe injury than, for example, a longitudinal barrier collision. Researchers investigating multi-vehicle side impacts have concluded that most occupant injuries in these cases result from thoracic injuries. Side impacts with roadside objects, in contrast, often result in serious head injuries. Each of these injury mechanisms imply a different strategy for reducing occupant injuries.

When vehicle occupants become involved in side impact accidents they are placed at grave risk of sustaining fatal or severe injuries. Improving the side impact performance of the roadside has great potential benefits for society but effectively reducing occupant
injuries in such collisions requires detailed knowledge about how such collisions occur and what aspects of the collision cause serious occupant trauma. The side impact problem can not be effectively addressed by any one roadside safety group or by the implementation of any single policy. Appurtenance designers and manufacturers must produce hardware that minimizes the side impact risk. Automobile manufacturers must design more crashworthy vehicles for side impacts. Utility companies and local transportation agencies must develop and adopt plans to remove or relocate poles and trees that present an unacceptable hazard to motorists. Unlike many roadside safety problems, the side impact problem must be addressed by all facets of the roadside safety community if meaningful improvements are to realized.

This presentation will examine some of the characteristics of side impact accidents derived from the National Accident Sampling System and Fatal Accident Reporting System data.