Proceedings of the Conference
*Road Safety in Europe*
Berlin, Germany, Sep. 30 – Oct. 2, 1992

- Opening
- European Perspective
- Roadside Safety Features
Proceedings of the Conference
*Road Safety in Europe*
Berlin, Germany, Sep. 30 – Oct. 2, 1992

- Opening
- European Perspective
- Roadside Safety Features
Title: Proceedings of the Conference Road Safety in Europe, Berlin, Germany, September 30 – October 2, 1992

Abstract (background, aims, methods, results) max 200 words:

Papers presented at the seminar were as follows:

- Opening Remarks (Faerm, G);
- Research and Road Safety in Europe (Koornstra, M J);
- General Overview of IRTAD – International Road Traffic and Accident Database (Nielsen, S K);
- Traffic Safety in Eastern and Western Europe at the Beginning of the Nineties (Bruehning, E);
- Predictions of Road Safety in Industrialized Countries and Eastern Europe (Koornstra, M J and Oppe, S);
- SARTRE: Social Attitudes to Road Traffic Risk in Europe: An Overview and Some Results from France (Barjone, P-E);
- Safety of City-Cars – Conflict Between Ecology, Economy, Road Traffic Benefits and Safety (Appel, H, Krabbel, G and Meissner, T);
- Use of Road Safety Audits in Great Britain (Proctor, S);
- Methodology for the Determination and Evaluation of Safety Improvement Alternatives for Roadside Hazards (Ramache, A);
- Justifying a Forgiving Highway (Dreznes, M G);
- Development of a New Concept in Emergency Truck Escape Ramp Design (Mileti, R A);
- Development and ON-road Use of a 4-Rope Safety Fence (Laker, I B and Naylor, A W);
- Crash Cushions and Terminals (McDevitt, C F);
- Cost Benefit of the Dutch RIMOB Impact Attenuator (van der Drift, R);
- Harmonisation of European Standards for Road-Safety Systems (Wink, B W);
PREFACE

The Swedish Road and Traffic Research Institute (VTI) and the Forum of European Road Safety Research Institutes (FERSI) were jointly organising this international conference. The objective was to review and examine some specific road safety issues and the increasing environment problems in road traffic in different countries.

The following areas, within the field of Road Safety, were presented.

- European perspectives
- roadside safety features
- safety in some European countries
- safety and traffic management
- elderly road users
- vulnerable road users
- markings, signs and signals
- vehicles

Linköping, November 1992

Kenneth Asp

Proceedings of the Conference ROAD SAFETY IN EUROPE in Berlin, Germany, September 30 - October 2, 1992

VTI RAPPORT 380A, Part 1
- Opening
- European Perspective
- Roadside Safety Features

VTI RAPPORT 380A, Part 2
- Safety in Some European Countries
- Safety & Traffic Management

VTI RAPPORT 380A, Part 3
- Elderly Road Users
- Vulnerable Road Users

VTI RAPPORT 380A, Part 4
- Markings, Signs and Signals
- Vehicles
CONTENTS

Program I
List of participants X

OPENING

Opening Remarks 1
Gunnel Färm

Research and Road Safety in Europe 5
Matthijs J Koornstra

COMMON EUROPEAN PERSPECTIVE

General Overview of IRTAD - International Road Traffic and Accident Database 23
Sven Krarup Nielsen

Traffic Safety in Eastern and Western Europe at the Beginning of the Nineties 33
Ekkehard Brühning

Predictions of Road Safety in Industrialized Countries and Eastern Europe 47
Matthijs J Koornstra and Siem Oppe

SARTRE: Social Attitudes to Road Traffic Risk in Europe: An Overview and Some Results from France 71
Pierre-Emmanuel Barjonet

Safety of City-Cars - Conflict Between Ecology, Economy, Road Traffic Benefits and Safety 87
Hermann Appel, Gerald Krabbel and Thomas Meissner

ROADSIDE SAFETY FEATURES

Use of Road Safety Audits in Great Britain 111
Stephen Proctor

Methodology for the Determination and Evaluation of Safety Improvement Alternatives for Roadside Hazards 133
Abdelkrim Ramache

Justifying a Forgiving Highway 151
Michael G Dreznes

VTI RAPPORT 380A
Development of a New Concept in Emergency Truck Escape Ramp Design
Robert A Mileti

Development and On-road Use of a 4-Rope Safety Fence
Ivor B Laker and A W Naylor

Crash Cushions and Terminals
Charles F McDevitt

Cost Benefit of the Dutch RIMOB Impact Attenuator
Rien van der Drift

Harmonisation of European Standards for Road-Safety-Systems
Bernd Wolfgang Wink

Page
193
215
237
253
265
WEDNESDAY SEPTEMBER 30

OPENING

11.00 - 12.00 (11 AM - 12 AM)

Welcome to Berlin
Prof Dr Herwig Haase, Senator für Verkehr und Betrieb, Germany

Opening Remarks
Mrs Gunnel Färm, Director General, Swedish Road and Traffic Research Institute (VTI), Sweden

FERSI - Forum of the European Road Safety Research Institutes
Drs Matthijs J Koornstra, SWOV, The Netherlands, Vice President of FERSI

SESSION I (COMMON) EUROPEAN PERSPECTIVE

14.00 - 16.00 (2 PM - 4 PM)

Chairman: Gunnar Carlsson, Swedish Road and Traffic Research Institute (VTI), Sweden

International Road Traffic and Accident Database (IRTAD)
Sven Krarup Nielsen, Road Directorate, Denmark

Traffic Safety in Eastern and Western Europe at the Beginning of the Nineties
Ekkehard Brühning and Susanne Berns, BASf, Germany

Predictions of Road Safety in Industrialized Countries and Eastern Europe
Matthijs J Koornstra and Siem Oppe, SWOV, The Netherlands

Social Attitudes to Road Traffic Risk in Europe: Goals, Methodology and First Results from France
Pierre-Emmanuel Barjonet and Jean-Pierre Cauzard, INRETS, France

Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety
Hermann Appel, Berlin Technical University, Germany

VTI RAPPORT 380A
WEDNESDAY SEPTEMBER 30

WORKSHOP

ROADSIDE SAFETY FEATURES

18.00 - 21.00 (6 PM - 9 PM)

Chairman: Thomas Turbell, Swedish Road and Traffic Research Institute (VTI), Sweden

Use of Safety Audits in the United Kingdom
Stephen Proctor, TMS Consultancy, USA

A Methodology for the Determination and Evaluation of Safety Improvement Alternatives for Roadside Hazards
Abdelkrim Ramache, University of Batna, Algeria

Justifying a Forgiving Highway
Michael G Dreznes, Energy Absorption Systems, USA

Development of a New Concept in Emergency Truck Escape Ramp Design
Robert A Mileti, Roadway Safety Service Inc, USA

Development and On-Road Use of a 4-Strand Wire Rope Safety Fence
Ivor B Laker, Road Accident and Road Safety Consultants, United Kingdom

Crash Cushions and Terminals
Charles F McDevitt, FHWA Turner-Fairbanks, USA

Cost Benefit of the Dutch Impact Attenuator RIMOB
Rien van der Drift, Ministerie van Verkeer en Waterstaat, The Netherlands

Harmonization of European Standards for Road Safety Systems
Bernd Wolfgang Wink, Volkmann & Rossbach GmbH, Germany

Update on the CEN-activities on Roadside Safety Features
Thomas Turbell, VTI, Sweden

Panel Discussion
THURSDAY OCTOBER 1

SESSION II A - SAFETY IN SOME EUROPEAN COUNTRIES

9.00 - 12.00 (9 AM - 12 AM)

Chairman: Karl-Olov Hedman, Swedish Road and Traffic Research Institute (VTI), Sweden

Coverage and Validity of Police Reported Traffic Accidents
Poul Henning Larsen, Danmarks Statistik, Denmark

Road Safety in Latvia
Juris Smirnovs, Riga Technical University, Latvia

Road Traffic Accidents Studies
Igor Korshakov, Moscow Automobile Highway Engineering Institute, Russia
(no oral presentation)

Traffic Safety Trends and Research in a Changing Road Transport System
- The Case of Portugal
Joao Lourenco Cardoso and Antonio Lemonde de Macedo, Laboratorio Nacional de Engenharia Civil, Portugal

The Swedish Traffic Safety Experience - of interest for anybody but the Swedes?
Birger Nygaard, VTI, Sweden

Safety and Traffic Management in CSFR
VM Medelska, STU Bratislava, Czechoslovakia

Comparison of the Problems of Austrian and Hungarian Road Users
Werner Klemenjak, Austrian Road Safety Board, Austria
THURSDAY OCTOBER 1
SESSION III A - ELDERLY ROAD USERS
9.00 - 12.00 (9 AM - 12 AM)

Chairman: Matthijs J Koornstra, Institute for Road Safety Research (SWOV), The Netherlands

Driving-Related Tasks of Elderly Drivers
Christhard Gelau, Thomas Metker and Ulrich Tränkle, Psychologisches Institut II der Universität Münster, Germany

Elderly People, Mobility and Safety
Hélène Fontaine and Yves Gourlet, INRETS-DERA, France

Road and Traffic Sign Design: The Needs of Older Drivers
Herbert T Morris, The Automobile Association, United Kingdom

Effects of Aging and the Development of Automatic and Controlled Processes in Car Driving
J E (Hans) Korteling, TNO Institute for Perception, The Netherlands
(no oral presentation)

Personal Factors of Drivers’ Self-Criticism
Tadeusz Rotter, Jagiellonian University, Poland
THURSDAY OCTOBER 1
SESSION II B - SAFETY & TRAFFIC MANAGEMENT
13.00 - 17.00 (1 PM - 5 PM)

Chairman: Sven Krarup Nielsen, Road Directorate, Denmark

Accident Reduction through Area-Wide Traffic Schemes
Stephen Proctor, TMS Consultancy, United Kingdom

Urban Safety Management
Chris J Lines, Transport Research Laboratory, United Kingdom

Traffic Safety on the Regional Roads Network
Bystrik Bezak and Ludovit Rondos, STU Faculty of Civil Eng., Czechoslovakia
(no oral presentation)

Capacity and Safety Considerations for Left Turn Phasing Control at the
Signalized Intersections
Mohammad A S Mustafa, M Pitslava-Latinopoulou and P Papaioannou, Aristotle’s
University of Thessaloniki, Greece

Towards an Intense Co-Operation on Accident Investigations and
Surveillance
Jef F Mortelmans, University of Leuven, Belgium

Drivers' Behaviour and Accidents at Traffic Controlled Junction
Dominique Fleury and Farida Saad, INRETS, France

Influence of Geometric Design Variables on Accident Rates on Two-Lane
Rural Highways
Koti Reddy Kalakota, M Nazrul Islam and Prianka N Seneviratne, Utah State University,
USA

Increased Speed Limit for Heavy Vehicles
Arne Carlsson and Göran Nilsson, VTI, Sweden

Monitoring Traffic Enforcement Effectiveness on a National Scale
David M Zaidel, Irit Hocherman and Alfred Shalom Hakkert, Technion-Israel Institute of
Technology, Israel
THURSDAY OCTOBER 1
SESSION III B - VULNERABLE ROAD USERS
13.00 - 17.00 (1 PM - 5 PM)

Chairman: David Lynam, Transport Research Laboratory (TRL), United Kingdom

The Prevention of Child Pedestrian Accidents and Road Safety Education for Children: A Comparison of Various European Approaches in the Perspective of Developmental Psychology
Jean-Pascal Assailly, INRETS-LPC, France

Comparison of Accident Risk for School Children as Bicyclists in Linköping, Sweden and Odense, Denmark
Erik L Nordentoft, Johnny Ludvigsson, Anders Svensson, Lars Vejde, Ole Helboe Nielsen and Ove Ramsussen, Odense University Hospital, Denmark

An Analysis of Bicycle Accidents in Western Europe and The United States: 1975-1989
Elias M Choueiri, North Country Community College, USA and Ruediger Lamm, University of Karlsruhe, Germany

Current State of Motorcycle Engineering and Research on the Active Safety Sector
Cristoph Albus, BAST, Germany

Rüdiger Lamm, University of Karlsruhe, Theodor Mailaender, Mailaender Ingenieur Consult GmbH, Germany and Elias M Choueiri, SUNY, USA

The Impact of UTC on Road Safety, with Particular Reference to Pedestrians
John Hunt, University of Wales College of Cardiff, United Kingdom

Characteristics and Circumstances of Child Pedestrian Accidents
Miles Tight, University of Leeds, United Kingdom

VRU-TOO: An ATT Project for Vulnerable Road User Safety
Oliver Carsten, The University of Leeds, United Kingdom
(presented by David Sherborne)
Why does UK have a Comparatively Poor Child Pedestrian Safety Record?
D A Lynam and Gordon Harland, Transport Research Laboratory, United Kingdom

Factors Affecting Pedestrian Safety at Signalised Crossings
Marian Tracz and Andrzej Tarko, Cracow University of Technology, Poland

Children's Traffic Environment and Road Safety Education
Pia Björklid, Stockholm Institute of Education, Sweden

The Problem of Road Safety in Greece - A Survey of Pedestrian and Two Wheeled Vehicles Accidents
Georgios Tsohos and A Dalaveras, University of Thessaloniki, Greece
FRIDAY OCTOBER 2

SESSION IV - MARKINGS, SIGNS AND SIGNALS

9.00 - 12.00 (9 AM - 12 AM)

Chairman: Prof Dr Karl-Heinz Lenz, Bundesanstalt für Strassenwesen (BASt), Germany

The M1 Chevron Trial
Robin Helliar-Symons, Transport and Road Research Laboratory, United Kingdom

Visual Guidance in Road-Work Zones
Johannes Aulbach, Technische Hochschule Darmstadt, Germany

Restructuring of Town Entrances on Roads Classified as Major
Jurgen Steinbrecher, Planquadrat, Germany

Right Turns on Red by a Constant "Green-Arrow-Sign"
Klaus Krause, BASt, Germany

Markings, an Important Visual Control System in Europe
Hans Dieter Schönborn, Road Management Rhineland Palatinate, Germany

Traffic Safety Related to Types of Road and Traffic Signals
Kazimierz Jamroz and Lech Michalski, Technical University of Gdansk, Poland

Route Choice Behavioural Models Analysis for the Realization of a Route Guidance System for a Congested Urban Area
Stefano Carrese, Gaetano Fusco and Stefano Gori, University of Rome "La Sapienza", Italy

Development of Checking System of Guiding Road Signs Using Digital Road Map Data Base
Masaharu Kawashima, Youichi Sakai and Setsuo Hirai, Ministry of Construction, Japan
FRIDAY OCTOBER 2
SESSION V - VEHICLES
9.00 - 12.00 (9 AM - 12 AM)

Chairman: Prof Dr Bernd Friedel, Bundesanstalt für Strassenwesen (BAST), Germany

Car Characteristics and Safety
Hélène Fontaine, INRETS-DERA, France

Vehicle Inspection - Its Importance for Road Safety
Stein Fosser, Institute of Transport Economics, Norway

On Stability of Four-Wheel Drive Motor Vehicles of Categories M1 and N1
A D Davidov, E N Nikulnikov and V I Salnikov, Research Centre for Testing and Refining
Automotive Vehicles, Russia
(no oral presentation)

Vehicle Design for Secondary Safety
Pete Thomas, Mo Bradford and Edmund Ward, Loughborough University of Technology,
United Kingdom

Vehicle Design for Primary Safety
Margaret Galer, Loughborough University of Technology, United Kingdom

On the Effectiveness of an Active Steering Wheel in Critical Driving
Situations
Josef Schumann, University of Armed Forces Munich and Karl Naab, BMW, Germany

The Role of Car Size and Aggressivity in Relative Collision Safety
Denis P Wood and S Mooney, Wood & Ass, Ireland

Transport of Dangerous Goods, a Risk Management Model
Niels O Jørgensen, Technical University of Denmark, Denmark

CLOSING REMARKS
Mr Georges Dobias, Director General, INRETS, France, President of FERSI
Saad Farida
Sabey Barbara
Sagberg Fridulv
Salusjärvi Markku
Schiöler-Andersen John
Schumann Josef
Schönborn Hans Dieter
Seneviratne Prianka
Sherborne David
Sigthorsson Haraldur
Silcock David
Simoes Anabela
Skusek Pete
Smiley Alison
Smirnovs Juris
Soelund Jesper
Spolander Kristoffer
Steinbrecher Jürgen
Straume Talis
Svensson Gösta
Tanttu Anneli
Thomas Pete
Thorntawaite Sian
Tight Miles
Tracz Marian
Tsochos Georgios
Turbell Thomas
Ulberger Karl
Vaeroe Henrik
Vaessen J P
Valač Zbyněk
Van der Drift Rein
Van Driel P.A.M.
Vansnick Marc
Verweij C Alfred
Várhely András
Wille Hans
Wink B Wolfgang
Wolfgang Metzler
Wood Denis
Ydstedt Anders
Zwielich Frank

INRETS
ROAD SAFETY CONSULTANT
INST. OF TRANSPORT ECONOMICS
VTT
FYNS AMT VEJVAESNET
UNIV. OF ARMED FORCE
ROAD MANAGEMENT RHINELAND
UTHA STATE UNIV.
LEEDS CITY COUNCIL
TRAFIKAPEDELING
ROSS SILCOCK PARTNERSHIP
UNIV. TECNICA DE LISABOA
HUMAN FACTORS NORTH INC.
RIGA TECH. UNIVERSITY
DANISH ROAD SAFETY COUNCIL
HEAD OF SAFETY STATISTICS
PLANQUADRAT
LATVIAN ROAD DEPARTMENT
SWEDISH MOTOR VEHICLE INSPEC.
LIT ENGINEERING LTD
HEAD OF ACCIDENT RESEARCH UNIT
SCHOOL TRANSPORTATION NEWS
THE UNIV. OF LEEDS
CRACOW UNIV.
UNIV. OF THESSALONIKI
VTI
SPS. SCHUTZPLANKEN GMBH
ROAD DIRECTORATE
CENT. BUREAU RIJWAARDIGHEIDSB.
ROAD FOUND ADM.
VERKEER EN WATERSTAAT
CENT. BUREAU RIJWAARDIGHEIDSB.
BELGIAN ROAD SAFETY INST.
BOUWDIENST RWS
UNIV. OF LUND
MINISTRY OF TRANSPORT
V & R GMBH & CO
TECH. ÜBERWACHUNGS-VEREIN
WOOD & ASSOCIATES
ROAD AND TRAFFIC COMMITÉ
BAST

FRANCE
UNITED KINGDOM
NORWAY
FINLAND
DENMARK
GERMANY
GERMANY
USA
UNITED KINGDOM
ICELAND
UNITED KINGDOM
PORTUGAL
SLOVENIA
CANADA
LATVIA
DENMARK
SWEDEN
GERMANY
LATVIA
SWEDEN
FINLAND
UNITED KINGDOM
UNITED KINGDOM
UNITED KINGDOM
POLAND
GREECE
SWEDEN
GERMANY
NETHERLANDS
CZECHOSLOVAKIA
NETHERLANDS
NETHERLANDS
BELGIUM
NETHERLANDS
SWEDEN
NETHERLANDS
GERMANY
GERMANY
IRELAND
SWEDEN
GERMANY
Opening Remarks

Gunnel Färm
Director General
Swedish Road and Traffic Research Institute (VTI)
Sweden
Herr Senator, meine sehr verehrten Damen und Herren! Mr Senator, Ladies and gentlemen!

In Namen des Schwedischen Instituts für Strassen- und Verkehrsforschung (VTI) möchte ich sie zu dieser Konferenz ganz herzlich willkommen heissen - und ich muss sagen, es freut mich ganz besonders, das gerade hier in Berlin zu tun.

In the name of the Swedish Road and Transport Research Institute (VTI), it is my pleasure to welcome you to this conference, and it is a special pleasure to be able to do so here in Berlin.

VTI has quite a tradition to arrange international conferences on traffic safety and transport research. For six years now we have done so. Gothenburg has been the site of these conferences up till now, and we have had several partners, the US Transportation Research Board, INRETS from France and BASt from Germany - and now we have both a new partner, FERSI, the Forum of European Road Safety Research Institutes, of which you will learn more in a few minutes by Mr Koornstra, and a new city, Berlin.

Gothenburg is also, as you may know, the site of the Volvo headquarters. I mention this because Volvo has been one of our partners, too, in arranging these conferences. And in a way you might say that this step from the Scandinavian peninsula to the European continent is a significant one for both Swedish industry and Swedish research and development. Of course, Volvo has been on the European continent for many years now, and so has VTI, but the general attitude in Sweden is now more openly directed towards Europe.

And when I say Europe, I don't refer only to the western part of the continent. The rapid development in Central and Eastern Europe also calls for our attention, not least in the field of road safety.

In this context, I would like to quote from a report made within the framework of the Nordic Council. The report covers the situation in Poland, Czechoslovakia and
Hungary, but I think the description is applicable also for the other economies in transition.

I quote from the summary of the report:

"Czechoslovakia, Hungary and Poland faced a marked or even catastrophic deterioration of road traffic safety in the late eighties. It coincided with a period of socio-political upheavals and the ongoing transformation towards an open democratic society and market economy system.

While the level of the road traffic safety hazard differs among these countries, the roots of the deterioration seem to be similar: a relatively sudden disappearance of many restrictions characteristic of the old regimes, liberalisation of import cars, opening widely the borders of traffic from abroad and last but not least, weakening or even at times absence of law enforcement by the traffic police.

The attitudes of the public and of the government bodies, pre-occupied with other problems of the transition period, do not seem adequate to the challenge on part of the irresponsible drivers of motor vehicles, who is the main category of traffic offenders!"

As you see, Ladies and Gentlemen, many - and new - problems in the field of road safety remain to be solved. It is my hope and belief that this conference will bring us at least a step further towards a society where we can spend our money on other things than hospital beds and wheel-chairs for victims of traffic accidents. Europe needs its young people - let us all help to keep them safe and alive!

Once again - welcome!
Research and Road Safety in Europe

Matthijs J Koornstra
Drs, Vice President of FERSI
Institute for Road Safety Research (SWOV)
The Netherlands
1. Introduction

Since the Treaty of Rome, the number of deaths in road traffic of the now twelve countries of the EEC has reached two million; the number of injured is over 40 million. The economic loss due to road accidents is very substantial and endangers the welfare in the community. Nowadays the macro-economic costs for the lack of road safety are about 70 billion Ecus per year in the countries of the EEC (depending on the calculation methods the estimate ranges between 45 to 90 billion Ecus). The fact that this figure is larger than the Gross Domestic Product of, for example, Greece, Ireland or Portugal, demonstrates the extent of the losses involved.

If we compare passenger transport on the road with air or rail transport than the fatality rate per kilometer passenger travel reveals that the risk to be killed on the road is much higher than for the other modes. Rail and air passenger transport are more than a factor of 200 times safer than passenger transport on our European roads.

<table>
<thead>
<tr>
<th>Traffic mode</th>
<th>Area</th>
<th>Fatality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>road 1)</td>
<td>EEC</td>
<td>3.5x10^{-8}</td>
</tr>
<tr>
<td>rail 2)</td>
<td>N-W. Europe</td>
<td>1.6x10^{-10}</td>
</tr>
<tr>
<td>air 3)</td>
<td>USA</td>
<td>0.4x10^{-10}</td>
</tr>
</tbody>
</table>

1) Gerondeau-report (1.3 pers. per vehicle)
2) Schopf (1989)
3) NTSB

Table 1. Risk per passenger kilometer for different transport modes

The comparison of the fatality rate per kilometrage for road traffic between the countries of the EEC on the one hand and United States of America and Japan on the other hand shows that road traffic is half less dangerous in the USA and about one-fourth less dangerous in Japan than in the countries of the EEC as a total.

<table>
<thead>
<tr>
<th>Area</th>
<th>Motorkilometers (x 10^8)</th>
<th>Fatalities (within 30 days)</th>
<th>Fatality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>34992</td>
<td>46405</td>
<td>1.3</td>
</tr>
<tr>
<td>Japan</td>
<td>6251</td>
<td>14595</td>
<td>2.3</td>
</tr>
<tr>
<td>EEC</td>
<td>19524</td>
<td>52689</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Table 2. Fatality rates 1990 in USA, Japan and EEC.
1. Introduction

Since the Treaty of Rome, the number of deaths in road traffic of the now twelve countries of the EEC has reached two million; the number of injured is over 40 million. The economic loss due to road accidents is very substantial and endangers the welfare in the community. Nowadays the macro-economic costs for the lack of road safety are about 70 billion Ecus per year in the countries of the EEC (depending on the calculation methods the estimate ranges between 45 to 90 billion Ecus). The fact that this figure is larger than the Gross Domestic Product of, for example, Greece, Ireland or Portugal, demonstrates the extent of the losses involved.

If we compare passenger transport on the road with air or rail transport than the fatality rate per kilometer passenger travel reveals that the risk to be killed on the road is much higher than for the other modes. Rail and air passenger transport are more than a factor of 200 times safer than passenger transport on our European roads.

<table>
<thead>
<tr>
<th>Traffic mode</th>
<th>Area</th>
<th>Fatality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>road *)</td>
<td>EEC</td>
<td>3.5x10^-8</td>
</tr>
<tr>
<td>rail *)</td>
<td>N-W. Europe</td>
<td>1.6x10^-10</td>
</tr>
<tr>
<td>air *)</td>
<td>USA</td>
<td>0.4x10^-10</td>
</tr>
</tbody>
</table>

1) Gerondeau-report (1.3 pers. per vehicle)
2) Schopf (1989)
3) NTSB

Table 1. Risk per passenger kilometer for different transport modes

The comparison of the fatality rate per kilometrage for road traffic between the countries of the EEC on the one hand and United States of America and Japan on the other hand shows that road traffic is half less dangerous in the USA and about one-fourth less dangerous in Japan than in the countries of the EEC as a total.

<table>
<thead>
<tr>
<th>Area</th>
<th>Motorkilometers ($x 10^8$)</th>
<th>Fatalities (within 30 days)</th>
<th>Fatality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>34992</td>
<td>46405</td>
<td>1.3</td>
</tr>
<tr>
<td>Japan</td>
<td>6251</td>
<td>14595</td>
<td>2.3</td>
</tr>
<tr>
<td>EEC</td>
<td>19524</td>
<td>52689</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Table 2. Fatality rates 1990 in USA, Japan and EEC.
There are also large differences in risk on the roads inside the European Community. Per million vehicles the Netherlands and Great Britain have a rate of road deaths which is less or about 250, while the rates in Spain, Greece or Portugal are 3 to 4 times higher.

---

**Figure 1.** Fatalities per million vehicles in the EEC in 1988 (Source: Gerondeau, 1991).

The fatality rate per motorized kilometrage differs even more with a factor up to 7 for these countries (UK and NL about 1.4; Portugal 10.5; per hundred million vehicle kilometers).

In view of the above figures and the differences between countries it can be concluded that road safety it is not an unavoidable corollary to the increasing motorization. On the contrary, authorities and their policies can, if not to abolish, at least reduce the number and seriousness of road accidents. In this matter, so states the High-level Expert Group in their report to the High Commissioner of Transport for the European Economic Community (Gerondeau, 1991, p. 15):

"the authorities have a fundamental part to play, through the action which they do (or do not) take:
- they are responsible for the road network and its equipment;
- they are responsible for the standards applying in building and controlling vehicles;
- they are responsible for organizing assistance;"
- lastly, they are to a very large degree responsible for the opinions and the behaviour of road users, whom they can influence through education and training, information, traffic regulation, enforcement and penalties.

The Gerondeau-report acknowledges that individual mistakes or bad conduct can be demonstrated in 90% or more of road accidents, but warns not to draw the wrong conclusion from that point. It states that:
"the behaviour of every road user is in fact largely dependent on circumstances of his journey outside his control (road network characteristics, other users' behaviour, the regulations, the degree of enforcement, etc.)."

A convincing illustration can be found in the fatality rate on motorways which is many times lower than on other main rural roads; it is hardly acceptable to assume that the responsibility of drivers on these roads is suddenly changed. The frequency of road user failures and the consequences vary considerably with the characteristics of the elements of the road traffic system he uses.

The Gerondeau-report concludes: "Whilst the part played in accidents by individual faulty actions of large numbers of users is often used as an excuse for inaction, there is a need for the awareness that, in spite of the appearances, the responsibility for taking action against traffic accidents is primarily collective and that it falls firstly on the various public authorities which might take such action. ... Progress is only possible through this approach, as is shown by the experience of those Community countries which have achieved the best results. ... Of course, other groups besides the authorities should and can take action on road safety: the car makers, the insurance companies, the media (etc.). And voluntary bodies also can play an important part in attaining public awareness and in changing attitudes in any coherent action, their potential support must be sought. Nonetheless, there is a fundamental need for a commitment of preventing accidents, from all the public authorities involved. That includes a commitment from the Community.

2. European Policy and Road Safety

The Gerondeau-report states three general objectives for a European strategy for road safety:
Firstly, set a quantified multi-year target for the whole of the Community, such as a reduction of between 20% and 30% in the number of victims in road accidents by the year 2000.

Secondly, establish gradually a European Road Safety and Road Traffic Zone by harmonization of the safety levels in the Member States, encouraging the countries with the worst problems of low safety to catch up without delaying progress in the countries more advanced in the field.

Thirdly, set the target of promoting a behaviour model for road users mindful of others, a model of driving calmly and unaggressively, both on urban and rural roads.

These three objectives can be reached, according to the Gerondeau-report, by adopting measures which have shown to be effective in reducing the number and seriousness of road accidents, but which are not applied in all Member States. This is a very pragmatic and realistic strategy which does not lean on modern innovations or propagate until now unapplied measures. It does not concentrate on modern electronics and telematics, despite the potential value which such measures may have. Nearly all the concrete proposals in the Gerondeau-report are already at least applied in one of the Member States with positive results on road safety which are judged to be also effective in the other Member Countries. The only innovations were some combinations of varieties of similar measures which were judged to yield a more optimal effect. The Gerondeau-report lists 64 proposals for such concrete measures. Not all proposed measures regard the European level, but on the level of the European Community action toward the national and regional levels can be taken by dissemination of knowledge and the pooling of experience in Member States. The EEC should actively facilitate the adoption of proposed measures and issue recommendations for actions, and if necessary, urge the adoption of some measures by Member States. For this active role of the European Economic Community, the Gerondeau-report presents 14 proposals of a more process and organization oriented nature.

Here it is not the place to elaborate on the 64 concrete proposals, but I shall highlight and illustrate some general ideas beyond the scope of the 14 organizational measures which are directed to the level of the European Economic Community. The main basis for the proposals of the Expert Group towards the level of the Community is the belief that there should be a
coherent policy across the continent of Europe, and that the Community must involve itself in new ways of road-accident prevention expressed by four chief aims:
- to improve knowledge;
- to produce technical reference material gradually;
- to establish a European 'Highway Code';
- to support road safety policy.

Since the Treaty of Rome it has been unclear what the authority of the European Commission was with respect to road safety, but since in its extension of Maastricht it has become a duty of the European Community to improve European road safety and to establish a harmonized and optimized transeuropean network of motor freeways. The authority of the European Parliament on transport issues is increased especially on matters concerning road safety and this transeuropean network. In Brussels the Ministers of Transport have agreed to put the topic of road safety on their agenda and so they have done earlier for the agendas of their meetings in the CEMT.

It can envisaged that the Gerondeau-report will become, and partly is already, a source for action on the level of the European Community. Among the recommendations which are in discussion now the Gerondeau-report identifies four schemes for the improvement of knowledge:
- sharing individual Member States' experience;
- establishing a detailed database of road accidents;
- introducing more suitable instruments of measurement;
- identifying European research programmes.

Moreover, the report recommend:
- a periodical organization at the Community level of a major conference on road safety, at which researchers and decision-makers from individual Member States might meet to monitor changes in accidents and the effectiveness of remedial action.

More specific the Gerondeau-report does not recommend the exclusive use of mandatory actions, but the coverage of road safety topics by the organization of advise to the national, regional and local levels of authority. That advise is thought to cover the following aspects:
- analysis of experience and action implemented in individual Member States in order to reveal the lessons of common benefit;
- initiation of new and participation in existing research programmes;
- publication of periodical surveys, information material and technical studies aimed at the public or specialists;
- compilation and monitoring developments in road safety, making use of a network of bodies in the Member States;
- production of recommendations or preparation of decisions at the request of Member States, the Commission, the Council or European Parliament;
- support to non-governmental bodies working on road safety.

3. Forum of European Road Safety Research Institutes

It is exactly in this spirit that this conference on Road Safety in Europe is organized in cooperation with FERSI: the Forum of European Road Safety Research Institutes. It is aimed by FERSI that this conference will grow out to the proposed major Road Safety Conference of the European Community. Now the members of FERSI are national road safety research institutes of 12 countries in the EEC or EFTA coming from:

- Austria, Kuratorium für Verkehrssicherheit (KfV);
- Belgium, Institut Belge de Sécurité Routière (IBSR);
- Denmark, Rådet for Trafiksikkerhedsforskning (RfT);
- Finland, Valtion Teknillinen Tutkimuskeskus (VTT);
- France, Institut National de Recherche sur les Transports et leur Sécurité (INRETS);
- Germany, Bundesanstalt für Strassenwesen (BASt);
- Netherlands, Institute for Road Safety Research (SWOV);
- Norway, Institute of Transport Economics (TØI);
- Portugal, Laboratorio Nacional de Engenharia Civil (LNEC);
- Sweden, Statens Väg- och Trafikinstitut (VTI);
- Switzerland, Schweizerische Beratungsstelle für Unfallverhütung (BFU);
- United Kingdom, Transport Research Laboratory (TRL).

The objectives of FERSI are in line with the recommendations of the Gerondeau-report and are achieved by:

- regular exchange between member institutes of information, experience, trends and new initiatives in research;
- the identification of research needs and opportunities for collaboration;
- undertaking joint research projects and sharing top-expertise and special (large and expensive) research facilities;

VTI RAPPORT 380A
furthering the development of European requirements and standards in the field of road safety;
- dissemination of the results of research by all possible means to policy makers, administrators, professionals and researchers in road safety and to the general public;
- encourage of exchange of researchers and of the set up and maintenance of appropriate data-bases.

Under the umbrella of FERSI the initiative is taken to propose some joint research projects for the oncoming second programme of European Research on Transport (EURET II) of the EEC. Some proposals (the numbered ones below) are worked out now by members of FERSI, while other ones are only suggested areas of interest.

It concerns the areas of:

- **Road User Behaviour**
  1. Europinion (periodic comparative inquiry on road safety attitudes)
  2. Improvement of novice training and reduction of novice accidents
  3. Legislation, enforcement practices, influence penalty levels
  4. Effects of speed and speed control.

- **Vehicle Safety**
  (* ) Assessment of passive safety
  (* ) Improvement of frontal impact test
  5. Lighting configuration.

- **Unprotected Road Users**
  (* ) Efficiency of regulations and policies for vulnerable road users

- **Accidentology**
  (* ) European observatory and 'road safety barometer'
  (* ) Improved data collection and analysis on the European level
  7. European accident causation databank
  8. Harmonization of definitions of accidents.

- **Prospective Analysis**
  9. Modelling developments, forecasts and interventions
  10. Trans-European goods transport
  11. Tourism and foreigners.

The organization of FERSI will be the basis for formation of consortia of top-experts from the member institutes in order to perform the needed
research on the highest quality level and with the most general validity of application in European countries. The only fact that the outcomes of collaborative research and their recommendations will now become explicitly shared by the leading national institutes, is of great importance for the impact on national and European policies for road safety.

4. Improved European Road Safety

Also the Gerondeau-report mentioned comparable area's as most beneficial for the improvement of the European road safety. I can not discuss all the concrete measures that has been proposed in the Gerondeau-report. However, beyond the proposals by FERSI and the measures proposed in the Gerondeau-report, it has been realized that human behaviour is not infallible and also that no one really wants to become involved in an accident by ones own behaviour. The frequency of the seldom failures of millions of road users, nonetheless, results in the enormous amounts of losses in road safety. The opportunity for failures is largely dependent on the human made traffic system. Since one can not create an infallible human being by measures, the reduction of that failure frequency must be sought in an improved traffic system which elicits less opportunity for failure. Such failure opportunities, however, are also elicited by the behaviours of other road users. Some of the concrete proposals concern the improvement of road user behaviour with respect to the others directly. The idea beyond them lies in the fundamental principal that human behaviour is conditional to circumstances and individual backgrounds as well as to the expected utility of the outcome of that behaviour. The individual background is mainly shaped by public information, education and training as well as by the experience in traffic which are conditioned by stimuli from the physical traffic structure as well as by traffic laws or regulations and their enforcement and penalties. The behavioural proposals are directed to these domains which condition the road user behaviour. However, it are not the "stand alone proposals" which are the most important ones. We can regard, apart from the European harmonization in the proposals, the integrated scope of the proposals for (a) graded licensing in combination with accompanied learner driving, (b) speed regulations and (c) specific and general enforcement practices as the most important behavioural proposals for an effective road safety strategy in both the proposals of FERSI and the Gerondeau-report.
If the proposals on the training and licensing of drivers would lead to an application throughout the Community, then the risks of young drivers could be reduced considerably. The French experience with such a procedure shows that skills and knowledge alone are insufficient for safe driving by youngsters, but that danger perception and responsible driving can be learned in a very practical way. If the French results apply in general, then the risks reduction of young drivers can even be reduced by a factor of seven times, which in the Member States would mean more than 10% less serious accidents, that is more than 150,000 injured and about 5,000 fatalities per year less and a gain of 7 billion Ecu's for the whole of the Community. A very cost-effective and important live saving measure indeed, which only depends on their proposed research validity for other countries and the political willingness of their adoption.

The level of mean speed given the road type and the variation in speeds are important factors in traffic safety. The variation in speeds on the road (also between categories of road users) determines to a large extent the number of accidents. If the standard deviation of speeds is reduced, then theory says that the number of accidents approximately can change nearly by a quadratic effect of that reduction. The absolute level of speeds determines also quadratically the seriousness of the outcomes of a given accident with the particular masses of vehicles involved. Since generally variation of speeds reduces with a reduction of absolute mean speed, it follows that mean speed reduction easily can have a fourth power effect on safety, which for example means that a reduction or increase of 10% in mean speed (factor .90 or 1.10) can change the number of fatalities by a reduction of 34% (factor .90^4 = .656) or an increase of 46% (factor 1.10^4 = 1.464). These considerations are confirmed by a Swedish study (Nilsson, 1982) and are also in line with results from speed limit changes on motorways in the USA and France in 1974 (See Figures 2 and 3).

But not only on motorways this relations between speeds (and speed variations) and accidents holds, also the Danish actual speed reduction from the urban speed limit change of 60 km/h to 50 km/h and the Dutch results on the so called "woonerf" by traffic calming measures in living areas which reduce speeds from 50 km/h limit to speeds below 30 km/h affirmed these relations between speeds and accidents. The network related proposals on speed limits, speed enforcement and automatic control,

VTI RAPPORT 380A
Figure 2. Fatality rates on US Interstate highways, in relation to the speed limit change in 1974.

Figure 3. Fatality rates on rural motorways in France in relation to the speed limit changes in 1974.
therefore, are of utmost importance. Their application in a harmonized way to all types of roads in the Member States could save many thousands of lives and also reduces billions of Ecus in the Community. This includes their application to the German motorways and rural roads; speed limits on these roads could stop the increase of fatalities which is observed in the last five years on the German motorways and also can reduce the increasing share of traffic fatalities from rural roads in Germany.

The importance of the proposals for a renewed enforcement practices of specific and general police control can be illustrated by the results of the intensified random breath testing in New South Wales in Australia (Arthurson, 1985). These results show that a high density of testing of about one out of three license holders per year leads to lasting reduction of about 25% of the number of fatalities. Such a high density also is still cost effective since it yields a return rate of 2 for 1 cost unit as Dutch research has shown.

![Figure 4](image.png)

**Figure 4.** Annual fatal crashes and number of random breath test in New South Wales (after Arthurson, 1985).

Up to now the research proposals formulated by FERSI are not so much directed to the safety aspects of the infrastructure of the road network. In the Gerondeau-report there are 12 proposals for infrastructural measures. The ideas beyond these infrastructure proposals are based on a hierarchical categorization of roads in the network with homogeneous
characteristics along the routes within each category and a uniform layout of connection links within and between types of roads. Our road system evolved gradually from the network that was originally fitted for carriage and pedestrian travel. The road transport system has never been designed in such a way that the opportunity for accidents is prevented a priori, like it has been in the rail- and air-transport systems. Despite the gradual upgrading of the road system nowadays the network of roads still constitutes a more or less unpredictable concatenation of a nearly infinite variety of road sections by an also nearly infinite variety of cross-connections. The result is a road system which is too complex for the road user to allow reliable predictions for the next oncoming situation. Only the layout of the motorway system permits relative reliable predictions. Since this road category is relative well predictable and because speed variation there is relative low it is a relative safe type of road, in spite of the high speeds driven. The fatality rate per kilometrage on motorways approximates the safety of rail and air transport. An acceptable level of safety also holds for well designed traffic calming areas, where speeds are so low that the variation in speeds is also low.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Max. km/h</th>
<th>Mixing fast/slow</th>
<th>Level crossings oncoming traffic</th>
<th>Injury rate per million veh. km.</th>
</tr>
</thead>
<tbody>
<tr>
<td>calming area</td>
<td>&lt; 30</td>
<td>yes</td>
<td>yes</td>
<td>0.20</td>
</tr>
<tr>
<td>resid. street</td>
<td>50</td>
<td>yes</td>
<td>yes</td>
<td>0.75</td>
</tr>
<tr>
<td>urban arterials</td>
<td>50</td>
<td>yes/no</td>
<td>yes</td>
<td>1.33</td>
</tr>
<tr>
<td>rural roads</td>
<td>80</td>
<td>yes/no</td>
<td>yes</td>
<td>0.64</td>
</tr>
<tr>
<td>rural motor road</td>
<td>80</td>
<td>no</td>
<td>yes</td>
<td>0.30</td>
</tr>
<tr>
<td>rural motor road</td>
<td>100</td>
<td>no</td>
<td>no</td>
<td>0.11</td>
</tr>
<tr>
<td>motorways</td>
<td>100/120</td>
<td>no</td>
<td>no</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 3. Injury rates for road categories in the Netherlands, 1986.
This can be derived from Table 3 with the injury rates on Dutch roads, which together with the British and Swedish networks belong to Europe's most safe road networks. All road types other than motor roads and calming areas have considerable high injury rates. The lack of safety varies with the combination of the level of speeds and the amount of variation in speeds due to discontinuities (level crossings and oncoming traffic) and mixture of slow and fast categories of road users on the road type. The rural main roads and the urban arterial roads are the most dangerous ones. The redesigning of the road categories between motorways and residential calming areas to limited number of categories of self-explaining roads with well predictable uniform layouts of routes and crossing types is most urgent. This is a major long term task which should be undertaken in a coordinated way on a European level, since diversity in the Community increases the unpredictability for the foreseen increase of cross-national travel of road users in Europe.

The ingredients of such a redesigned road network ask for more research on safer layouts, but some elements are known already. Separation of slow and fast traffic and traffic with large mass differences is one of the safe design principles. This means only pedestrians on sidewalks and cyclists on separated cycle paths, while crossings for pedestrians and cyclists on rural main roads and arterial urban roads preferably should not be designed as level crossings. It also may mean special truck routes for inter-regional heavy good transport and limitation of masses of trucks in urban areas, where delivery by smaller vans from just-in-time transit centers outside towns can be foreseen. Separation of tracks for oncoming traffic on rural main roads and urban arterial routes is also needed, combined with increased safety on reconstructed crossings and accesses to these roads. British research and research in France and the Netherlands has shown that the British round-about with priority for round-about traffic is a much safer level crossing than sign-regulated or unregulated crossings. Reductions to even 10% of the accidents has been observed after reconstruction of crossings to round-abouts in the Netherlands. The relative low share of fatal car-car accidents in the UK, compared to other Western European Countries may perhaps be explained by the frequency of the British round-abouts in their road network. On the other hand the British authorities could learn from other countries how their relative high share of fatal pedestrian accidents can be reduced by safe roadside and crossings constructions for these road users.
5. Policy for Sustainable Road Safety

There is a long way to go before the next generation of road users is educated to behave safely and before a consistent road categorization can be established. One first step, according to the proposals in the Gerondeau-report, is the conceptual creation of the hierarchical structure of the categorized and homogenized road network and the clarification of its principles on a European level. It has been proposed to begin with the introduction of a periodically systematic and compulsory external inspection of the safety of the road system and with the preparation and dissemination of reference material with all the principles and rules for an upgrading to the safest-possible road network by building new roads and rebuilding and modified maintenance of the existing road network. It must be possible to achieve such a safer road network in a time scope of the next 30 years. But we must begin now otherwise there will be 1.5 million Europeans killed on the roads in the Community in the next 30 years.

In view of the sad record of European road safety, compared with other industrialized continents as well as compared with other modes of transport, there clearly is a need for an active road safety policy. The Gerondeau-report has expressed the opinion that road accidents are too often seen as the inevitable price for the utility of travel and transport. And hence the possibility of an active road accident prevention policy is ignored. Such an active policy, however, can be possible on the basis of research and recommendations discussed above. The Gerondeau-report asks the European Community, that is the European Parliament, the Council and the Commission, to provide assistance in the work undertaken by the Member States against road accidents, because the Community is in the right position to do so. It has done so in matters of environmental protection and the advancement of science and technology in Europe. The Community should surely take a comparable action in a matter to which its citizens are highly sensitive, since it concerns the preservation of life itself and the safety of millions of its citizens. It seems not a too ambitious task to bring the level of road safety in the whole of the Community below the level of the USA, which is already nearly the level of safety in some of the more advanced countries in the Community; this would save more than 20,000 lives and over half a million injured on a yearly basis. In the achievement of such a target the national States (and their
regional and local authorities) still have to play a major role, but on the Community level the promotion of and assistance to the implementation of a common transport policy within which road safety is an integrated major element should be undertaken without further delay.

At present there is no entity on the Community level that matches these tasks and the establishment of such an organization, comparable to the European environment or technology organizations, is needed barely in view of the economic and human problem of the lack of road safety in Europe. The organization of FERSI is a first step which has to be followed by an organization for a European policy on road safety. It is, however, not only a matter of organization and political dedication. In a democratic Europe the basis for common action and their resource allocation is based on public support. The Community, therefore, should promote the need for a common road safety policy by an active social marketing and defeat the unjustified belief that road accidents are an inevitable phenomenon of motorized transport. Road transport is a man-made technology and this man-made technology can be made much safer. The know-how is partly there and can be further obtained by creative research, the organization for that improved safety and the measures for its realization can be proposed in concrete terms. The Forum of European Road Safety Research Institutes is ready to provide the research based scientific input to policies and practices for an improved road safety of intergovernmental bodies and central and local governments in Europe, the response to the appeal has to come from these responsible bodies in the Community.

References

General Overview of IRTAD

Sven Krarup Nielsen
Head of Road Data Laboratory
Road Directorate
Denmark
General overview of IRTAD


Sven Krarup Nielsen, Road Data Laboratory, Road Directorate, Denmark

Abstract

The idea of IRTAD
There is a growing need for reliable international traffic and accident data. They are becoming increasingly important in use of international comparisons of road safety.

In 1988 the OECD Scientific Expert Group T8 "Framework for Consistent Traffic and Accident Statistical Data Bases" concluded that the best way to achieve harmonization and completeness of data on an international level was to establish an "International Road Traffic and Accident Database (IRTAD)".

The organization of IRTAD
The IRTAD-activity was officially launched in December 1989. It is jointly financed and managed by the IRTAD members with BAST taking care of the database administration. There are different groups of active IRTAD members. They are represented in the operational committee, which meet twice a year.

How to get the IRTAD data
The database can be accessed direct on the BAST computer or it is possible to have a copy of the database for use on a microcomputer.

State of the art
The number of member countries, the extend of data and the contents of the database.

The database contains road traffic and accident data as well as figures on resident and vehicle population from about 20 countries.

Future developments
Considerations concerning new countries involved and new data elements included.

Context with other international database activities
How this work is situated in the world of information systems.
GENERAL OVERVIEW OF IRTAD,
International Road Traffic and Accident Database.

Sven Krarup Nielsen
Head of Road Data Laboratory
Road Directorate, Denmark

0. INTRODUCTION

As chairman of the Operational Committee of the International Road Traffic and Accident Database, or for short IRTAD, it is an honour for me to have the opportunity to open this session by giving you a general overview of IRTAD.

1. THE IDEA OF IRTAD

There is a growing need for reliable international traffic and accident data. They are becoming increasingly important in the use of international comparisons of road safety.

To assess one's own achievements in the area of traffic safety more accurately, it is necessary to view them in an international context as well. Consequently, there is a growing need for reliable international traffic and accident data. The data that are regularly published by various organizations, however, often turn out to be inadequate for differentiating international comparisons due to general lack of up-to-dateness and detail, differing definitions and obvious contradictions. Moreover, frequently there are no consistent time series reaching back to the periods when countries had maximum fatality records. Besides this, it is of considerable advantage to be able to update and process data on a computer-assisted basis.

In 1988 the OECD Scientific Expert Group T8 "Framework for Consistent Traffic and Accident Statistical Data Bases" concluded that the best way to achieve harmonization and completeness of data on an international level was to establish an "International Road Traffic and Accident Database (IRTAD)".

The T8-group further decided that such a database would be best maintained by experienced accident researchers. In the mideighties the Federal Highway Research Institute of Germany (BASt) had established an international road traffic and accident database for its own use. In 1988 BASt and the Commission of the European Communities (CEC) initiated a two-year cooperation, which established access to the database for the CEC and increased the number of countries included. It was therefore decided that BASt should serve as the host of IRTAD by extending its existing database to include all OECD member countries and by making it available for international use.
2. OBJECTIVES OF IRTAD

The purpose of IRTAD is as follows:

1) to enhance the international comparability (including definitions) of road accident and traffic data,
2) to extend the amount and quality of relevant and up-to-date data of OECD member countries,
3) to facilitate international dissemination and accessibility of these data,
4) to respond to the needs of research, governments, international organisations, private advisory bodies and relevant industries.

3. THE ORGANIZATION OF IRTAD

The IRTAD-activity was officially launched as an OECD-activity in December 1989. It is jointly financed and managed by the IRTAD members with BASt taking care of the database administration. There are three different groups of active IRTAD members:

1) National coordinating institutes representing the country as such,
2) Additional institutes from a participating country,
3) International organizations.

The OECD Steering Committee for Road Transport Research has the overall responsibility for the database project.

A Management Bureau has been formed to maintain the general management of the database. The bureau meets about once a year. The responsibilities of the Management Bureau are:

1) to monitor the evolution of the database,
2) to decide on the measures necessary to ensure the efficient running of the database,
3) to assess the needs for co-ordination with international bodies,
4) to submit proposals to the Steering Committee on questions of policy and finance.

The active members are represented in the Operational Committee, which meets twice a year. Its main functions are:

1) to determine the contents and specifications of the IRTAD,
2) to respond to evolving user needs,
3) to oversee the transfer of correct national data to the IRTAD,
4) to develop agreed forms of data access to the IRTAD,
5) and to report to the Management Bureau.
The IRTAD subscription fee is DM 7.000 per year for the national coordinating institute of a participating country. Additional members pay DM 2.000 per year.

4. IRTAD - AN AGGREGATED DATABASE

IRTAD is in the first priority implemented as an aggregated database. This means that no data on individual accidents and victims on individual persons, vehicles, road stretches or trips are included. The database contains information of groups or cells of accidents, victims and exposure. The data has to be retrospective, i.e. containing historical data beginning in a past year, preferably 1970. Only data on fatal and injury accidents and their victims will be included, i.e. no information on material damage. This is mainly due to differences in the way these accidents are treated in the different countries.

The database consists of the following groups of data on a yearly basis for 1965 and for every year since 1970:

- population figures with a breakdown by age group
- vehicle population with a breakdown by vehicle types
- kilometrage classified by network areas and vehicle types
- number of injury accidents classified by road network areas
- fatality figures with a breakdown by types of road usage, age groups and network areas
- in-patient figures with a breakdown by types of road usage, age groups and network areas
- network length classified by network areas
- modal split
- area of the state
- risk values: fatalities, in-patients or injury accidents in relation to population or kilometrage figures.

BASt is in regular working contact with the coordinating institutes in the participating countries. These institutes supply the required data by writing them into tables provided by BASt. BASt then check the supplied data for consistency, mathematical correctness and compliance with the database definitions before inclusion into the database. BASt warrants that all the data in the database are as correct as possible. In principle, the contributing country is responsible for the quality of its data. Errors that are detected in the database will be corrected by BASt.

5. HOW TO GET THE IRTAD DATA

Access to the database can be accomplished either directly on the BASt computer or by a copy of the database for use on a microcomputer.

By paying the subscription fee, BASt will guarantee access to the information included in IRTAD by enabling direct access to the host database via telephone.

VTI RAPPORT 380A
line or a package switching system (Datex-P) or by providing copies of the database in form of an export file on floppy disks at least twice a year.

The database is established using the SIR database management system. For the use of the database a basic knowledge of electronic data processing is required. As a user you need to be familiar with the writing of retrievals in the SIR-language and need to know at least one editor. To facilitate the work with the database, a number of standard SIR retrievals are available to you. If necessary, they can be adapted to your needs through a few quick and minor changes.

To introduce you to the database and to help you making your retrievals, you can use The IRTAD User Guide. This is a loose-leaf booklet, which is continuously updated. The user guide is a reference manual for the work with IRTAD. It is meant to provide you with all the necessary information for a successful use of the database regardless of whether you have only just begun using the system or you already possess profound knowledge of its functions and applications.

6. STATE OF THE ART

In the database space is reserved for data from 27 "countries":

<table>
<thead>
<tr>
<th>Code</th>
<th>Country</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Germany, (Unified Germany)</td>
<td>Member</td>
</tr>
<tr>
<td>D(W)</td>
<td>Germany, west (Old federal states)</td>
<td>-</td>
</tr>
<tr>
<td>I</td>
<td>Italy</td>
<td>(Member)</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom (incl Northern Ireland)</td>
<td>Member</td>
</tr>
<tr>
<td>GB</td>
<td>Great Britain</td>
<td>-</td>
</tr>
<tr>
<td>F</td>
<td>France</td>
<td>Member</td>
</tr>
<tr>
<td>TR</td>
<td>Turkey</td>
<td>Member</td>
</tr>
<tr>
<td>E</td>
<td>Spain</td>
<td>Member</td>
</tr>
<tr>
<td>D(O)</td>
<td>Germany, east (New federal states)</td>
<td>-</td>
</tr>
<tr>
<td>NL</td>
<td>Netherlands</td>
<td>Member</td>
</tr>
<tr>
<td>P</td>
<td>Portugal</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Belgium</td>
<td></td>
</tr>
<tr>
<td>Gr</td>
<td>Greece</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>Sweden</td>
<td>Member</td>
</tr>
<tr>
<td>A</td>
<td>Austria</td>
<td>Member</td>
</tr>
<tr>
<td>CH</td>
<td>Switzerland</td>
<td>Member</td>
</tr>
<tr>
<td>DK</td>
<td>Denmark</td>
<td>Member</td>
</tr>
<tr>
<td>SF</td>
<td>Finland</td>
<td>Member</td>
</tr>
<tr>
<td>N</td>
<td>Norway</td>
<td>Member</td>
</tr>
<tr>
<td>IRL</td>
<td>Ireland</td>
<td>(Member)</td>
</tr>
<tr>
<td>L</td>
<td>Luxembourg</td>
<td></td>
</tr>
<tr>
<td>IS</td>
<td>Iceland</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>USA</td>
<td>Member</td>
</tr>
<tr>
<td>J</td>
<td>Japan</td>
<td>(Member)</td>
</tr>
<tr>
<td>CND</td>
<td>Canada</td>
<td>Member</td>
</tr>
<tr>
<td>AUS</td>
<td>Australia</td>
<td>Member</td>
</tr>
<tr>
<td>NZ</td>
<td>New Zealand</td>
<td>Member</td>
</tr>
</tbody>
</table>

VTI RAPPORT 380A
Of these countries Turkey, Iceland, Canada, Australia and New Zealand have only recently been included into the database. This means that their data collection is still fairly incomplete. The database therefore contains road traffic and accident data as well as figures on resident and vehicle population as described in chapter 4 from about 20 - 25 countries.

The current participation of national coordinating institutes is shown on the list. This leads to a total of 15 full member countries. It is expected that at least 17 - 18 countries are shortly going to participate in IRTAD within the framework of full membership.

As agreed by the IRTAD Operational Committee, the number of variables included in the database has recently been increased. It was decided to introduce single-year age bands for the age group 15-20 years and to collect data for hospitalized victims (in-patients). Moreover, the road category "A-level roads" was implemented. The new data groups will be collected on every year from 1989 onwards and for the years 1970, 1980 and 1985.

Status of the direct use of IRTAD data is that
Federal Highway Research Institute, BASt (D),
Road Data Laboratory (DK),
Ministry of Transport (GB),
VTI (S),
Ministry of Transport (NZ),
KfV (A),
Federal Highway Administration (USA),
FinnRA (SF),
Land Transports Division (AUS),
SWOV (NL),
S.E.T.R.A. (F)
Directorate of Public Roads (N)
Daimler Benz (D),
Volkswagen AG (D)
and JARI (J)
are working with IRTAD as external users via floppy disk, on-line or both.

7. FUTURE DEVELOPMENTS

The future work in the framework of IRTAD is described in the working programme as decided by the Operational Committee in september 1991. This chapter will contain an annotated summary of this programme.

IRTAD is to serve as an international aggregated database for general international comparisons as well as for scientific research. Therefore, exact data, reliable data comparability and consistency are indispensable. Furthermore, the Federal Highway Research Institute (BASt) offers continuous technical support to the external user. Once the initial phase is completed, the working programme will strive for a consolidation of IRTAD taking the following items into account:
1) Familiarization of all participating institutions with the contents of the database as well as the practical use of it. Acquisition and installation of the necessary hard- and software. BASt support by training sessions and practical advice. Until now 4 training sessions have been held with great success.

2) Consolidation of data compilation, e.g. by state-of-the-art bulletin etc. Nomination of national data providing institutions for all or individual data categories for all countries.

3) Completion with regard to compilation of the newly introduced variables, and consolidation of their future collection. Compilation of further definitions, determination of data availability, current input of new data. The operational committee has discussed further activities in the field of harmonization of definitions on an international level.

4) Evaluation of comparability of the new data categories A-level roads and hospitalized victims. An evaluation has been made showing the current data availability of these newly introduced variables and gives an overview of national definitions. A special report will be published soon.

5) Compilation of methods and determination of availability of traffic data in participating countries. A summary report is being made by the Swedish delegate.

6) Bibliography of documents, publications and reports based on IRTAD data. This will be regularly made available.

7) General use and access to monthly data, which gives a better opportunity for making a quicker indicator for trends and changes within each country.

8) Regular exchange of information on latest developments and results in individual participating countries’s data compilation and analysis. This information is exchanged on the meeting of the operational committee written abstracts on trends and methodical changes in each country are added to the minutes.

9) Up-date of BASt User-Guide with regard to completion of data definitions.

10) Cooperation with regard to other international database activities such as OECD-DC2 group.

11) Cooperation with ECE, ECMT and WHO as far as data definitions, harmonisation and collection is concerned.
12) Preparation of a possible inclusion of non-OECD countries, e.g. Eastern European Countries. The Operational Committee has recommended the participation of non-OECD countries in IRTAD. A distinction should be made between a membership which includes the provision of data by the respective country and a passive use. No country should be included in the database if it cannot provide sufficient data.

8. CONTEXT WITH OTHER INTERNATIONAL DATABASE ACTIVITIES

The basic idea of IRTAD is to establish a fast, up-to-date and reliable database on road traffic and accident. This goal is reached by a computerised system supplied with data from responsible institutes in each country. The Operational Committee and the database administration centre (BASt) secure the overall function of IRTAD. At the same time, the Operational Committee is the forum of data-description, data-standardization and data-comparison.

IRTAD is now a full running and consolidated system. On this basis the cooperation with other international organizations should be increased to avoid duplication of efforts.
Traffic Safety in Eastern and Western Europe at the Beginning of the Nineties

Ekkehard Brühning
Dr
Head of "Accident Statistics, Accident Analysis"
Bundesanstalt für Strassenwesen (BASt)
Germany
TRAFFIC SAFETY IN EASTERN AND WESTERN EUROPE AT THE BEGINNING OF THE NINETIES

Contribution to the European Road Safety Conference, Berlin
30 September - 2 October 1992

Dr. Ekkehard Brühning, Bundesanstalt für Straßenwesen

ABSTRACT

At the beginning the paper provides a brief overview of traffic safety trends and national differences in Western Europe. It becomes clear that considerable differences exist between European OECD countries. National conditions playing a major role in the comparison of international traffic safety like population density, motorization and mobility are described with differing population-related risks and fatality rates being evaluated.

In the next step traffic safety and trends in selected Eastern European countries are compared. It can be concluded that in comparison with European OECD countries the risk values in Eastern European countries were quite favourable before the opening-up of Eastern Europe. Now, with increasing traffic and fatality figures, Eastern European countries are approaching the unfavourable end of the scale.

Finally, developments in traffic safety in East Germany are evaluated. There is no doubt that the political and social changes in Eastern Europe have had a dramatic impact on road traffic and traffic accident trends with East Germany being especially affected. It may even be assumed that, in contrast to other Eastern European countries, East Germany is experiencing these changes in a comparatively short period.

The data which will be provided for Western European countries and for East Germany are taken from the OECD-IRTAD-International Road Traffic and Accident Database.
TRAFFIC SAFETY IN EASTERN AND WESTERN EUROPE AT THE BEGINNING OF THE NINETIES

Dr. Ekkehard Brühning
Head of "Accident Statistics, Accident Analysis"
Bundesanstalt für Straßenwesen (BAst)

1. OVERVIEW

At the beginning this survey provides a brief overview of traffic safety trends and national differences in Western Europe. It becomes clear that considerable differences exist between European OECD countries. After that, traffic safety and trends in traffic safety are compared between some Eastern European countries. Finally, developments in traffic safety in East Germany are evaluated.

There is no doubt that the political and social changes in Eastern Europe have had a dramatic impact on road traffic and traffic accident trends with East Germany being especially affected. It may even be assumed that, in contrast to other Eastern European countries, East Germany is experiencing these changes in a comparatively short period.

The data provided for Western European countries and for East Germany were taken from IRTAD - International Road Traffic and Accident Database. In 1988 IRTAD was launched as a joint initiative of the OECD, in the framework of the RTR programme, and BASt (Federal Highway Research Institute). BASt serves as host of the database and offers on-line access to all IRTAD member institutes from OECD countries.

The following contribution forms part of the triple presentation related to IRTAD. A more detailed overview of IRTAD has been given by the previous speaker, Mr. Nielsen, whereas Dr. Koornstra will conclude the presentation by outlining future traffic safety developments in Eastern and Western Europe.

2. GLOBAL INTERNATIONAL COMPARISONS OF TRAFFIC SAFETY

International comparisons of traffic safety should be based on traffic fatality figures. Other characteristics like the number of injury accidents cannot be compared internationally since the individual definitions of injuries differ widely. The international fatality figures used in this survey have all been adjusted to the 30-day-definition.

VTI RAPPORT 380A
There is no doubt that absolute figures on fatalities alone do not suffice for an international comparison. Therefore, absolute numbers have to be translated into relativized figures which take road usage and exposure to accidents into account:

- the mean risk of inhabitants being involved in fatal accidents is calculated on the basis of the home population (killed per 100,000 inhabitants).
- the mean risk resulting from road usage and mobility is quantified on the basis of vehicle kilometres (killed per 1 billion vehicle kilometres).

In contrast to the two "risk figures" above a comparison based on the number of motor vehicles should be avoided since the number of motor vehicles does not describe adequately the accident exposure of road users.

Apart from the aforementioned "risk figures" it is also useful to derive percentages, e.g. the percentage of killed occupants of passenger cars against the total number of killed road users. This leads to a description of the accident structure.

3. TRAFFIC AND TRAFFIC SAFETY IN EUROPEAN OECD COUNTRIES

Table 1 provides an overview of some general figures in OECD countries (excl. Turkey and Iceland) which are important for judging traffic safety. (East Germany did not form part of OECD until 1990; figures for 1989 are included as well.)

The figures given in table 1 describe some of the national conditions playing a major role in the comparison of international traffic safety. Further information on road users, vehicles, traffic characteristics, settlement patterns, topography, climate, etc., cannot be taken into consideration in this brief survey. However, table 1 gives a first impression of the considerable differences which exist between individual OECD countries.

3.1 Population and Population Density

Table 1 shows that the population of 12 of the countries is under 15 million. However, there is no correlation between the total population and population density: the "smaller" countries have both the highest population densities (NL, B) and the lowest densities (S, SF, N). Comparison of North/South population density shows that Southern European countries range between Northern Europe and Central Europe (incl. GB). The highest population rate (NL) is approx. 27 times higher than the lowest rate (N).
3.2 Motorization

Table 1 shows the number of motor vehicles (excl. mofas/mopeds) in relation to home population. Vehicle population, and especially ownership of passenger cars, largely depends on the standard of living or the per capita disposable income in individual countries. Motorization is highest in L, D(W), I and CH (over 550 motor vehicles/1,000 inhabitants), and lowest in GR and IRL (around 300 vehicles/1,000 inhabitants). Statistically there is no correlation between population density and motorization; the motorization rate of B lies between the rates of SF and N.

3.3 Mobility

Since national kilometrage figures can only be compiled by means of estimates, samples and projections and since no uniform international method exists some distortions may occur when comparing international kilometrage data and resulting exposure data. Unfortunately, in many countries kilometrage data are not available at all (see table 1).

Comparison of the total vehicle kilometrage to the total population produces an average kilometrage figure which can be used to ascertain mobility.

The kilometrage data available indicate considerable differences in mobility in European OECD countries. In CH, the country with the highest (known) mobility rate in Europe, more than 8,000 vehicle kilometres are driven per inhabitant, three times more than in E. The mobility rates for the other highly motorized countries for which kilometrage data are available, lie between 6,512 (NL) and 7,992 (SF) veh·km/inh.; in Central Europe the figures are mostly around 7,000 veh·km/inh. Unfortunately, no kilometrage data are available for GR and P, where vehicle ownership is comparatively low.

3.4 Population-related Risk

The mean risk of being fatally injured in a traffic accident in European OECD countries has clearly diminished since the early seventies even though motorization and kilometrage have continously increased over the same period (see figure 1). In 1989 the mean risk rates ranged between 9.1 in Norway and 31.5 (killed/10^5 inhabitants) in Portugal. The most favourable figures in 1990 were recorded in N, S, NL and GB with the least favourable figures being recorded in Spain and Austria; no 1990 figures are available for Portugal for the time being (see table 1). At the beginning of the nineties most European OECD countries are situated at three different levels, i.e. countries with a low, medium, or high risk rate. Although the overall trend of risk rates has been positive for a long time on international level, they show a very inhomogeneous situation in Western Europe with extreme risk values differing by more than three times.
3.5 Fatality Rates

As described in section 2, fatality rates are obtained by relating the total number of killed road users to the total kilometrage.

It was possible to calculate fatality rates for 11 of the countries shown in table 1. Considerable differences emerged at an international level. GB recorded the most favourable figure (12.8 killed per $10^9$ veh·km). In other highly motorized European countries for which kilometrage data are available, fatality rates amounted to 20 or 30 killed per $10^9$ veh·km. Spain has an extremely high rate (82 killed per $10^9$ veh·km). Unfortunately, other Southern European countries cannot be included in this comparison. It may be assumed, however, that the rate would be even higher in Portugal.

It is thus clear that fatality rates differ considerably between European OECD countries. The risk of being killed related to vehicle kilometrage - where known - is six to seven times higher in the "most dangerous" country than in the "safest" country.

4. DEVELOPMENT OF TRAFFIC AND TRAFFIC SAFETY IN SELECTED EASTERN EUROPEAN COUNTRIES

The political changes of the past years in the former socialist countries have particularly affected road traffic. The newly gained freedom to travel, the opening-up of markets towards the West and increasing passenger car numbers (effects of Perestroika in the USSR) are only a few of the factors affecting road traffic conditions in those countries.

Yugoslavia figures as a non OECD country in table 2 although it was not isolated from the West. As result of the reshaping of the political landscape in Eastern Europe the political states of USSR and Yugoslavia are no longer in existence. Therefore, the respective time series cannot be continued. Regarding the former territory of Yugoslavia questions of traffic safety have become rather marginal compared to the high number of victims caused by the ongoing civil war.

4.1 Population Density and Growth in Motorization

Population and motorization differ widely in the countries included in table 2. Population density, however, is quite similar in PL, CS and HU. As far as motorization is concerned, CS and D(O) (until 1989) were leading among Eastern European countries whereas PL and HU were on average level. Compared to OECD countries (cf. table 1), it can be seen that in 1990 CS had a motorization rate similar to E and P and that motorization was far lower in GR and IRL.
The extent to which the political changes have influenced the development of motorization rates becomes clear when PL, D(O), CS and HU are compared: starting from low motorization levels, PL and HU experienced comparatively high percentage increases in motorization even before 1990. In contrast, in CS and D(O) there were only minor percentage increases until 1989. In 1990, i.e. after the political landscape in CS and D(O) had changed completely, motorization was no longer developing simultaneously in the two countries: German reunification had led to a sharp increase in motorization in D(O) (see section 5).

4.2 Population-related Risk

The differences in risk values in the countries shown in table 2 (excl. YU) were relatively small in 1987 (in 1987 the risk values in SU and HU were one and a half times higher than in CS). In the following years, the number of killed road users and hence the risk values increased considerably in SU, HU and PL. Thus, as soon as 1989 the risk value in HU was twice as high as in CS. After the political transition, a sudden increase was observed in CS and above all in D(O).

Compared to European OECD countries shown in table 1 and figure 1, the risk values in Eastern European countries were quite favourable before the opening-up of Eastern Europe. Now, with increasing traffic and fatality figures, Eastern European countries are approaching the unfavourable end of the scale found in Western Europe. It is not yet clear if they will reach or even overtake the extremely unfavourable risk values of Portugal.

4.3 Changes in Accident Structure

Not all aspects of traffic accidents in Eastern European countries have been equally affected by the overall rise in traffic accidents. Surveys in D(O) have shown (cf. Ernst et al., 1991), among other things, that the number of passenger car occupants killed or the number of fatalities in rural areas rose disproportionately (see section 5). The figures in table 3 underline two different trends:

- As expected, the two structural characteristics selected "Percentage of passenger car occupants killed" and "Percentage of killed road users in rural areas" differ considerably on international level.

- With the rise in traffic fatalities, the percentage of killed passenger car occupants has increased markedly in Eastern European countries. At the same time, the percentage of killed road users in rural areas has also increased, i.e. the number of fatalities is rising faster in rural areas than in built-up areas.
5. DEVELOPMENT IN TRAFFIC SAFETY IN EAST GERMANY

Until 1989 the population-related risk in East Germany - D(O) - was, in comparison to Western European countries, quite low, resulting from the comparatively low motorization and other system related factors. However, it was not lower than in the most favourable highly motorized European OECD countries (see figure 1). The accident figures for D(O) in 1990 show a clear structural break affecting all road traffic and accident trends. Although the figures only began to rise dramatically in the second half of 1990, the population-related risk of being fatally injured in D(O) almost doubled (see figure 1). The sharp increase in traffic fatalities continued in 1991.

Figure 2 compares the population-related risk of some Western countries regarding different age groups. In general the age group "15 to 24 years" shows the highest risk rates whereas risk rates for older people are considerably lower. Risk rates for middle-aged adults are even more favourable. With children the risk of being fatally injured in a traffic accident is the lowest. Only in the Netherlands older people run a higher risk than young people. Austria, Belgium and France show unfavourable risk rates especially for middle age groups. In 1989 D(W) had average risk rates for all age groups. In 1990 the West German risk rates continued to decrease. Until 1989 D(O) had more favourable risk rates than D(W) for all age groups indicated in fig. 2. Inspite of its low motorization the risk rates of D(O) were the highest for all age groups in the year 1989 compared with the highly motorized countries of fig. 2.

Figure 2 reflects that the sudden increase of fatalities in D(O) recorded in 1990 affected the individual age groups in different ways. All age groups show less favourable risk rates with extremely high increases in the two middle age bands. Population-related risk for the 15-to-24-year-old increased from 17.9 to 41.5 killed/100,000 inhabitants. Risk rates for 1991 are expected to be even higher.

As shown in table 2 the fatality rate has also increased sharply after 1989 with some accident types in D(O) being especially affected (e.g. rural accidents, of which especially accidents on motorways; passenger car occupants and young adults). The reasons for this increase in D(O) are manifold: an enormous increase in mobility, a dramatic increase in vehicle population including, to a large extent, powerful passenger cars, a sharp increase in driver population by inexperienced drivers - especially young drivers, changes in social values, non-existence of police traffic control which used to be very intensive, poor infrastructure, etc.

The abrupt change in traffic and accident trends in D(O) is due to the rapid changes taking place at all social levels and resulting from German reunification and the integration of East Germany in the West German social and economic system. Otherwise the sudden surge of motorization could not have been explained (357 veh/1,000 pop. in 1989, about 500 veh/1,000 pop. in 1991). It can now be observed
that changes - which have taken several years in other former socialist countries in Eastern Europe - are taking place in D(O) over a comparatively short period in time. Fortunately, in D(O) the sharp upward trend has meanwhile reached its peak with monthly fatatility figures stagnating at high level since August 1991. Even a slight decrease can now be observed.

Literature

Ernst, G.; Brühning, E.; Alevisos, E.:
Verkehrssicherheit in den Neuen und Alten Bundesländern. Forschungsberichte der Bundesanstalt für Straßenwesen, Nr. 239 (1991)
Table 1: Safety related 1990 Data of European OECD Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (thousand)</th>
<th>Population Density (Pers./sqkm)</th>
<th>Motorization (mot. veh/1000 Pers.)</th>
<th>Mobility (veh·km/Pers.)</th>
<th>Population related risk (Fatalities/10^5 Pers.)</th>
<th>Mobility related risk &quot;Death rates&quot; (Fatalities/10^9 veh·km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany W.</td>
<td>62,679</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany E.</td>
<td>16,675</td>
<td>1</td>
<td>252</td>
<td>570</td>
<td>7,315</td>
<td>12.6</td>
</tr>
<tr>
<td>D(O) 1989 -</td>
<td></td>
<td></td>
<td>152</td>
<td>420</td>
<td>3,995</td>
<td>19.1</td>
</tr>
<tr>
<td>Italy</td>
<td>57,746</td>
<td>3</td>
<td>192</td>
<td>357</td>
<td>3,058</td>
<td>10.7</td>
</tr>
<tr>
<td>Great Britain GB</td>
<td>55,821</td>
<td>5</td>
<td>243</td>
<td>428</td>
<td>7,301</td>
<td>9.4</td>
</tr>
<tr>
<td>France</td>
<td>56,304</td>
<td>11</td>
<td>102</td>
<td>470</td>
<td>6,840**</td>
<td>19.9</td>
</tr>
<tr>
<td>Spain</td>
<td>38,925</td>
<td>13</td>
<td>77</td>
<td>382</td>
<td>2,833</td>
<td>23.2</td>
</tr>
<tr>
<td>Netherlands NL</td>
<td>14,893</td>
<td>13</td>
<td>358</td>
<td>420</td>
<td>6,512</td>
<td>9.2</td>
</tr>
<tr>
<td>Greece</td>
<td>10,033*</td>
<td>14</td>
<td>76*</td>
<td>256*</td>
<td>--</td>
<td>19.5*</td>
</tr>
<tr>
<td>Belgium</td>
<td>9,948</td>
<td>2</td>
<td>326</td>
<td>462</td>
<td>--</td>
<td>19.9</td>
</tr>
<tr>
<td>Portugal</td>
<td>9,860*</td>
<td>10</td>
<td>106*</td>
<td>365*</td>
<td>--</td>
<td>31.5*</td>
</tr>
<tr>
<td>Sweden</td>
<td>8,527</td>
<td>6</td>
<td>19</td>
<td>507</td>
<td>9.1</td>
<td>--</td>
</tr>
<tr>
<td>Austria</td>
<td>7,660</td>
<td>12</td>
<td>91</td>
<td>485</td>
<td>7,292</td>
<td>20.3</td>
</tr>
<tr>
<td>Switzerland CH</td>
<td>6,674</td>
<td>12</td>
<td>162</td>
<td>550*</td>
<td>8,314</td>
<td>13.9</td>
</tr>
<tr>
<td>Denmark</td>
<td>5,135</td>
<td>9</td>
<td>119</td>
<td>403</td>
<td>7,128</td>
<td>12.4</td>
</tr>
<tr>
<td>Finland</td>
<td>4,974</td>
<td>17</td>
<td>15</td>
<td>447</td>
<td>7,992</td>
<td>13.1</td>
</tr>
<tr>
<td>Norway</td>
<td>4,233</td>
<td>18</td>
<td>13</td>
<td>521</td>
<td>--</td>
<td>7.8</td>
</tr>
<tr>
<td>Ireland</td>
<td>3,503</td>
<td>15</td>
<td>49</td>
<td>301</td>
<td>7,107</td>
<td>13.7</td>
</tr>
<tr>
<td>Luxemburg</td>
<td>378</td>
<td>8</td>
<td>146</td>
<td>579</td>
<td>--</td>
<td>18.0</td>
</tr>
<tr>
<td>Total/Average</td>
<td>373,676</td>
<td>104</td>
<td>472</td>
<td>6,351</td>
<td>15.4</td>
<td>24.3</td>
</tr>
</tbody>
</table>

1) *rank in row*

* 1989
** 1987

Source: IRTAD - International Road Traffic and Accident Database
### Table 2: Safety related data of some European Non OECD Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (thousand)</th>
<th>Population Density (Pers/sqkm)</th>
<th>Motorization (mot.veh/1000 Pers)</th>
<th>Population related risk (Fatalities/10^5 Pers)</th>
<th>Mobility related risk &quot;Fatality rates&quot; (Fatalities/10^9veh·km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1988</td>
<td></td>
<td>'87</td>
<td>'88</td>
<td>'89</td>
</tr>
<tr>
<td>USSR</td>
<td>SU</td>
<td>281,689</td>
<td>13</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Poland</td>
<td>PL</td>
<td>37,764</td>
<td>121</td>
<td>191</td>
<td>227</td>
</tr>
<tr>
<td>E. Germany^1</td>
<td>D(O)</td>
<td>16,675</td>
<td>154</td>
<td>338</td>
<td>347</td>
</tr>
<tr>
<td>CSFR</td>
<td>CS</td>
<td>15,587</td>
<td>122</td>
<td>347</td>
<td>352</td>
</tr>
<tr>
<td>Hungary</td>
<td>HU</td>
<td>10,604</td>
<td>114</td>
<td>205</td>
<td>214</td>
</tr>
<tr>
<td>Yugoslavia</td>
<td>YU</td>
<td>23,417</td>
<td>92</td>
<td>163</td>
<td>166</td>
</tr>
</tbody>
</table>

^1) Since 1990 part of OECD

Source: IRTAD, IRF, ECE, CEMT and correspondence

---

### Table 3: Structure of fatal accidents in some European Non OECD Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Killed total</th>
<th>Killed Car passengers (% of all fatalities)</th>
<th>Killed Outside urban areas (% of all fatalities)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1989</td>
<td>1990</td>
<td>'87</td>
</tr>
<tr>
<td>USSR</td>
<td>SU</td>
<td>58,650</td>
<td>63,362</td>
</tr>
<tr>
<td>Poland</td>
<td>PL</td>
<td>6,724</td>
<td>7,333</td>
</tr>
<tr>
<td>E. Germany^1</td>
<td>D(O)</td>
<td>1,784</td>
<td>3,140</td>
</tr>
<tr>
<td>CSFR</td>
<td>CS</td>
<td>1,606</td>
<td>2,022</td>
</tr>
<tr>
<td>Hungary</td>
<td>HU</td>
<td>2,162</td>
<td>2,432</td>
</tr>
<tr>
<td>Yugoslavia</td>
<td>YU</td>
<td>4,619</td>
<td>--</td>
</tr>
</tbody>
</table>

^1) Since 1990 part of OECD
1: Killed per 100,000 population
- selected countries -

VTI RAPPORT 380A
2: Killed per 100,000 population in 1989
- selected countries -

Killed / 100,000 population of the same age group

0 to 14 years

15 to 24 years

25 to 64 years

65 years and more

VTI RAPPORT 380A
Predictions of Road Safety in Industrialized Countries and Eastern Europe

Matthijs J Koornstra
Drs, Vice President of FERSI
Institute for Road Safety Research (SWOV)
The Netherlands

and

Siem Oppe
Institute for Road Safety Research (SWOV)
The Netherlands
PREDICTIONS OF ROAD SAFETY IN INDUSTRIALIZED COUNTRIES AND EASTERN EUROPE

An analysis based on models for time series of fatality rates and motorized vehicle kilometers or amounts of passenger cars

Paper presented at the International Conference "Road Safety in Europe", Berlin, 30 September - 2 October 1992

Matthijs J. Koornstra and Siem Oppe
Leidschendam, 1992
SWOV Institute for Road Safety Research, The Netherlands
ABSTRACT

Long term developments in growth of motorized mobility and accompanying developments in fatality rate (and injury rate) can be rather well described by relative simple functions of time. These functions are monotonic trends modulated by a cyclic wave function with a long period. The monotonic trends are sigmoid curves (logistic function) for saturating growth of motorized kilometrage and decreasing curves (exponential function) for risk adaptation. Analyses of data for many countries have shown that the parameters of the cyclic waves around these trends, as well as the trend parameters themselves, are related. This relation implies that the cyclic increase above trend in motorization is followed by a cyclic stagnation of the adaptive risk reduction (or even a temporary risk increase). With respect to safety this can mean a simultaneous combination of relative large increases in vehicle kilometers and an increase in fatality rate, which is disastrous.

The relation between mobility growth and risk adaptation is theoretically understood as the result of a technological evolution under socio-economic constraints. Differences in developments between countries are interpreted as differences in onset, speed and modulation of that technological evolution due to different socio-economic constraints. This, as well as the remarkable fit of the model and the relation between growth of kilometrage and risk adaptation, are illustrated by results for Japan, Germany (west) and the USA for time series of 40 year and longer.

For Eastern Europe it is argued that, due to socio-economic constraints in Eastern Europe up to now, the trend for the technological evolution of motorization is retarded socio-politically and that its cyclic wave function expresses the socio-economic repression of the last decade. The socio-political constraints in Eastern Europe are released nowadays and it can be assumed that the economic repression will turn into an upsurge in the next decade. A quantitative analysis show that these expectations are reflected in the growth of motorized mobility up to now and in the future. The analysis also confirms the close relation between mobility growth and risk adaptation from which the development of the fatality rate in the future can be deduced. An analysis is shown for the countries of Hungary, Poland and the Czech and Slovak Republic(s). The tentative results show a disastrous development of road fatalities in the next decade and a fast safety improvement thereafter. Some thoughts are given to means which may prevent these worse outcomes for the near future, but the possibility for success is doubted.
PREDICTIONS OF ROAD SAFETY IN INDUSTRIALIZED COUNTRIES AND EASTERN EUROPE.
- An analysis based on models for time series of fatality rates and motorized vehicle kilometers.


Matthijs J. Koornstra and Siem Oppe.

Institute for Road Safety Research SWOV
P.O. Box 170, 2260 AD Leidschendam, The Netherlands.

ABSTRACT. Long term developments in the growth of motorized vehicle kilometers and the accompanying developments in the fatality rate (and injury rate) in many industrialized countries can be rather well described by relative simple functions of time. These functions are monotonic trends modulated by a cyclic wave function with a long periodicity. The monotonic trends are a sigmoid curve (logistic function) for saturating growth of motorized kilometrage and a decreasing curve (exponential function) for risk adaptation. Analyses of data for many countries have shown that the parameters of the cyclic waves around these trends, as well as the trend parameters themselves, are related. This relation implies that the cyclic increase above trend in motorization is followed by a cyclic stagnation of the adaptive risk reduction (or even a temporary risk increase). With respect to safety this can mean a simultaneous combination of relative large increases in vehicle kilometers and an increase in fatality rate, which is disastrous.

The close relation between mobility growth and risk adaptation is theoretically understood as the result of a technological evolution under socio-economic system constraints. Differences in developments between industrialized countries can be interpreted as differences in onset, speed and modulation of that technological evolution due to different socio-economic constraints. This, as well as the remarkable fit of the model and the relation between growth of kilometrage and risk adaptation, are illustrated by results for the USA and Japan for time series of 40 year and longer.

For Eastern Europe it is argued that, due to the socio-economic system constraints in Eastern Europe up to now, the trend function of the technological evolution of motorization is retarded socio-politically and that its cyclic wave function expresses itself as a developmental repression economically in the last decade. The socio-political constraints in Eastern Europe are released nowadays and it can be assumed that the economic repression will turn into an upsurge in the next decade. Under these expectations the growth of motorized kilometers up to now and in the future can be quantitatively modelled and from the close relation between growth and risk adaptation the development of the fatality rate can be deduced. This is tentatively tried for the PIT-countries (Pol., Hung., Czech.). The tentative results show a disastrous development for the road fatalities in the next decade and a fast safety improvement thereafter. Some thoughts are given to means which may prevent these worse outcomes for the near future, but the possibility for success is doubted.
1. INTRODUCTION

The history of the annual number of fatalities in road traffic for the industrialized countries generally shows, besides some irregularities, a peak in the beginning of the seventies. Although many attempts have been made to explain the safety improvement after the mid seventies, it can be shown that the single peak is the necessary result of an initially high, but monotonic ever decreasing, percentage of growth in motorized kilometrage and a constant percentage of decrease for the fatality rate. This can be illustrated by the typical curves of Figure 1, which in fact contain the actual data from the Netherlands.

![Figure 1](image-url)

**Figure 1.** Typical curves for kilometrage x fatality rate = fatalities.

In fact the development of motor kilometers can be fairly well expressed by a logistic function of time (Oppe, Koornstra and Rosbach 1988, Koornstra 1988; Oppe 1989; Oppe & Koornstra, 1990). As an illustration the mileage data from the USA and their fit to the logistic function of time are shown in Figure 2.

The data for the USA are chosen for the illustration of the macroscopic validity of the logistic function for mobility growth, because it is the country with the longest history of registration e.g. from 1923 onward.

The macroscopic developments of the fatality rate for many countries have been often described by an exponential decreasing function of time.
Figure 2. Logistic development of mileage for the USA.

(Chatfield, 1987; Koornstra, 1987; Broughton, 1988; Haight, 1988, Oppe 1989). Although the use of the simple exponentially decreasing function assumes implicitly that the fatality rate as a probability measure reduces to zero in the end, it has shown to be a function which in a macroscopic sense fits the data for all countries rather well. As an illustration the figure of the analysis of Chatfield (1987) for the fatality rate in the USA from 1925 to 1985 is copied as Figure 3.

Figure 3. U.S. motor vehicle traffic fatality rates (Chatfield, 1987).
Since both functions for mobility growth and for fatality rate are functions of time, while time is perfectly predictable, one can predict the macro-development of fatalities from the fitted curves of these simple models. So has been done by Oppe (1989; 1991a) for the USA, Japan, Germany (west), Great Britain, Israel and the Netherlands, based on the data for time-series of the post second world war period of more than 40 years. From the above pictures and these analyses it can be seen that the actual developments show marked deviations from the model curves. The product of both fitted curves necessarily show a smooth single peaked curve as the expected number of fatalities from the model outcomes. As an illustration the retrospective and prospective prediction for the USA by these macroscopic models is shown in Figure 4, where the retrospective part is shown also by the actual vehicle mileage multiplied with the model prediction of the fatality rate. The fact that the fatalities in the second world war period are well predicted on the basis of the actual mileage indicates that the development of the fatality rates in the USA, in contrast to mileage, is not very much influenced by the war.

![Figure 4. Macroscopic model prediction of U.S. fatalities](image)

As can be seen the retrospective prediction is far from accurate, but it does reflect the macroscopic trend in the development and the prospective trend is one of increasing safety, because of the ever decreasing fatality rate to a virtual zero level in the infinity of time.
2. THEORETICAL BACKGROUND

On the basis of theoretical considerations from evolution theory there may exist a relation between growth and risk adaptation. In evolution theory Teilhard de Chardin was (to our knowledge) the first who has formulated such a general, more or less quantitative relation when he wrote: - "The <evolution> process for very large aggregations - as is the case for the human mass - has the tendency to 'evolve errorless', because on the one hand of chance the probabilities of success increase, and on the other hand of freedom the probabilities of refusal and failure decrease, proportional to the multiplicity of the related units" - (Teilhard de Chardin, 1948, Postscript Section 3). Applied to the technological traffic system the growth in kilometrage may be related to risk adaptation as the decreasing fatality rate. At an aggregate level and over a long period of time one may view traffic and traffic safety as long-term changes in system structure and throughput. Renewal of vehicles, enlargement and reconstruction of roads, enlargement and renewal of the population of licensed drivers, changing legislation and enforcement practices and last but not least changing social traffic norms in industrial societies are phenomena which are largely driven by growth of motorization and mobility. In an evolutionary systems approach these phenomena can be conceptualized as replacements of subsystems by sequences of better adapted subsystems within a total traffic system. The steadily decreasing fatality rate can be viewed as the lagged adaptation of the system as a whole.

Oppe found an empirical relation between the rate parameters of both developments. Koornstra realised that the resulting expression showed that the development of risk was related to the derivative of the logistic function. Working for several years on an evolutionary interpretation of social systems, he was inspired to look more generally at the quantitative relations between system growth and risk adaptation. The mathematical expressions for logistic growth of mobility and for exponentially decreasing fatality rate are related, such that the possible further growth divided by growth achieved is also an identical exponential function (Koornstra, 1988). Koornstra has shown (in Oppe et al., 1988) that, if the parameter for the slope of the fatality rate curve is half the value of that parameter for the growth curve, the number of fatalities than becomes a proportional function of the derivative of growth in kilometrage and does not dependent on the absolute level of kilometrage.

VTI RAPPORT 380A
The empirically found relation between the rate parameters is illustrated by Figure 5, taken from Oppe (1991a).

![Figure 5](image)

**Figure 5.** Relation between slope parameters for volume and rate.

The meaning of this figure that the slower the growth of mobility is the less the reduction in fatality rate is. It can also be seen from this figure that growth is slower (and risk adaptation less) the longer the unbroken history of motorization is, which is exemplified by the range of the positions from the USA to Japan. It seems, therefore, that the more recent the motorization is the larger the annual decrease in fatality rate and the more explosive the motorization is. This also may explain why for example Spain does not show its peak in fatalities at the onset of the seventies, but at the late eighties; the evolution of motorization in Spain just started later with respect to North-West Europe.

The product of the macroscopic model curves with their marked deviations as the resulting retrospective predictions of fatalities, such as the one shown for the USA in Figure 4, exhibit even relative larger deviations than the underlying pairs of curves for mobility growth and fatality rate. This indicates that the deviations from pairs of curves per country are not uncorrelated. Oppe (1991b) analyzed the residual deviations of the two curves and demonstrated that these are indeed correlated. He also showed in a model free way by polynomial analysis of curves as well as their derivates, that indeed that changes of increase and decrease in the respective actual curves are strongly correlated, which enabled him to predict retrospectively the development of fatalities in a much more accurate way.
In an earlier study we have modelled the deviations of logistic growth as a function of time also by cyclic waves are around the evolutionary S-shaped trend (Oppe & Koornstra, 1990). In that study this was done by cyclic variation of the estimated saturating level of kilometrage. This method improved the prediction of motorized mobility and fatalities considerably, although the deviations of the fatality rate were left untouched. However, this model for deviations does not and can not contribute to an intrinsic correlation between deviations in growth and rate. The intrinsic correlation between deviations for the fatality rate and the relative increase of mobility growth is nicely illustrated by Figure 6. This figure shows for the post second world war period in the USA the actual fatality rate and the smoothed, so called acceleration of growth which is the smoothed annual actual increase of growth divided by the actual growth level itself. As such both curves in this figure are curves of observed values without fitting any model to the data.

Figure 6. Observed fatality rate and acceleration of growth in the USA

This figure shows a cyclic deviation around the exponential fatality rate of Figure 3. It also shows that there are also cyclic deviations from a monotonic decreasing relative increase of mobility growth. A monotonic decrease for the relative growth increase is the mathematical result of the logistic function for the S-shaped growth itself. As can be deduced from this figure the cyclic deviations in both curves are strongly correlated. Since acceleration is a function of the derivative of the growth curve, it demonstrates that not only the macroscopic overall trends of growth and risk adaptation are related, as shown by Figure 5, but that
also cyclic deviations in both curves are related. The common cycle around these curves can also be described as a function of time. It seems as if relative higher growth of mobility above the S-shaped trend results in a less well adapted traffic system with a temporary stagnated or even increased fatality rate.

This inspired Koornstra (1991a; 1991b; 1992) to develop, on the basis of evolutionary relations between growth and adaptation, an integrated model for related cyclic deviations from logistic growth and exponential risk adaptation. In these studies the model parameter for the slope of the curves is cyclic varied as a function of time. This can be interpreted as long term cyclic influences on the speed of growth and speed of risk adaptation. In this integrated model not only the derivative of the growth of growth curve is related to the exponential fatality rate, but also the derivative of a cycle around the S-shaped growth curve is related to a cycle around the exponential fatality rate. The derivative of the cycles around macroscopic trend are cycles which are shifted by a quarter of the cycle period. This means that the cycle around the fatality rate will show a time lag of a quarter of its period with respect to the cycle around the S-shaped growth curve. Such a lagged influence of growth on safety can be understood as the lagged safety result from enlarged and improved infrastructures, renewal and enlargement of car fleets, revised and improved laws and improved licensing, education and enforcement practices. All together the technological evolution of road traffic is pushed by the demand for traffic and indeed do make the growth of traffic possible. The safety effects of these sequences of replacements in the traffic system are lagged in time with respect to the growth of traffic, because the realization of needed and planned changes asks for a certain time periods before the implementation is completed. Since in the integrated evolutionary model the macroscopic trend curves and the common cyclic deviations around these trend curves are both function of time, it enables us to predict retrospectively as well as prospectively the developments in growth and rates in a much more accurate way. It results in a marked improved prediction of the past and future development of road safety. This is shown in the next sections. The deviation cycles around macroscopic trends are interpreted as economic circumstances with relative long cycle periods which alternatingly deter and accelerate the technological evolution of system growth and risk adaptation.
3. FORECASTS FOR INDUSTRIALIZED COUNTRIES

3.1. Japan

In Figure 7 below we show the observed motorized kilometers (given as dots in the figure) from 1951 to 1990 in Japan and the predictions by simultaneous fit of logistic trend and cyclic deviations (given as a solid line). In order to show the influence of the cyclic deviations the underlying sigmoid curve is also presented (intermitted line). The optimal cycle has a period of 36 year and the saturating growth level reaches about $950 \times 10^9$ kilometers which implies a growth of about 50% from 1990 onward. Without the simultaneous fit of the cycle the sigmoid curve is closer to the observed data and its saturation level becomes much lower, allowing only a growth of about 15%. Not only has such a small amount of further growth less face validity, the additional cycle improved the fit significantly (F-test on residual variance yields p < 0.01).

![Figure 7. Prediction of vehicle kilometers in Japan.](image)

Despite the prediction is only a function of time the model with a cycle around logistic growth fits remarkable well, apart from a deviation shortly after 1973 which are the years of the oil crises of 1974. It will be noted that for Japan the steepest increase of the sigmoid curve nearly coincide with the steepest decrease of the cyclic deviations around the sigmoid curve at the end of the seventies. The actual increment of the joint predicted growth curve is the highest around 1970 and 1990. Here we note already that if fatalities are foremost a function of these increments, as it is conjectured by our integrated model, one would expect
the highest numbers of fatalities around these years and relative lower numbers before, between and after these periods.

Figure 8 gives the analysis for the fatality rate in Japan over the same observation period. Again the observed rates are given (dots) along with the fitted prediction curve (solid line) and the underlying exponential decreasing curve (interrupted line) which is modified by a proportional cyclic influence. The proportional effect of cyclic deviations means that small cyclic deviations at low values compare to large cyclic deviations at high values. The cyclic modification improves the fit significantly with respect to a simple exponential curve.

It will be noted that a fitted exponential curve without cycle will lay closer to the observed values than the simultaneous fitted exponential curve. The fitted cycle for deviations around the exponential curve is proportional to the derivative of the cyclic curve around the sigmoid growth curve and is, therefore, shifted by a quarter of the period. This means that relative cyclic increases or decreases of the fatality rate follow the cycle of the vehicle kilometers with a 9 year time-lag. Therefore, a partial delayed overlap of relative increments or decrements in growth of vehicle kilometers and in fatality rate is present. This can have disastrous effects on the number of fatalities in predicted periods of partial overlapping relative higher vehicle kilometers and relative higher fatality rates.
Figure 9 shows the results for the predicted fatalities in Japan. This prediction is based on the product of the predicted curve of Figure 7 and observed (and after 1990 predicted) values of Figure 8. Due to cyclic deviations in both underlying curves (Figures 7 and 8) and their locations in time with respect to the steepest increase of the sigmoid curve, the Japanese results show two peaks in the number of fatalities.

![Observed and predicted fatalities in Japan](image)

**Figure 9.** Observed and predicted fatalities in Japan.

The predictions from 1951 to 1990 fits remarkable good. Due to the saturating growth in vehicle kilometers and due to prediction of the fatality rate which virtually reduces to zero if time proceeds infinitely, the long term prediction of fatalities is very optimistic.

### 3.2. United States of America

Figures 2 to 4 pictured the analysis for the USA from 1923/25 onwards by an analysis without a cycle around the sigmoid growth curve and the exponentially decreasing fatality rate. Although the downward trend in the prediction of figure 4 may be correct, its actual prospective value is doubtful in view of marked deviations observed for the past prediction period. An analysis by the integrated model with a cycle shows that the apparent post war cycle is disrupted by World War II and does not have the same location (and perhaps phase) before that war. If we only analyze the post war period by our integrated model with cyclic deviations around monotonic curves the precision of the predicted values of mileage and fatalities enhances markedly. This is shown in the Figures 10 and 11, where the two-year mean values of mileage and fatalities from 1949 onward are given.

VTI RAPPORT 380A
Figure 10. Mobility analysis in the USA from 1949 to 1990.

Figure 11. Observed and predicted fatalities in the USA from 1949 to 1990.

The retrospective prediction error for yearly mileage for the USA remains within the 5% range and for fatalities per year within the range of 8%. The effects of the cycles with a period of 20 years in the USA are also very well visible in the forecast up to the year 2020.

3.3. Germany (west)

Figures 12 and 13 give the results for motorized kilometers and fatalities in former western Germany as two-years mean values from 1953/54 on ward to 1989/90 retrospectively and prospectively predicted to 2019/20, obtained by the same integrated model with cycles around monotonic trends.
Figure 12. Mobility analysis for Germany (west)

The saturation level for (West) Germany is not very well defined by the fit of its own growth development, but due to the theoretical relation with fatalities it can be taken to be about $675 \times 10^9$ km. Higher estimates, however, are not significant worse. There is a significant cyclical deviation from the sigmoid growth trend with a period of 38 years. The oil crisis of 1974 follows shortly after a positive cycle deviation and just precedes the steepest increase of the sigmoid trend, which seems to be a common aspect for the results of most other motorized countries. The oil crisis of 1974 seems, therefore, more an induced reaction to demand for oil than an unexpected disturbing factor. In contrast to Japan, the maximum increment of the underlying sigmoid growth does not coincides with a maximum decrease of the cyclic influence. Therefore and because of smaller cyclic influences than in Japan, the actual development of fatalities can not have a second peak in (West) Germany.

The retrospective and prospective prediction of fatalities (the solid lines of Figure 13) are again obtained from the observed and predicted vehicle kilometers and the fitted risk adaptation curve. The reduced cycle around the exponential risk curve fits the predicted time lag of a quarter of the cycle period compared to cycle around the sigmoid growth curve. The cycle around the exponential fatality rate contribute significantly to the fit of the estimated risk curve. The fit is only so optimal if the predicted fatality rate reduces infinitely to a virtual zero level. Hence fatalities will also reduce to virtually zero in the end.
Figure 13. Observed and predicted fatalities in (West) Germany.

The presented analyses for these three industrialized countries illustrate that mobility growth and traffic risk adaptation and the resulting fatalities can be modeled by processes which only depend on time, while the effects of relatively increased and unadapted growth can be disastrous for the development of the fatalities. So it has been in all industrialized countries with a peak in road fatalities in the beginning of the seventies and so it will be again for Japan (and Israel, see Koornstra, 1991) in the nineties. The non-decreasing (or even increasing) number fatalities in the period before or around 1990 in the presented countries is, according to our analysis, the result of the relative increased growth of mobility in the recent past which also causes, according to our analysis, a temporary delayed reduction of the fatality rate. As shown in the prospective predictions, this is not a sign of permanent worsening of the safety in the road traffic of the future. On the contrary, our long term predictions are optimistic due to the best fitting limit value of zero for the fatality rate (time proceeding to infinity). Since the independent variable is time which is a perfectly predictable variable and because the past period of 40 years or more in many countries is fairly accurately predicted by our time-based models it probably is a reliable prediction method for the future development of mobility and road safety in the next decade. Moreover, the integrated model is rooted in the general theory of technological evolutions (Koornstra 1991a; 1991b, 1992) and, therefore, these models also provide a scientific quite acceptable basis for its predictive results. This is more than any other model based on ad hoc independent variables (which themselves must be also predicted for the
prediction of safety in the future), such as socio-economic indicators for the prediction of fatalities (Partyka, 1991), can claim.

4. FORECASTS FOR EAST EUROPEAN COUNTRIES

The above theory and models may be as well applied to the development of motorization and safety in East European countries. The development in Eastern Europe can be seen as a technological evolution of motorization which up to 1989/90 has been retarded by socio-economic constraints and political system conditions. On top of this retardation a possibly present cyclic wave around starting developments may express the stagnation of further growth for the worsened situation after the seventies by a socio-economic repression in the last decade. Socio-political constraints in Eastern Europe are released some time ago and it can be assumed that the economic repression will turn into an upsurge in this decade. A quantitative analysis may show whether these expectations are reflected in the growth of motorized mobility up to now and if so it may be a basis for model prediction of the future. If such an analysis also confirms the close relation between mobility growth and risk adaptation, than the development of the fatality rate in the future is also sustained by theory.

In another paper we suggested developments of mobility and safety for Eastern European countries on the basis of the general trends only (Oppe & Koornstra, 1992). Here we will give an alternative and more detailed description, using the general trends as well as the cyclic deviations. The following analyses are restricted to the countries of Hungary, Poland and the Czech and Slovak Republic(s). For these countries we do not have a complete set of annual motor vehicle kilometers, but the number of annually registered passenger cars from the sixties onward can be used instead. Generally the development of the number of passenger cars is strongly correlated with the total motor vehicle kilometers. This can be also deduced from the fact that in the begin we have a relative small number of cars with a relative low mean kilometrage driven (actually about 7000 km per year) and a relative large share of kilometrage for busses, motorcycles and trucks, while in the end we have a large number of passenger cars with a relative larger mean kilometrage and a much smaller share of total kilometrage for busses, motorcycles and trucks.

A period of data of 30 years or less and the particular circumstances in the East European countries do not allow that we determine the estimation
of the saturation level of motorization from the development of the given
data over that period since the sixties. We, therefore, assume that the
saturation levels of motorization for these countries are the same as for
(West) Germany. This means we, given the predicted saturation for (West)
Germany which is 47% higher (see Figure 12) than the present level of
motorization (about 2 persons per car), we fix the saturation level of
motorization on 1.4 person per car. The resulting saturation levels for
the number of cars for a fixed number of inhabitants per country are given
in Table 1.

<table>
<thead>
<tr>
<th>Country</th>
<th>Inhabitants x1000</th>
<th>Cars '90 x1000</th>
<th>Ratio pers./cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany (W)</td>
<td>62.679</td>
<td>30.684</td>
<td>2.04</td>
</tr>
<tr>
<td>Czech/Slovak</td>
<td>15.519</td>
<td>3.122</td>
<td>4.97</td>
</tr>
<tr>
<td>Poland</td>
<td>38.038</td>
<td>5.261</td>
<td>7.32</td>
</tr>
<tr>
<td>Hungary</td>
<td>10.375</td>
<td>1.945</td>
<td>5.34</td>
</tr>
</tbody>
</table>

Table 1. Inhabitants, motorization and resulting saturation level.

With these tentatively fixed parameters the other parameters are fitted to
the data of passenger cars and fatalities for the three mentioned East
European countries. In Figures 14 to 19 the predictive results of the
analysis are given in the same way as before, but now for mobility growth
by passenger cars and implicitly by fatality rate per passenger car.

![Figure 14. Forecast analysis of motorization in Hungary.](image-url)
Figure 15. Forecast analysis of fatalities in Hungary.

Figure 16. Forecast analysis of motorization in Poland.

Figure 17. Forecast analysis of fatalities in Poland.
Despite a priori fixed saturation levels the retrospective prediction of the annual number of cars is quite satisfactory. The same holds for the fit to the observed fatalities over the 31 years period for Hungary and Poland, although less for Poland, and the 24 years period for the Czech and Slovak Republic(s). The optimal cycle period for these countries is about 40 years, a period comparable to the ones of Germany (west) and Japan. The most encouraging fact for the possible validity of the predictions, however, is that also the respective slope parameters for growth of motorization and fatality rate (per car in this case) also tend two show the theoretically expected ratio of a half, just as was shown for the industrialized countries in Figure 5. The values of the respective slope parameters are shown in Table 2.

VTI RAPPORT 380A
Table 2. Comparison between slope parameters of volume and rate.

<table>
<thead>
<tr>
<th>Country</th>
<th>Volume parameter</th>
<th>Risk parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech/Slovak</td>
<td>0.0981</td>
<td>0.0511</td>
</tr>
<tr>
<td>Poland</td>
<td>0.1174</td>
<td>0.0596</td>
</tr>
<tr>
<td>Hungary</td>
<td>0.1432</td>
<td>0.0685</td>
</tr>
</tbody>
</table>

The satisfactory retrospective fit and the above table in relation to Figure 5 can be seen as evidence for the tentative validity of the predictions. The prediction of the safety development is far from reassuring. The industrialized countries have experienced a tremendous increase in fatalities between the second half of the fifties and the onset of the seventies. Just in the same way the East European countries have to envisage a comparable increase in fatalities between today and the next ten years. Their development can be regarded to be retarded by about 30 years with respect to North-West Europe, but in the coming decades these countries catch up the backlash in motorization with the adverse consequences for road safety. The total number of fatalities for the sum of the three analyzed countries is predicted to increase from 12,000 nowadays per year to about 25,000 per year at its maximum around the year 2003. This prediction may even be somewhat optimistic, because the marked increases of fatalities in 1990 are already underestimated. On the other hand, one should realize that these forecasts are based on restricted empirical evidence and on a hypothetically assumed saturation level of motorization. After the first decade of the next century the annual number of fatalities is predicted to decrease gradually to about 5000 in the year 2025, but such long term predictions must be taken as far from reliable. However, from the evolutionary theory it follows, if the cyclic influence does not create a second peak, that a gradual reduction must be observed after the increase to a certain maximum.

One may wonder whether it is possible to prevent the increase of fatalities by safety policies. From our evolutionary theory (Koornstra, 1991a; 1991b, 1992) improved safety is the result of better adapted replacements of sequences of subsystems or elements in the traffic system. Whether these renewal processes concern infrastructure, cars, laws, or generations of better educated road users, all these processes asks for investments and time. Therefore, it is doubted whether the increase in fatalities can be actually reduced in the next ten years, given the economic circumstances in Eastern Europe. Specific actions which are...
beneficial may be taken, based on the joint experiences of West and East European countries with regard to effective measures, but is not the topic of this study. This study stresses the importance of international comparisons and validations of theoretical relation between traffic and safety developments on the basis of comparable defined data for traffic and safety. International cross validations increases the validity of forecasts for policies on national and international levels. It is hoped that the forecasts for Eastern Europe motivate decision makers to provide possibilities for research cooperation between East and West Europe in order to establish more effective policies, which surely ask also for joint financial support for the necessary actions to be taken.

REFERENCES

SARTRE: Social Attitudes to Road Traffic Risk in Europe: An Overview and Some Results from France

Pierre-Emmanuel Barjonet
Dr
Institut National de Recherche sur les Transports et leur Sécurité (INRETS)
France
Social attitudes to road traffic risk in Europe: goals, methodology and first results from France.

This presentation aims at giving an overview of a sociological survey on attitudes of drivers face to risk and road safety in Europe. SARTRE: "Social Attitudes to Road Traffic Risk in Europe" is carried out in almost all the European countries and involves most of the Institutes of traffic safety research.

This survey intends to bring new informations about the state of the public opinion in each country concerning traffic safety before the European opening. It also looks at measuring the level of adhesion or refusal to safety regulations and to define some sociocultural factors which control safe or risky behaviours.

SARTRE is performed in each country, with a standard questionnaire, on a representative sample of drivers.

In this presentation, we will describe the questionnaire and the methodological bases of the survey; the main hypothesis and the theoretical background will be explained. The first results coming from the French study will be mentioned.
SARTRE: SOCIAL ATTITUDES TO ROAD TRAFFIC RISK IN EUROPE: AN OVERVIEW AND SOME RESULTS FROM FRANCE.

PIERRE-EMMANUEL BARJONET
INSTITUT NATIONAL DE RECHERCHE SUR LES TRANSPORTS ET LEUR SECURITE
FRANCE.

SARTRE, what is it?

SARTRE is the name of a great french philosopher who was not, as far as we know, especially interested by traffic safety or even by the sociology of transport. But, his name, quite by chance, is like an acronym of "Social Attitudes to Road Traffic Risk in Europe" and it is in this way that the word SARTRE has to be understood.

More precisely, SARTRE is a sociological survey carried out in almost all the countries of Europe: the following map shows the participating countries: Austria, Belgium, Czechoslovakia, Denmark, France, Germany, Hungary, Italy, Ireland, the Netherlands, Portugal, Spain, Sweden, Switzerland, United Kingdom.

1 The participants

Austria

KfV (Road Safety Institute)

Belgium

ISBR (Belgian Institute for Road Safety).

Czechoslovakia

USMD (Research Institute for Road and Transport)

Denmark

RT (Danish Council for Traffic Safety Research)

France

INRETS (Institut National de Recherche sur les Transports et leur Sécurité.)

Germany

BASt (Federal Office for Transport Study)

Hungary

OKBT (National Council for Road Safety).

Italy

CENSIS (Socioeconomic Studies Center)

Ireland

ERU (Environmental Research Unit)

the Netherlands

SWOV (Institute for Road Safety Research).

Portugal

PRP (Road Prevention of Portugal)

Spain

University of Valencia

Sweden

VTI (Swedish Road and Traffic Research Institute.)

Switzerland

BPA/BFU (Swiss Council for Accident Prevention)

United Kingdom

TRL(Transport Research Laboratory).
SARTRE participating countries

participating country
out of study

VTI RAPPORT 380A
Each of these countries has carried out the survey with the same questionnaire translated in each language and the same methodology: a representative sample of the drivers (not less than 1000, so that the data analysis could be achieved) interviewed at home in a face-to-face situation. Thus, 16,226 drivers have been interviewed on the European area.

2 What are the purposes of such a survey?

1 - to know the state of public opinion in each involved country of Europe with regard to traffic safety just before the European opening.
2 - to measure the level of adhesion or refusal to safety regulations in each country.
3 - to define some social cultural factors which control safe or risky behaviours.

3 What kind of benefits can be expected from this survey?

1 - it is unprecedented: such a sociological study has never been carried out with such an extent. It will bring more knowledge on the opinions of drivers and, perhaps, will help us to begin to answer to social stereotypes like: northern drivers are more careful than southern, German drivers are more likely to obey the rules etc...
2 - it is opportune just before the European opening when this opening is the moment of harmonisation of safety rules which will lead to changing behaviours.
3 - it complementary with the European technological programs as DRIVE because safety is far from being only a matter of technical devices: it is more certainly a matter of human psychology and social influence.
4 - it is useful to prepare a common road safety policy and the so-called "Rapport Gérondeau" issued from EEC emphasises on the relevance of pool surveys not only to look for a social consensus face to regulations but also to forsake the responses of citizens and communities to safety countermeasures and to be able to answer to these reactions.

4 What about the finance?

Each participant finances its national survey. Most of the time, public authorities have supported the project and a grant from EEC DG VII was also received.
5 The schedule:

1990
1. The first task was to build the European research network, to find members and founds.
2. Then we had to fix a corpus of hypotheses and a methodology. The main difficulty was to build a common questionnaire.
3. The survey was achieved in the field for almost all the involved countries at the end of 1991 and in the beginning of 1992.
4. The main task is to produce and analyse the data. INRETS has centralised all the files and sent back to all members a report concerning 'flat' data. The simple 'flat' results of the European file has been published and a report on general analyse of all the data will be soon available.
5. A conference will be held in order to present the results of all the countries and to make recommendations especially in the field of social communication: how can we use these results to influence people to behave according to the legal rules?

1991

1992

1993

6 The framework of the questionnaire:

The first part identifies the interviewed people according to the chosen quotas: age, sex, occupation, area, type of town. The second part deals with the causes of accidents. The third one is centred on the behaviour of the interviewed drivers with regard to safety regulations as speed limit, seat-belt and driving habits. The following part is on drinking and driving and the last one on harmonisation of driving regulations within the European area.

7 The type of questions:

As you may notice on the following scale, all the items are "closed" and precoded for computer treatments:
"Would you be in favour or against the introduction of the following measures throughout the EEC?"

<table>
<thead>
<tr>
<th>Measure</th>
<th>In favour/against/D.K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 a minimum age for driving cars of 17 years</td>
<td>1 2 3</td>
</tr>
<tr>
<td>2 a tougher standard driving test used throughout Europe</td>
<td>1 2 3</td>
</tr>
<tr>
<td>3 A lower level of permitted alcohol for drivers</td>
<td>. . .</td>
</tr>
<tr>
<td>4 Regular technical check-ups for all types of vehicle</td>
<td>. . .</td>
</tr>
<tr>
<td>5 Similar penalties for the same traffic offences</td>
<td></td>
</tr>
<tr>
<td>6 A penalty point system for traffic offences which results in loss of licence when exceeded</td>
<td></td>
</tr>
<tr>
<td>7 A common speed limit of 50 kmph in residential areas</td>
<td></td>
</tr>
<tr>
<td>8 A common speed limit of 120 kmph on motorways</td>
<td></td>
</tr>
<tr>
<td>9 A requirement that manufacturers modify their vehicles to restrict their maximum speed</td>
<td></td>
</tr>
</tbody>
</table>

8 The context analysis:

The main objectives consist on informations about the background of attitudes to safety in each country: geography, demography, social structure, economy, environment, transport networks and mobility, safety regulations...

General background:

- Geographical context: number of people, density of population, surface...
demographic context: structure of the population, birthrate, expectation of life, type of population: urban/non urban...

economy: economic growth, development, gross national product, structure of the working population, unemployment, industrial product, car industry, wine industry, transport industry...

environment: regulations in the field of transport

transport:

transport policies: public transports, transport networks, number of cars, road system, highway policies...

mobility: number of travels by car, railway, airplane... motorization, mileage...

safety:

fatality rates, safety regulations, countermeasures, communication, advertising, enforcement, insurance system...
Some results from France.

The previous scale contains an item concerning the opinions about the penalty point system. As everyone knows, the implementation of this regulation in France last July was very successful! For more than ten days the French road system was completely blocked by lorry drivers refusing the penalty point system pretending that it will lead them to unemployment. The period was well chosen both by the government and the lorry drivers: in the middle of July with a lot of people going on holidays, trying to avoid the blocking of motorways and highways, loosing their way on local roads, the tired tourists driving around with road maps trying to escape from this soup, big cities like Lyon encircled etc... Finally, the government asked the army and the police to clear the blocking by force and the lorry drivers offered not many resistance.

During and after the event, the government was said to be accountable of the disorder for the reason that the implementation of the penalty point system would not have been very well "prepared". But, who could have been able to forsake the response of the drivers? Was it foreseeable? Six months before the event, the SARTRE French survey was achieved in France. Just one item was about the topic but it brings interesting things about the state of the opinion of drivers face to the penalty point system.

The following graph gives us an idea about the opinions of drivers in France and in Europe (the European sample). 1008 drivers have been interviewed in France. Only one out of two (50% vs 47%) is in favour of the PPS. The European sample (about 16 000 drivers interviewed) shows that almost 2 drivers out of 3 are in favour...
It appears clearly that the French drivers were less in favour of the PPS than the European mean and half of them were opposed to its implementation.
But what about the lorry drivers? Among the national sample of drivers interviewed we had 141 people with a driving licence for lorries and some have a bus licence. As we can notice the differences between car drivers and lorry drivers are not so deep:
In fact, a large part of the lorry drivers, according these results, were not against the PPS and it is difficult to oppose the population of car drivers and the one of lorry drivers; in both, we have two tendencies almost in equilibrium.

How can we explain these apparently paradoxal data? We know, because they told us for weeks at the TV, that lorry drivers are against the PPS mainly because they are afraid to lose their licence, which means, in their case, that they might also lose their job or their company (many of them are owner of small company of transport with one or two lorries only). This statement means also that they do not always obey the legal rules when they drive.

More generally, shall we consider that those who are against the PPS are those who commit more offences? It is of course difficult to answer this question without precise BAC data but we may have some hypotheses considering the next graph:

If we believe in our data we have then to consider that those drivers who exceed the speed limit are not so different of those who do not, considering the PPS. Would it be no link between illegal driving behaviours and the attitude to PPS?
Do looking at other data lead us to confirm this trend?

In this case it seems that to wear the seat-belt is not clearly opposed to not to wear with regard to PPS. The trend shows that the wearing is more frequent for those who support the PPS, when it concerns the driving in town; on main roads the trend is inverse: among those who never wear the belt on these roads, the part of the supporter of the PPS is higher than the part of the opponents! And, among those who say that they wear it always, the part of the opponents is quite important.

Drive after drinking a small amount of alcohol/conduit après avoir bu une petite quantité d'alcool.
Let us look at this figure. We asked the opinion to PPS according the drinking and driving. In this case, drinking consists in 'drinking just a little bit before driving' and we measure the frequency of this behaviour per day in a week; so, we have drivers who drink a little bit almost every day (79), those who drink once a week (289) and those who do not drink at all (223). (By the way, let us notice that in this sample, the drinking and driving people are more numerous than those who do not drink). Half of the 'drink-driving every day' are in favour of the PPS, the other half are against; it is almost the same trend among those who drink and drive once a week. (the 'same trend' means that we have not an obvious, noticeable opposition to PPS according the drinking habits.) It is those who never drink who are the most in favour of the PPS.

The most credible conclusion may be that there is not a clear relationship (perhaps not a relationship at all) between the related behaviours concerning speed limit, seat-belt, drinking and driving with regard to the opinion to PPS. Maybe some other data would show the link between a general attitude to safety and the opinion to PPS, but not those of the SARTRE survey.

If it is difficult for us to define the opinion to PPS according to the attitude to safety, this to say: to show that a positive opinion to PPS goes with a positive attitude to safety and, reciprocally, that a negative opinion to PPS goes with a negative attitude to safety (in fact, this simple pattern does not exists, except in my imagination). We will also see that it is difficult to show that a special group of driver is significantly more in favour to PPS than another.

For instance, we could presume that the women who drive are more in favour to PPS than the men. This presupposition is related to some other data (Barjonet, 1988) showing that women are more careful to drive and more attracted by safety and that they usually commit less offences (especially concerning drinking and driving).

What can we learn from the next figure?
In favour or against the PPS according sex/Pour ou contre le permis à point selon le sexe.

There is not quite a big difference between the sexes: women look just a little bit in favour than the men, but we expected quite a higher difference: in France, almost one woman who drives out of two is against the PPS.

What about age now?

This figure shows that the higher part of the opponents belongs to the youngest drivers (18-24 years old) and the higher part of the supporters to the drivers aged 55 and more. This result seems to be more in concordance with what we could expect as long as we know that obedience to safety rules increases with aging. Nevertheless, the majority of the drivers, between 25 to 54 is cut
in two parts with regard to PPS. and, as for sex, we may say that there is no majority in favour, and no majority against the PPS.

Another interesting item is the school level:

![Graph showing percentage of in favour and against the penalty point system according to school level.]

The part of the supporter is greater among the drivers having the highest school level and this is confirmed by the occupation scale:

![Graph showing percentage of in favour and against the penalty point system according to occupation.]

In our sample, the executives have the highest level of consensus with the PPS, this is in agreement with the previous figure, then the retired people, what is also in concordance with the data about age. If we agree with the fact that a large part of the housekeepers are women, then we may say that they are more likely to support the PPS than the other women of the sample.
A large part of the farmers and the businessmen are against, we could say a 'majority' among these two groups. Also a majority of the manual workers is against. It has been stated (Barjonet, 1988) that these groups and particularly the businessmen and the 'blue collars' do not support very much safety countermeasures and more generally, do not support the action of public authorities which limit the use of cars.

To resume, there is not a large, significative majority in favour or against the PPS. Some of the studied social groups are more in favour, some other more against but we noticed no strong minority, even among the lorry drivers. So, we will express one optimistic hypothesis : this opinion may be influenced, changed unto the required way; this is to say that we could hope that a relevant information will transform this divided opinion in a majority in favour of the PPS.

To sum up, we have seen the interest of SARTRE which has provided data about a particular field of traffic safety, the PPS, in quite an objective view because the survey was not especially centred on the PPS and this allowed us to avoid a lot of bias which characterises many 'ad hoc' surveys which look too much 'guided', 'prepared'. SARTRE offers us many informations about what is" in the mind" of people and this helps us to understand their reactions to regulations. It also provides us new ideas to communicate with people in a relevant way.

This presentations which concerns some results from France is a first step in the exploitation of SARTRE: the comparison between countries will provide us more interesting and useful results. The comparison will show us that our national behaviours are not necessarily the bests, that they are not so natural, that some other possibilities exist.


I am very grateful to Pierre-Olivier Flavigny for SAS.
Safety of City-Cars - Conflict Between Ecology, Economy, Road Traffic Benefits and Safety

Hermann Appel
Prof Dr-Ing
Berlin University of Technology
Institute of Automotive Engineering

Gerald Krabbel
Dipl-Ing
Berlin University of Technology
Institute of Automotive Engineering

and

Thomas Meissner
Dipl-Ing
Berlin University of Technology
Institute of Automotive Engineering
Germany
Future impacts for road traffic and for road vehicles will result from "natural boundary conditions" like energy shortage or the limited capacity of the atmosphere to absorb gaseous emissions as well as from "anthropogenic boundary conditions" like the increasing number of cars, the traffic congestion or the road accidents. Different strategies are under discussion to overcome these problems without giving up mobility by more stringent standards, by new organizational concepts of an integrated traffic system, by introducing new technologies of the infrastructure, of the vehicles, of the links between different vehicles or of telematics.

One contribution within numerous others could be the wider introduction of subcompact cars or "Only-City-Cars". The design features of these cars are

- limited transportation capacity (1, 2 or 3 seats)
- low curbweight (400-600 kg)
- short dimensions (length less than 3,200 mm)
- low fuel consumption (3 - 4 l/100 km)
- ULEV or ZEV emission standards
- modest acceleration and modest maximum speed

Beside the obvious advantages in ecology, economy and traffic space requisition there are possibly additional safety advantages on behalf of lower accident frequency (lower acceleration), lower accident severity (lower velocity), and lower aggressiveness (lower masses), that means higher "partner-protection".
On the other hand these small and lightweight cars are more vulnerable especially in car-to-car crashes because of larger deformations/intrusions and higher speed variations/accelerations. Beside the lower level of "self-protection" there could arise disadvantages from the higher number of these cars overcompensating the space saving of the single subcompact car.

In the paper the raised questions will be stressed. The central questions are whether city-cars give their users a tolerable safety level, whether they can contribute to an increase of the overall safety or not and which safety standards for them should be required.
1. Introduction

Future impacts on the improvement of road traffic and vehicles will result primarily from limited emissions, limited energy resources and from traffic congestions. Different strategies and measures are up for discussion to overcome these problems without giving up mobility. One contribution among numerous others could be the wide introduction of "Mini-Compact-Cars" as "Only-City-Cars". But these very small and lightweighting cars might rated not only positively with regard to both, fuel consumption, emissions and efficiency in road traffic as well as crashworthiness and the considerable number of cars.

This paper deals with the polylemma of different aspects coming up as a result of the wide introduction of city-cars. The situation will be analysed and solutions will be indicated.

2. Boundary Conditions for Future Road Traffic

The future automobile is part of the future around the automobile and therefore not only depending on but also determining the "anthropogeneous" boundary conditions, see Fig. 1. On account of being linked with more or less all human activities nowadays the automobile cannot be seen isolated [3].

Of different quality are the "natural" boundary conditions which are given by limited resources and by limited absorbent capacities of the earth resp. of the nature, see Fig. 1.

<table>
<thead>
<tr>
<th>anthropogeneous</th>
<th>natural</th>
</tr>
</thead>
<tbody>
<tr>
<td>social conditions</td>
<td>resources in energy</td>
</tr>
<tr>
<td>economical development</td>
<td>resources in materials</td>
</tr>
<tr>
<td>life-style</td>
<td>resources in landscape</td>
</tr>
<tr>
<td>policy</td>
<td>capacity of the earth for</td>
</tr>
<tr>
<td>traffic policy</td>
<td>absorption of pollutants,</td>
</tr>
<tr>
<td>environmental strategies</td>
<td>particulates, waste</td>
</tr>
<tr>
<td>infrastructural conditions</td>
<td>noxious effects of emissions</td>
</tr>
<tr>
<td>peripheral technologies</td>
<td>on human beings</td>
</tr>
</tbody>
</table>

Fig. 1: Boundary Conditions, Future of the Automobile.


There are some fundamental strategies and policies to be expected for the near future, see Fig. 2. Accordingly changes of traffic concepts can be derived. Changing traffic concepts result in changing car concepts, see Fig. 3 [3].
Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety
Appel, Hermann
Prof. Dr.-Ing.
Berlin Technical University

- introduction of the "principle of causation",
- charging of the "external costs"
- limitation of emissions (CO₂)
- market-oriented incentives in combination with but superior to legislative limits
- emission-oriented taxation
- demand-oriented prices for riding and parking
- organisational concepts for transport chains
- optimisation of links between different transportation means

Fig. 2: Strategies for the Road-Traffic in the Future.

<table>
<thead>
<tr>
<th>Changing Traffic Concepts</th>
<th>Changing Car Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>diminution of traffic</td>
<td>special vehicles like city-cars or city-trucks</td>
</tr>
<tr>
<td>strengthening of mass transp.</td>
<td>network-cars and trucks</td>
</tr>
<tr>
<td>restrictions for private transp.</td>
<td>eco-cars: light, compact, fuel-efficient, ultra low emissions</td>
</tr>
<tr>
<td>acceleration of public transp.</td>
<td>combination-cars between private and public transp.</td>
</tr>
<tr>
<td>changing of the modus operandi</td>
<td>telematic-vehicles regarding information, guidance, control</td>
</tr>
<tr>
<td>linking of different transp. means</td>
<td>telematics, traffic inform./guidance/assist.</td>
</tr>
</tbody>
</table>

Fig. 3: Traffic Concepts and Car Concepts.

Specific measures of traffic policy to be expected in the future are given as examples in Fig. 4.

<table>
<thead>
<tr>
<th>measures</th>
<th>vehicle</th>
<th>user</th>
<th>roads</th>
<th>traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>legislation</td>
<td>emissions</td>
<td>fuel consum</td>
<td>driving style</td>
<td>restrictions</td>
</tr>
<tr>
<td>incentives pricing</td>
<td>size pricing taxes</td>
<td>taxes</td>
<td>road pricing</td>
<td>parking spaces</td>
</tr>
<tr>
<td>organization</td>
<td>test fleets</td>
<td>car pooling</td>
<td>links</td>
<td>HOV-lanes</td>
</tr>
<tr>
<td>infrastructure</td>
<td>technologies of commun. and inform.</td>
<td>F&amp;R-relations</td>
<td>electric-vehicles</td>
<td>physical links</td>
</tr>
</tbody>
</table>

Fig. 4: Traffic Policy, Measures to be Expected.

VTI RAPPORT 380A
4. City-Cars, Design Features and Specifications

City-Cars have to be especially designed for operations in urban areas, otherwise they are not city-cars but universal cars. Universal cars suitable for cities too shall be called "too-city-cars". City-Cars which can or should operate only in cities are called "only-city-cars". This new type of car is shown in comparison with the two different, well-known types in Fig. 5 [1], [4], [11]. Another type of vehicle serving for passenger transportation in urban areas is the "people-mover". This type of car shall not be emphasized here.

![Fig. 5: Side Elevation of three Types of Cars.](image)

If we take the maximum speed, the transportation capacity, the cruise range, the mass, the length and the torque density as leading design parameter, we will get the description of city-cars as shown in Fig. 6 to 8.

![Fig. 6: Concepts of Cars.](image)
Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety
Appel, Hermann
Prof. Dr.-Ing.
Berlin Technical University

![Fig. 7: Concepts of Cars.](image)

![Fig. 8: City-Cars, Design Features and Specifications.](image)

<table>
<thead>
<tr>
<th></th>
<th>no. of occupants</th>
<th>mass kg</th>
<th>length m</th>
<th>max. speed km/h</th>
<th>torque density Nm/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Only-CityCars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>2</td>
<td>2</td>
<td>600</td>
<td>280</td>
<td>100</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
<td>2</td>
<td>600</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>Too-CityCars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>1-2</td>
<td>1-2</td>
<td>800</td>
<td>3200</td>
<td>100</td>
</tr>
<tr>
<td>B2</td>
<td>2+2</td>
<td>2+2</td>
<td>700</td>
<td>3400</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>People-Mover</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>5</td>
<td>5</td>
<td>130</td>
<td></td>
<td>medium</td>
</tr>
<tr>
<td>C2</td>
<td>5</td>
<td>5</td>
<td>150</td>
<td></td>
<td>medium</td>
</tr>
</tbody>
</table>
5. Examples of City-Cars

As examples of city-cars could serve the modern prototypes VW Chico and BMW E 1 as "too-city-cars" and the concept study ERI-CAR II as "only-city-car", see Fig. 9 to 11 [3].

**Fig. 9: Prototype VW Chico.**

Main Parameter:
- Length/Wide/Height: 3150/1600/1480 mm
- Curb Weight: 785 kg
- 2 Cyl.-Petrol Engine: 636 cm³, 25 kW
- Electric Motor: 6 kW
- NiCd-Battery: 2,1 kWh
- Consumption (ECE City): 1,4 l + 13,0 kWh/100 km

**Fig. 10: Prototype BMW E 1.**

Main Parameter:
- Length/Wide/Height: 3460/1648/1500 mm
- Curb Weight: 900 kg
- Electric Motor: 32 kW, 150 Nm
- NaS-Battery: 19 kWh, 200 kg
- Max. Speed: 120 km/h
- Range: 150 to 200 km
6. Size and Weight as Influencing Factors

In the past the curb weight of cars has increased, as can be seen in Fig. 12 for different well known car models.

The cumulation frequency of the 80 most registered cars in Germany (78% of all registered cars in 1991) shows that the average curb weight is 1080 kg, the 10% value is 790 kg, see Fig. 13. That means that the before defined class of "only-city-cars" is not on the road today [12].
6.1 Size/Weight and Traffic Properties

Small cars have size advantages under operation condition, not so much with reference to flowing traffic but in parking situations. Fig. 14 indicates the correlation between car length and curb weight. A car with a length of 3 m could adjust to a weight of 550 kg [12].

Fig. 14: Length versus Curb Weight (78% of the most registered car models in Germany).
6.2 Size/Weight and Economy

The purchase price of smaller cars is lower and their operation respectively their maintaining easier than of large ones, see Fig. 16 and 17. The operation costs (DM per kilometer) are calculated for 15000 km/a including the loss resale value [12].
Fig. 17: Operating Costs versus Curb Weight (78% of the most registered car models in Germany).

Prices and costs will continually decrease until extreme small and lightweighted cars are considered. It must be started that the view of customers is different from the view of car manufacturers who are interested in a high value product. On the other hand it can be expected that "only-city-cars" will be high-tech cars which will penetrate the market more likely "top down" than "bottom up".

6.3 Size/Weight and Ecology

Within the last years the fuel consumption of new cars has been lowered on the average from 10 to 8 l/100km in the 1/3-Mix, see Fig. 18 [10].

Fig. 18: Fuel Consumption of Passenger Cars Versus Time.

To fulfill the requirement of the German Government for a CO₂-reduction of 25% until the year 2005 a further decrease below the 6 l/100km-level for new cars is necessary. That is to say, a combination of measures in regard to the engine, the power train, the body and the chassis is
required, either to improve the efficiency or to lower the resistances, e.g. by reducing the weight of the car [10]. If we observe the situation of sold cars nowadays, we see that the fuel consumption correlates stringently with the curb weight:

+ 0.6 l/100km for + 100 kg (Otto)
+ 0.4 l/100km for + 100 kg (Diesel)

and that a 600 kg car with conventional technologies reveals a fuel consumption of 6 l/100km [10], see Fig. 19. That means that weight reduction is the most important factor in reducing the fuel consumption, followed by applying fuel efficient engines. The "Eco-Polo" for instance has a consumption of 4.3 l/100km at a curb weight of 845 kg [1].

![Graph](image)

**Fig. 19:** Fuel Consumption of New Passenger Cars Versus Weight.

### 6.4 Size/Weight and Safety

#### 6.4.1 Injury Severity in Road Accidents

The US-accident statistics indicate that smaller cars in single vehicle accidents on the one hand are nearly not different from large cars, but that they reveal on the other hand a much higher risk for having serious or fatal injuries in car-to-car collisions, see **Fig. 20 to 22** [7].

![Graph](image)

**Fig. 20:** Fatality Rates Versus Car Weight. Data Base: FARS 1978-1987 USA.
Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety  
Appel, Hermann  
Prof. Dr.-Ing.  
Berlin Technical University

---

**Fig. 21:** Driver Fatality Risk in Two-Car Crashes.

**Fig. 22:** Driver Fatality Risk in Two-Car Crashes.

Similar results were found by the investigation of head-on car-to-car collisions in Germany [5], see Fig. 23 and 24.

**Fig. 23:** Risk for Fatal Injuries in Light Car/Heavy Car Frontal Collisions in Rural Areas.
Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety
Appel, Hermann
Prof. Dr.-Ing.
Berlin Technical University

Fig. 24: Risk for Fatal Injuries in Light Car/Heavy Car Frontal Collisions in Rural Areas.

6.4.2 Dummy Loadings under Different Crash Test Conditions

The results of frontal barrier crash tests from USA (New Car Assessment Program, 35 mph) and Germany (Auto, Motor und Sport, 35 mph, 50-%-Offset) demonstrate the remarkable fact that the Head Injury Criterion (HIC) is independent of the mass and the length of the car, see Fig. 25 to 28 [8], [13]. This is in accordance with the real world situation where the injury level in single vehicle accidents is more or less independent of the mass.

Fig. 25: HIC versus curb weight (NCAP)
Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety
Appel, Hermann
Prof. Dr.-Ing.
Berlin Technical University

Fig. 26: HIC versus curb weight (Auto, Motor und Sport)

Fig. 27: HIC versus length (NCAP)

Fig. 28: HIC versus length (Auto, Motor und Sport)
If we look at the crush length of a 35-mph-frontal barrier crash we find constant values for light and heavy cars, but higher values for large cars than for small cars, see Fig. 29 and 30 [14]. This is not a contradiction to the result of Fig. 14, because the cars with large crush lengths are mainly US models. These cars are not included in Fig. 14.

![Fig. 29: crush versus curb weight](image)

![Fig. 30: crush versus length](image)

Independent of the car weight is the strong correlation between the dummy loadings, in this case HIC, for the driver and the type of occupant restraint system. As the best system reveals in the FMVSS 208 test (only passive restraint systems) and the NCAP-test (all available systems) the airbag, see Fig. 31 [8].
Simplified the test results show that small cars have no problems in single vehicle accidents and that the disadvantages in car-to-car collisions can be diminished by installation of optimized restraint systems.

6.4.3 Primary Safety

Up to now it cannot be proved but can be assumed that cars with lower power and torque density, this means with low acceleration rates, will be involved less often in collisions than highly powered cars. This seems to be the case especially under urban conditions where most of the injuries and fatalities concern unprotected road users like pedestrians, cyclists and motor cyclists.

6.4.4 Secondary Safety

Current test results and accident analyses have shown that in single vehicle accidents the potential for "self-protection" is more or less equal for small and large cars, see Fig. 32. This is due to the fact that the crush is equivalent in both cases although the dimension of the front end of a large car is longer, see Fig. 33 [1].

In car-to-car collisions the difference of masses and stiffness put higher decelerations, higher speed variations and higher intrusions on the small car. But in the same way as small cars in this case behave weakly large cars behave aggressively. This means for small cars the lower "self-protection" is balanced by higher "opponent protection". The overall crashworthiness of small cars is therefore estimated to be only a little bit worse than that of large cars. It is an open question if this can also be transferred to collisions with unprotected road users.
Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety
Appel, Hermann
Prof. Dr.-Ing.
Berlin Technical University

Fig. 32: Overall Secondary Car Safety for Different Weight Classes.

Fig. 33: Package for Cars Different in Size.

It can be derived from simplified equations that cars need for the 50 km/h fixed barrier crash test a crush length at the minimum of 400 mm if the interior free distance is roughly 600 mm, see Fig. 34 and 35. The sum of the "necessary interior and exterior deformation zone" is nowadays roughly 1000 mm. The portion of exterior and interior deformation can only be shifted by "increasing" the compartment, this means e.g. automatic retraction of the steering wheel. The sum can be diminished if either the test speed is lowered or if advanced technologies (see Fig. 35) are applied. For "only-city-cars" the reduced test speed is justified on behalf of the fact that the average collision speed is 10 km/h lower in urban areas compared with rural areas, see Fig. 36.
Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety
Appel, Hermann
Prof. Dr.-Ing.
Berlin Technical University

Fig. 34: Necessary Exterior Deformation Zone for an "Only-City-Car".

Fig. 35: Interior and Exterior Deformation Area for City-Cars.

Fig. 36: Cumulative Frequency of the Collision Speed in Urban and Rural Areas. Data Base: MHH 1973-1988, Germany.
6.4.5 Overall Assessment in the Conflict of Targets

With the wide introduction of small "only-city-cars" conflicts between the different targets become important.
Advantages for ecology, safety, economy and traffic conditions are given by:
- lower fuel consumption
- lower consumption of resources
- lower exhaust emissions
- lower operation costs
- higher primary safety (possibly)
- higher opponent protection
- better performance in road traffic.

On the other hand evident disadvantages are caused in:
- ecology on behalf of more cars on the street
- safety on behalf of lower self-protection
- economy on behalf of lower value added
- traffic condition on behalf of more cars.

In an overall assessment and with regard to more stringent boundary conditions in the future the partial introduction of light "only-city-cars" is estimated to be desirable, see Fig. 37.

![Fig. 37: Polylemma Ecology-Safety-Traffic for Mini-Compact-Cars.](image)

Preconditions for the introduction should be:
- test procedures for the new class of cars are to be set up
- test results have to be published
- customers have to be informed in order to induce them to a defensive driving
- test procedures with regard to compatibility should be set up
- test procedures with regard to electric cars should be elaborated.

In view of so many advantages, the argument of lower self-protection of "only-city-cars" and of light subcompact cars should not be used to eliminate them generally from our roads, if they fulfill a certain safety level.
7 References


VTI RAPPORT 380A
Safety of City-Cars, Conflict between Ecology, Economy, Road Traffic Benefits and Safety
Appel, Hermann
Prof. Dr.-Ing.
Berlin Technical University

The Use of Road Safety Audits in Great Britain

Stephen Proctor
Engineer
TMS Consultancy
U S A
USE OF SAFETY AUDITS IN THE UNITED KINGDOM

1. Accident Causation Factors
   - A brief introduction to the highway contributory factor, and to the philosophy of accident investigation and prevention.

2. Definition of Safety Audit
   - The concept that "Prevention is better than Cure."

3. History of Safety Audit in the UK

4. The Principles of Safety Audit
   - When should schemes be audited? Who should carry out the audits? What information is required to carry out the audit and the costs and benefits of the audit?

5. Case Studies (i)
   - Examples of the Safety Audit process as undertaken by leading UK Highway Authorities and Consultants.

6. Case Studies (ii)
   - Illustrated examples of what can go wrong (from accident scenarios) if Safety Audit is not carried out, an examination of some of the design standards that might need reviewing as a result of the early findings from Safety Audit.

7. The Future
   - How will Safety Audit benefit the consumer in the UK? What are the legal implications, and what is the position on Safety Audit in the rest of the European Community?
THE USE OF ROAD SAFETY AUDITS IN GREAT BRITAIN
by Stephen Proctor, MSc, MIHT, MCIT, FRGS,
Partner, TMS Consultancy

1. INTRODUCTION

This paper sets out the background to the adoption of a formal Road Safety Audit process in Great Britain. The Audit process is described in detail. Reference is made to a series of case studies describing different approaches to Audit, and illustrating some of the road safety issues that Road Safety Audit can identify. The paper concludes by examining some of the ways in which the process can move forward.

2. AN INTRODUCTION TO ACCIDENT CAUSATION AND HIGHWAY CONTRIBUTORY FACTORS.

Road Safety Engineering in Great Britain has seen something of a resurgence in recent years as the Government and Local Authorities have started to take accident reduction more seriously from a political point of view. The 1974 & 1988 Road Traffic Acts place a mandatory responsibility on highway authorities 'to carry out studies into road accidents', and 'to take such measures as are appropriate' to reduce accidents. A number of recent initiatives provide greater incentives in this area:

1987- The Department of Transport publish "Road Safety: The Next Steps" (reference 1), and set Casualty Reduction Targets of 33% by 2000 AD.
1989- The Local Authorities Associations publish a Road Safety Code of Good Practice (reference 2), with many recommendations.
1990- Local Authorities start to publish Road Safety plans, setting out casualty reduction objectives at a local level.
1990- The government announces that local safety schemes will now be eligible for Transport Supplementary Grant (TSG) for the first time.
1991- Road Safety Audits become compulsory on all trunk road and motorway schemes from April, and 20mph zones are introduced in urban residential areas through Traffic Calming techniques.
1992- TSG is increased to £50 millions for local safety scheme work.

2.1 The role of the safety engineer

Against this background of increased awareness of safety issues, the role of the safety engineer has been given an added impetus. A safety engineer in a large local authority can expect to be involved in a number of areas of work. These include the maintenance of a computerised accident database, and the analysis of accident trends throughout the area covered by the Local Authority. The safety engineer will also carry out Accident Investigation at single sites and along routes, undertake Traffic
Calming in residential areas with high levels of child pedestrian accidents, and participate in Road Safety Audits of new road schemes.

2.2 The philosophy behind Accident Investigation work

The philosophy behind safety engineering work is based on work carried out twenty years ago at the then Transport and Road Research Laboratory (references 3 & 4). The researchers examined the factors involved in thousands of road accidents, and they discovered two important points.

Firstly, accidents are "rare, random, multi-factor" events. In other words they do not occur very often (to individual members of society), they tend to occur at a variety of relatively unpredictable locations, and each accident can be viewed as a sequential chain of events.

Secondly the "multi-factors" that go to make up these chains of events can be classified into three broad categories. These are:

- Vehicle Safety Factors (V) (eg failed brakes)
- Human/Behavioural Factors (B) (eg drink/driving)
- Environmental/Highway Factors (H) (eg adverse camber)

So the multi-factor chains look like this:

\[
\begin{align*}
V_1 + H_1 + B_1 + B_2 &= \text{accident!} \\
V_1 + B_1 &= \text{accident!} \\
B_1 + H_1 &= \text{accident!} \\
B_1 + B_2 + H_1 + H_2 + H_3 + B_3 + V_1 + B_4 + H_4 + V_2 &= \text{accident!}
\end{align*}
\]

Some of the chains are simple, and some are more complex as the above examples imply. In the third example there is just one behavioural factor and one highway factor in the chain leading to the accident. In the fourth example, the chain is far more complex, with two vehicle factors, and four highway and behavioural factors.

The vital point in terms of reducing accidents is to remove one of the factors from the chain of events, to prevent the sequence from going on to it's traumatic conclusion.

The research went on to quantify the contributions that the three factors make to accident causation. They are often working in combination, as the examples above show, so the percentages do not add up to 100.

- Vehicle Factor Contribution: 10% road accidents
- Behavioural Factor Contribution: 95% road accidents
- Highway Factor Contribution: 25% road accidents

Safety engineers are more likely to be interested in the highway factor, as this is where their skills can be best used to reduce accidents.
2.3 Treating problem sites

The first task of the safety engineer is therefore to identify those accidents where a highway contributory factor can be removed. The traditional approach to this type of work has been to concentrate effort at single sites where groups of accidents with a similar pattern cluster at blackspots. The reason for the cluster can often be found to relate to some highway fault that can be treated with a remedial measure.

For example, a severe bend, with an adverse camber, poor road surface, poor street lighting, inadequate signing, and a preponderance of off-street objects; leading to a situation of vehicles leaving the road at night in wet weather, and going on to cause occupant injury in collisions with street furniture.
The solution; Improve skid resistance/camber, improve lighting/warning of hazard, set objects back from kerb edge.

This approach depends on good accident data, and a thorough investigation of that data. The philosophy behind the single-site approach can be extended to area-wide measures such as traffic calming. The approach also serves as a starting point for predicting future potential problems on new schemes, now formalised into the Road Safety Audit process.

Road Safety Audit represents a change in emphasis within the traditional philosophy described above. Whereas blackspot work is based on accident reduction techniques, with Safety Audit the engineer concentrates effort on accident prevention.

3. BACKGROUND TO SAFETY AUDIT IN GREAT BRITAIN

The Department of Transport’s Casualty Reduction Targets have been endorsed by the Local Authorities Associations. While much effort will be concentrated on accident-reducing local safety schemes, it is clear that resources will be required in other areas if the target is to be met. One of these other areas is Road Safety Audit.

The Institution of Highways and Transportation (IHT) has published a set of Guidelines for carrying out Safety Audits (reference 5), and the Department of Transport has published an Advice Note and a Departmental Standard referring to Safety Audit (references 6 & 7). Audits have been compulsory on all trunk and motorway schemes in England and Wales since April 1991.

3.1 Existing design guidelines

Department of Transport guidelines in the form of Departmental Standards, Advice Notes, and Technical Memoranda are available on most elements of highway and traffic management design. In many cases, adherence to these guidelines will result in substantial elements of schemes being designed with minimal safety problems. However, it is often necessary, because of other constraints, to adopt standards close to the recommended minimum for individual design elements. A combination of two or three elements, all close to the minimum, can create safety problems.
Furthermore, many of the existing standards only refer to safety in a general way, whereby it is assumed that merely by strict adherence to the standard, a safe road will be constructed. Detailed accident studies reveal that this is not always the case, and that in specific situations safety problems can be "designed in" despite the road being built to standard.

3.2 Some definitions of Road Safety Audit

A general definition of Safety Audit can be given as follows: 
"A systematic method of checking the safety aspects of new schemes affecting roads"

The Department of Transport define Road Safety Audits as: 
"The evaluation of physical elements and their interaction having a direct bearing on the safety of road users and others affected by a road construction scheme, in order to detect foreseeable potential safety hazards before a new road is open to traffic. It is not concerned with the strategic design of the road scheme." (reference 7)

These definitions assume some fundamental objectives: Firstly, and self evidently, the Safety Audit process seeks to ensure that all highway schemes should operate as safely as possible. Secondly, that "preventable accident-producing elements" should not be present in a completed scheme, for example lamp columns should not be sited at the edge of the carriageway. Thirdly the process should seek to ensure that suitable "accident-reducing elements" are included in a completed scheme, for example specifying the use of "anti-skid" surfacing on the approach to a pelican crossing on a downhill stretch of dual carriageway.

Road Safety Audit is therefore the technical term for a formal procedure of checking proposals affecting the highway network in terms related to their accident potential. The term is generally considered to refer to all new highway and traffic engineering schemes, including modifications to existing layouts, but can apply equally to development proposals.

The Departmental Standard on Road Safety Audit (reference 7) provides for its mandatory inclusion into the design process on trunk roads (roads of strategic national importance) and motorways only. The Departmental Advice Note (reference 6) gives guidance as to how to carry out the Audit. It is up to individual highway authorities to consider its adoption on local roads. This point will be addressed in more detail in section 4 of this paper.

It is essential that this audit is carried out independently from the scheme design, and that it is carried out in a formal manner at clearly defined points in the design process. It is very important that as many safety comments as possible are based on well researched data, rather than "gut feelings". Both of these items are discussed in section 3 of this paper.
3.3 A history of Safety Audit

The formal process of Safety Audit has developed through a number of initiatives over the past 12 years. Some of these have already been referred to in the introduction to this paper. The following developments refer specifically to safety checking, or a more formal audit process:

1980- The IHT Guidelines "Accident Reduction and Prevention" recommend the safety checking of major road improvements.

1988- The Road Traffic Act (Section 39). A local authority must in constructing new roads: "take measures as appear to the authority to be appropriate to reduce the possibility of accidents when the roads come into use".

1989- The Local Authorities Associations "Road Safety Code of Good Practice" recommends carrying out safety audits on schemes affecting the highway network.

1990- HA 42/90 and HD 19/90 "Road Safety Audits" gives advice on how to carry out audits, and makes them mandatory for trunk road and motorway schemes from April 1991.

1990- IHT Guidelines "Safety Audit of Highways" gives detailed advice on carrying out audits with some sample check-lists.

The wording of the 1988 Road Traffic Act has led some observers to suggest that Road Safety Audits are effectively compulsory on local roads, as well as the strategic road network covered by the Standard.

4. THE PRINCIPLES OF THE ROAD SAFETY AUDIT PROCESS

This paper has so far reviewed the background to the introduction of Road Safety Audits in Great Britain. There exists a two-tier system, Audits being compulsory on "strategic" roads, and voluntary on "local" roads. This has led to the development of some differences in the practices adopted within the Safety Audits carried out. This section of the paper describes the Safety Audit process, and tries to draw distinctions, where they exist.

4.1 Organisation of the audit

Regardless of the type of audit being carried out, it must be supported by the senior management of the design organisation. This is so that it can be fitted properly into the overall scheme management (critical path network). Within a local authority set-up Road Safety Audit should be part of an overall safety management strategy (via the Road Safety Plan).

4.2 Personnel to be involved in audits

It is widely accepted that Road Safety Audit work is best carried out as a team task. This is the case with consultants working on the Department's strategic schemes, and in most local authorities, working on both strategic and local schemes. Some authorities do carry out the task with a single person.
It is essential that the audit team is independent of the design team. This is insisted on by the Department of Transport. It is too much to expect someone who has spent months, possibly years, designing a road, with all the constraints imposed by land costs, geology, and services, to then cast an independent and critical eye over their own design in terms of road safety.

The audit could be undertaken by another design team, but it is strongly recommended that it is carried out by specialist safety engineers. In some audits it may be a good idea to co-opt other team members, for example the police, road safety officers, people with disabilities, traffic signal experts.

The audit team will require a variety of skills in order to carry out their task. The most important is safety experience so that “gut feelings” on safety issues are kept to a minimum. The audit team should have knowledge of design standards so that auditors will know what is and is not possible in terms of changing designs.

In the local authority situation, the audit is often a more iterative process as the design progresses, compared to the more formal mandatory process for trunk roads and motorways. The audit team and the design team usually work in the same office, and diplomacy is vital, especially in the early days of implementing safety audit procedures. There is opportunity for teaching and learning while the auditors and the design teams are embarking on a new system.

4.3 Formal Stages in the Audit Process

The Department of Transport insist that schemes...”shall be audited prior to the completion of three specific stages in the preparation of the scheme”” (reference 7). These are:

Stage 1: Completion of preliminary design (Order Publication Report Stage)
Stage 2: Completion of detailed design (Works Commitment Stage)
Stage 3: Completion of construction (prior to opening of the scheme).

In their Guidelines (reference 5), the Institution of Highways and Transportation suggest 4 stages are appropriate. The IHT’s stages 2, 3 & 4 conform to those listed above, but they add in an initial stage 1, which is prior to the Department’s first stage. The IHT stage 1 is...”as an input to feasibility/initial design of schemes...in order to influence route choice, standards, impact on and continuity with existing network, junction provision, etc...”

The Department of Transport considers that this is not necessary for Safety Audit on strategic roads. Their Advice Note (reference 6) states that...”the road safety of all schemes should also be considered at the pre-public consultation stage as part of the strategic or conceptual evaluation of alternatives. This is not a Road Safety Audit within the terms of the Standard and this Advice Note but is an examination of many factors including road safety.”

The implications of this difference in opinion are that local authorities are free to examine Road Safety Audit at the feasibility stage on their own local schemes, but that the Department will not provide a formal opportunity for an audit at this earliest stage.

VTI RAPPORT 380A
on strategic schemes. Clearly aspects that influence route choice and junction type will have important safety implications, and many Departmental Stage 1 schemes could be presented for audit with a number of issues already decided. In some cases the Auditors will inevitably end up in a situation where their suggestions are to mitigate against predicted problems.

It has already been suggested that in the local situation the design and audit teams have opportunities for informal contact outside of the process laid down by the Department of Transport. Where they are acting as agents to the Department they must seek to ensure that the audit team remains independent from the design. This can also be an issue in large consultancies with in-house audit teams. Examples have occurred whereby a second independent audit has been requested, possibly because it was felt that the original audit team had become too involved with the design of the scheme.

4.4 Technical aspects of Road Safety Audit

Having described the procedure for carrying out Road Safety Audits, it is now appropriate to look at the task itself. Before commencing work information should be obtained from the design team (such as plans, a list of standards used and departures made, traffic and pedestrian counts, and accident records where relevant).

4.4.1 Examination of plans

The audit task itself involves a detailed ordered examination of all of the drawings for that stage of the scheme. At detailed design stages this often involves overlaying the details from one plan on to another, as there will be different drawings for road layout, street lighting, safety fences, signs and markings. It is often the inter-action of features that causes problems, for example no one intends that lamp columns should be erected on the wrong side of safety fences!

4.4.2 The use of check-lists

The Department of Transport, the IHT, and many individual local authorities have produced series of Safety Audit Check-lists to assist the auditor in the task. Schemes can be checked for problems against these lists, and this is a useful exercise, particularly for new auditors. However, the checklists are not exhaustive, and should not be used as a substitute for a team member with genuine safety engineering experience.

4.4.3 The use of safety guidelines and "control data"

Safety engineers will find that their experience is invaluable in two ways. First, they should be aware of the safety guidelines relevant for design through their knowledge of published safety research, sometimes known as "control data". This information will help them make predictions about the type of accidents that can be expected in association with various aspects of the design. It will be more difficult to quantify actual numbers, but in some specific cases this may be possible, for example in the case of 4 arm traffic signal junctions (reference 8).
The second way in which the safety engineer will provide an input is from a knowledge of the success (or otherwise) of safety schemes that have been implemented. Figure 1 shows an extract from a monitoring programme for this type of work (reference 9). Once the auditor has predicted the type of accident problem that is likely to be associated with an aspect of the design, he/she should suggest a known remedy to mitigate against that problem.

A flow chart for this part of the process is shown in Figure 2. A proposal exists to construct an urban 3 lane dual carriageway along the line of an existing 4 lane road, through a suburban shopping centre.

At Stage 1 Audit (preliminary design) the auditor should establish that pedestrian accident involvement is likely to increase, that pedestrian accident severity could increase by around 100%, and that vehicle speeds will increase by around 50%. These estimates are generated from a comparison of the safety performance of the existing 4 lane road, with that for urban dual carriageways in similar situations.

Were a formal feasibility stage audit to be carried out, there might be an opportunity to question route choice, or indeed whether to build the road at all. It is not known how much safety engineering experience is input into schemes at the pre-public consultation stage of scheme design.

When presented with the detailed contract drawings at Stage 2, the auditor will have an idea of the likely accident problems, and can now suggest mitigating factors, from previous successful remedies to accident problems. These might include narrower carriageway width at pedestrian crossing points, overhead pedestrian signals, particular types of guard rails, anti-slip surfaces, and red light cameras.

4.4.4 The role of different road users

The auditor must consider the needs of all potential road users when carrying out the audit. Therefore he/she needs to consider pedestrians, especially children; cyclists and motor-cyclists; people with various disabilities; equestrians; bus drivers and passengers; as well as private motorists.

At Stage 3 (pre-opening) Audits it will be possible to walk, cycle and drive the scheme. At earlier stages the auditor must do this conceptually, in 2 dimensions only, from a plan. The auditor should devise potential problem scenarios - "...what if a bus pulls out at night from this lay-by on a left-hand bend at the same time as a motorcyclist emerges from behind this area of planting..." , and so on, in order to detect safety problems for specific groups of road users.

4.4.5 Production of audit reports

Within the local situation it is likely the audit team will discuss their findings with the design team, possibly with an informal report. This will not be the case on a strategic Road Safety Audit for the Department of Transport, where a formal report is required to be produced, and sent to the Department direct.
The report should address safety issues only, and not seek to re-design the scheme, or comment on adherence to Design Standards generally. The report should take the form of a series of stated problems, together with outline recommendations for improvement. The Department of Transport can then either implement the Safety Audit recommendations, or write an Exception Report to any of the items that will not be implemented.

4.4.6 Monitoring

Following the completion of the Safety Audit process at all three stages, and the adoption (or otherwise) of the Audit recommendations, the scheme will be built. It is then important to monitor the accident record of the scheme, and to feedback the results of this exercise to the Design Team and the Audit Team. This monitoring is the responsibility of the Department of Transport on strategic road schemes.

4.5 Costs and Benefits

The cost of an Audit is generally less than £2,000-£3,000 per check depending on the size of the scheme. If the Audit is carried out at all three mandatory stages the Audit would cost in the order of £6,000-£8,000 in total. Safety Audits invariably recommend additional engineering works, and so there is a further cost implication here.

It is difficult to estimate the number of future accidents that would be avoided, but one per year per scheme checked would seem reasonable. The current average accident cost (reference 10) for urban roads is £20,120, and £44,030 for rural roads. Saving just one accident per scheme will therefore yield a very high first year rate of return. It will also be more cost effective to make changes at the design stage, than to wait until accident problems emerge.

5. EXAMPLES OF THE ROAD SAFETY AUDIT PROCESS IN GREAT BRITAIN

This paper has so far concentrated on the background to Road Safety Audit and the Safety Audit process in general terms. This section of the paper briefly describes different ways in which some audit practitioners are tackling the problem.

5.1 Birmingham City Council

Birmingham is the largest Metropolitan Authority in Great Britain. Around 4,000 injury accidents are reported each year in the city. Birmingham does not have an agency arrangement for the few sections of trunk road and motorway that run through this exclusively urban environment, and so the Safety Audits that are carried out are done so voluntarily, as part of the city’s commitment to casualty reduction. Over the past few years there has been a considerable road building programme in the city, with the development of a new International Convention Centre, and the dualling of the Middle Ring Road.
Birmingham have appointed two full-time Safety Audit Engineers to carry out Audit work. Both officers have previous experience as Safety Engineers, and Audits are carried out independent from the Design Team. The Safety Audit Engineers work as part of the Accident Investigation Team. Their approach is based on the IHT Safety Audit Guidelines. In the first year they carried out around 70 Safety Audits on mainly traffic management schemes, with input to major design schemes too. Procedures are currently being developed, but it is the intention to extend Safety Audit to cover street lighting and maintenance work.

5.2 Kent County Council

The formal Road Safety Audit process is widely reputed to have originated at Kent during the 1980's. Kent is one of the largest County Councils, with an annual total of over 6,000 accidents. The county has the largest number of non-British drivers on its roads, many of which are rural in nature. The County has an agency arrangement for the strategic trunk road and motorway, which includes part of the M25, and the M20 and M2.

Safety Audits in Kent are carried out by Safety Engineers working within the County’s Accident Investigation Unit. These officers are not devoted exclusively to Safety Audit work, but use the experience they have developed from other Safety Engineering activities in the 25% of their time that they spend on Audits. Kent undertake Audits on both strategic and local roads.

The County have developed their own internal procedures for Audits carried out on local roads (reference 11). These procedures include a pro-forma to be completed by the Design Team. This procedure shows the extent to which interaction between the Audit and Design Teams has been of benefit in Kent. The Designers are already "thinking safety" before the scheme reaches the Auditor. Unless the Safety Audit Team accept a design as safe, it does not generally move to Tender Stage in Kent. This ultimate safety authority is unusual, but indicates the level to which the practice has been developed in this County.

5.3 Oxfordshire County Council

Oxfordshire is a medium-sized County Council, with an annual total of around 2,500 accidents. Many of the roads are rural in nature. The county has an agency arrangement for the strategic trunk road and motorway, which includes part of the M40.

The County Council has recently produced its own Guidelines for Road Safety Audit procedures (reference 12), which are a combination of the Department of Transport and IHT Guidelines. Audits are carried out within highway design, development control, traffic engineering & road safety, and maintenance schemes.

A commitment to carrying out audit in all the above areas has led Oxfordshire to adopt a process of independent audit within the main design group. There are two highway design groups, they each audit each other's schemes. Development control schemes are checked at feasibility stage within that group. Traffic and safety schemes
are checked by the road safety group, who also have an overall monitoring and co-
ordinating role, and are able to offer advice on specific safety issues. Both Kent and Oxfordshire appear to carry out audits at feasibility stage, prior to the Department of Transport Stage 1.

5.4 Scottish Office

In Scotland, Road Safety Audits have been mandatory on the strategic road network since October 1989 (reference 13). Since then, over 100 audits of major schemes have been carried out by the Roads Directorate of the Scottish Office.

Safety Audits are managed by the Directorate's Project Manager, who must decide whether or not to implement the Audit recommendations. The audit work is carried out by the Scottish Office's Accident Investigation Unit, in conjunction with local authority staff. Considerable emphasis is placed on Stage 3 (pre-opening) Audits, in which the police are involved.

5.5 Consultant's audits

Much of the design work for new trunk and motorway schemes is carried out by consultants, and this work must be audited solely in accordance with the Department of Transport procedures set out in the Standard and Advice Note.

Many design consultants do not have the necessary safety expertise in-house, although some do employ safety engineers to carry out audit work. Smaller independent safety consultants sometimes work with larger organisations to carry out Safety Audits, where the audit team will be a combination of safety and highway engineers.

6. SAFETY AUDIT CASE STUDIES

This section of the paper illustrates some of the points that arise during typical Safety Audit work. It is not the intention here to categorise the potential problems either in terms of severity, or likely frequency of occurrence.

6.1 Examples from accident remedial work

This paper has already emphasised the need for Safety Auditors to have experience of successful accident remedial treatments so that these can be adopted within new designs. There are many well established remedies that can be specified at early stages of the design. For example the "staggered" cross-roads junction, which has a safer accident record than conventional cross-roads.

Treatments to mitigate high speed loss of control collisions now include the use of "crash cushions", placed in front of narrow rigid objects in median strip areas where vehicles are merging. The energy absorbing crash cushion provides the occupants of an impacting vehicle with a "long, slow crash". Crash cushions have only recently been introduced to British roads, and the Department of Transport has yet to provide a
product specification for these treatments. Early experiences of their use in Great Britain suggest that they are an effective casualty reduction measure (reference 15).

6.2 Example from Stage 2 Safety Audit

Figures 3 & 4 show some detail from a Stage 2 Road Safety Audit. This is a large grade separated junction, with access via the flyover section to a motorway. The comments below are taken from the Stage 2 Safety Audit report, and illustrate how safety experience in predicting likely accident problems has been used to suggest measures to mitigate against those problems:

**Figure 3**
There is concern that a vehicle losing control on the southbound carriageway would cross the maintenance pull-in (A) and would be likely to strike either a bridge pier (B) or the end of the 750mm high wall (C). A possible solution would be to remove the pull-in and extend the wall parallel to the edge of carriageway. The pull-in could be sited on the off-side of the northbound carriageway. This problem is accentuated by the location of the bus lay-by (D). A bus pulling out of the lay-by into the path of a southbound vehicle could cause the driver of the vehicle to swerve and lose control.

The bus lay-by on the south bound carriageway (D) could lead to pedestrians crossing the road at grade, at a point where drivers may not be expecting pedestrians. Consideration should be given to re-siting the bus stop further north (E), although it is acknowledged that it may not be possible to provide a lay-by. If the bus stop can not be moved, a marked footpath should be provided from the bus stop (F), through the landscaped areas to the footbridge (G).

**Figure 4**
All lamp columns and signs should be placed behind safety fences where provided, in order to avoid vehicles being directed towards columns in the event of loss of control.

Lamp columns on ends of splitter islands at the roundabouts are vulnerable in loss of control accidents and should be sited 3m back from the circulating carriageway.

Chevron signs on the central islands of the roundabouts should be erected on breakable posts so that damage to vehicles leaving the carriageway is minimised.

The flag type direction signs on all roundabout exits should be positioned carefully on site, both horizontally and vertically, to ensure that sight lines are not impeded.

In order to improve the advance warning of the roundabouts, Roundabout Ahead signs with Reduce Speed Now plates should be sited all the new road approaches.

A plain bollard should be introduced on the splitter island of the southbound slip (H).

The lamp column, sign and parapet at the start of the northbound slip are vulnerable to loss of control accidents (I). These features should be protected by a crash cushion.
7. SOME CONCLUDING REMARKS

This paper has introduced the concepts behind the Road Safety Audit process, and given detailed examples of procedures adopted throughout Great Britain.

Safety Audits provide a systematic means for checking the road safety aspects of new schemes effecting roads. Independent Audits are compulsory on strategic trunk road and motorway schemes, and must be carried out at three stages of the design process in accordance with Departmental Standards. Local Highway Authorities have more flexibility in their approach to drawing up Safety Audit procedures on local roads.

The final section of the paper raises some issues for the future and broadens the discussion into an international context.

7.1 Development of Standards

The Safety Audit process for the strategic road network is currently being evaluated by the EPP Division of the Department of Transport. They estimate that between 150 - 200 Safety Audits have been carried out under their Standard since April 1991. Many times this number will have been undertaken on local roads, by individual highway authorities.

In some cases the Department’s Project Managers will have written Exception Reports to part of the Safety Audit recommendations. This may be due in part to a lack of safety experience in some of the audit teams leading to a “Technical Engineering Audit”, rather than a Road Safety Audit. There is clearly a need to increase the amount of trained safety engineers available to carry out this type of work.

The IHT are currently examining all Road Safety training offered in Great Britain, with a view to developing a more co-ordinated approach. Whilst this may help to improve the quality and consistency of training offered, there is also a need to increase resources to fund training, and to raise the general status of safety engineering.

Both the Department of Transport and the IHT are reviewing and may amend their audit guidelines in the light of current developments. Furthermore, in the medium term the Department see Safety Audit as a means of flagging issues for future changes to their general Standards and Advice Notes.

One of the main areas of concern could be safety fencing. The “ramped end” treatment to safety fencing, standard on most British designs, was outlawed in the USA in June 1990. The ramped end launches vehicles, sometimes into collisions with rigid objects placed behind the barrier. It is estimated that there are 40,000 of these treatments on British highways. Crash cushions are just one potential alternative to the ramped end, but progress towards a British product specification for these devices seems to be held up in CEN committees on European harmonisation of standards. Meanwhile the status of crash cushions on British roads is ambiguous, the Department
of Transport’s Regional offices understandably reluctant to authorise their use on strategic roads, without an agreed specification.

Recent research into single vehicle accidents (reference 14) suggests that collisions with boundary fencing (often post and rail type) alongside strategic dual carriageways and motorways may result in around fatalities per year on British roads. This is nearly one per cent of all road deaths. The author is not aware of any standard that specifically covers this type of fencing, as it is implicitly assumed that it will not cause safety problems.

7.2 The need for more safety guidelines

One of the problems that the auditor encounters is the difficulty in using safety guidelines and control data to predict future accident problems. Although one can make general statements about the type of accidents that may occur, predicting numbers and ranking severity of potential problems is not possible, given the relatively small amount of information currently available. This inevitably leads to a number of comments being made based on “engineering experience” or “gut feeling”.

Various initiatives have attempted to collect data, but not specifically for this purpose. There is a need to carry out research on a Safety Audit database to provide auditors with this type of information. In the USA the Federal Highways Administration produces an annual report on Highway Safety Improvements (reference 16). This type of database could be a starting point for Safety Audit control data.

7.3 Consumer benefits and legal implications

The general public are increasingly viewed as paying customers by Public Sector bodies in Great Britain. Safety Audit is provided by some local authorities as a part of their overall quality assurance procedures. The implementation of Road Safety Audits should show considerable economic benefits to the community.

It is too early to state the legal aspects of Safety Audit with any certainty. Issues of interest include the question of who might be liable if a scheme is audited, and subsequently accidents happen. More intriguingly, one can imagine a scenario where an Audit reveals a potential problem and suggests a means of mitigation, only for an Exception Report to be written. Subsequently a serious accident occurs of the type predicted. The claim that the 1988 Road Traffic Act actually enforces highway authorities to carry out audits on local roads has yet to be tested in court.

7.4 Road Safety Audit - A European perspective.


In terms of road deaths per million inhabitants, Great Britain is one of the safest countries in the EEC. The Girondeau Report sets a general objective of a 20-30%
reduction in fatal and serious injuries by the year 2000. Individual countries have set
their own targets. In order to achieve their target reduction of one third, the British
Authorities have introduced a number of new initiatives, including Road Safety Audit.

As far as the author is aware, Road Safety Audits are currently practised only in Great
Britain amongst the countries in the EEC, although discussions are taking place be-
tween auditors and safety engineers in France. It is suggested that the process is studied
detail by the authorities of the other nations, with a view to formal adoption across
the Community.

REFERENCES

1. The Department of Transport: "Road Safety: The Next Steps"; An inter-depart-
2. Local Authority Associations: "Road Safety Code of Good Practice"; Association
of County Councils; London, 1989.
3. Sabey B.E., and Staughton G.C.: "Inter-acting Roles of Road Environment, Vehi-
cles and Road Users in Accidents"; 5th Annual Conference of International Associa-
tion for Accident and traffic Medicine, London, 1975.
567, Crowthorne, 1980.
5. The Institution for Highways and Transportation: "Guidelines for the Safety Audit
6. The Department of Transport: "Road Safety Audits"; Advice Note HA 42/90,
7. The Department of Transport: "Road Safety Audits"; Departmental Standard HD
10. The Department of Transport "Road Accident Costs" Highways Economic Note 1
13. Barton J.G.: "Road Safety Audit"; Scottish Office Roads Directorate, Edinburgh,
14. Rattenbury S.J.: "Accident Patterns in Rural Areas and Scope for Counter-meas-
ures: Vehicles and Highways"; PTRC Seminar Crash Protection and Roadside
15. Proctor S, and Belcher M.: "The Development of Roadside Crash Cushions in the
ment Programs".
### Extract from the Monitoring System

<table>
<thead>
<tr>
<th>Scheme/Site</th>
<th>Project Ref</th>
<th>Proposed Eng</th>
<th>Proposed Works</th>
<th>Final Eng</th>
<th>Final Works</th>
<th>Main Acc</th>
<th>Main Acc Types</th>
<th>Treated Acc</th>
<th>Treated Acc Period</th>
<th>Treated Acc Cost</th>
<th>Total Cost</th>
<th>Cost Reduction</th>
<th>Rate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1**
Proposal: The construction of a 3 lane dual carriageway.
A Methodology for the Determination and Evaluation of Safety Improvement Alternatives for Roadside Hazards

Abdelkrim Ramache
PhD
University of Batna
Algeria
A Methodology for the Determination and Evaluation of Safety Improvement Alternatives for Roadside Hazards.

A. Ramache
PhD
University of Batna (Algeria)

ABSTRACT

The serious problem associated with the placement of potential roadside hazards (such as lighting columns, signposts, traffic signs etc.) close to the edge of roads has been recognised for many decades. The usefulness and justification of the presence of these objects, installed for a variety of purposes (such as illumination, signing, indispensable structures, aesthetic considerations are well established. However, their location and their structure have not always been selected carefully from the point of view of safety. Collisions of vehicles with fixed roadside objects involve not only the responsibility of drivers but also that of the highway or traffic engineer whose responsibility can no longer be confined to the road only and must include the careful and detailed design of the roadside as well.

Highway administrators, faced with the difficult task of reducing roadside hazards must therefore make decisions on the nature and the desired roadside designs subject to constraints that affect those decisions. The major one is generally limited funds, so they must strive for a strategy that allows the greatest benefits for available funds.

This paper examines first, the relationship between the frequency of single vehicle roadside accidents and the lateral placement of the most common roadside hazards and shows how this relationship could be used as a basis for the development of a roadside safety improvement programme. The roadside hazard concept and system safety technology are then combined in a unified methodology to the quantitative evaluation of roadside safety. All relevant roadside safety knowledge has been encapsulated in a computer system called ROSDIS ROadside Safety Design and Improvement System. This system enables the user to experiment with different configurations of fixed roadside objects and select the configuration which minimises the probability of collision using fault tree analysis. The structure of the fault tree allows the incorporation of other factors such as the severity associated with each roadside hazard. Costs for different alternatives can also be included to determine the most economical one. It is intended to extend the system in the future using severity and cost. Safety assessment will thus be based on risk (i.e. possible loss in terms of hazard probability and hazard severity) and safety investments.

The work reported here is a part of a research undertaken by the author while on a study leave at the University of Newcastle upon Tyne (United Kingdom).
A Methodology for the Determination and Evaluation of Safety Improvement Alternatives for Roadside Hazards.
A. Ramache
PhD
University of Batna (Algeria)

1 Introduction

The serious accident problem associated with the placement of potential roadside hazards (such as lighting columns, sign posts, traffic signs etc.) close to the edge of roads has been recognised for many decades. Since encroachments on the roadside cannot be prevented, one possible solution to the single vehicle roadside accident problem is the configuration of fixed roadside objects such that the frequency and severity of this type of accident will be reduced.

Recently, increasing emphasis has been given to system safety approach to design which is a new way of thinking for problem solving. System safety is entirely rational rather than intuitive and uses formalised techniques such as accident cause-consequence analysis and fault tree analysis. Knowledge-based technology provides also a new approach to problem solving that may be very helpful in roadside safety and has been already suggested (1). Roadside safety, system safety and knowledge-based technology have thus been combined in a single methodology to quantitative evaluation of roadside safety. A knowledge-based system called ROSDIS (Roadside Safety Design and Improvement System) intended to assist highway and traffic engineers in making decisions on the location of roadside furniture to achieve an acceptable level of safety has been developed.

Accident records do not provide all necessary information on the engineering aspect of single vehicle roadside accidents. This lack of information led to the design and implementation of a field procedure to collect the missing data.

2 Data Collection

The main objective of the field procedure was to identify objects that have been involved in collisions and measure their lateral distances from the edge of the pavement. Prior to data collection, accidents were organised by area in order to make the maximum number of measurements during a day. Maps of the Tyne and Wear area were used to identify their locations. Despite this organisation by area, locations of accidents were found to be quite far from each other, increasing the number of trips to accident sites.

Because of the difficulties involved in data collection, field investigations were limited to 195 sites. The investigations identified those fixed objects that have been involved in reported accidents during a year in the Tyne and Wear area (U.K.). The identity of fixed roadside objects is described in the accident records by one of
10 object codes as follows:

01 Road sign or traffic signal
02 Lamppost
03 Telegraph or electricity pole
04 Tree
05 Bus stop or bus shelter
06 Central crash barrier
07 Nearside or offside crash barrier
08 Submerged in water (completely)
09 Entered ditch
10 Other permanent objects (which include walls, fences, buildings and other fixed roadside objects.)

The following procedure was adopted:

1. Accident records were used to identify where the accidents happened and what types of objects were involved in collisions. Most of the information was extracted from the descriptive part of the accident records.

2. Maps of Tyne and Wear area were used to locate accidents.

3. Site visits were later made to identify objects that have been involved in collisions and match them with accident records.

4. A 30 metres cloth tape was used for measuring distances from the edge of the pavement to objects. The distances were measured perpendicularly to the edge of the pavement.

2.1 Distribution of Lateral Distances to Objects Hit

The results of the field procedure are summarised by Figure 1 which shows the distribution of collisions with fixed roadside objects as a function of the lateral distance from the edge of the pavement. The points were drawn by sorting the accidents in order of distances away from the edge of the pavement starting from the most remote one (9.83 metres) to the closest one (0.06 metre). The frequencies are expressed as a percentage and were accumulated going toward the edge of the pavement such that 100 per cent is reached at the edge of the pavement.

The curve obtained by joining all the points is quite similar to the ones derived from previous studies (2,3). This curve describes the nature of the roadsides on which these accidents happened. No information regarding the minimum safest distance between the edge of the pavement and fixed roadside objects is suggested. However, there are strong indications that relatively safer roadsides can be developed by providing a recovery area up to at least 3 metres from the edge of the pavement.

Lampposts were the most common objects struck, at 38%; walls accounted for 19%; crash barriers for 12%; fences for 10%; trees for 6%; road or traffic signs for 2
Since lampposts are the objects struck most frequently, the same procedure was employed for them. It was found that 88% of the lampposts that were involved in collisions were within 1.5 metres. A large number of lampposts (60%) were located within one metre and almost 50% were positioned less than one metre from the edge of the pavement. This is due to the old street lighting practices that...
introduced a lighting layout in many parts of the County with lampposts set very close to the edge of the pavement. The data were then segregated for individual objects and the results are summarised in Figure 3.

3 Remedial Measures

The treatment of roadside hazards poses some problems despite the knowledge of where collisions with fixed roadside objects are more common since these accidents have a tendency not to cluster at individual sites and any remedial measure must deal with long lengths of roads. A program such as ROSDIS can be used in this case. This does not mean that spot improvement programmes using hazard analysis to uncover roadside hazards or high accident frequency identification procedures should be discarded. Both approaches are advisable.

In addition to predictive modelling, the following procedure can be applied:

1. As a general rule, fixed roadside objects should be positioned as far as practically possible from the edge of the pavement.
2. The number of fixed roadside objects should be kept to a minimum by eliminating unnecessary objects and use should be made of pole-sharing every time it is possible.
3. Use of more forgiving roadside equipment such as breakaway or slip-base lampposts.
4. Protection of vehicle occupants from fixed roadside objects by using impact attenuating devices such as crash cushions.

Due to the frequency and severity of collisions with lampposts, these roadside elements pose a special problem. The field procedure described in the previous section identified the types of lampposts being used in the Tyne and Wear County. Old style lampposts (whether made of steel or reinforced concrete) had very short reach and were located most of the time very close to the edge of the pavement. This problem can be solved easily. In order to obtain the same amount of illumination, lampposts can be moved further away from the edge of the pavement and their reach can be made longer.

Traffic and direction signs present another problem since they are generally located where they can be easily seen by motorists. Although much research has been done concerning their conspicuity, not much has been done to relate conspicuity to safety. Further research is needed in this area.

3.1 Accident Migration

It has been argued that some remedial safety measures directed towards reducing the frequency or severity of collisions with fixed roadside objects redistribute risk from one class of road user (e.g. vehicle occupants) to another (e.g. pedestrians) (4,5). There is also a belief by some safety professionals that an improvement in safety at a treated site leads to the degradation in safety in its neighbourhood, a phenomenon that has become known as accident migration (6). The authors found that an appreciable number of the accidents prevented at treated black spots in
Figure 3 — Distances to fixed roadside objects accidents
London had apparently *migrated* to surrounding sites.

Although it is right to consider this possibility, it should borne in mind that single vehicle roadside accidents have a tendency to happen when and where there are relatively few or no pedestrians. Point objects such as lampposts cannot be used to protect pedestrians. The intended use of a lamppost is of course to provide proper illumination in the hours of darkness for motorists as well as pedestrians, so using it as as a protective device is definitely a misuse.

No research seems to exist on the extent to which elimination or relocation of fixed roadside objects has transferred risk to pedestrians. However, there are many ways to implement remedial measures without putting these road users at risk.

### 4 Roadside Subdivision

It is recognised that most accidents have an identifiable sequence of events associated with them. During the examination of a roadside, it appears that a single vehicle roadside accident might happen at different lateral distances from the edge of the pavement to the fixed obstacles. For ease of processing and analysis, objects were assigned to three adjacent bands running parallel to the edge of the pavement (the shoulder width being included) to describe the area in which an errant vehicle can possibly hit a fixed object (see Figure 4).

This subdivision is quite useful for the estimation of the probabilities of non-recovery, which will strongly depend on the distance of excursion of out-of-control vehicles into the roadside. The main idea behind the use of bands is to enable the highway or traffic engineer to map out the relative roadside risk at various distances from the edge of pavement.

![Figure 4 — Subdivision of the roadside area](image-url)
5 Conceptual Modelling

Because the accident frequency associated with any roadside hazard is very small, the probabilistic model approach is the best available method to identify hazardous roadside conditions on a large scale. The system was thus based on a roadside hazard model and uses system safety techniques which lend themselves to both qualitative and quantitative analyses. The roadside hazard model and the fault tree encapsulated into the system have been described in detail previously (7).

A fault tree depicting the process behind any single vehicle roadside accident was built and is summarised by the following equation:

\[ P_{\text{vra}} = P_e(P_{nr1}P_1 + P_{nr1}M_1P_{nr2}P_2 + P_{nr1}M_1M_2P_{nr3}P_3) \]

where:

- \( P_e \) = probability of encroachment
- \( P_{nr1}, P_{nr2}, P_{nr3} \) = probabilities of non-recovery in each band
- \( P_1, P_2, P_3 \) = probabilities of an obstacle lying in the path of a vehicle in each band
- \( M_1 = 1 - P_1 \) probability of missing an obstacle in band1
- \( M_2 = 1 - P_2 \) probability of missing an obstacle in band2

An estimate of \( P_e \), the probability of encroachment can be obtained from the following formula (8):

\[ \frac{\text{(encroachments/km/year) \times section length}(L)}{ADT \times 365} \] (1)

6 Determination of the Probabilities of the Basic Events

The most important part of the fault tree lies in the determination of the probabilities of the basic events located at the bottom of the fault tree and how they can be related to available and measurable data. These probabilities are very often difficult to obtain although they are required for computing the probability of the top event.

6.1 Probability that Some Obstacle Lies in the Path of an Encroaching Vehicle

The roadside hazard model has been used to determine the total exposure lengths TEL's (i.e. the segments of roadside lengths in which an encroaching vehicle must not find itself in order to avoid a collision with an obstacle) for rectangular as well as circular objects and their corresponding probabilities as follows:

- \( TEL_{ro} = 2C \csc \theta + d \cot \theta + W \) for a rectangular object and
- \( TEL_{co} = 2(C + R) \csc \theta \) for a circular object.
If a road section of length $L$ is considered, the corresponding probabilities for these two types of objects will be:

$$
P_{ro} = \frac{2C \csc \theta + d \cot \theta + W}{L}$$

$$
P_{co} = \frac{2(C + R) \csc \theta}{L}$$

The ratio of the summation of the total exposure lengths of all obstacles in each band to $L$ will yield an estimate of the probability that a fixed roadside object will lie in the trajectory of an out-of-control vehicle in that particular band, after substracting overlaps. Henceforth only rectangular objects are considered, but the method generalises straightforwardly to admit circular and rectangular objects. The corresponding probability is then:

$$
P_i = \frac{\sum_{i=1}^{N} 2C \csc \theta + d_i \cot \theta + W_i}{L}$$

(2)

if all objects are rectangular. $N$ is the number of objects in band $i$.

The probability that an encroaching vehicle will collide with a fixed roadside object depends on the number, size and location of fixed objects on the roadside; the width of the vehicle and the angle of encroachment. The more objects there are along the roadside, the greater will be the probability of collision. There are situations where fixed objects in the roadside are positioned so close to each other that their respective total exposure length will overlap. To account for this, the length of the overlap between each successive pair of objects must thus be substracted from the summation of equation (2). If objects are numbered from left to right according to increasing $(x - h \cot \theta)$, then the overlap between object $i$ and $i+1$ in band 1 is:

$$
O_{i,i+1} = 0.5(TEL_i + TEL_{i+1}) - (x_{i+1} - x_i) + (h_{i+1} - h_i) \cot \theta
$$

(3)

The total overlap in band 1 ($TO_1$) is expressed by:

$$
TO_1 = \sum_{i=1}^{N_1-1} 0.5(TEL_i + TEL_{i+1}) - (x_{i+1} - x_i) + (h_{i+1} - h_i) \cot \theta
$$

(4)

The equations developed by Horodnicianu (8) omitted the overlap between bands, to take it into account the following formulation was developed:

$$
U_j = \sum_{i=1}^{N_j} \frac{TEL_i}{L} - \sum_{i=1}^{N_j-1} K_i \frac{TO_i}{L}
$$

(5)

where $U_j$ is the probability of a fixed roadside object lying in the path of an encroaching vehicle in band $j$ ($j=1,2,3$) and

$$
K_i = \begin{cases} 
1, & \text{if } TO_i \geq 0; \\
0, & \text{otherwise.}
\end{cases}
$$
The expressions for probabilities presented in this paper relate to a fixed angle of encroachment ($\theta$). In practice a range of angles is encountered. The consequences of this are explored in section (5.4).

$$P_1 = U_1$$
$$P_2 = U_2 - U_1$$
$$P_3 = U_3 - U_2$$

with

$$N_1 = \text{Number of objects in band1}$$
$$N_2 = \text{Number of objects in band2}$$
$$N_3 = \text{Number of objects in band3}$$

6.2 Probabilities of Non-recovery

Every time a vehicle encroaches on the roadside, this vehicle might not recover. This means that if the driver is unable to stop or redirect the vehicle to the carriageway, it will continue to travel through the roadside until it is stopped by a collision with some fixed object. The probabilities of non-recovery $P_{nr1}$, $P_{nr2}$ and $P_{nr3}$ are functions of the characteristics of the roadside under consideration. In the case where data exist on encroachments in which vehicles either recovered or were involved in accidents, they can be computed. However, most of the time data of this nature are not available and the analyst has to rely on previous studies done in this area for their estimation. Many studies have attempted to determine the relationship between the frequency of single vehicle roadside accidents and the lateral distance of objects from the edge of the pavement. The General Motors distribution has been used in this study to compute the probabilities of non-recovery since it represents nearly the ideal conditions (2).

6.3 Quantitative Evaluation of Alternatives

The purpose in quantifying the fault tree is to consider various alternative configurations of fixed roadside objects and their effect on the probability of the top event. To perform the quantification, the following procedure is used:

- Conduct a roadside inventory of all fixed objects located on the roadside section under study and record the following information: road section number, road section length, average daily traffic (ADT), name of object, shape of object, lateral distance of object from the edge of pavement, longitudinal distance of object from road section staring point, width and length of object if the object is rectangular, radius of object if the object is circular. All this information may be recorded in the tabular form shown in table 1. Roadside inventory can also be computerised (9).
- Compute the probabilities $P_1$, $P_2$ and $P_3$ of a fixed roadside object lying in the path of an encroaching vehicle using equations (6), (7) and (8).
- The probabilities of non-recovery of a vehicle at various distances from the edge of the pavement $P_{nr1}$, $P_{nr2}$ and $P_{nr3}$ can be either derived from a database of the road section under analysis if it exists or estimated from Figure 5.
• Compute the probability of encroachment of a vehicle using formula (1). Accident records can be used to determine the frequency of single vehicle roadside accidents (i.e. the number of encroachments per km per year).

<table>
<thead>
<tr>
<th>Road Section No.</th>
<th>Road Section length</th>
<th>Average Daily Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of Objects</td>
<td>Shapes</td>
<td>Location of Objects</td>
</tr>
<tr>
<td></td>
<td>(r) (c)</td>
<td>(L) (S) (T) (W) (D)</td>
</tr>
</tbody>
</table>

Table 1 — Roadside inventory data sheet

![Figure 5 — General Motors Proving Ground hazard curve](image)

The fault tree does not suggest remedial measures. However, the following strategy can be applied (10):
• Remove unnecessary fixed roadside objects completely.
• Move objects that cannot be moved laterally.
• Reduce the severity of collisions by using other forms of roadside objects such as breakaway.
• Protect occupants of vehicles from those objects that cannot otherwise be improved by using attenuating or deflecting devices.

The quantification of the fault tree is performed first to estimate the probability of occurrence of the top event (in this case collision with a fixed roadside object) in terms of the probabilities of the basic events located at the bottom of the fault tree. Once this probability is computed, tests on changes in the roadside section under study applying the above strategy are carried out. This will result in a change of the probability of the top event and in the severity of this type of accident. The amount by which that probability is reduced will provide a measure of the effectiveness of the action taken. The fault tree is then updated and the process reiterated until further significant improvements in the safety level (expressed as the relative probability of collision) are not obtainable.

The use of the equations developed so far presupposes the determination of a specific value for the angle of encroachment (θ). Applying the fault tree analysis to a specific roadside section would require the availability of a value for the angle of vehicle encroachment. Unfortunately, data at such detailed level are most of the time not available. Knowledge about the angles with which vehicles encroach on the roadside is very limited. In fact, the only pure encroachment data are those collected by Hutchinson and Kennedy on freeway medians (11). The distribution of encroachment angles is shown on Figure 6.

![Figure 6 — Distribution of encroachment angle (11)](image)

It includes the combined data from Federal Aid Interstate (F.A.I.) Route 74 and 57. The distribution represents the encroachment angles for all unintentional encroachments that happened during the period of study and having a lateral
movement greater than three feet. The equation approximating their distribution is:

\[ F(\theta) = 10^{-0.044\theta + 2.087} \]

where \( \theta \) = encroachment angle in degrees and \( F(\theta) \) = percentage of \( \theta \)'s greater or equal to a given \( \theta \).

6.4 Calculation of the Expected Collision Probabilities

The idea of the expected values of a random variable is an extremely useful one and is used here to calculate the expected collision probabilities. If \( X \) is a discrete random variable which can take values \( z_1, z_2, ..., z_n \) with probabilities \( p_1, p_2, ..., p_n \) then the average or expected value of \( X \) is given by:

\[ E(X) = \sum_{i=1}^{n} z_i p_i \]

The angle of encroachment \( \theta \) is a random variable.

1. In Figure 6, the range of encroachment angles \( \theta \) is divided into \( N = 9 \) intervals of size \( I = (45 - \varepsilon)/N \) where, 45 degrees is the maximum value for \( \theta \) and \( \varepsilon = 0.4 \) degree is the minimum value recorded for \( \theta \) in the data collected by Hutchinson and Kennedy.

2. If

\[ F(\theta) = \text{proportion of encroachments with angles greater than } \theta, \]

\[ F((k-1)I) - F(kI) = \text{proportion of encroachments with angle in the range } (k-1)I \text{ to } kI \]

\[ P_i((k - 0.5)I) = \text{probability of collision calculated at the midpoint of the range.} \]

3. The expected probabilities of collisions (i.e. expectations over angle of encroachment (\( \theta \)) for band1, band2 and band3 are given by:

\[
\bar{P}_1 = \sum_{k=1}^{N_1} \left( F((k-1)I) - F(kI) \right) P_1((k-0.5)I) \tag{9}
\]

\[
\bar{P}_2 = \sum_{k=1}^{N_2} \left( F((k-1)I) - F(kI) \right) P_2((k-0.5)I) \tag{10}
\]

\[
\bar{P}_3 = \sum_{k=1}^{N_3} \left( F((k-1)I) - F(kI) \right) P_3((k-0.5)I) \tag{11}
\]

where \( k=1, \ldots, 9 \) and \( P_1((k-0.5)I), P_2((k-0.5)I) \) and \( P_3((k-0.5)I) \) are obtained by replacing \( \theta \) by \((k-1)I\) in the expressions of \( P_1, P_2 \) and \( P_3 \). From the above inputs, the computer system will generate:

- The probability of an obstacle being in the path of an encroaching vehicle in each band.
- The probability of having a single vehicle roadside accident given that a vehicle encroaches on the roadside section under consideration (\( P_{\text{svra}} \)).
7 Demonstration of the Methodology

To demonstrate the use of the methodology presented in this paper, it was used to evaluate safety improvement alternatives on the hypothetical roadside section of Figure 7. The demonstration was conducted with the aid of the computer system developed which facilitated the computations. It involved the removal of objects from the hypothetical roadside section and the variation of the average daily traffic (ADT) to assess the change on the probability of single vehicle roadside accident $P_{sura}$ for that particular roadside section.

Every time an object is removed from the roadside, the probability of a single vehicle roadside accident is reduced. Objects were removed one by one until all of them have been eliminated leading each time to a different configuration of fixed roadside objects for the same roadside section. Objects located near the edge of the pavement were removed first because of the hazards they might present and the operation proceeded to the ones positioned further from the edge of the pavement.

This exercise has been repeated for several levels of average daily traffic. A graph has been plotted to show the relationship between $P_{sura}$ and ADT at low volumes (see Figure 8). Values obtained for the $P_{sura}$ show that this probability is high at low volumes and as ADT increases $P_{sura}$ decreases. This result is in agreement with most past research which has shown that single vehicle fixed-object accidents have the tendency to occur on roads with low traffic volumes (12,13,14).
8 Conclusion

This paper examined first, the relationship between the frequency of single vehicle roadside accidents and the lateral placement of the most common roadside hazards and showed how this relationship could be used as a basis for the development of a roadside safety improvement programme. The roadside hazard concept and system safety technology were then combined in a unified methodology to the quantitative evaluation of roadside safety. All relevant roadside safety knowledge has been encapsulated in a computer system called ROSDIS ROadside Safety Design and Improvement System.

In the presentation of the formulation of the methodology, results from previous research on the nature and frequency encroachments have been used to compute the probability of the top event. Their inclusion was mainly for the purpose of showing the nature of these factors and how they fit within the methodology. However, the validity of the methodology would not be compromised by modifying the values of these factors in accordance with results of more recent or future studies. In fact such modifications should be introduced as more knowledge is acquired. During system development, special effort was made so that the system can be easily maintained. The modularity of the system design eases further development and enhancement of the system.

Even in its present state, the system is a potentially useful tool for highway and traffic engineers. However, subsequent research will contribute to the refinement and growth of the knowledge encapsulated into the system. What follows are specific recommendations for future research:

- Models that will include curvature and inclination and the combination of both features can be built to extend ROSDIS. This will require their development before they can be implemented.
- Further research on the frequency of roadside encroachments on curvature,
inclination and their combination is also required.

- Costs for different alternatives can also be included to determine the most economical one.

ACKNOWLEDGEMENTS

The author wishes to thank the Algerian Ministry of Higher Education for granting him study leave to conduct this research. He also wants to thank Dr. M.G.H. Bell for his advice and all staff of the Transport Engineering Division of the University of Newcastle upon Tyne (U.K.) and Computer Department for their help.

9 References


Justifying a Forgiving Highway

Michael G Dreznes
Vice President-International
Energy Absorption Systems, Inc
U S A
ABSTRACT

A Financial Justification for Crash Cushions based on Specific Site Analysis

Crash Cushions have become a more common site in Europe over the past few years. Highway authorities in certain European countries have difficulty justifying the initial cost of a crash cushion.

Studies completed in the United States have proven the effectiveness of crash cushions.

They clearly show how crash cushions can reduce the severity of accidents at certain locations. Using these studies and the concept of the cost to society of a fatality, a site can be evaluated based on its previous accident history to determine if a crash cushion is financially feasible.

This paper explains the U.S. studies and gives case studies of different European sites to clearly illustrate how to determine the cost benefit and cost effectiveness of this road safety measure.
1. INTRODUCTION

Locating a roadside hazard is not difficult. Ask any traffic policeman where additional roadside hazard protection is needed, and he will quickly start to tell you when he last used the "jaws of life" to free a mangled body from a crashed vehicle. Ask an experienced highway design engineer to unfold new highway drawings, and he will undoubtedly be able to identify a location with poor geometrics that could be a problem. Ask a safety audit inspector in England to review an evaluated highway, and he will be aware of many roadside locations that could be made safer with improved crash protection.

Most qualified experts in the highway safety industry could travel any road in any country and easily identify a dangerous roadside hazard that is not properly shielded. The experts will also identify stopped or slow moving trucks in work zones that are extremely dangerous to motorists, even when these trucks are fitted with arrowboards, lights and variable message signs.

Locating roadside hazards is not difficult; locating the funds and justifying the expense of crash protection presents more of a challenge. This paper presents a method that will help to justify the cost to install one form of crash protection called a crash cushion, or an impact attenuator. The results of the evaluation illustrate why not correcting a dangerous condition on the highway can prove to be a much more costly option than treating the site with a properly designed and tested crash cushion.

2. BACKGROUND

In the decades of the 1950's and 1960's, the number of vehicles and the kilometers of roads grew around the world. As they grew, so did the number of fatalities on the roads. About one third of these fatalities were due to single vehicle, non-pedestrian (SVNP) collisions. Unfortunately, little was done to prevent this carnage on the highways.

Many road administrators argued that the SVNP accidents were often the result of excess speed or alcohol consumption. They contended that drivers involved in these SVNP accidents were "authors of their own misfortunes." In some countries, imprecise reporting made it difficult to identify the hazard that was the cause of the accident. Therefore, the dangers posed by a particular site were not clear.

Most road administrators in the 1950's and 1960's generally believed that satisfactory levels of highway safety could be achieved by alert and competent drivers using the highways provided by conventional engineering design. By the mid 1960's, it was obvious that the logic was no longer valid. Between 1956 and 1966 the number of motor vehicles on the American roads had grown 47% in 10

VTI RAPPORT 380A
years to over 96 million. In 1966 the number of deaths on the United States roads alone had reached 53,000, and more than 2,000,000 people were subjected to disabling injuries. These fatality levels and vehicle growth figures were being reflected in countries around the world. Something needed to be done to make roads safer.

In the late 1960's, concentrated efforts to create a "Forgiving Highway", or a safe road that would not make driver error a capital offense, were initiated in many parts of the world. The United States Department of Transportation Federal Highway Administration (FHWA) was at the forefront of the effort to develop the "Forgiving Highway" concept. During the 1970's and into the 1980's, many countries evaluated the success of the United States Department of Transportation Federal Highway Administration programs and incorporated some of the American ideas, along with remedial actions that were more appropriate to the needs of their country. In every case the goal was to create a "Forgiving Highway."

Ideally, the road design for a "Forgiving Highway" should incorporate the clear zone concept by removing hazards that are near the road. This is not always practical, especially in high volume urban roads that are surrounded by a variety of complex highway structures, traffic signs or lighting columns.

The first two options for creating a "Forgiving Highway", i.e., removing or moving the hazard, are the most effective and desirable. However, if designing out or removing the hazard is not possible, then the next option is to design these hazards that are near the road so they will "breakaway" when impacted. This will lessen the severity of the impact for the occupants of the vehicles. If a breakaway feature is not feasible, the hazard should be shielded using a crash barrier (e.g., steel guardrail or concrete barrier) or a crash cushion. The remainder of this paper will concentrate on the last option; shielding the hazard using a crash cushion.

Crash cushions, also called impact attenuators, are passive restraint systems and not designed to prevent an accident from happening. A crash cushion is designed to reduce the consequences of an accident by slowly decelerating an errant vehicle before it impacts a rigid roadside hazard. It is a means for "extending the time of the crash event", or simply decreasing the severity of the impact by reducing the rate of deceleration.

A crash cushion can be compared to a parachute. If a person jumps from an airplane at 1000 meters with no parachute, the effects of the high deceleration and the abrupt, unyielding impact with the ground will result in certain death. However, if this same person correctly wears a properly tested and proven parachute before jumping from the plane at 1000 meters, the fall will be much slower and the impact with the ground much less severe. The parachute will "extend the length of time for the event." Installing a properly tested and proven crash cushion will give this same protection to the occupants of a misguided vehicle.
Crash cushions have become a common site on roads in the United States, and over 20,000 systems are currently installed. Road authorities require these appurtenances to be tested before they are allowed on the roads.

Their insistence on the use of tested and proven crash cushions has resulted in over 13,000 lives being saved and over 25,000 serious injuries prevented over the past 20 years on American roads alone.

Crash cushions are also saving lives on roads in Europe, Asia and the Middle East. By the mid 1980's most of Western Europe as well as Australia, Saudia Arabia and Kuwait, had developed plans to utilize crash cushions on their roads. These crash cushions are performing very well in these countries. One preliminary report from England noted that during a 26 month evaluation only one minor injury was experienced at sites where crash cushions had been installed. At these same sites during the 7 years before crash cushions were installed, 5 people had been killed, 4 people had been subjected to serious injury and 7 others had experienced minor injuries due to impacts with these rigid roadside obstacles. (20)

3. ROADSIDE HAZARDS

Most high risk sites on a highway occur at a point when the driver must make a decision. If an unprotected rigid object is in the driver's decision area, the results can be disastrous. The hazards that cannot be removed, or made breakaway, and therefore must be shielded from errant vehicles, are similar in all countries.

Table 1 illustrates the similarities between the most frequently impacted hazards involved in SVNP fatal accidents in the United States and Great Britain. Successful concepts used to design a "Forgiving Highway" can be translated between countries.

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>UNITED STATES (1990)</th>
<th>GREAT BRITAIN (1988)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percentage</td>
</tr>
<tr>
<td>NONE</td>
<td>4394</td>
<td>27.4</td>
</tr>
<tr>
<td>TREES</td>
<td>2938</td>
<td>18.3</td>
</tr>
<tr>
<td>POLE/POST</td>
<td>2137</td>
<td>13.3</td>
</tr>
<tr>
<td>GUARD RAIL/BARRIER</td>
<td>1117</td>
<td>7.0</td>
</tr>
<tr>
<td>CULVERT/CURB/DITCH</td>
<td>2043</td>
<td>12.7</td>
</tr>
<tr>
<td>OTHER</td>
<td>3432</td>
<td>21.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>16061</td>
<td>100.1</td>
</tr>
</tbody>
</table>

SOURCE: RAGB, 1988, (20)
FARS, 1990, (19)

VTI RAPPORT 380A
ROADSIDE HAZARDS (continued)

Trees are the most frequently impacted object in both countries. Inherited from past decades of slower traffic, it continues to be common practice to beautify roads by planting trees, or allowing trees to exist close to the travelled way. The general public and government officials often remain reluctant to remove existing trees despite the fact that motor vehicle impacts into trees resulted in over 18% of the SVNP deaths in the United States in 1990 and over 23% of the SVNP deaths in Great Britain in 1988.

Indiscriminate removal of all trees from the adjacent roadside is not the answer because it is not cost-effective. Rather, a firm policy could be followed to remove trees which were either frequently impacted or considered, by experience, to be potentially dangerous. Should it be decided not to remove a hazardous tree, then shielding may be the last resort to provide safety to occupants of errant vehicles that collide with the tree. This can be accomplished through the use of guardrail (crash barrier) or crash cushions or a combination of both.

It has been estimated that in the United States alone about 130 million utility poles, sometimes referred to as telegraph or telephone poles, exist. About 80 million of these are estimated to be installed in close proximity to the travelled way of highways, roads, and streets. Of these, approximately 25 million can be considered as hazardous roadside objects. As shown in Table 1, about 2,100 lives are lost each year by vehicle impacts with poles and posts in the United States, and 140 more in Great Britain. One product that would make these poles and sign posts safer is the breakaway system invented by the Transportation Research Laboratory (TRL) in Great Britain in the early 1960's. Breakaway poles sever when impacted and allow the vehicle to pass through with a minimum change in velocity. In all of the breakaway type systems, the overhead wiring systems are left intact after the breakaway features have functioned. Although the breakaway pole and sign post concept was invented in Great Britain, they are not currently being used in Great Britain, but are being used in other countries.

The United States Department of Transportation Federal Highway Administration is now promoting a new technology which utilizes the breakaway concept, the breakaway timber utility pole. This pole, which is designed to break away upon vehicle impact, is intended for use in situations where a rigid pole is known to be in a potentially hazardous location, and its removal or relocation is not possible or practical. The pole features a steel slip base at ground level which works along with a steel strap hinge located about 4.5 meters up on a typical 12 meter utility pole. The slip base absorbs the force of impact, and breaks away from its foundation. The hinge mechanism absorbs the bending moment created in the pole by the vehicle impact forces, so that the upper section of the pole (and all of the attached utility cables) are not affected by the forces of the collision. It is this isolation from impact forces which enables the breakaway timber utility pole to prevent the interruption of utility service even when the pole is hit.
ROADSIDE HAZARDS (continued)

These poles have been field tested in 19 roadside installations in Massachusetts over a two-year period. This evaluation is ongoing; it is noteworthy that in five hits to date, there have been no serious injuries to vehicle occupants, at no time has utility service been interrupted, and there has been no litigation filed against any of the participants in this evaluation. (11)

In the late 1980's the collapsible pole was introduced in Sweden. This pole is designed to capture an impacting vehicle and slowly decelerate it. The pole has been successful in the Scandinavian countries; highway agencies in the United States and Europe are currently evaluating this concept.

Another method used to provide motorist protection from a utility pole installed near a multi-road intersection is to install a wrap-around crash cushion of small diameter collapsible tubes filled with water. These systems are recommended when anticipated vehicle impact speeds of 70 kilometers per hour or less are envisaged. The tubes are covered with caps to limit evaporation. When the tubes are impacted, the caps lift off exuding water, or a water and anti-freeze mixture, and the vehicle is slowly decelerated to a safe stop.

Nearly all countries throughout the world are using crash barriers to shield hazards. Errant vehicles colliding with barriers accounted for over 1,100 fatalities in the United States in 1990 and 35 lives in Great Britain in 1988. The number of annual fatalities has been reduced greatly in recent years by improvements such as the use of block-outs, shorter spacing of guardrail posts, and the use of the triple corrugated railing. At least 10 different types of roadside barrier systems, also known as guardrails, guiderails, longitudinal barriers or crash barriers, are being used around the world. Some barriers use several strands of wire rope fastened to steel posts. Others use a steel box beam or a double corrugated steel railing or triple corrugated steel railing as its longitudinal member fastened to steel or wood posts. Concrete barriers that utilize various designs of safety shapes also are being used where no deflection of the barrier is acceptable.

These barriers all have extremely dangerous ends. Many efforts have been made to treat the ends, including breakaway cable terminals (BCT), and ramped ends. Neither solution is totally acceptable today.

The small car, which became prelevant on European and American roads in the 1970's, creates a real problem for the breakaway cable end terminal. Guardrail ends using the breakaway cable terminal have been known to penetrate or spear smaller cars during an impact causing driver injuries and deaths. The turned down or ramped end has proven itself to be extremely dangerous by causing the vehicle to ramp and the driver to lose control. In June of 1990, the United States recognized this danger and outlawed the use of ramped ends on high speed, high volume roads. Disastrous experiences with turned down ends in Europe have many road authorities looking for options to improve their barrier terminals.
Crashworthy end treatments and crash cushions that do not spear, roll or vault an impacting vehicle are commercially available. Their use has been increasing in the United States in recent years and the trend is expected to be followed in Europe and other countries around the world.

A major reason given for not undertaking a program to replace dangerous turned downed ends or breakaway cable terminals with crashworthy end treatments and crash cushions relate to liability. Road authorities are concerned that if they admit that one turned down end is dangerous and replace it with a crashworthy end treatment, and then an errant vehicle hits another turned down end, the highway agency will be subjected to serious liability issues for allowing this admittedly dangerous condition to exist.

Road authorities do not need to correct every similar hazard once they correct one hazard. This is financially unrealistic. Legal precedent in certain countries has shown that if a highway agency has a written plan that is realistic and based on financial restraints and time parameters, the courts will rule that the agency is doing everything in its power to correct the problem. The important issue is that the agency recognized the problem and implemented an action plan.

Today, most countries with sophisticated highway systems, and a desire for safer roads are investigating how they can incorporate crash cushions into their highway design. Their goal continues to be the "Forgiving Highway". The crash cushion is one tool that can be used to reach their goal.

The next section illustrates methods used to compare safety improvements to determine which would be the most effective utilization of limited funds. It will also explain why doing nothing to correct a hazard could ultimately be a far more expensive option for society. Since highway agencies typically exist to serve society, neglecting a hazard is intolerable.

4. JUSTIFICATION

A variety of methods are used around the world to cost justify a crash cushion. Regardless of the method used, the crash cushion is installed after the authorities are convinced the benefits of having the crash cushion outweigh the costs involved.

Each year the United States Department of Transportation Federal Highway Administration assimilates available information on many types of safety improvements from the states to help them understand the benefits of the highway safety improvements. All fifty states, plus the District of Columbia and Puerto Rico, are required to submit data which is subsequently summarized in the Annual Report on Highway Safety Improvement Programs. This report deals with the highway environment as it relates to safety. It contains current accident data and trends, and examines the effectiveness of implemented highway safety improvement projects in reducing the number and severity of highway accidents. This report develops a numerical value called the "Benefit/Cost Ratio" for each improvement, which helps design engineers to compare the effectiveness of different safety improvements.
JUSTIFICATION (continued)

4.1 Benefit/Cost Ratio

The Annual Report on Highway Safety Improvement Programs analyzes the effectiveness of all safety improvements, including crash cushions, by comparing the benefit i.e., reduction in accident costs, with the safety improvement costs. The ratio between the present value of annual benefits and the present value of safety improvement costs is called the Benefit/Cost Ratio, and is determined by estimating the benefits to be derived from a specific course of action compared to the costs to implement such an action.

The primary reason one safety improvement project is selected over another is a higher expected reduction in future accident costs during the life of the improvement. These reductions may be obtained by eliminating the accident or, as in the case of a crash cushion, by reducing the severity of an impact. If the estimated benefits exceed the costs of implementing and maintaining a safety improvement over the life of the improvement, the project may be implemented. However, simply by having a Benefit/Cost Ratio greater than 1 does not in itself, justify a safety project. Each safety project competes with other projects for limited funds. A decision must be made which will maximize the utilization of the available funds to make roads safer.

To make direct comparisons between projects with different anticipated project lives, benefits and costs must be annualized. To do this, interest rates must be considered. An annualized Benefit/Cost Ratio will compare the expected savings to society through reduced accident costs to the cost to construct and maintain a specific treatment.

4.2 DETERMINING THE BENEFITS IN A BENEFIT/COST RATIO

The benefit portion of the Benefit/Cost Ratio is determined by analyzing accident reductions from comparisons of accident rates before and after the project. In the Annual Report on Highway Safety Improvement Programs, evaluations are made on crash cushion projects for which a large amount of data is available, i.e., before and after accident data, average daily traffic, number of vehicles passing through the locations, or vehicle kilometer of travel.

To determine the total, or comprehensive costs for injuries and fatalities, direct costs of the injuries or deaths are added to the indirect costs. This total is also referred to as the cost to society.

Direct costs of an accident will include property damage, medical costs, crash related travel delay, funeral costs, emergency services, vocational rehabilitation, workplace costs for replacing the disabled, legal costs, insurance and public program administration. These costs are readily available and verifiable in most countries throughout the world.

Indirect costs, such as loss of human productivity, are more difficult to appraise. Loss of human productivity can be measured using seven dimensions; mobility, cognitive, self care, sensory, cosmetic, pain and suffering, and the
JUSTIFICATION (continued)

ability to perform household responsibilities and to be employed (lost quality of life). Extensive research has broken down each of these seven human productivity categories according to severity levels and an arguable monetary value is then assigned to each of these levels.

The costs of pain, suffering and lost quality of life account for 65% of the total indirect costs, and thus dominate the comprehensive costs. (6)

Placing monetary values on fatal, non fatal and/or fatal plus injury accidents is very difficult, but it must be done to utilize a benefit cost comparison. The values assigned to accident severity levels vary throughout the world based on a variety of factors.

The 1991 Annual Report on Highway Safety Improvement Programs uses US$1,500,000 per fatality and US$11,000 per injury. In England, the value per fatality ranges between £600,000 and £750,000. Germany uses DM2,000,000 per fatality while Finland uses FIM7,550,000 for a fatality, FIM276,000 for an injury cost and FIM86,800 for a non fatal injury. In 1992, the United States Federal Highway Administration increased their cost per fatality to US$2,754,788 and per injury to US$53,369. These figures are scheduled for use in reporting and analysis purposes starting in 1993. Many countries will use fatality and injury monetary values to develop an average cost per accident, regardless of the level of severity. This can be useful in certain analysis projects.

The AASHTO Roadside Design Guide is constantly updating their suggested comprehensive accident costs. They currently recommend the following comprehensive costs for different types of accidents: (1)

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatality</td>
<td>US$500,000</td>
</tr>
<tr>
<td>Severe Personal Injury</td>
<td>$110,000</td>
</tr>
<tr>
<td>Moderate Personal Injury</td>
<td>$10,000</td>
</tr>
<tr>
<td>Slight Personal Injury</td>
<td>$3,000</td>
</tr>
<tr>
<td>Property Damage Only (Level 2)</td>
<td>$2,500</td>
</tr>
<tr>
<td>Property Damage Only (Level 1)</td>
<td>$500</td>
</tr>
</tbody>
</table>

The severity of every accident can be ranked according to the probability of a certain degree of injury or number of fatalities involved. This ranking allows researchers to place monetary values on the accident once they have determined the costs per injury or death. The AASHTO Roadside Design Guide uses the Severity Index and Cost by Accident Type Distribution (Severity Index) (Table 2) to rank accident costs by severity. The Severity Index is based on a scale of 0 to 10. A "0" represents an accident with no significant property damage or injury while severity level "10" relates to an accident with 100% chance of a fatality.
JUSTIFICATION (continued)

TABLE 2
SEVERITY INDEX AND COST BY ACCIDENT TYPE DISTRIBUTION

<table>
<thead>
<tr>
<th>SEVERITY INDEX</th>
<th>PROPERTY</th>
<th>DAMAGE (1)</th>
<th>DAMAGE (2)</th>
<th>SLIGHT INJURY</th>
<th>MODERATE INJURY</th>
<th>SEVERE INJURY</th>
<th>FATAL INJURY</th>
<th>ACCIDENT COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>US$000</td>
</tr>
<tr>
<td>0.5</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>500</td>
</tr>
<tr>
<td>1.0</td>
<td>66.7</td>
<td>23.7</td>
<td>7.3</td>
<td>2.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1,375</td>
</tr>
<tr>
<td>2.0</td>
<td>0.0</td>
<td>71.0</td>
<td>22.0</td>
<td>7.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3,135</td>
</tr>
<tr>
<td>3.0</td>
<td>0.0</td>
<td>43.0</td>
<td>34.0</td>
<td>21.0</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
<td>10,295</td>
</tr>
<tr>
<td>4.0</td>
<td>0.0</td>
<td>30.0</td>
<td>30.0</td>
<td>32.0</td>
<td>5.0</td>
<td>0.0</td>
<td>3.0</td>
<td>25,350</td>
</tr>
<tr>
<td>5.0</td>
<td>0.0</td>
<td>15.0</td>
<td>22.0</td>
<td>45.0</td>
<td>10.0</td>
<td>0.0</td>
<td>8.0</td>
<td>56,535</td>
</tr>
<tr>
<td>6.0</td>
<td>0.0</td>
<td>7.0</td>
<td>16.0</td>
<td>39.0</td>
<td>20.0</td>
<td>0.0</td>
<td>18.0</td>
<td>116,555</td>
</tr>
<tr>
<td>7.0</td>
<td>0.0</td>
<td>2.0</td>
<td>10.0</td>
<td>28.0</td>
<td>30.0</td>
<td>0.0</td>
<td>30.0</td>
<td>186,150</td>
</tr>
<tr>
<td>8.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.0</td>
<td>19.0</td>
<td>27.0</td>
<td>0.0</td>
<td>50.0</td>
<td>281,720</td>
</tr>
<tr>
<td>9.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>7.0</td>
<td>18.0</td>
<td>0.0</td>
<td>75.0</td>
<td>395,500</td>
</tr>
<tr>
<td>10.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
<td>500,000</td>
</tr>
</tbody>
</table>

Source: AASHTO Roadside Design Guide 1989 (1)

The total accident cost associated with a particular severity index is the product of the cost assigned to each accident type times the probability of that type of injury or fatality occurring.

4.3 DETERMINING COST IN A BENEFIT/COST RATIO

The cost factor of the Benefit/Cost Ratio uses the project life, or the period of time that the crash cushion will be useful, as the time in the economic analysis. A discount or interest rate is used to calculate the present value of annual costs. Other costs considered are installation costs, maintenance and repair costs and salvage value.

Determining the cost of a crash cushion over its life is a very important aspect of benefit cost analysis. Too often only the initial price is considered, instead of the cost of the unit during its project life. Repair costs are very important. A redirective crash cushion that will continue to function after a "nuisance hit", from a sideswipe or just a light hit, may cost more initially, but will be cheaper over repeated hits. Some crash cushions are designed to be replaced totally after an impact while others will be up to 95% reusable. Typically the higher the initial cost, the higher the reusability of the unit. If the unit has a low initial price, it probably is designed to be replaced after one impact.

The Benefit/Cost Ratio Analysis is an excellent method to evaluate different safety options. Crash cushions traditionally have a very high Benefit/Cost Ratio. In the 1991 Annual Report on Highway Safety Improvement Programs, the Benefit/Cost Ratio for crash cushions evaluated between 1974 and 1990 was 3.1. This ratio ranks crash cushions among the top 7 safety improvements in the United States as shown in Table 3.
Table 3
Highway Safety Improvements With the Highest Benefit/Cost Ratios
1974–1990

<table>
<thead>
<tr>
<th>Rank</th>
<th>Improvement Description</th>
<th>Benefit/Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Illumination</td>
<td>9.0</td>
</tr>
<tr>
<td>2</td>
<td>Traffic Signs</td>
<td>4.6</td>
</tr>
<tr>
<td>3</td>
<td>New Median Barrier</td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>Upgrade Bridge Rail</td>
<td>3.7</td>
</tr>
<tr>
<td>5</td>
<td>New Traffic Signals</td>
<td>3.7</td>
</tr>
<tr>
<td>6</td>
<td>Upgrade Guardrail</td>
<td>3.7</td>
</tr>
<tr>
<td>7</td>
<td>IMPACT ATTENUATORS</td>
<td>3.1</td>
</tr>
<tr>
<td>8</td>
<td>Remove Obstacles</td>
<td>2.7</td>
</tr>
<tr>
<td>9</td>
<td>Upgrade Median Barrier</td>
<td>2.5</td>
</tr>
<tr>
<td>10</td>
<td>Groove Pavement for Skid</td>
<td>2.4</td>
</tr>
<tr>
<td>11</td>
<td>Improve Sight Distance</td>
<td>2.4</td>
</tr>
<tr>
<td>12</td>
<td>Upgrade Traffic Signals</td>
<td>2.4</td>
</tr>
<tr>
<td>13</td>
<td>Improve Minor Structure</td>
<td>2.4</td>
</tr>
<tr>
<td>14</td>
<td>Upgrade RR Crossing Flashing Lights</td>
<td>2.1</td>
</tr>
<tr>
<td>15</td>
<td>New RR Crossing Gates</td>
<td>2.0</td>
</tr>
<tr>
<td>16</td>
<td>Median for Traffic Separation</td>
<td>2.0</td>
</tr>
<tr>
<td>17</td>
<td>Turning Lanes and Channelization</td>
<td>1.8</td>
</tr>
<tr>
<td>18</td>
<td>New RR Crossing Flashing Lights</td>
<td>1.6</td>
</tr>
<tr>
<td>19</td>
<td>New RR Crossing Lights &amp; Gates</td>
<td>1.4</td>
</tr>
<tr>
<td>20</td>
<td>Construct New Bridge</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Source: United States Federal Highway Administration, Highway Evaluation Safety System
1991 Annual Report on Highway Safety Improvement Programs (5)

* * * *

The Benefit/Cost Ratio in the 1991 Annual Report on Highway Safety Improvement Programs uses an interest rate of 10%, zero maintenance and salvage costs, an index that converts all project costs to 1988 dollars and a service life of 10 years for impact attenuators. These same parameters are used in the examples in this paper.

A variety of programs to determine the Benefit/Cost Ratio have been proposed over the years. These programs can be very detailed and take into account a great variety of different variables which are needed to compare many different types of roadside safety features. One of the best programs is the "Roadside Micro-Computer Program" ("Roadside"(6)) developed for the United States Federal Highway Administration. "Roadside" utilizes the AASHTO Barrier Design Guide cost effectiveness methodology, is very quick, and provides a high degree of user flexibility to customize a safety program for a certain site.
JUSTIFICATION (continued)

Many of the existing Benefit/Cost Ratio analyses are designed for a variety of road safety improvements, and can be complex. A quick, simple method for a highway engineer to use to understand the real benefits of a crash cushion is needed to justify the initial price of the crash cushion.

The next section introduces a simple analysis that quickly determines the feasibility of a crash cushion for a particular location. The analysis will clearly show if a crash cushion is an economical solution to correct a specific dangerous roadside condition.

4.4 A SIMPLE METHOD FOR EVALUATING THE COST EFFECTIVENESS OF CRASH CUSHIONS

A report entitled "Impact Attenuators: An Overview of Their Characteristics and Effectiveness" prepared in 1989 by Taminini utilized actual reports from different states in the United States to evaluate the effectiveness of crash cushions. A Texas report notes "...crash cushions reduced fatalities by 78% and injuries by 22%". A Wisconsin report covering 16 crash cushions notes, "...more than 170 people would have been seriously injured or killed if impact attenuators had not been used." An Oregon report covering four sites notes "...crash cushions were credited with saving 5 lives and preventing 7 serious injuries in 1 year."

Taminini summarized the available data and determined that crash cushions had saved over 12,500 lives and prevented over 21,000 serious injuries in less than 20 years. He claims that crash cushions saved over 1,300 lives in 1985 in the United States alone. As the number of crash cushion installations increase around the world, so do the number of lives saved and injuries prevented by crash cushions. Research data such as Taminini's and other information from the United States Federal Highway Administration, as well as highway agencies from other countries is available, and it can be used to develop a quick and easy means to evaluate crash cushion effectiveness as follows:

As shown in Table 2, the AASHTO Roadside Design guide used $500,000 per fatality for its Severity Index and Cost by Accident Type distribution. For purposes of this paper, Table 2 was updated as shown in Table 4 to reflect the current United States Federal Highway Administration $1,500,000 value per fatality. This table can be modified for any currencies once the local value of a fatality is known. Severity Index And Cost By Accident Type Distribution charts using British Pound, German Mark and Finnish Mark, as well as local fatality and accident comprehensive costs, are included in Appendix I.
TABLE 4
SEVERITY INDEX AND COST BY ACCIDENT TYPE DISTRIBUTION
REVISED TO REFLECT CURRENT
UNITED STATES FEDERAL HIGHWAY ADMINISTRATION
ACCIDENT VALUES

<table>
<thead>
<tr>
<th>SEVERITY INDEX</th>
<th>DAMAGE PROPERTY</th>
<th>SLIGHT INJURY</th>
<th>MODERATE INJURY</th>
<th>SEVERE INJURY</th>
<th>FATAL INJURY</th>
<th>ACCIDENT COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.5</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1.0</td>
<td>66.7</td>
<td>23.7</td>
<td>7.3</td>
<td>2.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2.0</td>
<td>0.0</td>
<td>71.0</td>
<td>22.0</td>
<td>7.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3.0</td>
<td>0.0</td>
<td>43.0</td>
<td>34.0</td>
<td>21.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>4.0</td>
<td>0.0</td>
<td>30.0</td>
<td>30.0</td>
<td>32.0</td>
<td>5.0</td>
<td>3.0</td>
</tr>
<tr>
<td>5.0</td>
<td>0.0</td>
<td>15.0</td>
<td>22.0</td>
<td>45.0</td>
<td>10.0</td>
<td>8.0</td>
</tr>
<tr>
<td>6.0</td>
<td>0.0</td>
<td>7.0</td>
<td>16.0</td>
<td>39.0</td>
<td>20.0</td>
<td>18.0</td>
</tr>
<tr>
<td>7.0</td>
<td>0.0</td>
<td>2.0</td>
<td>10.0</td>
<td>28.0</td>
<td>30.0</td>
<td>30.0</td>
</tr>
<tr>
<td>8.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.0</td>
<td>19.0</td>
<td>27.0</td>
<td>50.0</td>
</tr>
<tr>
<td>9.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>7.0</td>
<td>18.0</td>
<td>75.0</td>
</tr>
<tr>
<td>10.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: AASHTO Roadside Design Guide 1989 (1)

The United States Federal Highway Administration, in the Supplemental Information for Use with Roadside Computer Program (5), categorizes accident severities for impacts at different speeds based on different roadside conditions (Appendix II). Table 1 of Appendix II shows a 60 mph (97 kph) impact with a crash cushion such as a G-R-E-A-T System will result in a 2.6 to 3.4 severity index range or an average of 3.0. Table 4 of Appendix II shows that a 60 mph (97 kph) impact with a rigid object, such as a utility pole, will have a 3.8 to 7.2 severity index range or an average of 5.5. Using the information in Table 4 and Appendix II plus a present value factor, a quick basic method can be developed to evaluate the effectiveness of impact attenuators.

As a part of this evaluation, it is necessary to determine the encroachment and the expected number of impacts, both with and without crash cushions. The traffic flow, both existing and anticipated, speed limit, geometric conditions, location of hazard in relation to the road, and width of lane, etc., all must be considered. Many excellent, and very complex studies estimate encroachment and frequency of impacts, and are available in most countries. This paper will use a fairly simple approach to anticipate the number of impacts with and without a crash cushion.

In the United States, studies have used 0.73 impacts per installation per year for crash cushion evaluation (13). The Oregon study mentioned earlier in the Taminini report stated that crash cushions were hit 4.75 times a year. Prior to the installation of the crash cushions, these sites were hit 3.0 times per year. A study in England revealed that 8 crash cushions were hit an average of about 1.3 times per year. These same sites were hit about 0.5 times per year prior to treatment (20).
It can be concluded that depending on the installation, crash cushions could increase the number of impacts by as much as 50%. For sake of argument, this figure can be used in this evaluation method unless better data is available. Although the number of impacts may increase because the crash cushion encroaches on the driver's decision area, the severity of these impacts in all cases will be reduced. As the number of impacts increases, so will the Benefit/Cost Ratio for a highly reusable crash cushion.

This paper uses an average of 0.6 impacts per year with a crash cushion, and 0.4 without a crash cushion. These are conservative numbers of annual impacts based on actual crash cushion field observations from around the world.

The estimated number of annual impacts is multiplied by the accident severity levels from Table 4, or a similar table reflecting a particular country's currency and severity values (see Appendix I), for the crash cushions and the unprotected hazard. This yields the annual accident cost with and without a crash cushion. By subtracting the annual cost with a crash cushion from the annual cost without a crash cushion, an annual benefit can be determined.

The present value factor is determined using Appendix III and local interest rates and the expected life of the crash cushion. The United States Federal Highway Administration's Annual Report for Highway Safety Improvement Programs uses 10% for interest rates, and 10 years for the useful life of a crash cushion. The present value factor from Appendix III is 6.145. The previously calculated annual benefit is multiplied by the present value factor to determine the present value of benefits.

The next step is to determine the life cost of the impact attenuator from its installation cost and the present value of the annual repair cost. Crash cushions may have different reusability percentages ranging from 0% to 99%. This figure must be known or estimated to determine the present value of the annual repair cost. As the reusability percentage increases, so does the value of the long term benefit. Once the reusability percentage is known, the cost to repair the unit can be calculated. The repair cost is then multiplied by the average number of yearly anticipated impacts to arrive at the annual repair cost. Multiplying the annual repair cost times the present value factor yields the present value of the annual repair costs.

The present value of all costs can be calculated by adding the installed cost of the impact attenuator to the present value of the annual repair cost. A Benefit/Cost Ratio can now be determined by dividing the present value of all benefits by the present value of all costs.

Two other useful tools can also be quickly determined. The Present Value of Annual Savings can be calculated by subtracting the present value of the repair costs plus the installation cost from the present value of benefits. A second evaluation tool, the Annual Savings as a Percentage of the Installed Cost or First Year Rate of Return, can be calculated by subtracting the annual repair cost from the annual benefit, dividing the total by the installation cost and multiplying the result by 100.
These steps can be used to quickly develop the Benefit/Cost Ratio, the Annual Benefit and the Present Value of Total Savings for any potential crash cushion site. The steps are summarized below:

1. Determine the severity levels for the crash cushion and the unshielded roadside hazard from Appendix II.

2. Determine the severity costs with and without crash cushions, using a table which uses local injury and fatality costs such as those in Appendix I or Table 4.

3. Estimate the annual number of encroachments from actual data for the unshielded site, if available, or use an available means to determine encroachment. For simplicity, if the crash cushion enroaches into the driver's decision area, multiply the unshielded impact figure by 1.5 to estimate the annual impacts with the crash cushion installed.

4. Determine the annual accident costs by multiplying the respective number of impacts by the accident costs for crash cushions and the unshielded hazard. Subtract the crash cushion accident costs from the accident cost without a crash cushion to get the annual benefit.

5. Calculate the present value factor using Appendix III after determining the local interest rate and life expectancy of the crash cushion.

6. Multiply the annual benefit from step 4 by the present value factor from step 5 to get the present value of the benefits.

7. Determine the crash cushion's repair cost by multiplying the repair cost by the number of impacts from step 3. This will determine the annual repair cost.

8. Multiply the annual repair cost by the present value factor from step 5 to get the present value of repair costs.

9. Determine the present value of all costs by adding the present value of the repair costs in step 8 plus the cost of the installed crash cushion.

10. Divide the present value of the benefits from step 6, by the present value of the costs from step 9 to get the Benefit/Cost Ratio.

11. Subtract the present value of all costs from step 9, from the present value of benefits from step 6, to calculate the Present Value of Total Savings.

12. Subtract the annual repair costs from step 7 from the annual benefit from step 4. Divide this total by the installation cost and multiply by 100 to arrive at the Annual Savings as a Percentage of Installed Cost.

This process can be clearly understood by using the following typical examples:
4.5 **EXAMPLE 1**

A bridge pier in an exit area in the United States is to be shielded by a redirective crash cushion designated for 100 kph narrow hazard protection (e.g., a 6-Bay G-R-E-A-T System). The traffic volume is 40,000 vehicles per day and no significant increases are anticipated. The speed limit is 100 kph.

**Step 1 - Determine Severity Levels**

Using the figures from Table 4 in Appendix II, the average severity index for an unprotected bridge pier for a vehicle travelling at 97 kph (60 mph) is 5.5. Table 1 of Appendix II indicates that the average severity range for a G-R-E-A-T System protecting a vehicle travelling at 97 kph (60 mph) is 3.0.

**Step 2 - Determine Severity Costs**

Per Table 4, the following severity costs can be developed:

- Accident Without a Crash Cushion (level 5,5) = US$259,635
- Accident With a Crash Cushion (level 3) = US$30,885

**Step 3 - Determine Number of Impacts**

Evaluating actual impact history, it is found that the bridge pier is impacted .4 times per year. Since the crash cushion will diminish the driver's decision area, the impact total is multiplied by 1.5 to arrive at .6 impacts per year. This figure is used as the annual average number of impacts for crash cushions.

**Step 4 - Determine Annual Benefit**

\[
\text{Annual Benefit} = \text{Annual Cost Without a Crash Cushion} - \text{Annual Cost With a Crash Cushion}
\]

\[
\text{Annual Cost Without a Crash Cushion} = \text{Number of Annual Impacts Without a Crash Cushion} \times \text{Accident Severity Level Without a Crash Cushion}
\]

\[
\text{Annual Cost Without a Crash Cushion} = .4 \times \text{US$259,635} = \text{US$103,854}
\]

\[
\text{Annual Cost With a Crash Cushion} = \text{Number of Annual Impacts With a Crash Cushion} \times \text{Accident Severity Level With a Crash Cushion}
\]

\[
\text{Annual Cost With a Crash Cushion} = .6 \times \text{US$30,885} = \text{US$18,531}
\]

\[
\text{Annual Benefit} = \text{Annual Cost Without a Crash Cushion} - \text{Annual Cost With a Crash Cushion}
\]

\[
\text{Annual Benefit} = \text{US$103,854} - \text{US$18,531} = \text{US$85,323}
\]
EXAMPLE 1 (continued)

Step 5 - Determine Present Value Factor

Using an interest rate of 10% and a useful life of 10 years, per the guidelines for impact attenuators in the United States Federal Highway Administration Annual Report for Highway Safety Improvement Programs, a present value factor of 6.145 is determined from Appendix III.

Step 6 - Determine Present Value of Annual Benefit

The present value of the annual benefit is calculated as follows:

\[
\text{Present Value of Annual Benefit} = \text{Present Value Factor} \times \text{Annual Benefit}
\]

Present Value of Annual Benefit = 6.145 \times \text{US$85,323} = \text{US$524,310}

Step 7 - Determine Crash Cushion Installation Costs and Annual Repair Cost

A 6-Bay G-R-E-A-T System will have an average installed cost of about US$20,000. The manufacturer of the G-R-E-A-T System indicates that the G-R-E-A-T System has 80% reusability. The repair cost per incident would be US$20,000 \times 0.20 or US$4,000. Since the impact attenuator is projected to be impacted .6 times per year, the annual repair cost will equal:

Annual Repair Costs = \frac{\text{Number of Impacts}}{\text{With a Crash Cushion}} \times \text{Repair Cost per Incident}

Annual Repair Costs = 0.6 \times \text{US$4,000} = \text{US$2,400}

Step 8 - Determine Present Value of Annual Repair Cost

\[
\text{Present Value of Annual Repair Cost} = \text{Present Value Factor} \times \text{Annual Repair Cost}
\]

Present Value of Annual Repair Cost = 6.145 \times \text{US$2,400} = \text{US$14,748}

Step 9 - Determine Present Value of all Costs

\[
\text{Present Value of All Costs} = \text{Installed Cost of Impact Attenuator} + \text{Present Value of Annual Repair Cost}
\]

Present Value of All Costs = \text{US$20,000} + \text{US$14,748} = \text{US$34,748}

VTI RAPPORT 380A
EXAMPLE 1 (continued)

Step 10 - Determine Benefit/Cost Ratio

\[
\text{Benefit/Cost Ratio} = \frac{\text{Present Value of Annual Benefits}}{\text{Present Value of All Costs}}
\]

\[
\text{Benefit/Cost Ratio} = \frac{\text{US}\$524,310}{\text{US}\$34,748} = 15.1
\]

Step 11 - Determine the Present Value of Total Savings

\[
\text{Present Value of Total Savings} = \text{Annual Benefits} - \text{All Costs}
\]

\[
\text{Present Value of Total Savings} = \text{US}\$524,310 - \text{US}\$34,748 = \text{US}\$489,562
\]

Step 12 - Determine Annual Savings as a Percentage of Installed Cost

\[
\text{Annual Savings as a Percentage of Installed Cost} = \frac{\text{Annual Benefit} - \text{Annual Repair Cost}}{\text{Installation Cost}} \times 100
\]

\[
\text{Annual Savings as a Percentage of Installed Cost} = \frac{\text{US}\$85,323 - \text{US}\$2,400}{\text{US}\$20,000} \times 100 = 415\%
\]

The extremely high Benefit/Cost Ratio, Present Value to Total Savings and Annual Savings as a Percentage of Installed Cost would qualify this site as a very viable crash cushion installation. The highway authority would be losing money by not making the installation.

4.6 EXAMPLE 2

On an M-Road in Great Britain, a turned down guardrail end at an emergency turnaround crossover point in a median is to be protected with a redirective crash cushion designed for 110 kph narrow hazard protection (e.g., a 9-Bay G-R-E-A-T System). The traffic volume is 50,000 vehicles per day and no significant increases are anticipated. The speed limit is 110 kph.

Step 1 - Determine Severity Levels

Using the figures from Table 1 in Appendix II, the average severity index for a turned down barrier terminal for a vehicle travelling at 112 kph (70 mph) is 4.8. Table 1 of Appendix II indicates that the average severity range for a G-R-E-A-T System protecting a vehicle travelling at 112 kph (70 mph) is 3.3.

VTI RAPPORT 380A
EXAMPLE 2 (continued)

Step 2 - Determine Severity Costs

Per Table 1 of Appendix I, the following severity costs can be developed for Great Britain:

Accident Without a Crash Cushion (level 4,8) = £70,417
Accident With a Crash Cushion (level 3.3) = £21,439

Step 3 - Determine Number of Impacts

Evaluating actual impact history, it is found that the crossover point is impacted .2 times per year. Sections of safety barrier can be removed to allow the crash cushion to end at the same location the ramped end currently ends. Therefore, no additional impacts are anticipated once the crash cushion is installed.

Step 4 - Determine Annual Benefit

\[
\text{Annual Cost Without a Crash Cushion} = \text{Number of Annual Impacts Without a Crash Cushion} \times \text{Accident Severity Level Without a Crash Cushion}
\]

\[
\text{Annual Cost Without a Crash Cushion} = .2 \times £70,417 = £14,084
\]

\[
\text{Annual Cost With a Crash Cushion} = \text{Number of Annual Impacts With a Crash Cushion} \times \text{Accident Severity Level With a Crash Cushion}
\]

\[
\text{Annual Cost With a Crash Cushion} = .2 \times £21,439 = £4,289
\]

\[
\text{Annual Benefit} = \text{Annual Accident Cost Without a Crash Cushion} - \text{Annual Accident Cost With a Crash Cushion}
\]

\[
\text{Annual Benefit} = £14,084 - £4,289 = £9,795
\]

Step 5 - Determine Present Value Factor

Using an assumed interest rate of 10% and a useful life of 10 years, per the guidelines for impact attenuators in the United States Federal Highway Administration "Annual Report for Highway Safety Improvement Programs", a present value factor of 6.145 is determined from Appendix III.
EXAMPLE 2 (continued)

Step 6 - Determine Present Value of Annual Benefit

The present value of the annual benefit is then calculated as follows:

\[
\text{Present Value of Annual Benefit} = \text{Present Value Factor} \times \text{Annual Benefit (from Step 4)}
\]

\[6.145 \times £9,795 = £60,190\]

Step 7 - Determine Crash Cushion Installation Costs and Annual Repair Cost

A 9-Bay G-R-E-A-T System will have an average installed cost of about US £15,000. Using the 80% reusability figure for the G-R-E-A-T System, the repair cost per incident would be £15,000 \(\times\) 0.20 or £3,000. Since the impact attenuator is projected to be impacted 0.2 times per year, the annual repair cost will equal:

\[
\text{Annual Repair Costs} = \text{Number of Impacts} \times \text{Repair Cost Per Incident}
\]

\[0.2 \times £3,000 = £600\]

Step 8 - Determine Present Value of Annual Repair Cost

\[
\text{Present Value of Annual Repair Cost} = \text{Present Value Factor} \times \text{Annual Repair Costs (from Step 7)}
\]

\[6.145 \times £600 = £3,687\]

Step 9 - Determine Present Value of All Costs

\[
\text{Present Value of All Costs} = \text{Installed Cost of Impact Attenuator (from Step 7)} + \text{Present Value of Annual Repair cost (from Step 8)}
\]

\[£15,000 + £3,687 = £18,687\]

Step 10 - Determine Benefit/Cost Ratio

\[
\text{Benefit/Cost Ratio} = \frac{\text{Present Value of All Benefits}}{\text{Present Value of All Costs}}
\]

\[
\frac{£60,190}{£18,687} = 3.2
\]
EXAMPLE 2 (continued)

Step 11 - Determine the Present Value of Total Savings

<table>
<thead>
<tr>
<th>Present Value of Total Savings</th>
<th>Present Value of Annual Benefits (from Step 6)</th>
<th>Present Value of All Costs (from Step 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>£60,190 - £18,687 = £41,503</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Step 12 - Determine Annual Savings as a Percentage of Installed Cost

\[
\text{Annual Savings as a Percentage of Installed Cost} = \frac{\text{Annual Benefit} - \text{Annual Repair Cost}}{\text{Installation Cost}} \times 100
\]

Annual Savings as a Percentage of Installed Cost = \(\frac{\£9,795 - \£600}{\£15,000} \times 100 = 61.3\%\)

A 3.2 Benefit/Cost Ratio and £41,503 Present Value of Total Savings would qualify this site for further consideration for a crash cushion installation.

4.7 EXAMPLE 3

Emergency turnaround points in Finland are currently using turned down ends on 100 kph roads. A redirective crash cushion that has low reusability and a low initial cost (e.g., Brakemaster) is to be used at these sites. The traffic volume is 25,000 vehicles per day and no significant increases are anticipated. The speed limit is 100 kph.

Step 1 - Determine Severity Levels

Using the figures from Table 1 in Appendix II, the average severity index for a turned down barrier turnaround for a vehicle travelling at 97 kph (60 mph) is 4.1. Since the Brakemaster System performs similarly to the G-R-E-A-T System the average severity range for a G-R-E-A-T type System protecting a vehicle travelling at 97 kph (60 mph) can be used. Table I of Appendix II indicates that this average severity range is 3.0.

Step 2 - Determine Severity Costs

Per Table 3 of Appendix I, the following severity costs can be developed for Finland:

- Accident Without a Crash Cushion (level 4,1) = FIM429,897
- Accident With a Crash Cushion (level 3) = FIM155,455
EXAMPLE 3 (continued)

Step 3 - Determine Number of Impacts

Evaluating actual impact history, it is found that the crossover points are impacted .2 times per year. Sections of the safety barrier can be removed to allow the Brakemaster to end at the same spot the turned down end currently ends. Therefore, no change in accident frequency is anticipated once the crash cushion is installed.

Step 4 - Determine Annual Benefit

Annual Cost Without a Crash Cushion = Number of Annual Impacts Without a Crash Cushion x Accident Severity Level Without a Crash Cushion

Annual Cost Without a Crash Cushion = .2 x FIM429,897 = FIM85,979

Annual Cost With a Crash Cushion = Number of Annual Impacts With a Crash Cushion x Accident Severity Level With a Crash Cushion

Annual Cost With a Crash Cushion = .2 x FIM155,455 = FIM31,091

Annual Benefit = Annual Accident Cost Without a Crash Cushion - Annual Accident Cost With a Crash Cushion

Annual Benefit = FIM85,979 - FIM31,091 = FIM54,888

Step 5 - Determine Present Value Factor

Using an assumed interest rate of 10% and a useful life of 10 years, per the guidelines for impact attenuators in the United States Federal Highway Administration Annual Report for Highway Safety Improvement Programs, a present value factor of 6.145 is determined from Appendix III.

Step 6 - Determine Present Value of Annual Benefit

The present value of the annual benefit is then calculated as follows:

Present Value of Annual Benefit = Present Value factor x Annual benefit

Present Value of Annual Benefit = 6.145 x FIM54,888 = FIM337,287
EXAMPLE 3 (continued)

Step 7 - Determine Crash Cushion Installation Costs and Annual Repair Cost

A Brakemaster System will have an average installed cost of about FIM30,000. The manufacturer of the Brakemaster System indicates that the System has about 40% reusability. Using this reusability figure the repair cost per incident would be FIM30,000 x .60 or FIM18,000. Since the impact attenuator is projected to be impacted .2 times per year, the annual repair cost will equal:

Annual Repair Costs = Number of Impacts x Repair Cost Per With a Crash Cushion Incident

Annual Repair Costs = .2 x FIM18,000 = FIM3,600

Step 8 - Determine Present Value of Annual Repair Cost

Present Value of Annual Repair Cost = Present Value Factor x Annual Repair Costs (from Step 7)

Present Value of Annual Repair Cost = 6.145 x FIM3,600 = FIM22,122

Step 9 - Determine Present Value of all Costs

Present Value of All Costs = Installed Cost of Impact Attenuator + Present Value of Annual Repair Cost (from Step 7) (from Step 8)

Present Value of All Costs = FIM30,000 + FIM22,122 = FIM52,122

10 - Determine Benefit/Cost Ratio

Benefit/Cost Ratio = Present Value of All Benefits Present Value of All Costs

Benefit/Cost Ratio: FIM337,287 FIM 52,122 = 6.5

Step 11 - Determine the Present Value of Total Savings

Present value of Total Savings = Present Value of Annual Benefits - Present Value of All Costs

Present Value of Total Savings = FIM337,287 - FIM52,122 = FIM285,165
EXAMPLE 3 (continued)

Step 12 - Determine Annual Savings as a Percentage of Installed Cost

Annual Savings as a Percentage of Installed Cost = \frac{\text{Annual Benefit} - \text{Annual Repair Cost}}{\text{Installation Cost}} \times 100

Annual Savings as a Percentage of Installed Cost = \frac{\text{FIM54,888} - \text{FIM3,600}}{\text{FIM30,000}} \times 100 = 171\%

The 6.5 Benefit/Cost Ratio is very high, as is the FIM285,165 Present Value of Total Savings. Any safety improvement project that will pay for itself in approximately 7 months and will save lives must be strongly considered for implementation.

4.8 EXAMPLE 4

A rigid cantilevered overhead sign with a wide base in a gore in Germany is to be shielded by a delta shaped redirective crash cushion designed for 100 kph wide hazard protection (e.g., an 8-Bay Hex Foam Sandwich System). The traffic volume is 80,000 vehicles per day and no significant increases are anticipated. The speed limit is 100 kph.

Step 1 - Determine Severity Levels

Using the figures from Table 4 in Appendix II, the average severity index for a rigid cantilevered/overhead sign support for a vehicle travelling at 97 kph (60 mph) is 5.5. Table 1 of Appendix II indicates that the average severity range for a Hex Foam Sandwich System protecting a vehicle travelling at 97 kph (60 mph) is 3.0.

Step 2 - Determine Severity Costs

Per Table 2 of Appendix I, the following severity costs can be developed:

\begin{align*}
\text{Accident Without a Crash Cushion (level 5.5)} &= \text{DM207,720} \\
\text{Accident With a Crash Cushion (level 3.0)} &= \text{DM24,708}
\end{align*}

Step 3 - Determine Number of Impacts

Evaluating actual impact history, it is found that the overhead sign is impacted .4 times per year. Since the crash cushion will be placed in the motorist's decision area, this impact total is multiplied by 1.5 to arrive at .6 impacts per year, which is used as the impact average for crash cushions.
EXAMPLE 4 (continued)

Step 4 – Determine Annual Benefit

Annual Cost Without a Crash Cushion = Number of Annual Impacts Without a Crash Cushion x Accident Severity Level Without a Crash Cushion

Annual Cost Without a Crash Cushion = .4 x DM207,720 = DM83,088

Annual Cost With a Crash Cushion = Number of Annual Impacts With a Crash Cushion x Accident Severity Level With Crash Cushion

Annual Cost With a Crash Cushion = .6 x DM24,708 = DM14,825

Annual Benefit = Annual Accident Cost Without a Crash Cushion - Annual Accident Cost With a Crash Cushion

Annual Benefit = DM83,088 - DM14,825 = DM68,263

Step 5 – Determine Present Value Factor

Using an assumed interest rate of 10% and a useful life of 10 years, per the guidelines for impact attenuators in the United States Federal Highway Administration Annual Report for Highway Safety Improvement Programs, a present value factor of 6.145 is determined from Appendix III.

Step 6 – Determine Present Value of Annual Benefit

The present value of the annual benefit is then calculated as follows:

Present value of Annual Benefit = Present Value Factor x Annual Benefit (from Step 4)

Present value of Annual Benefit = 6.145 x DM68,263 = DM419,476

Step 7 – Determine Crash Cushion Installation Costs and Annual Repair Cost

An 8-Bay Hex Foam Sandwich System will have an average installed cost in Germany of about DM48,000. The manufacturer of the Hex Foam Sandwich System indicates that the Hex Foam Sandwich System has about 80% reusability. Using this reusability figure the repair cost per incident would be DM48,000 x .20 or DM9,600. Since the impact attenuator is projected to be impacted .6 times per year, the annual repair cost will equal:
EXAMPLE 4 (continued)

Annual Repair Costs = Number of Impacts With a Crash Cushion x Repair Cost Per Incident

Annual Repair Costs = .6 x DM9,600 = DM5,760

Step 8 - Determine Present Value of Annual Repair Cost

Present Value of Annual Repair Cost = Present Value Factor x Annual Repair Costs (from Step 7)

Present Value of Annual Repair Cost = 6.145 x DM5,760 = DM35,395

Step 9 - Determine Present Value of all Costs

Present Value of All Costs = Installed Cost of Impact Attenuator (from Step 7) + Present Value of Annual Repair Cost (from Step 8)

Present Value of All Costs = DM48,000 + DM35,395 = DM83,395

Step 10 - Determine Benefit/Cost Ratio

Benefit/Cost Ratio = Present Value of All Benefits / Present Value of All Costs

Benefit/Cost Ratio = DM419,476 / DM83,395 = 5.03

Step 11 - Determine the Present Value of Total Savings

Present value of Total Savings = Present Value of Annual Benefits - Present Value of All Costs

Present Value of Total Savings = DM419,476 - DM83,395 = DM336,081

Step 12 - Determine Annual Savings as a Percentage of Installed Cost

Annual Savings as a Percentage of Installed Cost = \( \frac{\text{Annual Benefit} - \text{Annual Repair Cost}}{\text{Installation Cost}} \times 100 \)

Annual Savings as a Percentage of Installed Cost = \( \frac{\text{DM68,263} - \text{DM5,760}}{\text{DM48,000}} \times 100 = 130.2\% \)
EXAMPLE 4 (continued)

This site has a 5.03 Benefit/Cost Ratio and a DM336,081 Present Value of Total Savings, and a 130.2% Annual Savings as a Percentage of Installed cost which should make this installation very attractive to highway engineers. The decision whether or not to install this crash cushion will depend on the budget available and the Benefit/Cost Ratio, Present Value of Total Savings, and Annual Savings as a Percentage of Installed Costs for other possible safety improvement projects under consideration.

4.9 EXAMPLE 5

A bridge pier in a wide median in the United States is shielded by a non-redirective, sand filled plastic barrier designed for 100 kph wide hazard protection (e.g., an Energite array). The traffic volume is 25,000 vehicles per day and no significant increases are anticipated. The speed limit is 100 kph.

Step 1 - Determine Severity Levels

Using the figures from Table 4 in Appendix II, the average severity index for an unprotected bridge pier for a vehicle travelling at 97 kph (60 mph) is 5.5. Table 1 of Appendix II indicates that the average severity range for a sand filled plastic barrier array protecting a vehicle travelling at 97 kph (60 mph) is 3.0

Step 2 - Determine Severity Costs

Per Table 4, the following severity costs can be developed:

Accident Without a Crash Cushion (level 5,5) = US$259,635
Accident With a Crash Cushion (level 3) = US$30,885

Step 3 - Determine Number of Impacts

The bridge pier has not been impacted to date. Based on an evaluation program, it is determined that the unprotected hazard would be impacted .1 times per year. Due to the length of the inertial barrier array and the fact that it will diminish the drivers decision area, this figure is multiplied by 1.5 to arrive at .15 impacts per year for the crash cushion.
EXAMPLE 5 (continued)

Step 4 - Determine Annual Benefit

<table>
<thead>
<tr>
<th>Step</th>
<th>Formula</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Annual Cost Without a Crash Cushion</td>
<td>Number of Annual Impacts Without a Crash Cushion x Accident Severity Level Without a Crash Cushion</td>
</tr>
<tr>
<td>4.2</td>
<td>Annual Cost Without a Crash Cushion</td>
<td>(0.1 \times \text{US$259,635} = \text{US$25,964})</td>
</tr>
<tr>
<td>4.3</td>
<td>Annual Cost With a Crash Cushion</td>
<td>Number of Annual Impacts With a Crash Cushion x Accident Severity Level With a Crash Cushion</td>
</tr>
<tr>
<td>4.4</td>
<td>Annual Cost With a Crash Cushion</td>
<td>(1.5 \times \text{US$30,885} = \text{US$4,331})</td>
</tr>
<tr>
<td>4.5</td>
<td>Annual Benefit</td>
<td>Annual Accident Cost Without a Crash Cushion - Annual Accident Cost With a Crash Cushion</td>
</tr>
<tr>
<td>4.6</td>
<td>Annual Benefit</td>
<td>(\text{US$25,964} - \text{US$4,331} = \text{US$21,331})</td>
</tr>
</tbody>
</table>

Step 5 - Determine Present Value Factor

Using an interest rate of 10% and a useful life of 10 years, per the guidelines for impact attenuators in the United States Federal Highway Administration Annual Report for Highway Safety Improvement Programs, a present value factor of 6.145 is determined from Appendix III.

Step 6 - Determine Present Value of Annual Benefit

The present value of the annual benefit is calculated as follows:

Present Value of Annual Benefit = Present Value Factor \(\times\) Annual Benefit

\[\text{Present Value of Annual Benefit} = 6.145 \times \text{US$21,331} = \text{US$131,079}\]

Step 7 - Determine Crash Cushion Installation Costs and Annual Repair Cost

An inertial barrier array designed to protect 820 to 2040 kgs travelling at 97 kph will contain 16 barrels. The average installed cost for this system will be about $5,000. Sand filled plastic barrels are designed to break when impacted to allow the sand to dissipate the energy of the vehicle. None of the barrels are reused. Therefore, the repair cost per incident would be $5,000. Since the inertial barrier array will be hit .15 times per year, the annual repair cost will equal:

VTI RAPPORT 380A
EXAMPLE 5 (continued)

Annual Repair Costs = Number of Impacts With a Crash Cushion x Repair Cost per Incident

Annual Repair Costs = .15 x US$5,000 = US$750

Step 8 - Determine Present Value of Annual Repair Cost

Present Value of Annual Repair Cost = Present Value Factor x Annual Repair Cost (from Step 7)

Present Value of Annual Repair Cost = 6.145 x US$750 = US$4,609

Step 9 - Determine Present Value of all Costs

Present Value of All Costs = Installed Cost of Impact Attenuator + Present Value of Annual Repair Cost (from Step 7) (from Step 8)

Present Value of All Costs = US$5,000 + US$4,609 = US$9,609

Step 10 - Determine Benefit/Cost Ratio

Benefit/Cost Ratio = Present Value of Annual Benefits

Benefit/Cost Ratio = US$131,079

Benefit/Cost Ratio = US$9,609 = 13.6

Step 11 - Determine the Present Value of Total Savings

Present Value of Total Savings = Present Value of Annual Benefits - Present Value of All Costs (from Step 6) (from Step 9)

Present Value of Total Savings = US$131,079 - US$9,609 = US$121,470

Step 12 - Determine Annual Savings as a Percentage of Installed Cost

Annual Savings as a Percentage of Installed Cost = \[
\frac{\text{Annual Benefit} - \text{Annual Repair Cost}}{\text{Installation Cost}} \times 100
\]

Annual Savings as a Percentage of Installed Cost = \[
\frac{US$21,331 - US$750}{US$5,000} \times 100 = 411\%
\]
This very high Benefit/Cost Ratio of 13.6, US$121,470 Present Value of Total Savings and 411% Annual Savings as a Percentage of Installed Cost, makes this installation very viable. The low initial cost for the sand filled plastic barrel array makes them very attractive for this site which is far enough from the travelled road that redirection is not considered necessary.

Specific sites must be carefully evaluated to assess the potential dangers that could be caused by a non redirective crash cushion, like a plastic barrel array. Sand filled plastic barrel arrays that elevate the sand in the barrels to maintain a constant center of gravity can be a good corrective measure for hazards far from the roads that are infrequently impacted. If the number of impacts at this site was to increase, the highway agency may consider a crash cushion with more reusability and less maintenance demands.

5.0 SUMMARY

Highway Engineers agree that their responsibility is to provide a safe road for the motoring public. Any modifications or changes to the road that they make should not lessen the safety of the road. This becomes difficult as more and more kilometers of road are being placed in and around municipal areas causing the luxury of geometry to disappear. Black spots or frequent accident areas become more prevalent, and they must be treated. Protecting motorists is the highway engineer's responsibility and obligation.

Everyone agrees that the value of one life is invaluable. If a safety engineer in a highway agency was able to install a highway safety appurtenance free of charge and be reasonably certain that this safety feature would save a motorist's life, he would certainly do it.

Unfortunately, no safety devices are available free of charge. The safety engineer must decide how to wisely spend his limited funds to make his road safe. Highway Safety engineers around the world are learning a very valuable lesson: crash cushions that have been tested to a respected, rigid set of guidelines, and have been proven effective on roads around the world are an excellent investment. They are tools that, if used wisely, can ultimately maximize a budget by providing a safe road for the motoring public.

Crash cushions will not solve every problem, but they will help a safety engineer do a better job. They are passive safety devices that will not eliminate accidents, but will reduce the severity of an accident. A crash cushion should not be evaluated solely on its initial price. It must be evaluated on the effect it will have on the motoring public during its life.

If a person's life is invaluable, and if a crash cushion helps to save even one person's life during its existence, then whatever the price that is paid, the crash cushion is an excellent investment. The Benefit/Cost Ratio gives the Safety Engineer the convincing data he needs to get the necessary funds allocated for crash cushion installations. The data will clearly show that the public's money spent on crash cushions is money wisely spent.
APPENDIX 1, TABLE 1  
SEVERITY INDEX AND COST BY ACCIDENT TYPE DISTRIBUTION  
REVISED TO REFLECT GREAT BRITAIN ACCIDENT VALUES

<table>
<thead>
<tr>
<th>SEVERITY INDEX</th>
<th>PROPERTY DAMAGE</th>
<th>DAMAGE</th>
<th>SLIGHT INJURY</th>
<th>MODERATE INJURY</th>
<th>SEVERE INJURY</th>
<th>FATAL INJURY</th>
<th>ACCIDENT COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>£ 000</td>
</tr>
<tr>
<td>0.5</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>£ 700</td>
</tr>
<tr>
<td>1.0</td>
<td>66.7</td>
<td>23.7</td>
<td>7.3</td>
<td>2.3</td>
<td>0.0</td>
<td>0.0</td>
<td>£ 1,925</td>
</tr>
<tr>
<td>2.0</td>
<td>0.0</td>
<td>71.0</td>
<td>22.0</td>
<td>7.0</td>
<td>0.0</td>
<td>0.0</td>
<td>£ 4,389</td>
</tr>
<tr>
<td>3.0</td>
<td>0.0</td>
<td>43.0</td>
<td>34.0</td>
<td>21.0</td>
<td>1.0</td>
<td>0.0</td>
<td>£ 14,413</td>
</tr>
<tr>
<td>4.0</td>
<td>0.0</td>
<td>30.0</td>
<td>30.0</td>
<td>32.0</td>
<td>5.0</td>
<td>0.0</td>
<td>£ 35,490</td>
</tr>
<tr>
<td>5.0</td>
<td>0.0</td>
<td>15.0</td>
<td>22.0</td>
<td>45.0</td>
<td>10.0</td>
<td>0.0</td>
<td>£ 79,149</td>
</tr>
<tr>
<td>6.0</td>
<td>0.0</td>
<td>7.0</td>
<td>16.0</td>
<td>39.0</td>
<td>20.0</td>
<td>0.0</td>
<td>£ 163,177</td>
</tr>
<tr>
<td>7.0</td>
<td>0.0</td>
<td>2.0</td>
<td>10.0</td>
<td>28.0</td>
<td>30.0</td>
<td>0.0</td>
<td>£ 260,610</td>
</tr>
<tr>
<td>8.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.0</td>
<td>19.0</td>
<td>27.0</td>
<td>50.0</td>
<td>£ 394,408</td>
</tr>
<tr>
<td>9.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>7.0</td>
<td>18.0</td>
<td>75.0</td>
<td>£ 553,700</td>
</tr>
<tr>
<td>10.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
<td>£ 700,000</td>
</tr>
</tbody>
</table>

Source: AASHTO Roadside Design Guide 1989 (1)
### APPENDIX 1, TABLE 2
SEVERITY INDEX AND COST BY ACCIDENT TYPE DISTRIBUTION
REVISED TO REFLECT GERMAN VALUES

<table>
<thead>
<tr>
<th>SEVERITY INDEX</th>
<th>PROPERTY</th>
<th>SLIGHT INJURY</th>
<th>MODERATE INJURY</th>
<th>SEVERE INJURY</th>
<th>FATAL INJURY</th>
<th>ACCIDENT COST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DAMAGE (1)</td>
<td>DAMAGE (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>DM 000</td>
</tr>
<tr>
<td>0.5</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>DM 1,200</td>
</tr>
<tr>
<td>1.0</td>
<td>66.7</td>
<td>23.7</td>
<td>7.3</td>
<td>2.3</td>
<td>0.0</td>
<td>DM 3,300</td>
</tr>
<tr>
<td>2.0</td>
<td>0.0</td>
<td>71.0</td>
<td>22.0</td>
<td>7.0</td>
<td>0.0</td>
<td>DM 7,524</td>
</tr>
<tr>
<td>3.0</td>
<td>0.0</td>
<td>43.0</td>
<td>34.0</td>
<td>21.0</td>
<td>1.0</td>
<td>DM 24,708</td>
</tr>
<tr>
<td>4.0</td>
<td>0.0</td>
<td>30.0</td>
<td>30.0</td>
<td>32.0</td>
<td>5.0</td>
<td>DM 60,840</td>
</tr>
<tr>
<td>5.0</td>
<td>0.0</td>
<td>15.0</td>
<td>22.0</td>
<td>45.0</td>
<td>10.0</td>
<td>DM 135,720</td>
</tr>
<tr>
<td>6.0</td>
<td>0.0</td>
<td>7.0</td>
<td>16.0</td>
<td>39.0</td>
<td>20.0</td>
<td>DM 279,720</td>
</tr>
<tr>
<td>7.0</td>
<td>0.0</td>
<td>2.0</td>
<td>10.0</td>
<td>28.0</td>
<td>30.0</td>
<td>DM 446,760</td>
</tr>
<tr>
<td>8.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.0</td>
<td>19.0</td>
<td>27.0</td>
<td>DM 676,080</td>
</tr>
<tr>
<td>9.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>7.0</td>
<td>18.0</td>
<td>DM 949,200</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>DM 2,000,000</td>
</tr>
</tbody>
</table>

Source: AASHTO Roadside Design Guide 1989 (1)
### APPENDIX 1, TABLE 3

**SEVERITY INDEX AND COST BY ACCIDENT TYPE DISTRIBUTION**

*REVISED TO REFLECT FINNISH VALUES*

<table>
<thead>
<tr>
<th>EVERITY INDEX</th>
<th>DAMAGE (1)</th>
<th>DAMAGE (2)</th>
<th>SLIGHT INJURY</th>
<th>MODERATE INJURY</th>
<th>SEVERE INJURY</th>
<th>FATAL INJURY</th>
<th>ACCIDENT COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>FIM 7,550</td>
</tr>
<tr>
<td>0.5</td>
<td>66.7</td>
<td>23.7</td>
<td>7.3</td>
<td>2.3</td>
<td>0.0</td>
<td>0.0</td>
<td>FIM 20,763</td>
</tr>
<tr>
<td>1.0</td>
<td>0.0</td>
<td>71.0</td>
<td>22.0</td>
<td>7.0</td>
<td>0.0</td>
<td>0.0</td>
<td>FIM 47,339</td>
</tr>
<tr>
<td>2.0</td>
<td>0.0</td>
<td>43.0</td>
<td>34.0</td>
<td>21.0</td>
<td>1.0</td>
<td>0.0</td>
<td>FIM 155,455</td>
</tr>
<tr>
<td>3.0</td>
<td>0.0</td>
<td>30.0</td>
<td>30.0</td>
<td>32.0</td>
<td>5.0</td>
<td>0.0</td>
<td>FIM 382,785</td>
</tr>
<tr>
<td>4.0</td>
<td>0.0</td>
<td>15.0</td>
<td>22.0</td>
<td>45.0</td>
<td>10.0</td>
<td>0.0</td>
<td>FIM 853,905</td>
</tr>
<tr>
<td>5.0</td>
<td>0.0</td>
<td>7.0</td>
<td>16.0</td>
<td>39.0</td>
<td>20.0</td>
<td>0.0</td>
<td>FIM 1,759,905</td>
</tr>
<tr>
<td>6.0</td>
<td>0.0</td>
<td>2.0</td>
<td>10.0</td>
<td>28.0</td>
<td>30.0</td>
<td>0.0</td>
<td>FIM 2,810,865</td>
</tr>
<tr>
<td>7.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.0</td>
<td>19.0</td>
<td>27.0</td>
<td>0.0</td>
<td>FIM 4,253,670</td>
</tr>
<tr>
<td>8.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>7.0</td>
<td>18.0</td>
<td>0.0</td>
<td>FIM 5,972,050</td>
</tr>
<tr>
<td>9.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>FIM 7,550,000</td>
</tr>
<tr>
<td>10.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

*Source: AASHTO Roadside Design Guide 1989 (1)*
## APPENDIX II

### SUGGESTED SEVERITY INDICES

<table>
<thead>
<tr>
<th>TYPE OF HAZARD</th>
<th>FACE</th>
<th>40 MPH</th>
<th>50 MPH</th>
<th>60 MPH</th>
<th>70 MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SIDE</td>
<td>RANGE</td>
<td>AVG</td>
<td>RANGE</td>
<td>AVG</td>
</tr>
<tr>
<td><strong>LONGITUDINAL BARRIER</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-Strand Cable</td>
<td>Face</td>
<td>2.0 - 2.4</td>
<td>2.2</td>
<td>2.2 - 2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>W-Beam (Weak)</td>
<td>Face</td>
<td>2.2 - 2.6</td>
<td>2.4</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Thrie Beam (Weak)</td>
<td>Face</td>
<td>2.2 - 2.6</td>
<td>2.4</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Blocked-out W-Beam (Strong)</td>
<td>Face</td>
<td>2.4 - 2.8</td>
<td>2.6</td>
<td>2.8 - 3.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Blocked-out Thrie-Beam (Strong)</td>
<td>Face</td>
<td>2.4 - 2.8</td>
<td>2.6</td>
<td>2.8 - 3.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Concrete Safety Shape</td>
<td>Face</td>
<td>1.8 - 2.6</td>
<td>2.3</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Stone Masonry Wall</td>
<td>Face</td>
<td>2.4 - 2.8</td>
<td>2.6</td>
<td>2.8 - 3.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Retaining Wall/Vertical Barrier</td>
<td>Face</td>
<td>2.4 - 2.8</td>
<td>2.6</td>
<td>2.8 - 3.4</td>
<td>3.1</td>
</tr>
<tr>
<td><strong>BARRIER TERMINAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-Strand Cable</td>
<td>Side</td>
<td>2.0 - 2.6</td>
<td>2.3</td>
<td>2.4 - 3.2</td>
<td>2.8</td>
</tr>
<tr>
<td>W-Beam</td>
<td>Side</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
<td>2.8 - 3.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Anchored in Backslope</td>
<td>Side</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
<td>2.8 - 3.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Breakaway Cable Terminal</td>
<td>Side</td>
<td>2.8 - 3.2</td>
<td>2.9</td>
<td>3.0 - 3.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Turned-Down</td>
<td>Side</td>
<td>2.6 - 3.2</td>
<td>2.9</td>
<td>3.0 - 3.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Concrete Safety Shape</td>
<td>Side</td>
<td>2.8 - 3.2</td>
<td>2.9</td>
<td>3.0 - 3.8</td>
<td>3.4</td>
</tr>
<tr>
<td>80 ft Sloped End</td>
<td>Side</td>
<td>2.6 - 5.0</td>
<td>3.8</td>
<td>3.2 - 6.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Obsolete/Nonfunctional</td>
<td>Side</td>
<td>2.6 - 3.2</td>
<td>2.9</td>
<td>3.0 - 3.8</td>
<td>3.4</td>
</tr>
<tr>
<td><strong>CRASH CUSHION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hi-Dro Cell</td>
<td>Both</td>
<td>2.0 - 2.6</td>
<td>2.3</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>G-R-E-A-T System</td>
<td>Both</td>
<td>2.0 - 2.6</td>
<td>2.3</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Hex-Form Sandwich</td>
<td>Both</td>
<td>2.0 - 2.6</td>
<td>2.3</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Sand-Filled Plastic Barrels</td>
<td>Both</td>
<td>2.0 - 2.6</td>
<td>2.3</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
</tr>
</tbody>
</table>

### FACTORS THAT AFFECT SEVERITY RANGE

**Low Range:**
New installation with proper design, placement and maintenance, area between the travel lane and hardware is flat and free of obstructions, runout area behind hardware clear, recovery area for redirection, adequate soil resistance, proper clearance from obstacle behind barrier, no curb in front/under.

**Mid Range:**
Existing installation in fair condition and properly maintained, area between the travel lane and hardware is relatively flat and free of obstructions, no runout area behind hardware, some recovery area for redirection, questionable soil resistance, proper clearance from obstacle behind barrier in most cases, curb under barrier.

**High Range:**
Existing installation in questionable condition and/or poorly maintained, height of rail low, bolts or blockouts missing, steep shoulder slope, curb in front, questionable placement with respect to hinge point, inadequate length for tension, high possibility of impact from several directions, insufficient anchorage improper flare or runout cross-section at terminal, not anchored properly.

Source: Supplemental Information for Use with the Roadside Computer Program, 1991 (6)
### APPENDIX II

#### SUGGESTED SEVERITY INDICES

<table>
<thead>
<tr>
<th>TYPE OF HAZARD</th>
<th>FACE SIDE</th>
<th>40 MPH</th>
<th>50 MPH</th>
<th>60 MPH</th>
<th>70 MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RANGE</td>
<td>AVG</td>
<td>RANGE</td>
<td>AVG</td>
<td>RANGE</td>
</tr>
<tr>
<td>PARALLEL SLOPES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreslopes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:1</td>
<td>Face</td>
<td>0.2 - 0.6</td>
<td>0.4</td>
<td>0.4 - 1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>6:1</td>
<td>Face</td>
<td>0.4 - 0.8</td>
<td>0.6</td>
<td>0.8 - 1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>4:1</td>
<td>Face</td>
<td>1.0 - 1.4</td>
<td>1.2</td>
<td>1.4 - 2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>3:1</td>
<td>Face</td>
<td>1.8 - 2.0</td>
<td>1.8</td>
<td>2.2 - 2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>2:1</td>
<td>Face</td>
<td>2.4 - 2.8</td>
<td>2.6</td>
<td>3.2 - 3.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Backslopes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4:1</td>
<td>Face</td>
<td>0.8 - 1.0</td>
<td>0.8</td>
<td>0.8 - 1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>3:1</td>
<td>Face</td>
<td>1.0 - 1.4</td>
<td>1.2</td>
<td>1.4 - 2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>2:1</td>
<td>Face</td>
<td>1.8 - 2.2</td>
<td>2.0</td>
<td>2.2 - 2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Vertical Rock Cut</td>
<td>Smooth</td>
<td>Face</td>
<td>2.4 - 2.8</td>
<td>2.6</td>
<td>2.8 - 3.4</td>
</tr>
<tr>
<td></td>
<td>Rough</td>
<td>Face</td>
<td>2.8 - 3.2</td>
<td>3.0</td>
<td>3.4 - 4.0</td>
</tr>
<tr>
<td>CROSS SLOPES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Embankment (Uphill)</td>
<td>Side</td>
<td>0.2 - 0.8</td>
<td>0.4</td>
<td>0.8 - 1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>10:1</td>
<td>Side</td>
<td>1.0 - 1.4</td>
<td>1.2</td>
<td>1.4 - 2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>6:1</td>
<td>Side</td>
<td>1.8 - 2.2</td>
<td>2.0</td>
<td>2.4 - 3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>4:1</td>
<td>Side</td>
<td>2.0 - 2.4</td>
<td>2.2</td>
<td>2.8 - 3.4</td>
<td>3.1</td>
</tr>
<tr>
<td>3:1</td>
<td>Side</td>
<td>2.2 - 3.6</td>
<td>3.4</td>
<td>4.0 - 4.6</td>
<td>4.3</td>
</tr>
<tr>
<td>Vertical Rock Cut</td>
<td>Side</td>
<td>4.2 - 5.0</td>
<td>4.6</td>
<td>5.0 - 6.0</td>
<td>5.5</td>
</tr>
</tbody>
</table>

#### FACTORS THAT AFFECT SEVERITY RANGE

**Low Range:**
- Low fill or cut height (0 ft to 4 ft), no objects on slope, traversable (smooth texture such as cut turf or soil), no erosion to trip vehicle, recoverable area within clear zone, rounded hinge points.

**Mid Range:**
- Medium fill or cut height (4 ft to 8 ft), objects on slope with less severity (high range) than slope, minor irregular texture (such as uncut or bush-type vegetation, poorly graded soil), minor erosion, recoverable area within clear zone (maybe slightly less if consistent through corridor), hinge point with minimum rounding.

**High Range:**
- Fill or cut height greater than 8 ft, objects with approximately same severity within clear zone, rough texture (i.e. riprap etc), hinge point not rounded.

*Source: Supplemental Information for Use with the Roadside Computer Program, 1991 (6)*
### SUGGESTED SEVERITY INDICES

<table>
<thead>
<tr>
<th>TYPE OF HAZARD</th>
<th>FACE SIDE</th>
<th>40 MPH</th>
<th>50 MPH</th>
<th>60 MPH</th>
<th>70 MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>DITCH</td>
<td>BOTH</td>
<td>RANGE</td>
<td>AVG</td>
<td>RANGE</td>
<td>AVG</td>
</tr>
<tr>
<td>Foreslope</td>
<td>Backslope</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:1 Face</td>
<td></td>
<td>1.8 - 3.2</td>
<td>2.1</td>
<td>2.2 - 3.2</td>
<td>2.7</td>
</tr>
<tr>
<td>4:1 Face</td>
<td></td>
<td>1.2 - 2.6</td>
<td>1.5</td>
<td>1.8 - 2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>6:1 Face</td>
<td></td>
<td>1.0 - 2.2</td>
<td>1.3</td>
<td>1.4 - 2.2</td>
<td>1.8</td>
</tr>
<tr>
<td>3:1 Face</td>
<td></td>
<td>1.2 - 2.6</td>
<td>1.5</td>
<td>1.8 - 2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>4:1 Face</td>
<td></td>
<td>1.0 - 2.2</td>
<td>1.3</td>
<td>1.4 - 2.2</td>
<td>1.8</td>
</tr>
<tr>
<td>6:1 Face</td>
<td></td>
<td>0.8 - 1.1</td>
<td>1.1</td>
<td>1.2 - 1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>3:1 Face</td>
<td></td>
<td>1.0 - 2.2</td>
<td>1.3</td>
<td>1.4 - 2.2</td>
<td>1.8</td>
</tr>
<tr>
<td>4:1 Face</td>
<td></td>
<td>0.8 - 1.1</td>
<td>1.1</td>
<td>1.2 - 1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>6:1 Face</td>
<td></td>
<td>0.6 - 1.2</td>
<td>0.9</td>
<td>1.0 - 1.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

| CULVERT OPENING |          |        |        |        |        |        |        |        |        |        |        |
| Cross Culvert   |          |        |        |        |        |        |        |        |        |        |        |
| Pipe End Dia. < 3 ft Both | 1.6 - 2.8 | 2.2 | 1.8 - 3.2 | 2.5 | 2.2 - 3.8 | 3.0 | 2.8 - 4.4 | 3.5 |
| Pipe End Dia. > 3 ft Both | 2.8 - 4.0 | 3.4 | 3.2 - 4.6 | 3.9 | 3.6 - 5.4 | 4.6 | 4.4 - 6.2 | 5.3 |
| Sloped w/Bar Grates Both | <--- USE VALUES FOR APPROPRIATE PARALLEL SLOPE----- --> |

| Parallel Culvert |          |        |        |        |        |        |        |        |        |        |        |
| Pipe End Dia. < 3 ft Side | 1.8 - 3.0 | 2.4 | 2.0 - 3.4 | 2.7 | 2.4 - 4.0 | 3.2 | 2.8 - 4.8 | 3.7 |
| Pipe End Dia. > 3 ft Side | 3.0 - 4.2 | 3.6 | 3.4 - 4.8 | 4.1 | 4.0 - 5.6 | 4.8 | 4.6 - 6.4 | 5.5 |
| Sloped w/Bar Grates Side | <--- USE VALUES FOR APPROPRIATE CROSS SLOPE----- --> |

| MISC. DRAINAGE ITEMS |          |        |        |        |        |        |        |        |        |        |        |
| Raised inlet w/Grate Both | <--- USE VARIABLE HEIGHT VALUES WITH APPROPRIATE HEIGHT --> |
| Rip-rap               |          |        |        |        |        |        |        |        |        |        |        |
| Avg. D1a. < 6" Both   | 0.4 - 1.0 | 0.7 | 1.0 - 1.8 | 1.4 | 1.4 - 2.4 | 1.9 | 1.8 - 3.0 | 2.4 |
| Avg. D1a. = 6" - 10" Both | 1.0 - 2.6 | 1.8 | 1.4 - 3.2 | 2.3 | 1.8 - 3.8 | 2.8 | 2.2 - 4.4 | 3.3 |
| Avg. D1a. > 10" Both   | 2.6 - 5.0 | 3.8 | 3.2 - 6.0 | 4.6 | 3.8 - 7.2 | 5.5 | 4.4 - 8.6 | 6.5 |
| Permanent Stream/Pond   |          |        |        |        |        |        |        |        |        |        |        |
| Depth < 3 ft Both   | 1.0 - 5.0 | 3.0 | 1.6 - 5.6 | 3.6 | 2.2 - 6.2 | 4.2 | 3.0 - 7.0 | 5.0 |
| Depth > 3 ft Both   | 5.0 - 6.0 | 5.5 | 5.6 - 6.8 | 6.2 | 6.2 - 7.8 | 6.9 | 7.0 - 8.6 | 7.8 |

### FACTORS THAT AFFECT SEVERITY RANGE

**Note:** For slopes flatter than 6:1 or greater than 3:1, use the appropriate parallel slope values.

**Low Range:**
- Depth of ditch 0 ft to 1 ft, flat ditch cross-section (rounded with bottom width > 8 ft, trapezoidal with bottom > 4 ft), smooth graded surface, rounded hinge points, backslopes clear of objects, flat recoverable area between culvert opening and travelway, smaller diameter culvert pipe, tapered culvert end section (18 inches or less), no erosion, properly maintained and clear of debris.

**Mid Range:**
- Depth of ditch 1 ft to 2.5 ft, objects with approximately the same severity within cross-section, recoverable cross-section between obstacle and travelway, projecting 24 inch (or less) culvert end section, minor erosion around opening or inlet.

**High Range:**
- Depth of ditch greater than 2.5 ft, cross-section with abrupt slope changes (Vee ditch, rounded with bottom width < 8 ft, trapezoidal bottom width < 4 ft), fixed objects on backslopes, steeper cross-section between obstacle and travelway, projecting culvert end section, large culvert diameter, erosion around opening or inlet.

*Source: Supplemental Information for Use with the Roadside Computer Program, 1991 (6)*
## SUGGESTED SEVERITY INDICES

<table>
<thead>
<tr>
<th>TYPE OF HAZARD</th>
<th>FACE SIDE</th>
<th>(40) MPH</th>
<th>(50) MPH</th>
<th>(60) MPH</th>
<th>(70) MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BOTH</td>
<td>RANGE</td>
<td>AVG</td>
<td>RANGE</td>
<td>AVG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(40) MPH</td>
<td>(50) MPH</td>
<td>(60) MPH</td>
<td>(70) MPH</td>
</tr>
<tr>
<td>RIGID OBJECTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree</td>
<td>Both</td>
<td>0.4 - 2.6</td>
<td>1.5</td>
<td>0.6 - 3.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Diameter &lt; 4 in.</td>
<td>Both</td>
<td>2.6 - 5.0</td>
<td>3.8</td>
<td>3.2 - 6.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Diameter &gt; 4 in.</td>
<td>Both</td>
<td>2.6 - 5.0</td>
<td>3.8</td>
<td>3.2 - 6.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Utility Pole</td>
<td>Both</td>
<td>2.6 - 5.0</td>
<td>3.8</td>
<td>3.2 - 6.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Bridge Pier</td>
<td>Both</td>
<td>2.6 - 5.0</td>
<td>3.8</td>
<td>3.2 - 6.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Rigid Sign Support</td>
<td>Single/Multiple</td>
<td>2.2 - 4.6</td>
<td>3.4</td>
<td>2.8 - 5.6</td>
<td>4.2</td>
</tr>
<tr>
<td>Cantilever/Overhead</td>
<td>Both</td>
<td>2.6 - 5.0</td>
<td>3.8</td>
<td>3.2 - 6.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Breakaway Sign support</td>
<td>Fracture</td>
<td>Both</td>
<td>0.6 - 1.0</td>
<td>0.8</td>
<td>0.8 - 1.4</td>
</tr>
<tr>
<td>Mechanical/Yielding</td>
<td>Both</td>
<td>0.8 - 1.2</td>
<td>1.0</td>
<td>1.0 - 1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Rigid Base Luminaire Support</td>
<td>Both</td>
<td>2.6 - 5.0</td>
<td>3.8</td>
<td>3.2 - 6.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Breakaway Luminaire Support</td>
<td>Both</td>
<td>2.0 - 2.4</td>
<td>2.2</td>
<td>2.2 - 2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Headwall, Pedestal, Foundation</td>
<td>Height &lt; 4°</td>
<td>Both</td>
<td>0.6 - 1.0</td>
<td>0.8</td>
<td>1.0 - 1.8</td>
</tr>
<tr>
<td></td>
<td>Height = 4°-10°</td>
<td>Both</td>
<td>1.0 - 2.6</td>
<td>1.8</td>
<td>1.8 - 3.2</td>
</tr>
<tr>
<td></td>
<td>Height &gt; 10°</td>
<td>Both</td>
<td>2.6 - 5.0</td>
<td>3.8</td>
<td>3.2 - 6.0</td>
</tr>
<tr>
<td>Edge Drop-Off</td>
<td>Height &lt; 4°</td>
<td>Face</td>
<td>0.4 - 1.0</td>
<td>0.7</td>
<td>0.6 - 1.4</td>
</tr>
<tr>
<td></td>
<td>Height = 4°-10°</td>
<td>Face</td>
<td>1.0 - 1.6</td>
<td>1.3</td>
<td>1.4 - 2.2</td>
</tr>
<tr>
<td></td>
<td>Height &gt; 10°</td>
<td>Face</td>
<td>1.6 - 2.2</td>
<td>1.9</td>
<td>2.2 - 3.0</td>
</tr>
<tr>
<td>Curb</td>
<td>Mountable (&lt; 6 in.)</td>
<td>Face</td>
<td>0.6 - 1.0</td>
<td>0.8</td>
<td>1.0 - 1.8</td>
</tr>
<tr>
<td>Non-Mountable (6-10 in.)</td>
<td>Face</td>
<td>1.2 - 2.6</td>
<td>1.9</td>
<td>1.6 - 3.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Barrier (&gt; 10 in.)</td>
<td>Face</td>
<td>2.6 - 3.2</td>
<td>2.9</td>
<td>3.0 - 3.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Fire Hydrant</td>
<td>Both</td>
<td>1.8 - 2.4</td>
<td>2.1</td>
<td>2.2 - 3.0</td>
<td>2.6</td>
</tr>
<tr>
<td>Mail Box</td>
<td>Both</td>
<td>1.2 - 2.2</td>
<td>1.7</td>
<td>1.6 - 2.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Chainlink Fence</td>
<td>Face</td>
<td>1.4 - 1.8</td>
<td>1.6</td>
<td>2.0 - 2.6</td>
<td>2.3</td>
</tr>
</tbody>
</table>

### FACTORS THAT AFFECT SEVERITY RANGE

Note: The surrounding slope may be more severe than the object on it. Additionally, another hazard directly beyond the object may be more severe. In most cases the highest severity index should be used.

**Low Range:**
Object on uphill backslope where less likely to be hit, non-fragile diameter is small, new installation of frangible object with clear recovery area behind, top of base flush with ground, no erosion around base.

**Mid Range:**
Object on relatively flat slope (recoverable), new installation of sign support on relatively flat slope, proper design, installation and maintenance, top of base less than 4 inches above ground, no erosion around base.

**High Range:**
Object on 4:1 or steeper slope (non-recoverable), non-frangible diameter is large, improper placement and/or design of post, base located at hinge, erosion around base, improper maintenance of sign support and breakaway device.

Source: Supplemental Information for Use with the Roadside Computer Program, 1991(6)
## APPENDIX III

### PRESENT VALUE FACTORS

<table>
<thead>
<tr>
<th>Discount Rate (Percent)</th>
<th>0.0</th>
<th>1.0</th>
<th>2.0</th>
<th>3.0</th>
<th>4.0</th>
<th>5.0</th>
<th>6.0</th>
<th>7.0</th>
<th>8.0</th>
<th>9.0</th>
<th>10.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1.000</td>
<td>0.990</td>
<td>0.980</td>
<td>0.971</td>
<td>0.962</td>
<td>0.952</td>
<td>0.943</td>
<td>0.935</td>
<td>0.926</td>
<td>0.917</td>
<td>0.909</td>
</tr>
<tr>
<td>2.0</td>
<td>0.970</td>
<td>0.941</td>
<td>0.913</td>
<td>0.886</td>
<td>0.859</td>
<td>0.833</td>
<td>0.808</td>
<td>0.783</td>
<td>0.757</td>
<td>0.731</td>
<td>0.707</td>
</tr>
<tr>
<td>3.0</td>
<td>0.941</td>
<td>0.884</td>
<td>0.829</td>
<td>0.775</td>
<td>0.723</td>
<td>0.673</td>
<td>0.624</td>
<td>0.577</td>
<td>0.531</td>
<td>0.497</td>
<td>0.463</td>
</tr>
<tr>
<td>4.0</td>
<td>0.902</td>
<td>0.808</td>
<td>0.717</td>
<td>0.630</td>
<td>0.546</td>
<td>0.465</td>
<td>0.387</td>
<td>0.312</td>
<td>0.240</td>
<td>0.170</td>
<td>0.115</td>
</tr>
<tr>
<td>5.0</td>
<td>0.853</td>
<td>0.713</td>
<td>0.580</td>
<td>0.452</td>
<td>0.329</td>
<td>0.212</td>
<td>0.100</td>
<td>0.039</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>6.0</td>
<td>0.795</td>
<td>0.561</td>
<td>0.417</td>
<td>0.242</td>
<td>0.107</td>
<td>0.047</td>
<td>0.007</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>7.0</td>
<td>0.728</td>
<td>0.472</td>
<td>0.230</td>
<td>0.002</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>8.0</td>
<td>0.651</td>
<td>0.325</td>
<td>0.020</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>9.0</td>
<td>0.565</td>
<td>0.162</td>
<td>0.086</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>10.0</td>
<td>0.471</td>
<td>0.082</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Source: AASHTO Roadside Design Guide, 1989 (1)

VTI RAPPORT 380A
REFERENCES


REFERENCES (continued)


Development of a New Concept in Emergency Truck Escape Ramp Design

Robert A Mileti, P E
Chief Engineer
Roadway Safety Services, Inc
U S A
DEVELOPMENT OF A NEW CONCEPT IN EMERGENCY TRUCK ESCAPE RAMP DESIGN

R. A. Mileti, P.E.
Roadway Safety Service, Inc.
Ronkonkoma, New York

Large commercial vehicles which have lost control in hilly terrain present a major challenge to engineers concerned with highway safety. The criteria of 37,000 Kg at 100 kilometers per hour and under 1.0 "G" must be met. The most common approach to this problem is the construction of truck emergency escape ramps, usually employing deep-gravel arrestor beds. In this approach, a separate lane is constructed off the main road. This lane, or ramp, is typically one hundred to two hundred meters in length and surfaced with either rounded riverbed gravel or angular crushed gravel in depths varying from one to two meters. While these arrestor beds are generally effective in bringing an out-of-control truck to a stop, there are many serious drawbacks to their use. First, there is the problem of extracting the stopped vehicle from the arrestor bed, since it is now mired in gravel up to its axles. A high-capacity tow truck is usually required. Even then, some means of rigid under-wheel planking is needed to distribute the load more evenly as the truck is being hauled out. The "porpoising" of the truck as it enters the gravel is another disadvantage. In addition, constant maintenance of the arrestor bed is required to prevent settling and compaction. In freezing temperature special attention must be paid to de-icing, as well as grooming and combing the gravel to maintain efficacy.

The Dragnet Vehicle Arresting Barrier has seen widespread use in the United States to safely stop passenger vehicles from intruding into perilous areas such as construction zones, open drawbridges, reversible traffic lanes, emergency road closures, etc. It is designed to stop errant vehicles with very low accelerations and minimal damage. A typical system consists of a net made of steel cables and chain link fence attached at each end to energy absorbers. The energy absorbers are supported by anchor posts that are either imbedded into the pavement or attached to the longitudinal barriers. The energy absorbers are steel chambers containing a series of staggered rollers around which a long length of metal tape or strap is bent back and forth as it is pulled through this "torture chamber". Each end of the net is attached to one end of these metal tapes protruding from the energy absorber case. These devices are designed so that a specific force is required to pull the tape through the chamber. This force is constant and not dependent of the impact velocity. It is rather a function of the geometry and material properties of the tape material. Basically, the capability of the system to absorb kinetic energy is the product of the restraining force of both energy
The success of the Dragnet, which was originally developed for use on board aircraft carriers, led its designers to investigate the possibility of adapting it for use in emergency truck ramps. A series of development tests was performed to determine changes in net materials and geometries that were required to make it function when subjected to the vastly increased kinetic energies of the broad spectrum of impacting trucks. A full-scale crash test of a prototype Dragnet truck escape ramp was successfully performed. This ramp employed a series of Dragnet installations at various stations along a paved surface. The energy absorbers were anchored to concrete median barrier on either side of the paved ramp.

Installation of several Dragnet emergency truck escape ramps are scheduled for construction early in 1993 in Hawaii, Massachusetts, and British Columbia.
DEVELOPMENT OF A NEW CONCEPT IN EMERGENCY TRUCK ESCAPE RAMP DESIGN
Robert A. Mileti, P.E.
Chief Engineer
Roadway Safety Services, Inc.
Ronkonkoma, NY

1. INTRODUCTION

Large commercial vehicles which have lost control in hilly terrain present a major challenge to engineers concerned with highway safety. The desired criteria for constructing escape ramps is to stop an 80,000 lb. (36,400 kg.) truck entering the ramp at 80 mph (129 km/hr) with a deceleration of 0.5 g or less.

The most common approach to this problem is the construction of truck emergency escape ramps employing deep-gravel arrestor beds. In this approach, a separate lane is constructed off the main road. See Figure 1. This lane, or ramp, is typically one hundred to two hundred meters in length and surfaced with either riverbed gravel or angular crushed gravel in depths varying from one to two meters. While these arrestor beds are generally effective in bringing an out-of-control truck to a stop, there are many serious drawbacks to their use. First, there is the problem of extracting the stopped truck from the arrestor bed, since it is now mired up to its axles in deep gravel. A high-capacity tow truck is usually required. Even then some means of rigid under-wheel planking will be needed to distribute the load more evenly as the truck is being hauled out. The pitching and yawing of the truck as it enters the bed is yet another disadvantage of this type escape ramp.

Roadway Safety Service, Inc. engineers, in their search for an improved emergency truck ramp, have modified and tested a ramp equipped with a series of Dragnet Vehicle Arresting Barriers which can be easily erected on a paved surface equipped with longitudinal concrete median barriers on both sides.

2. THE DRAGNET SYSTEM

The Dragnet Vehicle Arresting Barrier System is patented and manufactured by the Entwistle Company of Hudson, Massachusetts, a major supplier of products and technology for the various branches of the U.S. Armed Forces. The system is an outgrowth of the crash nets formerly used on aircraft carriers.

It has seen widespread use in the United States to safely stop passenger vehicles from intruding into perilous areas such as construction zones, open drawbridges, reversible traffic lanes, railroad crossings, emergency road closures, etc. It is designed to stop errant vehicles with very low accelerations and minimal damage. A typical system, shown in Figure 2, consists of a net made of a continuous steel cable and chain link fence attached at each end to energy absorbers. The energy absorbers are supported by anchor posts that are embedded into the pavement or the road shoulder or attached to longitudinal barriers. These energy absorbers, which are the heart of the Dragnet System, are steel chambers containing a series of staggered rollers around which a long length of metal tape or strap is bent back and forth as it is pulled through this deformation chamber. Each end of the net is attached to one end of these metal tapes protruding from the energy absorber case. A cut-a-way view of the device is shown in Figure 3. A photograph is included as Figure 4. These energy absorbers are designed so that a specific force is required to pull the tape through the chamber. This force is constant and not dependent on the impact velocity or environmental conditions.
conditions. It is rather a function of the geometry and the material properties of the tape material. Basically, the capability of the system to absorb kinetic energy is the product of the restraining force of both energy absorbers and the runout distance of the metal tapes.

Equation 1  \[ C = T \left( R_1 + R_2 \right) \]

where

\( C \) = capacity of Dragnet,

\( T \) = pullout force of one energy absorber,

\( R_1 \) = runout distance of left side absorber,

\( R_2 \) = runout distance of right side absorber,

Dragnet System absorber units are rated first by the amount of force needed to initiate pull of the tape. The absorber units are provided in differing lengths as follows:

<table>
<thead>
<tr>
<th>RATED PULL OUT FORCE</th>
<th>TAPE LENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,500 pounds (20.016 kilonewtons)</td>
<td>75 feet (22.86 meters)</td>
</tr>
<tr>
<td>4,500 pounds (20.016 kilonewtons)</td>
<td>200 feet (60.96 meters)</td>
</tr>
<tr>
<td>18,000 pounds (80.064 kilonewtons)</td>
<td>40 feet (12.19 meters)</td>
</tr>
</tbody>
</table>

As there is one absorber at each end of the fence or net assembly, a hit automatically activates both absorbers. Therefore, to calculate total capacity, the combined energy force of two absorbers must be used. By reference to Equation 1, we can then determine the attenuating capacities for these standard units as follows:

2 Units of 4500 lbs with 75 foot tape \[ 675,000 \text{ ft lbs (915.132 kn•m)} \]
2 Units of 4500 lbs with 200 foot tape \[ 1,800,000 \text{ ft lbs (2440.351 kn•m)} \]
2 Units of 18,000 lbs with 40 foot tape \[ 1,440,000 \text{ ft lbs (1951.960 kn•m)} \]

By equating these capacities to the kinetic energy of an impacting vehicle we can calculate the maximum permissible impact velocity of a given weight car. This has been done for a range of vehicle weights in Table 1 for the 4500 lb Energy Absorber with 75 foot tapes and in Table 2 for the 4500 lb Energy Absorber with 200 foot tapes. Tables 1A and 2A report the same data in the metric system. It should be noted that these values are somewhat conservative since only the restraining force of the tapes has been considered effective in stopping the vehicle. Other factors such as tire friction, braking and aerodynamic drag have been ignored.

The maximum theoretical acceleration is simply the restraining force in the tapes divided by the weight of the vehicle and can only be approached when the tapes are parallel to the velocity vector of the impacting vehicle. Initial accelerations may be lower as indicated in the schematic of Figure 5.

The Dragnet System has been extensively tested for a wide variety of vehicle weights up to speeds of 70 mph (112.7 km/hr) and at impact angles up to 30°. Many in-service reports have substantiated the excellent performance of the Dragnet System in the field.
### Table 1
Capacity of 4500 lb Energy Absorbers with 75 foot tapes

<table>
<thead>
<tr>
<th>Vehicle Weight (lbs)</th>
<th>Max Permissible Velocity (ft/sec)</th>
<th>Max Velocity (mph)</th>
<th>Max Theoretical Acceleration (G's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>155.4</td>
<td>106.0</td>
<td>5.0</td>
</tr>
<tr>
<td>4500</td>
<td>98.3</td>
<td>67.0</td>
<td>2.0</td>
</tr>
<tr>
<td>20000</td>
<td>46.6</td>
<td>31.8</td>
<td>0.45</td>
</tr>
<tr>
<td>40000</td>
<td>33.0</td>
<td>22.5</td>
<td>0.23</td>
</tr>
</tbody>
</table>

### Table 1A
Capacity of 20 kn Energy Absorbers with 22.86 m tapes

<table>
<thead>
<tr>
<th>Vehicle Weight (kgs)</th>
<th>Max Permissible Velocity (km/hr)</th>
<th>Max Theoretical Acceleration (G's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>549</td>
<td>170.6</td>
<td>5.0</td>
</tr>
<tr>
<td>1372</td>
<td>107.8</td>
<td>2.0</td>
</tr>
<tr>
<td>6096</td>
<td>51.2</td>
<td>0.45</td>
</tr>
<tr>
<td>12192</td>
<td>36.2</td>
<td>0.23</td>
</tr>
</tbody>
</table>

### Table 2
Capacity of 4500 lb Energy Absorbers with 200 foot tapes

<table>
<thead>
<tr>
<th>Vehicle Weight (lbs)</th>
<th>Max Permissible Velocity (ft/sec)</th>
<th>Max Velocity (mph)</th>
<th>Max Theoretical Acceleration (G's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>253.8</td>
<td>173.0</td>
<td>5.0</td>
</tr>
<tr>
<td>4500</td>
<td>160.5</td>
<td>109.4</td>
<td>2.0</td>
</tr>
<tr>
<td>20000</td>
<td>76.1</td>
<td>51.9</td>
<td>0.45</td>
</tr>
<tr>
<td>40000</td>
<td>53.8</td>
<td>36.7</td>
<td>0.23</td>
</tr>
<tr>
<td>80000</td>
<td>38.1</td>
<td>26.0</td>
<td>0.11</td>
</tr>
</tbody>
</table>

### Table 2A
Capacity of 20 kn Energy Absorbers with 60.9 m tapes

<table>
<thead>
<tr>
<th>Vehicle Weight (kgs)</th>
<th>Max Permissible Velocity (km/hr)</th>
<th>Max Theoretical Acceleration (G's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>549</td>
<td>278.4</td>
<td>5.0</td>
</tr>
<tr>
<td>1372</td>
<td>176.0</td>
<td>2.0</td>
</tr>
<tr>
<td>6096</td>
<td>83.5</td>
<td>0.45</td>
</tr>
<tr>
<td>12192</td>
<td>59.1</td>
<td>0.23</td>
</tr>
<tr>
<td>24384</td>
<td>41.8</td>
<td>0.11</td>
</tr>
</tbody>
</table>
3. **APPLICATIONS**

Some current applications for the Dragnet are illustrated in Figures 6 through 10.

4. **INITIAL UP-SCALING OF THE DRAGNET**

There are some problems to be investigated in up-scaling the performance of the Dragnet to include runaway trucks weighing 80,000 lbs (36,400 kg) travelling at 80 mph (129 km/hr). Such a vehicle possesses 40 times the kinetic energy of a passenger vehicle weighing 3500 lbs (1590 kg) travelling at 60 mph (97 km/hr). In order to minimize load shifting and jack-knifing of articulated trucks, it is desirable to keep the restraining forces down to 0.5 g. In addition, the population of heavy trucks on the road today, represents a large variety in front-end geometry which must interface with the arresting nets. In some vehicles, especially the cab-over-engine types the vertical plane of the front bumper/radiator may be as little as six inches (15.25 cm) forward of the plane formed by vertical tangents to the front of the front tires. (See Figure 11) In these cases there is the possibility of the net being pulled under the tires before it is actually secured to the front of the truck, rendering the system ineffective. It is also necessary to allow for the possibility of a passenger vehicle entering the ramp without serious damage or harm to its occupants.

Last but not least, is the difficulty in performing full-scale crash tests of such large vehicles travelling at these high velocities.

During the course of a series of full-scale passenger vehicles crash tests at CALSPAN to investigate the performance of a new reusable fiber net, Roadway Safety Service, Inc had the opportunity to perform a test using a truck tractor which was available at the test facility. The facility did not have the capability to tow the truck into the net but agreed to use a live driver to impact a single net at 37 mph (60 km/hr). The weight of the tractor was 14,300 lbs (6,492 kg). No brakes were applied but the driver de-clutched at impact so that the truck was “free-wheeling” during deceleration. Performance was ideal. The truck was brought to a stop in 85.8 feet (26.2 meters). Tape runouts were 67.6 feet (20.6 meters) and 69.1 feet (21.1 meters) with no significant yawing. The Spectra fiber net was undamaged except the plastic (PVC) end posts which are designed to be expendable.

While encouraged by this initial test we realized its shortcomings. The speed and mass were still far below desired criteria. The tractor had no trailer which might jack-knife and, furthermore, the truck bumper was protuberant affording an excellent target for the net. Nevertheless, the favorable results pointed strongly to the need for an operational test.

5. **OPERATIONAL TESTS**

5.1 **Test Objectives**

5.1.1 To demonstrate the performance of a Dragnet Truck Escape ramp under realistic operational conditions.

5.1.2 To demonstrate the capability of the Dragnet ramp to engage multiple nets.

5.1.3 To investigate the effects of “unfavorable” (flat cab-over-engine) truck geometry.
5.2 Test Description

5.2.1 The Ramp

A simulated escape ramp was constructed on an inactive runway of the Orange Municipal Airport in Orange, Massachusetts. A double line of 10 foot (3 meter) sections of standard pre-cast concrete median barriers 210 feet (64 meters) in length, spaced 25 feet (7.6 meters) apart were set onto the asphalt runway surface. The barrier segments were not attached to the runway surface but were connected to adjacent sections with vertical pins made from rebar looped through rebar “eyes” protruding from each section. See Figure 12. Three Dragnet assemblies were installed at 50 foot (15.2 meter) intervals beginning 12.5 feet (3.8 meters) from the start of the concrete median barriers. A fourth set of energy absorbers supporting a single steel cable across the lane was installed in the next to last set of concrete median barriers as a safety measure although calculations showed the truck would stop prior to engaging this station.

The energy absorbers were installed in weldments attached to 1 1/2 diameter (38 mm) threaded rod passing through the concrete median and a back-up section of median barrier as shown in Figure 13. Had 20 foot sections been available this would have been unnecessary but the ten-foot sections were not heavy enough to provide sufficient friction to resist the 4500 pound (20.016 kilonewton) force generated by the pull of the energy absorbers.

5.2.2 The Nets

The nets were constructed from 1/2 inch (12.7 mm) Spectra (Extended Chain Polyethylene Fiber) rope woven in a 6 inch (15.24 cm) by 8 inch (20.32 cm) mesh. Each horizontal rope strand was woven into a loop through which passed an end post fabricated from 3 inch (7.62 cm) polyvinyl chloride plastic pipe. Steel cable, 3/8 inch (9.53 mm) in diameter looped through each endpost and the fitting at the end of the energy absorber tape at each end as shown in Figure 14. The width of each net was approximately 12 feet (3.66 meters).

5.2.3 The Truck

The test vehicle was a 1980 Kenilworth cab-over-engine tractor pulling a standard enclosed 40 foot (12.2 meter) trailer loaded with palletized sand bags. The pallets were not tied down to the floor of the trailer. The gross weight of the rig was 52,460 lbs (23,817 kg).

5.2.4 Test Conditions

The truck, operated by a live driver, impacted the net at 50 mph (80.5 km/hr) in a light rain. The road surface was wet. The driver de-clutched at impact; no brakes were applied.

5.2.5 Test Results

The test vehicle was brought to a safe stop in 128.5 feet (39.2 meters). There was little or no pitch roll or yaw which could be detected. The truck suffered only minor damage limited to broken headlights on the left side and minor bending of the bumper.
In an unexpected development, the nets were able to bunch-up and pass through the space between the top of the bumper and the bottom of the radiator grill, permitting the tensioned nets to come into contact with the front tires. This provided considerable additional braking force which resulted in the vehicle stopping well short of its calculated stopping distance of 226 feet (68.9 meters). This calculated value was based on only the restraining forces of the energy absorbers and ignored tire-pavement friction, aerodynamic drag and any thermal energy developed by heating several hundred pounds of steel tape to considerable temperatures.

Neither the driver nor the onboard cameraman suffered any discomfort, experiencing the same sensations caused by a hard braking stop.

After removal of the nets, the truck was able to back out of the ramp.

The average acceleration based on the initial velocity and the stopping distance was 0.65 g.

6. CONCLUSIONS

All the test objectives were successfully achieved.

6.1 The performance of the Dragnet truck ramp has been demonstrated under realistic operational conditions.

6.2 The capability of the system to engage multiple nets has been demonstrated.

6.3 The capability of the system to successfully stop “worst case” cab-over-engine trucks with only minor problems has been shown.

7. FUTURE EFFORT

Roadway Safety Service, Inc. believes the Dragnet truck ramp to be a viable alternative to the gravel arrestor beds. We feel, however, that additional testing to optimize net materials and geometry suitable for the largest percentage of the truck population may be required. Each type net which has been tested, chain link/cable, Spectra fiber and steel cable has its particular advantages for a specific vehicle. We hope to develop a Universal net design which will be acceptable for all vehicles and to demonstrate its capability in the very near future.
Figure 1 – Typical Gravel Bed Arrestor Truck Ramp
1. Net ass'y comes complete with end support brackets & center support disc.
2. Energy absorber comes complete with tape assembly, cable spool and attachment bolt.
3. Post socket -4 may be used if anchor post is to be removable.

Figure 2 – Typical Dragnet System
Figure 3 – Cut-a-way View of Energy Absorber
Figure 4 – Photograph of Energy Absorbers
Figure 5 — Schematic of “G” onset as a function of distance travelled.
Figure 7 - Dragnet Protecting Openings Between Parallel Highways
Figure 8 – Dragnet at Railroad Crossing
Figure 10 – Dragnet Use for Emergency Road Closing
Figure 11 - Critical Truck Geometry

y must be < x

net depth
Figure 12 – Overall View of Test Ramp

Figure 13 – Mounting of Energy Absorbers to Concrete Median Barrier

VTI RAPPORT 380A
Figure 14 – Energy Absorber to Net Connection
The Development and On-road Use of a 4-Rope Safety Fence

Ivor B Laker
Road Safety Consultants

and

A W Naylor
Bridon Ropes Ltd
United Kingdom
TECHNICAL REPORT

The Development and Use of a 4-Rope Safety Fence

by

I. B. Laker (Consultant)

and

A. W. Naylor (Bridon PLC)

Reference: BR1.792

Report Date: July 1992

I. B. Laker
Road Safety Consultants
Brockendene
Foxhill
Farley Hill
Berkshire
RG7 1UH

Telephone or facsimile: 0734 732756

A. W. Naylor
Bridon Ropes Ltd
Carr Hill
Doncaster
South Yorkshire
DN4 8DG

Telephone: 0302 344010
Facsimile: 0302 382268
In 1986 BRIDON PLC took a policy decision to update the performance of the 2-strand wire rope safety fence developed in the 1960's by the Transport and Road Research Laboratory, Crowthorne, England. The early fence, because of its shallow profile, needed to be mounted on a hardened running surface to prevent tyres from sinking into the surface. This, in turn, prevented the possibility of a rope riding over the bonnet of a small car.

BRIDON took the view that the need for a hardened surface could be removed by using a 4-rope system if the vertical distance between the ropes was at least as deep as a W-section steel beam. The solution would eliminate the need for hardening the ground within the effective area of the fence, thus considerably reducing the cost of the fence.

A total of 10 tests were made on the length of need. From test to test variations were made on rope height, tension, post strength and the method of attaching the rope to the posts. The development program showed that the WRSF (Brifen wire rope safety fence) was successful against the standard UK Department of Transport test with a 1500 kg car at an impact angle of 20 degrees and speed of 70 mile/h (113km/h).

To ensure that the rope height problem had been soundly solved, further tests, not required by regulations, were made with small 850 kg cars. These tests also proved successful; the rope did not ride up over the bonnet.

Vehicle impact severity was recorded, according to UK practice, whereby the impact speed and deceleration of a theoretical occupant are monitored (THIV and PHD). Due to the compliant characteristics of the fence the values obtained were well within the accepted tolerable range of both impact speed and deceleration.

There are locations where restricted road site conditions prevent the advantages given by flexible fences of cushioning vehicle impact; these sites are unavoidable and occur near such fixings as lighting columns or road signs. In order to produce a stiffer fence, BRIDON PLC carried out further tests with closer post spacings. The modification reduced the maximum deflection of the fence, under standard impact conditions, from 1.7 metres to 1.2 metres. The lower value of deflection permits the use of the fence in locations were space is more confined.
The UK Department of Transport approves for use on motorways and other highways, fences and barriers of varying rigidity made of both steel and concrete. BRIDON PLC in association with the Transport and Road Research Laboratory, have successfully completed tests on a transition from wire rope safety fence to other designs of fence or barrier.

This report presents the development program that led to the approval and application, in the UK and world-wide, of the 4-strand Brifen wire rope safety fence, including a stiffer version of the fence and its transition to another type of barrier.

Accident statistics associated with the fence have been gathered over a period of 3 years. The report discusses its performance with regard to the available accident statistics. To date none have proved fatal and only 3 percent were in the serious category.

I B Laker.
THE DEVELOPMENT AND ON-ROAD USE OF A 4-ROPE SAFETY FENCE

BY

I B LAKER AND A W NAYLOR.

1.0 INTRODUCTION.

In the early 1960’s British Ropes Ltd, now BRIDON PLC, collaborated with the Transport and Road Research Laboratory on the development of a weak post wire rope safety fence for the containment of private cars. After a sequence of tests and prototype development, the final design consisted of two wire ropes, mounted above ground at approximately the same height, which rested freely in a vertical slot cut into the top of steel posts. The weak post concept avoided the then common problem of vehicles snagging on posts and spinning out of the fence in a hazardous condition. At that time, controlled vehicle impact test facilities were at an early stage of development and vehicle impact speeds were limited to about 105 km/h, (65 miles/h) with a 1.34 tonne vehicle.

The early tests had shown that the performance of the single height wire rope safety fence was sensitive to rope height above the surrounding surface (Jehu and Laker 1967). A fence with ropes too low could be ridden down by large vehicles, and in addition, if the ropes were fixed too high there was a danger that the ropes could slide over the bonnet of a small car. To overcome this, a restricted number of tests were completed with an additional rope placed at a second height, but the tests proved unsuccessful. There was a tendency for the rear lower rope, either to be trapped and carried to the ground by the posts, or to break free too soon from its attachment to the post, fall to the ground, and then be run over by the vehicle.

The solution adopted at that time, and included in the UK, Department of Transport (DTp), Technical Memorandum H9/73 (Issued 1973), was to retain the single height two rope system in slotted posts and overcome the rope height problem by ensuring the the wire rope fence was always installed on a hardened running surface. This of course added to the cost, and in consequence, only very little of the single height wire rope fence was installed on UK highways. The longest length was in place on the M62 Motorway across the Pennine Mountains. The road is subject to snow drifting and one of the benefits of the wire rope fence is that its narrow profile reduces the tendency for snow drifts to form. (It is interesting to note that this early installation of the two rope single height fence has now been replaced by the four rope system which is the subject of this report).

Eventually, because of low demand caused by the high cost of preparing a hard running surface on which to mount the fence, the single height rope fence was dropped from UK, DTp Regulations. Nevertheless, the fence has had considerable use overseas, in Europe.
and the Middle East, where its ability to limit snow and sand drifting is a most attractive feature.

2.0 THE DEVELOPMENT OF THE DOUBLE HEIGHT, 4 ROPE SAFETY FENCE.

To overcome the need to provide a hardened running surface, Bridon PLC, in 1986, decided to re-examine the single height design. The depth of the fence which comes into contact with a vehicle was increased by the addition of two lower ropes (Fig.1; Plate I). The distance between the upper and lower ropes, and the heights of the ropes above ground, were selected to permit impact vehicles to traverse an undulating surface without the risk of a rope slipping over the bonnet.

![Diagram showing rope heights](image)

**FIG. 1. Z-SECTION SLOTTED POST SHOWING ROPE HEIGHTS.**

The use of the fence on UK roads has been approved by the UK DTp in Departmental Standard TD 32/89. Also, the fence design has been submitted and approved by the European Commission and Member States of the EEC.

This report describes the development of the new safety fence incorporating four ropes located at two heights above ground, mounted on knock-down posts. The posts may be held in socketed footings for easy replacement on repair; or soil mounted posts can be used as an alternative.
2.1 STANDARD IMPACT TESTS.

The UK standard impact conditions for the testing of safety fences and barriers are quoted in British Standard BS6579 and in DTp Departmental Standard TD32/89. In the UK, for roads which have a maximum speed limit of 70 mile/h (113 km/h), the fence should contain and safely redirect, a 1500kg, 113 km/h vehicle impact at 20 degrees.

In addition to the standard test, the UK DTp requested, of the Bridon design, that the maximum dynamic deflection of the fence should be less than 2.0 metres. Also, the vehicle exit trajectory had to meet the 'box' criteria of BS6779 which states in part -

'... if redirection takes place the vehicle shall be redirected so that no part of it crosses the line drawn parallel with and 2.13 metres plus the width of the vehicle from the face of the parapet, within a distance of 10 metres from the break point of vehicle contact with the parapet (fence). The test vehicle shall neither turn on its side nor roll over within the paved parapet test area'.

Bridon Ropes Ltd, (a subsidiary of Bridon PLC), were asked to meet all of these requirements in the design of their vehicle safety barrier.

One of the main purposes of the planned impact tests was to demonstrate that the new 4-rope design could perform successfully when mounted on a non-hardened surface.

The material specification for the running surface over the impact test area, led to considerable discussion. On-road sites, where safety barriers are installed, have a wide range of surfaces; from grass, to aggregate, to hardened tarmacadam; all with varying degrees of undulation and hardness. Repeatability of tests was a prime consideration. The solution adopted, in part, followed previous practise using a hardened running surface for the standard 1.5 tonne saloon car test, but for the 4-rope fence, this was followed by a second test, with a 750kg Mini car. In so doing, the smaller, lower car profile would, to a reasonable degree, represent a standard vehicle which had either, penetrated into a soft running surface or was traversing an undulating surface where a rope could slip over the bonnet when the car was at the lowest part of the undulation. The test would also explore the impact severity and vehicle trajectory response of the fence, with a lightweight car.

2.2 THE DESIGN OF THE 4-ROPE SAFETY FENCE.

A series of eight tests was carried out during 1987/88; these were followed by a further two tests in 1991, on a stiffer fence designed for lower deflection on impact.

The tests undertaken in the 1960's had shown that a wire rope, fixed to the non-impact side of the posts, was likely to be taken to the ground and be run over as the posts were run down. To overcome this the final design employed two ropes located in a shallow slot in the
top of the posts, with two further lower ropes placed on simple brackets fixed to each side; the two lower ropes were interlaced between posts. This design was retained for all subsequent tests. From test to test variations were made to the precise heights of the ropes, to the tension in the ropes and to the method of interlacing the lower pair of ropes (Fig. 2; Plate I).

FIG. 2. GENERAL ARRANGEMENT.

2.2.1 POST SPACINGS AND ROPE HEIGHTS.

Bridon Ropes Ltd considered that fence post spacings of 2.4 metres would be needed to meet the 2.0 metre maximum dynamic deflection criteria, requested by the DTp, when tested under standard impact conditions with the 1500kg car.

Both the 2.4 metre and the 1.0 metre fence designs were dynamically tested by impact with driverless 1500kg, and 750kg Mini cars, at a target impact speed of 113 km/h at 20 degrees.

In the final design, posts of Z-shaped cross-section were manufactured from 6mm gauge steel having a yield strength of 355 N/mm². A short slot supported the two upper ropes at a height of 585 mm; the lower ropes were supported by small brackets each side of the Z-posts at a height of 490 mm (Fig. 1). The posts were held in concrete sockets with sufficient clearance for easy removal and replacement of damaged posts.
2.2.2 ROPE CHARACTERISTICS.

Vehicle impact tests showed that static rope tensions between 13.3kN (3000lbs) and 26.7kN (6000lbs) had little effect on dynamic deflection of the fence. This result is beneficial in service, in that the fence deflection performance is not sensitive to variations in tension brought about by changes in ambient temperature. A static tension value of 22.25kN (5000lbs), set at 15 degrees Centigrade, is specified for the final design. For a temperature range of -10 to 30 degrees Centigrade the rope tension ranges from 36.0 kN to 14.0 kN.

The ropes are 19 mm in diameter, zinc coated, with a minimum breaking load for each rope of 173.6 kN (17.7 tonne). The rope is formed by twisting six wires around a king wire to form a strand; three strands are twisted together to form the rope. The maximum tension recorded in all of the tests was 22.6 kN.

Throughout the series of tests, there was no necessity to replace or re-tension any of the ropes; at the end of the program the ropes were in a condition suitable for on-road use. All of the initial impacts occurred at the same point on the fence test length.

2.2.3 INTERLACING OF THE ROPES BETWEEN POSTS.

A rope fixed to the non-impact side of a post is likely to be carried to the ground as had been shown in early tests. Ropes in contact with the side of the impacting car form a shallow groove in the bodywork; this helps to maintain rope height. Clearly, the rear rope on the remote side of the posts cannot be in continuous contact with the car. Should it break free from the posts ahead of the vehicle it tends to drop, and so may be run down as the vehicle penetrates into the fence.

The possibility of the rear rope falling prematurely to the ground was overcome by interlacing the lower pair of the four ropes between posts, as shown in Fig. 2 and Plate I. Two methods were tried; interlacing the ropes at every other post and interlacing at every post. Impact tests showed that the first method to offer little improvement; the lower rear rope tended to be run down. However, the second arrangement, with the lower ropes crossing between every post, proved successful. The interlacing had formed a simple mechanism, whereby the posts ahead of the car gave sufficient support to the ropes at the position of the car and so held them at an effective operational height.

2.3 PROVING TESTS OF THE 4-ROPE SAFETY FENCE.

2.3.1 WIRE ROPE SAFETY FENCE WITH 2.4 METRE POST SPACINGS.

Posts were spaced at 2.4 metre intervals to span the impact area of length 48 metres. The length of rope between anchorages was 626.4 metres; turnbuckles were adjusted to set the static tension in all four ropes at 22.24 kN. Rope heights were set at 585 and 490 mm. The lower pair of cables were interwoven at every post.
The standard weight (1500 kg) car test at 113 km/h (70 mile/h), impacted at an angle of 19 degrees, deflected the fence a maximum distance of 1.7 metres, and it was safely redirected onto a departure path of 7 degrees to the line of the fence, with zero yaw angle. First contact was over a length of about 19 metres. The car then steered back, remained in contact with the fence for a further 19 metres and then came to rest about 125 metres from the first point of impact (Fig. 3).

**WIRE ROPE SAFETY FENCE**

- STANDARD UNIT LENGTH: 626.4m
- IMPACT AREA LENGTH: 48m (21 POSTS AT 2.4M SPACINGS)
- IMPACT AREA: HARD MEDIAN
- ROPE TENSIONS:
  - UPPER 5001bf
  - LOWER 5001bf
- ROPE HEIGHTS:
  - UPPER 585mm
  - LOWER 490mm
- ROPE DIAMETER: 19mm
- POST SPACINGS: 2.4m
- Upper ropes located in short slots of 2-posts, lower ropes either side of 2-posts and crossed at every spacing.

**VEHICLE**

- ROVER SDI SALOON
- MASS: 1480kg.

**DAMAGE**:

- Front left-side corner pushed in approx 300mm. Rope witness marks along EWS at bumper height. Front LH suspension collapsed at second impact at post 25.
- Passenger compartment undeformed; all doors could be opened.

**VEHICLE-SCENE RESPONSE**

<table>
<thead>
<tr>
<th>POST NO</th>
<th>MAX PENETRATION 1.7 m</th>
<th>POST NO</th>
<th>3 to 17 IN HARD MEDIAN IMPACT AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.7</td>
<td>9</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>1.6</td>
<td>10</td>
<td>1.4</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>11</td>
<td>1.3</td>
</tr>
<tr>
<td>4</td>
<td>1.4</td>
<td>12</td>
<td>1.2</td>
</tr>
</tbody>
</table>

**TEST RESULTS**

- Maximum Penetration: Vehicle 1.7m, Wheel 1.5m
- Damage Fence Lengths: 19.2 m from Posts 0 - 8, 19.2 m from Posts 25 - 34
- Posts Pushed 10 Sundae: 0, 8, 25 - 34, 35, 36 - 38

**FIG 3. SUMMARY OF 1500kg STANDARD CAR TEST.**

(2.4 metre post spacings)

The main damage to the car was restricted to the area around the impact wheel station; the passenger compartment was undeformed, all four doors could be opened and closed and all safety glass remained intact. The front left-side corner was pushed in about 300 mm. On the second impact, at about 60 metres from impact point, the front left-side wheel station collapsed. The vehicle came to rest about 125 metres from impact point alongside and just touching the fence. In the primary impact, nine posts were damaged over a length of 19.2 metres; a similar length was damaged in the secondary impact.

The test complied with the requirements laid down by the UK, DTp, and the test also met the exit trajectory criteria stipulated in BS6779.

The Mini car (750kg) impact test is not a formal requirement within the UK DTp Regulations for safety fences on highways; however, it was carried out, by request of the DTp, to observe whether the lighter car would either snag on the posts and spin-out or be
redirected, after impact, at a high angle, due to stored energy in the ropes being returned to the mini car. Additionally, the test represented an impact on the fence, of a lower profile car at a lower running height; a condition that could occur with a heavier vehicle on soft ground, both of which might result in the upper rope slipping over the bonnet.

The fence configuration was identical to the previous 1500kg car test.

The test speed and angle were 116km/h (72.1 mile/h) and 19 degrees. The maximum penetration into the fence was 1.2 metres and the damaged length was about 15 metres. The Mini car was safely redirected on an exit path of 7 degrees (centre of gravity point) with the car at a yaw angle of about 1.5 degrees to the line of the fence.

On impact, the four wire ropes were forced together and made contact with the front left hand corner of the car at headlamp height; there was no indication of a rope slipping over the bonnet.

The wire rope fence impact test with the Mini car had successfully met the performance requirements required by the DTp, and met the exit path criteria laid down in BS6779: Part I. In addition, the fence had met the running height conditions for soft ground, and the approved fence no longer required to be mounted on an hardened running surface.

2.3.2 WIRE ROPE SAFETY FENCE WITH 1.0 METRE POST SPACINGS.

The rope lengths, heights and post cross-sectional dimensions for the fence with the 1.0 metre post spacings, were identical to those in the 1500kg and 750kg mini car tests, on the 2.4 metre fence.

Over a 30 metre length of fence, designated the impact area, Z-posts were slotted into sockets 1.0 metres apart. The remaining lengths of rope near the impact area were supported on posts placed 2.4 metres apart. The overall length of the fence was 319 metres; the rope static tension was set, by turnbuckles, to 26.5 kN.

The standard weight (1500 kg) car impacted at 115.8 km/h at an angle of 19 degrees. An anthropometric dummy, representing a 50th percentile male was installed in the passenger seat of the car. The exit speed was 90 km/h at an angle of 8 degrees (Fig 4).

On impact the four ropes were forced together and cut into the vehicle at head lamp height. At 0.24 seconds after impact the car was parallel with the fence and had penetrated 1.1 metres; the ropes pressed into the left hand side body panels and at this point their maximum deflection was 1.08 metres. As the vehicle continued along the fence, the maximum penetration was recorded as 1.12 metres where the ropes had cut into the rear left hand side wheel arch.
WIRE ROPE SAFETY FENCE

IMPACT AREA LENGTH - 30m (POSTS AT 1.0M SPACINGS)
ROPE TENSIONS - UPPER 2.7t LOWER 2.7t
ROPE HEIGHTS - UPPER 585mm LOWER 490mm
MAX. DEFLECTION - 1.12m
MAX. PENETRATION - 1.12m

DAMAGE - 18 POSTS FIRST IMPACT; 10 POSTS SECOND.

VEHICLE

DAMAGE: Front LH corner pushed in 300mm.
Front LH suspension unit pushed forwards and partially detached from unit.
All access doors opened with normal force.

MASS: 1510kg incl dummy.

VEHICLE BARRIER RESPONSE

Impact vel. (m/s) Lateral: 10.5 Long: 30.4

Vehicle barrier response

The maximum penetrations and deflections are recorded in Table 1.

<table>
<thead>
<tr>
<th>TIME (seconds)</th>
<th>VEHICLE PENETRATION (metres)</th>
<th>ROPE DEFLECTION (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.6</td>
<td>0.58</td>
</tr>
<tr>
<td>0.24</td>
<td>1.1</td>
<td>1.08</td>
</tr>
<tr>
<td>0.30</td>
<td>1.2 (max.)</td>
<td>1.12</td>
</tr>
<tr>
<td>0.30</td>
<td>1.3 (loose bonnet)</td>
<td>1.12</td>
</tr>
</tbody>
</table>

TABLE 1. VEHICLE PENETRATION AND ROPE DEFLECTIONS.
STANDARD 1500 KG CAR TEST.
During the impact 17 posts were damaged. After leaving the fence, at a shallow angle the car made second contact about 13 metres from the break point. Another 10 posts (2.4 metre spacings) were knocked down and the vehicle came to rest some 52 metres from the initial contact point.

The front left hand corner of the vehicle had been pushed in about 300 mm; superficial rope marks could be seen along the left hand side of the car at head lamp height. The front left side suspension was badly damaged, the wheel had been pushed forward and had twisted 90 degrees from its true position. There was no visual damage to the occupant area and all four doors could be opened after the vehicle was moved from alongside the fence. Damage is shown in Plate II. Analysis showed that the test had complied with DTp requirements and also had met the exit path requirement stipulated in BS6779. The results of the analysis are shown in Fig. 4.

The effect of reducing the post spacings from 2.4 metres to 1.0 metres had reduced the deflection of the wire rope fence from 1.7 metres to 1.12 metres.

A 750kg Mini car test on the fence with 1.0 metre post spacings was also carried out (Plate III). As mentioned above, this test is not a requirement within the DTp Regulations, however there was a possibility that the closer post spacing could cause wheel snagging to induce a mini car to spin out. Also there was the possibility that the lower profile of the Mini, compared with the 1500 kg car, could permit the higher ropes to slip over the bonnet. Conversely, the Mini could represent a larger vehicle running on soft ground, whose height, relative to the fence, was lowered by the road wheels penetrating the running surface. In addition the test with a light vehicle would give an indication of the severity of impact.

Impact speed was 113.4 km/h at an angle of 19 degrees; the vehicle left the fence at a speed of 90 km/h at an angle of 1 degree to the line of the fence, with the rear of the vehicle furthest from the fence. During impact, there was no indication of a rope sliding over the bonnet.

The test had successfully passed the DTp requirements and the exit angle had complied with BS6779. Also, all ropes had remained in contact with the side of the car; none had slipped over the bonnet. The Mini test had demonstrated that the 4-rope fence had met the running height conditions for soft ground.
2.4 VEHICLE IMPACT SEVERITY.

The severity of impact was estimated using the value of the Theoretical Head Impact Velocity (THIV). The THIV value estimates the impact velocity with which a freely moving object, representing an occupants head, would impact a surface in its path inside the vehicle compartment.

Fig. 5 compares THIV values for standard tests with a 1500kg and a 750kg mini car, both at 113km/h, in collision with a concrete barrier, a steel tensioned corrugated beam (TCB) fence and the wire rope fence with 2.4 metre and 1.0 metre spacings.

In terms of the THIV impact values, the 2.4 metre wire rope fence is no worse than the Tensioned Corrugated Beam (TCB) fence at about 4m/sec for the 1500kg car and about 5.5m/sec for the Mini car.

A comparable THIV value for impact into a concrete barrier (VCB) is about 7m/sec for the standard 1500kg car.

The THIV value increased from 4m/sec for the wire rope fence with 2.4 metre post spacings, to 5.6m/sec for the 1500kg car impact into the 1.0 metre fence.

The Mini car THIV value for impact into the 1.0 metre fence was 6.4m/sec compared with 8.4m/sec for a Mini impact into a Vertical Concrete Barrier (VCB).

The CEN Standard on Road Restraint Systems is likely to recommend that THIV values should not exceed 9m/sec for impact severity Level A, and 12m/sec at Level B. The impact tests demonstrated that both the 2.4 metre and the 1.0 metre wire rope fences met the proposed...
CEN Standard for impact severity with THIV values less than lower recommended value of Level A.

The Head Injury Criteria (HIC) for the passenger dummy was very low at 56, in the 1500 kg car test on the fence with 1.0 metre post spacing test; the limiting injury value defined in FMVSS is 1000.

3.0 WIRE ROPE FENCE ON-ROAD INSTALLATION AND USE.

3.1 INSTALLATION.

Before work commences the site should be surveyed, paying particular attention to interfaces with other barrier types and structures, and accurately establishing the overall length of each fence, measured from each end anchor. The measurement is best achieved by use of a steel measuring tape. Where the fence length exceeds 627 metres the positions of intermediate anchors need also to be established. (Ref. TD32/89, DRG No. WR/01; DTp, London)

Once the various datum points have been established then the anchorage blocks are excavated, the anchor frames inserted and back-filled with concrete. The type of line posts used may be driven or concreted in place, depending on ground resistance conditions. Post centres of 2.4 metres,(or 1.0 metres where necessary) are chained, and installation of posts can commence. The datum height of the post should be accurately maintained by use of sighting equipment. The rounded edge of the posts face the on-coming traffic with the sighted line of the fence true and to the general installation requirements.

For each length of fence a reeling list indicates, in a table, the position and sequence along the fence where the individual four ropes are to be positioned, (Upper ropes - A and B; lower ropes - C and D). The fence comprises a number of tail ropes, (approximately 6 metres long), standard ropes, (approximately 153 metres long), and non-standard lengths. Rigging screw bodies connect the ropes end to end by threaded terminations on each rope. A safety check rope is attached to a tail rope at every ground anchor point.

The fence is roped, starting with the lower D ropes at the inner end-anchor frame, and progressively laid out along its length, making rigging screw connections where necessary. Once the rope is connected to the anchor frames, the D-rope is interwoven between posts, placing the rope on locating pegs provided on every post. The same procedure is carried out for the C-rope but starting from the outer end anchor. (Ref. TD32/89, DRG No. WR/12: DTp, London).

The sequence is continued with the upper B and A ropes; starting from the inner and outer end anchors and terminating at the outer and inner ends respectively. The ropes are tensioned by moving along the fence taking up the adjustment by the rigging screws until the tensioning requirements listed in Ref. TD32/89 are met within a tolerance of ±0.5kN. The fence installation is completed by placing plastic caps, which may incorporate reflectors, onto the tops of the posts.
3.2 INSTALLATION EQUIPMENT.

The ropes are supplied on reel carriers mounted on a vehicle. The ropes are progressively payed out as the vehicle moves down the line of the fence. Rope tension is measured using a calibrated Tensionmeter which operates on the three roller principle; the centre roller deflects the rope between two fixed ropes enabling direct readout of rope tension.

The wire rope fence has been designed so that specialised equipment and material handling has been kept to a minimum. An added feature is that the wire rope fence uses less individual parts than other common w-beam section fences.

3.3 MAINTENANCE AND REPAIR.

There is virtually no routine maintenance required with the wire rope safety fence; damaged posts can be quickly replaced and the fence returned to normal operation. It is most unlikely that, after vehicle impact, the wire ropes need replacement or re-tensioning. Following an impact, it takes an average of less than one hour for a trained maintenance worker to restore the socketed post fence system, causing little disruption to traffic. In addition the repair is inexpensive so keeping costs to a minimum.

4.0 WIRE ROPE FENCE ACCIDENT PERFORMANCE.

Following the UK DTp approval in late 1989, the 4-rope fence has performed as well as its 2-rope predecessor. As mentioned earlier, the first major installation of the 2-rope fence was on the M62 motorway in the UK. Subsequently this was replaced by the 4-rope fence after some 20 years in operation. Table 2 shows published statistics for the M62. The data shows the fence has performed well in all-weather road conditions. The collection of accident statistics is an on-going activity for all major installations.

To date, no fatal accident has been reported, nor has a vehicle crossed the central median at any wire rope fence installation.

The fence was not designed for heavy goods vehicle (HGV) impacts. Nevertheless there have been a number of fence impacts from HGVs. So far the fence has contained these vehicles by preventing carriageway crossover; the vehicles have been trapped by the ropes on the median.

In practise the wire rope fence has performed well by avoiding ramping accidents. Ramping accidents have occurred on w-beam and open box fences where the vehicle has been launched, after hitting an end anchorage, and subsequently impacted other vehicles or objects or rolled over. In contrast, accident have occurred where the wire rope fence has been struck end-on without any difficulties arising. The vehicle has come to rest straddling and on top of the fence after running down a number of posts.
### TABLE 1. ANALYSIS OF M62 ACCIDENT STATISTICS INVOLVING THE SINGLE HEIGHT WIRE ROPE SAFETY FENCE.

**JUNE 1971 TO JANUARY 1987**

<table>
<thead>
<tr>
<th>Driving Conditions</th>
<th>No of accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Surface</td>
<td></td>
</tr>
<tr>
<td>- Dry</td>
<td>53 %</td>
</tr>
<tr>
<td>- Wet</td>
<td>25 %</td>
</tr>
<tr>
<td>- Snow/ice</td>
<td>22 %</td>
</tr>
<tr>
<td>Weather</td>
<td></td>
</tr>
<tr>
<td>- Fine</td>
<td>58 %</td>
</tr>
<tr>
<td>- Wet</td>
<td>18 %</td>
</tr>
<tr>
<td>- Snow/ice</td>
<td>18 %</td>
</tr>
<tr>
<td>- High Winds</td>
<td>3 %</td>
</tr>
<tr>
<td>- Fog</td>
<td>3 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Car</td>
<td>79 %</td>
</tr>
<tr>
<td>- Coach/HGV</td>
<td>18 %</td>
</tr>
<tr>
<td>- Motor Cycle</td>
<td>3 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accident Details/Outcome</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed on barrier impact</td>
<td></td>
</tr>
<tr>
<td>- 50 mph</td>
<td>40 %</td>
</tr>
<tr>
<td>50-70</td>
<td>57 %</td>
</tr>
<tr>
<td>Above 70</td>
<td>3 %</td>
</tr>
<tr>
<td>Injuries</td>
<td></td>
</tr>
<tr>
<td>- None</td>
<td>68 %</td>
</tr>
<tr>
<td>- Slight</td>
<td>29 %</td>
</tr>
<tr>
<td>- Serious</td>
<td>3 %</td>
</tr>
<tr>
<td>Damage to vehicle</td>
<td></td>
</tr>
<tr>
<td>- Minor</td>
<td>50 %</td>
</tr>
<tr>
<td>- Extensive</td>
<td>50 %</td>
</tr>
<tr>
<td>No. of posts knocked over</td>
<td></td>
</tr>
<tr>
<td>- 1-10</td>
<td>64 %</td>
</tr>
<tr>
<td>11-30</td>
<td>14 %</td>
</tr>
<tr>
<td>Above 30</td>
<td>21 %</td>
</tr>
<tr>
<td>Final positioning of vehicle</td>
<td></td>
</tr>
<tr>
<td>- Carriageway</td>
<td>11 %</td>
</tr>
<tr>
<td>- Central Reservation</td>
<td>89 %</td>
</tr>
<tr>
<td>Vehicles crossing/penetrating</td>
<td></td>
</tr>
<tr>
<td>to opposing carriageway</td>
<td></td>
</tr>
<tr>
<td>- Yes</td>
<td>Nil</td>
</tr>
<tr>
<td>- No</td>
<td>100%</td>
</tr>
</tbody>
</table>

*In one instance a vehicle (articulated HGV) straddled the barrier.

The wire rope fence has an open structure. It has been reported that excessive vehicle speeds tend to reduce, in the locality of the fence, because of an increased awareness of the on-coming vehicles in the opposite carriageway.

Since UK DTp approval of the 4-rope fence in 1989 over 200km has been installed in the UK. Also, over 12 countries world-wide have adopted the system.
5.0 CONCLUSIONS

5.1 The BRIFEN Wire Rope Safety fences, with post spacings at
2.4 metres and at 1.0 metres, met the impact performance
requirements, laid down by the UK Department of Transport, for
highway safety fences. The fences also complied with the
vehicle trajectory after impact given in BS6779:Part I.

5.2 The 1500kg vehicle was safely contained and redirected,
after a standard 113km/h impact into the 2.4 metre 4-rope
fence; the vehicle departure path was 7 degrees to the line of
the fence. The maximum penetration was 1.7 metres.

This test was repeated for the 1.0 metre fence; the maximum
vehicle penetration was 1.2 metres. The reduction in
penetration of 0.5 metres permits the wire rope fence to be
considered for use where site space is restricted. For example,
reduced post spacing would be used to restrict fence deflection
where lighting columns were placed close to the safety fence.

5.3 Additional tests with 750kg Mini car impacts at target
speeds of 113km/h at 20 degrees also successfully met the UK
DTP and BS6779:Part I. requirements. The maximum penetrations
were 1.2 metres for the 2.4 metre fence, and 0.86 metres for
the 1.0 metre fence.

5.4 The maximum tension measured in all vehicle impact tests
was 22.6kN; the breaking load of a single rope is 173.6kN. The
same ropes were used for all the tests; none of the ropes
received damage that would require rope replacement at a
roadside installation. The fence was quickly repaired after
each test by manually extracting the damaged posts from
concrete sockets and replacing new ones. The wire ropes were
lifted into place without the need for re-tensioning or the
need for mechanical power equipment.

5.5 Vehicle impact severity for the standard 1500kg car test,
using the Theoretical Head Impact Velocity (THIV) measure,
showed that the 2.4 metre post spacing 4-wire rope fence THIV
value to be 4m/sec; this is similar to that of the tensioned
corrugated beam fence (TCB) for the standard 1.5 tonne car
test. The THIV value increased from 4m/sec to 5.6m/sec for the
1.0 metre fence.

The respective values for the Mini car tests on the 2.4 metre
and the 1.0 metre fences were 5.5m/sec and 6.4m/sec.

Both the 2.4 metre and the 1.0 metre fences met the lower THIV
level (Level A), of the proposed CEN Standard for impact
severity, with THIV values considerably less than the
recommended 9m/sec for Level A and 12m/sec for level B.

The Head Injury Criteria (HIC) value of 56, recorded for the
standard 1500 kg car test into the 1.0 metre post spacing fence
was considerably lower than the injury threshold of 1000 units
quoted by FMVSS.
5.6 The 4-rope fence is simple to install with the minimum of specialised equipment. The complexity of material handling is considered to be less than other approved fences. The fence is virtually maintenance free and cheap to repair after vehicle impact.

5.7 To date, over a period of three years, there has been no report of a fatal accident associated with the fence or central reserve cross-over by any type of vehicle private or commercial.

6.0 References


7.0 ACKNOWLEDGEMENTS.

The Authors are indebted to Bridon PLC. for permitting the use of the material contained in this report. Dr. Andrew Stacey, Technical Director of British Ropes Ltd., was primarily responsible for the project, and his enthusiastic guidance on the design of the double height wire rope fence is freely acknowledged.

The impact tests were carried out by the Motor Industry Research Association (MIRA) under contract to BRIDON PLC.
PLATE I. THE 4-ROPE SAFETY FENCE.
PLATE II. FINAL POSITION OF 1.5 TONNE CAR.
(1.0 metre post spacings)
Crash Cushions and Terminals

Charles F McDevitt
Project Manager
U S Department of Transportation
Federal Highway Administration
U S A
Crash Cushions and Terminals
by
Charles F. McDevitt
Project Manager
Federal Highway Administration
U.S. Department of Transportation

This paper will give an overview of the crash cushions and terminals currently being used in the United States. This State-of-the-Practice paper will discuss their crash test performance, construction and maintenance costs, and selection considerations. The emphasis will be on presenting practical information that will be useful in selecting, locating and designing these safety devices. Both operational and experimental devices will be covered. Most of the newer crash cushions and terminals are patented, proprietary devices. Therefore, some low-cost, non-proprietary systems such as breakaway curved guardrails will also be discussed.

In order to give the audience a better appreciation of the safety performance and the aesthetic qualities of these crash cushions and terminals, a videotape showing crash tests of these safety devices will be used in the presentation. This videotape will be suitable for distribution after the conference.
CRASH CUSHIONS AND TERMINALS

Charles F. McDevitt
Project Manager
U.S. Department of Transportation
Federal Highway Administration

1. INTRODUCTION

This paper will briefly discuss the crash cushions and terminals currently in use in the United States. Most of the newer crash cushions and terminals are patented, proprietary devices. Therefore, some low-cost, non-proprietary systems will also be discussed. The accident rate in the United States went down steadily over the last 25 years, until in 1990 it reached an all-time low of 2.1 fatalities per 100 million vehicle miles travelled. The fatal accident rate for 1990 matched the 1989 rate of 1.9 fatal accidents per 100 million vehicle miles, the lowest rate on record (1). These lower accident rates are due to improvements in vehicle design, changes in driver behavior, and stronger enforcement of tougher State laws, as well as highway safety improvements. However, it is safe to say that new and improved crash cushions and terminals have made significant contributions to highway safety.

The American Association of State Highway and Transportation Official’s (AASHTO) 1977 "Guide for Selecting, Locating and Designing Traffic Barriers" classified the roadside safety devices that were then being used as either operational systems or experimental features (2). Until 1991, the Federal Highway Administration’s Office of Engineering continued to use the same classifications when reviewing and approving crash-tested safety devices for use on Federal-aid construction projects. A safety device that had been classified as an experimental feature could be used on any federally funded construction project, but the construction, maintenance, and performance of the device had to be monitored by the State over a period of several years. Since this delayed the widespread use of promising new devices that had been crash tested, the approval process was changed in 1991. Currently, the Federal Highway Administration (FHWA) either accepts or rejects new and improved devices for use on Federal-aid construction projects. Any State may still classify a device as an experimental feature and monitor it in the field. However, there is no requirement for the State to make an in-service evaluation of the type recommended in NCHRP Report No. 230 (3).

2. GATING TERMINALS

Guardrails must be designed so that the end facing traffic is not a fixed-obstacle hazard. Unfortunately, it was not uncommon for the W-beam rail and the "spoon end" used on some early guardrails to spear through the front end of a vehicle and penetrate into the passenger compartment. In order to reduce the probability of spearing, the end of the guardrail was sometimes flared back and offset from the roadway. This was
not sufficient to solve the spearing problem. Moreover, this type of end treatment did not develop enough tension in the W-beam rail to safely redirect vehicles that impacted near the end of the guardrail.

The "Texas Twist," or turned-down terminal that was developed in 1963 solved the spearing and the rail anchorage problems. Today there are at least 250,000 turned-down terminals in use by the States. The 12 different turned-down designs differ in details, but all have a 7.6 m (25 ft) long W-beam rail that is twisted through 90 degrees, turned down to the ground and bolted to a recessed concrete block (4). In some designs, an additional 7.6 m (25 ft) of rail is connected to the posts with connections that are meant to break away when subjected to vertical loads. Turned-down terminals have been very popular because they have a lower initial cost and a lower maintenance cost than any other terminal. The cost of the materials is about $350 to $400. The labor cost varies from $100 to $300, so the installed cost of 15.2 m (50 ft) of a turned-down terminal varies from $450 to $700.

This type of terminal is considered a "gating" terminal because errant vehicles can pass over the turned down W-beam rail and continue running behind the guardrail. Gating terminals can pose another problem because vehicles can travel 45.7 m (150 ft) or more along the guardrail before coming to a stop. If the guardrail and terminal are not long enough, then the vehicle may impact the bridge pier or other fixed object that the guardrail was meant to shield.

When some turned-down terminals are impacted by a vehicle, the rail-to-post connections are designed to break away and allow the W-beam rail to fall to the ground. Premature failures of these connections caused by snow loads, wind loads, and vibrations from passing traffic have caused maintenance problems. This led to the development of the Texas "nested" system which uses a steel clip to help support the W-beam rail. When additional crash tests were conducted on the Texas nested system to adapt it to other State's turned-down designs, it was found that the terminal did not meet all of the tests recommended for terminals in NCHRP Report No. 230 (4). Rollovers were observed in end-on impacts at 96.6 km/h (60 mi/h) with cars weighing 1020 kg (2,250 lb) and 816 kg (1,800 lb). The turned-down W-beam formed a ramp that launched the test vehicles. A modified nested system was subsequently developed for the State of Maryland, but field experience showed that it did not solve the maintenance problems caused by premature release of the clips (4). In 1989, the State of Nebraska conducted a series of static tests and developed a modified design that uses shear bolts to strengthen the connections (5).

In 1980, a test conducted on a turned-down terminal with the first four posts removed showed that the unsupported W-beam rail was too stiff for a subcompact car weighing 771 kg (1700 lb) to push it down to the ground (4). This led to the development of the Controlled Releasing Terminal (CRT). In this turned-down design, the turned down W-beam was replaced by a cold-formed steel channel section. The wood posts were made breakaway by drilling a 89 mm (3.5 in) hole through them at the groundline and at 406 mm (16 in) below grade. "Bend-away" bolt connections were used to connect
the W-beam to the posts. This non-proprietary terminal passed all of the crash tests recommended by NCHRP Report No. 230. However, a small car rolled over after an end-on impact with its centerline offset 381 mm (15 in) with respect to the centerline of the terminal. The CRT terminal was approved as an experimental feature on October 10, 1984. To date, only a few CRT terminals have been installed. The installed cost of $1,300, which includes $800 for material and $500 for labor, is significantly greater than that of other turned-down terminals.

On June 28, 1990, the Federal Highway Administration prohibited the use of turned-down terminals on new installations of guardrails for freeways, expressways, or other high speed, high volume facilities (6). This was based upon crash test results, accident data and the fact that safer terminal designs were readily available. Some States consider high speed, high volume facilities to be roads with operating speeds of 80.5 km/h (50 mi/h) and above, and with traffic volumes in excess of 6,000 vehicles per day. The use of turned-down terminals on low-volume, low speed roads where there is a lower risk of a serious accident is still permitted. Turned-down terminals can still be used as down-stream anchors for guardrails on one-way roads, divided roadways and other locations where end-on impacts are unlikely. However, it is generally more economical to use a cable anchorage attached to the end post as the downstream anchor.

A non-proprietary, turned-down end for 3-cable guardrails was tested and developed by the State of New York in 1976. Field experience with this terminal has been very favorable. The installed cost is about $2,000. However, a crash test conducted in 1985 showed that the steel rods that connect the cables to the foundation can fail to release when a car impacts the terminal from the reverse direction. These rods can stick into the front of the car and cause it to roll over. New York recently crash tested an improved terminal that has a large concrete foundation (7).

The Breakaway Cable Terminal (BCT) was designed and crash tested in 1971 (8). It solved the spearing problem without creating a launching problem, and became widely used. At this time, there are more than 450,000 BCT terminals in service. Most of these BCT terminals have wood posts. When BCT terminals are used on guardrails with strong steel posts, the first two posts are usually made of wood, and the remaining posts are made of steel. This is more economical than the steel post BCT terminal which has posts mounted on slipbases. However, a few States prefer to use the steel post BCT terminal. The hardware details have been standardized so that components produced by different manufacturers will be compatible and interchangeable (9). Most of these non-proprietary BCT terminals have been fabricated either by Syro Steel Company of Girard, Ohio, or Trinity Industries of Dallas, Texas. A BCT terminal is 11.4 m (37.5 ft) long. The installed cost of $1,050 includes $550 for material and $500 for labor. This estimated labor cost assumes that a BCT terminal can be installed by four men in 4 hours. However, it is possible for an experienced crew to install a BCT terminal in only 2.5 hours, depending upon site conditions and the amount of site preparation required.
The BCT terminal generally performs satisfactorily for full-size cars when it is properly installed. When impacted end-on, the W-beam rail is intended to behave like a long column and buckle out of the way. The parabolic flare with a 1.2 m (4 ft) offset is critical to minimize the buckling load, and to allow the vehicle to pass behind this gating terminal after it has broken away the first two posts. However, due to right-of-way and side slope grading constraints, BCT terminals have sometimes been installed improperly with no flare, or with only a 0.6 mm (2 ft) flare. In 1984, the Federal Highway Administration sent a Technical Advisory to its field offices to provide guidance on proper design and installation of BCT terminals (10). This Technical Advisory stressed the importance of the 1.2 m (4 ft) parabolic flare, and pointed out that the rectangular washers should be removed from the bolts that connect the W-beam rails to the bolts. These washers should not be used because they restrain the W-beam rail from buckling.

However, crash tests have shown that even a properly installed BCT terminal can overturn or spear 816 kg (1,800 lb) subcompact cars in end-on impacts as shown in Figure 3 because the W-beam rail is too stiff (11). BCT terminals have a cable anchorage that is connected to the back of the W-beam rail and extends downward to a hole drilled in the end post near the groundline. This cable anchorage is necessary to develop the tensile strength of the W-beam rail when a vehicle impacts the guardrail near its end. In end-on impacts, this cable is released when the first post is broken away. However, until the post breaks, this cable anchorage restrains the end of the W-beam and inhibits it from buckling.

Since BCT terminals were so popular and so numerous, major efforts were made to develop a retrofit design that would improve their performance for small cars in end-on impacts. The Eccentric Loader BCT, sometimes called the ELT, was tested and developed in 1986 (12). It was patented, but put in the public domain so that any highway agency could make and use it. There are two versions of this terminal, one with a 1.2 m (4 ft) flare, and another with a 0.5 m (18 in) flare. Both versions were classified as operational on January 27, 1991. The version with a 1.2 m (4 ft) flare is the preferred design because it performed significantly better in the crash tests than the other version. The Eccentric Loader BCT with a 0.5 m (18 in) flare should be used only where there is insufficient right-of-way to install the 1.2 m (4 ft) flare. Some States will not use the Eccentric Loader BCT with a 0.5 m (18 in) flare because this design has a 203 mm (8 in) bulge in the W-beam rail that can interfere with snow plow operations.

The Eccentric Loader BCT has a culvert pipe end section that prevents the end of the W-beam rail from spearing into the car. This corrugated steel pipe nose contains a fabricated steel moment arm that produces a bending moment which helps to buckle the W-beam. A 178 mm (7 in) long slot in the moment arm prevents longitudinal forces from building up in the W-beam until after the first post breaks and releases the anchor cable. To promote buckling, all of the bolts used to connect the W-beam rail to the post have been removed from posts nos 2 through 6. Since these bolts are missing, all of the longitudinal force in the rail produced by a vehicle impacting the
guardrail has to be resisted by the cable anchorage and the end post. In order to keep the end post from falling and releasing the cable, a channel strut and yoke assembly is installed between the first two posts at the groundline. To reduce the possibility of vehicles rolling over after end-on impacts, posts nos 3 through 5 were replaced with the weakened wooden posts used in the CRT terminal. These details increase the cost of the materials to about $900. The labor cost is about the same as for the BCT, so the installed cost of this terminal is about $1,400.

Although the Eccentric Loader BCT passed all of the crash tests recommended in NCHRP Report No. 230 and was significantly safer for small cars in end-on impacts, it has been used by only a few States. Additional research aimed at reducing the cost and improving the appearance of this terminal resulted in the development of the Modified Eccentric Loader Terminal (MELT). The two crash tests conducted on a MELT terminal with a 1.2 m (4 ft) flare demonstrated that its performance was very similar to that of the Eccentric Loader BCT (13). Consequently, the non-proprietary MELT was classified as operational on January 27, 1991 (14). Except for the nose piece, the design details of this terminal are identical to those of the Eccentric Loader BCT. The nose piece is the same as that used in the BCT terminal. A pair of 12 gage steel diaphragms are bolted inside this nose section. These diaphragms apply forces to the top of the end post that cause it to break quickly and release the cable anchorage. The MELT has been adopted by a few States as their standard end treatment for high-speed, high volume roads. Due to their similarities, the $1,400 installed cost of the MELT is the same as that of the Eccentric Loader BCT.

Since all of the BCT-type terminals and turned-down designs are gating terminals, the grading of the approach and the terrain along the back of the guardrail and terminal should be as flat as feasible. The standard drawings for the MELT show some recommended grading details (14).

Crash tests have shown that the BCT and the Eccentric Loader BCT terminals do not perform well in end-on impacts with aerodynamically styled small cars. The nose and the W-beam rail can slide up the wedge-shaped front ends of these cars and impact the windshield or the roof (15). This type of behavior has also been observed in a crash test conducted under a pooled-fund study in progress at Texas Transportation Institute that is aimed at developing a retrofit design for the BCT terminal (16). No tests have been conducted on any other terminal designs with wedge shaped vehicles.

As part of a current research study on side impacts at Vanderbilt University, a series of crash tests have been conducted at the Turner-Fairbank Highway Research Center's Federal Outdoor Impact Laboratory (FOIL) test facility in McLean, Virginia (17). Side impact tests were conducted at 48 km/h (30 mi/h) into the ends of the BCT, the Eccentric Loader BCT and the MELT terminals. In each test, the nose of the terminal buckled the door and penetrated deeply into the passenger compartment of the 816 kg (1800 lb) car. To date, no side impact tests have been conducted to investigate the performance of the energy-absorbing type terminals. There are no requirements for side impact tests in NCHRP Report No. 230 (3).
In view of the poor performance of BCT-type terminals in side impacts, and the fact that wedge-shaped cars are becoming more numerous in the vehicle fleet, it may become necessary to develop new nose piece designs that will spread the impact loads over a greater area of the vehicle, and to make more use of terminals with energy absorbing features. However, such efforts may not be fully successful unless improvements (e.g. stronger, stiffer doors), are also made to the vehicles.

3. OTHER END TREATMENTS

It is a common practice to flare back the end of a W-beam rail and bury it in a cut slope. This anchors the rail and eliminates spearing problems. However, for some impact conditions, it is possible that the slope can cause vehicles to roll over. In a crash test, a full-size car vaulted over the guardrail because the 10:1 approach slope lowered the effective height of the rail. To prevent vaulting, it is important that the height of the guardrail remain constant relative to the roadway grade. A W-beam rub rail should be added to the guardrail to prevent vehicles from snagging on the exposed posts.

When concrete safety shapes are used for roadside barriers, the ends are sometimes flared back and buried in a cut slope. To prevent the underside of the vehicle from snagging on the top of the barrier, it is important for the slope to extend above the barrier. Earth ramps with a 20:1 approach slope and 6:1 side slopes have sometimes been used on median barriers and on roadside barriers, particularly on park roads where aesthetics are an important consideration. These designs have never been evaluated by crash testing.

A 1.5 m (5 ft) radius curved guardrail known as the Minnesota Bullnose or Bullnose Attenuator was crash tested with full-size cars in 1975. It was shown in the 1977 AASHTO Barrier Guide as an operational system (2). Some States use the Bullnose Attenuator in median areas on low volume roads. When a vehicle impacts it on the nose, the wood posts break away and the W-beam rail wraps around the vehicle. The grading in front of the curved nose is very critical. If it is not relatively flat, the W-beam rail will slide up the hood of the car and impact the windshield.

In some cases, a road will intersect another road so near to the end of a bridge that there is insufficient space to install a conventional end terminal and transition section. A 2.6 m (8.5 ft) radius curved guardrail with CRT breakaway wood posts has been crash tested and developed for use at such sites (18). A 10.7 m (35 ft) radius design is also available. A stiffer 2.6 m (8.5 ft) radius curved guardrail has been tested and developed by Yuma County, Arizona for use on 80.5 km/h (50 mi/h) roads where a canal is located close to the back of the guardrail (18).
4. ENERGY ABSORBING TERMINALS

The Safety End Treatment Terminal (SENTRE) is manufactured by Energy Absorption Systems, Inc. of Chicago, Illinois. The crash tests met all of the evaluation criteria in NCHRP Report No. 230, so it was classified as an operational system on April 7, 1989. The SENTRE terminal has three beam side panels that telescope longitudinally in end-on impacts. These three beam rails are supported by steel posts that are mounted on slip bases. A cable that is threaded through holes in the posts at groundline is used to redirect vehicles laterally as the terminal collapses. This cable ordinarily does not cause problems with mowing operations. Plastic boxes filled with sand are mounted on the posts to absorb energy. This proprietary guardrail terminal can be installed either straight or flared. The installed price of a SENTRE terminal is between $4,000 to $15,000, depending upon the type of anchoring that is selected.

The Transition End Treatment (TREND) is similar to the SENTRE. The key difference is that it can also serve as a transition. A steel tension strap that is attached to the back of each post helps to redirect vehicles that impact the traffic side of this guardrail terminal. Since it is only 6.1 m (20 ft) long, it would be useful for a short approach terminal and transition to shield bridge rails, safety shaped barriers, abutments and railroad signals. This proprietary product of Energy Absorption Systems, Inc. passed the crash tests recommended by NCHRP Report No. 230. The TREND was classified as an experimental feature on January 8, 1986. The installed price is approximately $6,000.

The Crash Cushion Attenuating Terminal (CAT), a proprietary product of Syro Steel Company, was originally called the "Shredder" because energy was absorbed in end-on impacts by bolts which tore through the steel between a series of slotted holes in the W-beam rails. Research at Southwest Research Institute for Syro Steel Company built upon earlier work from an FHWA contract to develop a design that was called the Vehicle Attenuating Terminal (VAT). The VAT was classified as an experimental feature on July 23, 1986. Syro Steel Company then sponsored additional research to test and develop the CAT. The CAT is a double-sided unit so it can also be used as a median barrier terminal and a crash cushion. The wood posts of the CAT are set in steel sockets. This facilitates removal and replacement of the broken posts. The CAT was classified as an operational system on June 6, 1990. The $3,500 installed cost of the CAT includes $3,000 for materials and about $500 for labor. The CAT can readily be transitioned to steel median barriers, concrete safety shapes, bridge rails and vertical walls or piers. When the CAT is used to shield the end of a concrete barrier, the installed cost of the CAT and the transition section is about $4,500.

The Texas Transportation Institute and the Texas Department of Transportation were recently given an award by the FHWA for the development of the ET-2000 terminal. This guardrail terminal was originally called the "Extruder". The nose of this terminal is designed to slide backwards over the W-beam rail. During an end-on impact, the W-beam enters a feeder chute and is flattened and redirected away from the vehicle.

VTI RAPPORT 380A
The impact energy is absorbed by flattening the steel W-beam and by breaking away the wood posts. Steel foundation sleeves must be used on posts nos 1 through 4. This proprietary product of Syro Steel Company was classified as an experimental feature on September 6, 1989. The installed cost of the ET-2000 is about $2,100. The cost of the material for the ET-2000 is about $1,800 and the labor cost is $250 to $300. Therefore, the installed cost of the ET-2000 is about $2,100.

The BRAKEMASTER system is a proprietary product of Energy Absorption Systems, Inc. It was classified as an experimental feature on January 3, 1990 for use in either median or roadside applications. Its narrow 0.5 m (18 in) width makes it easily adaptable to most steel guardrails and median barriers. This low maintenance terminal has a special braking system that engages a longitudinal cable and dissipates energy by friction in end-on impacts. Its installed price is approximately $12,000.

The Advanced Dynamic Impact Extension Module (ADIEM) is a proprietary product of Syro Steel Company. The ADIEM consists of a series of crushable concrete modules that are mounted on a tapered concrete ramp. The ADIEM was designed for use on the end of a concrete safety shape barrier. This patented product is being manufactured by Syro Steel Company. It was accepted for Federal-aid projects on October 24, 1991 for use as a terminal. It has not been tested as a crash cushion in accordance with NCHRP Report No. 230. The installed cost of the ADIEM is about $7,500. This includes $7,000 for the cost of the material and $500 for the labor to construct it.

The available terminals were recently reviewed and compared on the basis of their crash test performance, costs and field experience in order to provide information that would be useful in selecting the most cost-effective terminals for specific needs (19). California, Minnesota and other States have recently reviewed the available terminal designs and developed their own selection criteria. The States are also currently making in-service evaluations of the newer terminal designs. Instances of poor construction and improper installation practices have been observed (20,21). As a result, the State of Indiana has recently required that contractors who install proprietary terminals be certified by the manufacturer (21). Since certification appears to be beneficial to both the State and the manufacturer, this process of giving "hands-on" training and a written examination will probably become widely adopted.

5. CRASH CUSHIONS AND IMPACT ATTENUATORS

Crash cushions and impact attenuators are such well-engineered and well-tested products that only a few people are killed each year in collisions with them. In general, all of them have been tested and evaluated in accordance with the recommendations in NCHRP Report No. 230. The 1977 AASHTO Barrier Guide provided some information on the design of crash cushions (2). Additional information on designing, selecting and locating crash cushions was published by the Federal
Highway Administration in 1975 (22). The operational systems were described and discussed in the 1989 AASHTO Roadside Design Guide (23).

Crash cushions are designed to safely decelerate vehicles to a safe stop after end-on impacts. Some crash cushions do this by crushing or plastically deforming material to absorb energy. This type of crash cushion needs a rigid backup or support to help crush the energy absorbing material. Other crash cushions transfer the momentum of the vehicle to sand particles. This type of crash cushion does not require a backup structure (23).

Sand-filled inertial barrels have been widely used in the United States. They were shown as an operational system in the 1977 AASHTO Barrier Guide. Energy Absorption Systems, Inc. holds the patent obtained by Mr. John Fitch. Roadway Safety Systems, Inc. of Boston has been licensed to make the Fitch Inertial System. The barrels are made of plastic that shatters upon impact. Plastic pedestals are placed inside the barrels to keep the sand at the optimum height with respect to the vehicle's center of gravity. The plastic barrels are usually colored bright yellow to make them more visible. This reduces the number of "nuisance hits" or minor impacts that can damage barrels enough to necessitate their replacement. The sides of sand-filled barrels have virtually no redirective capabilities. In order to prevent the sand particles from freezing into a solid mass, anti-freezing agents such as salt are sometimes mixed in with the sand. The use of calcium chloride or other compounds that can bond or cement sand particles together is not recommended (24). An array of inertial barrels will contain several different sizes of barrels. To reduce the severity of minor head-on collisions, the lightest barrels are placed near the nose of the array. The heaviest barrels are located near the back. The installed price of each barrel varies between $500 and $800 depending upon the size and the quality of the sand. To put this into perspective, an array of 14 barrels would cost $7,000 to $11,200.

The Hi-Dro Cushion Cell Sandwich System is a proprietary product of Energy Absorption Systems. It was shown as an operational system in the 1977 AASHTO Barrier Guide (2). The Hi-Dro system consists of flexible water-filled tubular cartridges placed between rigid diaphragms. On end-on collisions, the impact energy is absorbed by forcing water through orifices in the tops of the cartridges. To prevent freezing in cold climates, the tubes are filled with brine or anti-freeze solution. This system must have a rigid backup structure. The sides of the Hi-Dro Cushion are tapered outward and have side fender panels and cables for redirecting cars. The Hi-Dro Cushion is very reusable. Usually, only the expelled liquid must be replaced. The standard sizes range from 4 to 12 bays in length. The installed price of the Hi-Dro Cushion runs between $20,000 to $50,000.

The Guardrail Energy Absorbing Terminal (GREAT) has been widely used for many years. It is often used as an end treatment for concrete safety shaped barriers. A pair of GREAT terminals are often used to shield the ends of cross-over openings in concrete median barriers. The GREAT was shown as an operational system in the 1977 AASHTO Barrier Guide. At that time, it had crushable cartridges made of
vermiculite concrete. Energy Absorption Systems, Inc. developed Hex-Foam cartridges for the GREAT in order to improve its performance for the smaller 816 kg (1,800 lb) cars. The proprietary GREAT with Hex-Foam II cartridges was classified as operational on October 31, 1986. The GREAT has steel posts set in rails which must be anchored to the ground. The crushable cartridges are inserted between the diaphragms that connect the posts. The thrie beam side panels of the GREAT are designed to telescope during frontal impacts. These side panels can redirect vehicles that impact the side of the terminal. A portable version of the GREAT has been developed for use in construction work zones. A portable concrete slab has sometimes been used to anchor the rails. The GREAT is modular. One to twelve attenuator bays are used, depending upon the expected impact speed. Depending upon the number of bays, the installed price runs between $18,000 and $40,000.

The Low Maintenance Attenuator (LMA) is a patented device manufactured and distributed by Energy Absorption Systems, Inc. It was classified as an experimental feature on June 20, 1989. Three units have been installed in the State of Texas. In appearance and function, the LMA is very similar to the GREAT terminal, but the hardware items are not interchangeable. The LMA has special rubber cartridges that slowly return to their original shape after a collision. The manufacturer recommends that all curbs, islands and other objects near the unit be removed. The installed price of a LMA is approximately $70,000.

The Connecticut Impact Attenuation System (CIAS) consists of an array of 14 thin-walled steel cylinders that are bolted together and then attached to a 2.7 m (9 ft) wide backup wall. The three cylinders in the back row are 3.7 m (12 ft) wide. The cylinders rest on two steel rails that are mounted on a concrete pad. This system is designed to redirect vehicles that impact the sides near the backup wall. This unique redirection capability is due to the internal tension straps and compression pipes that stiffen the cylinders in the last three rows. The CAIS was classified as operational on November 6, 1986. The State of Connecticut has licensed Syro Steel Company to make and market the CAIS. The material will cost $12,000 to $14,000, so the installed cost will be $15,000 to $18,000.

The Narrow Connecticut Impact Attenuation System (NCIAS) was designed specifically to protect the end of a concrete safety shape barrier. The NCIAS is 0.9 m (3 ft) wide. It was classified as an experimental feature on April 5, 1989. Syro Steel Company has been licensed by the State of Connecticut to manufacture and distribute the NCAIS. The cost of the material will be a little less than for the CIAS. Therefore, the installed cost of the NCIAS will be about $14,000 to $17,000.

It has been estimated that the use of reflective sheeting and reflective panels to delineate the ends of terminals and crash cushions can reduce the number of accidents by as much as 50 percent. A field study was made of the effectiveness of several different types of delineation on crash cushions (25). The recommendations from this study are currently being implemented in the Houston District of the Texas Department of Transportation.
6. **TRUCK-MOUNTED ATTENUATORS**

In order to protect both the motorists and the workers in construction and maintenance zones, truck mounted attenuators have recently been developed for use on "shadow" vehicles. These truck mounted attenuators or TMA's have generally been crash tested with automobiles at about 72 km/h (45 mi/h). One of the early designs used steel drums (26). The State of Connecticut subsequently developed a TMA made of clusters of large diameter steel pipes that was the forerunner of the CAIS and the NCAIS systems. Energy Absorption Systems, Inc. currently makes and markets the Hex-Foam TMA, the Alpha 500 TMA and the Alpha 1000 TMA. Hydraulic mechanisms have been developed that can tilt the TMA upward for travelling. The installed price of these TMA's varies between $15,000 and $25,000 depending on the hardware, hydraulics and type of crushable cartridge.

7. **CONCLUSION**

Crash cushions and terminals are very cost-effective. Crash cushions and impact attenuators have a benefit-to-cost ratio of 3.2 (1). Guardrail end treatments have a benefit-to-cost ratio of 1.5 (1). Therefore, serious consideration should be given to utilizing them where they are warranted.

8. **REFERENCES**


Cost Benefit of the Dutch RIMOB Impact Attenuator

Rien van der Drift
Ministerie van Verkeer en Waterstaat
The Netherlands
Isolated obstacles in the road-verges of motorways can not always be avoided. In order to prevent collisions with these obstacles a crash cushion or impact attenuator sometimes can be the only solution. In order to provide a construction adjusted for the European situation a crash cushion has been developed in the Netherlands in the early eighties, the RIMOB (an abbreviation of the dutch name RImpelbuis OBstakelbeveiliging).

The RIMOB is composed of a nose segment and a series of interconnected deformable segments each comprising of a box-structure containing aluminium crumpling tubes. Both sides of the construction are formed by overlapping flank members in such a way that during a front collision there will be dissipation of energy. The segments deform and the crumpling tubes can be reduced up to 20% of their original length.

During a side collision the RIMOB acts as a guard rail. The vehicle is guided along past the obstacle. Three standard types are available.

Since 1982 more than 200 RIMOB's are installed along the motorways in the Netherlands. To ascertain whether the RIMOB has proven as effective and safe in practice as tests originally suggested an evaluation has been carried out. In 1989 approx. 100 RIMOB's had been collided with.

The evaluation appeared that the performance of the RIMOB is quit well. The construction is in both front and side collisions very stable. Vehicles were restrained from going under or over the construction.

The most important findings regarding front collisions are: The vehicles came to rest within the length of the construction and there was not any noticeable rotation of the colliding vehicles. The conclusion is that the chance of injury to the occupants was limited.

The risks for the occupants of vehicles is substantially reduced when isolated obstacles are protected against collision with a RIMOB. The average chance for occupants to be injured when hitting an unprotected bare obstacle is more than 25 %. The global chance of injuries in a collision with a RIMOB is reduced to about 5 - 10 %.

The overall conclusion is that the cost benefit of the RIMOB as a road safety measure is ascertained.
COST BENEFITS OF THE DUTCH RIMOB IMPACT ATTENUATOR

by Rien van der Drift
Transportation and Traffic Research Division
The Netherlands

1 INTRODUCTION

It is not always possible to eliminate all obstacles on road shoulders, and they can be lethal if vehicles accidentally leave the road. Certainly on motorways, protection should be provided for obstacles close to the road. Where a continuous structure is not feasible, an impact attenuator should be used. In a head-on collision, this device will bring a vehicle to a stop in a short distance. In the event of a side collision, the attenuator acts as a conventional guide rail.

The Netherlands has some ten years' experience with the RIMOB impact attenuator - short for RIMpelbuis OBstakelbeveiliger (crumple tube obstacle protector). More than 270 have now been installed. To ascertain whether the RIMOB has been as effective and safe in practice as the original tests suggested, an evaluation has been carried out by the Road Safety Research Institute (SWOV) and DHV Consulting Engineers at the request of the Traffic Engineering Division of the Directorate General for Public Works & Water Management (Rijkswaterstaat).

This paper examines traffic hazards on road shoulders, and looks at the development and application of RIMOB and Dutch experience with it. Finally it assesses the effectiveness of the RIMOB.

2 ROAD SHOULDER HAZARDS

Road safety has to be one of the great social issues of our time. Every year 50,000 people are killed and 1.5 million injured on European roads. There were 1,281 road deaths in the Netherlands in 1991 compared with 3,200 in 1970. So we have achieved a great deal already.

The number of accidents involving obstacles, however, has remained about the same. About 22% of fatal accidents (all roads) involve obstacles - the largest single category. The next largest category is accidents in which vehicles are in collision with pedestrians.

<table>
<thead>
<tr>
<th></th>
<th>number</th>
<th>percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>front/rear</td>
<td>5000</td>
<td>39</td>
</tr>
<tr>
<td>fixed obstacle</td>
<td>3050</td>
<td>24</td>
</tr>
<tr>
<td>one vehicle</td>
<td>1100</td>
<td>9</td>
</tr>
<tr>
<td>other</td>
<td>3650</td>
<td>28</td>
</tr>
<tr>
<td>TOTAL</td>
<td>12800</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1 Accidents on motorways in the Netherlands (year on average)

VTI RAPPORT 380A
Motorway safety is relatively weakly correlated with traffic behaviour. Accidents involving injury occur at the rate of 0.07 per million vehicle kilometres on motorways. On other roads with all kinds of traffic, the figure is 1.33 per million vehicle kilometres.

The following factors play a part in road shoulder hazards:

a) the probability that a vehicle will leave the road
b) the distance the vehicle drives into the shoulder
c) the design of the shoulder.

We distinguish between hazards faced by those in the car, and hazards faced by third parties. The latter are involved when a vehicle leaving the road comes to rest in the oncoming lane or on another road below.

Probability of leaving the road

The probability that a vehicle will leave the road can be roughly calculated from a motorway model which predicts the chances of a vehicle colliding with the crash barrier on the central reservation. The most important variables in that model are:

- traffic density
- distance to the barrier
- existence of a wide hard shoulder or correcting lane

existence of acceleration/deceleration lanes or other kinds of merging lanes which disrupt traffic flow.

The formula to calculate the number of accidents with the central reservation crash barrier on a two-lane motorway is as follows:

\[ N = 0.265 \times C_i \times C_m \times C_a \times C_z \times L \]

where

N = number of accidents
L = length of road section in kilometres
C_i = weekday traffic density
C_m = coefficient of left-hand emergency refuge
C_a = coefficient for crash barrier-carriageway distance
C_z = coefficient for any special lane on the right-hand side of the carriageway

Example: 2x2 lane urban motorway

traffic density 55,000 vehicles per day : \( C_i = 5.47 \)
no emergency lane on central reservation : \( C_m = 1.0 \)
exit lane on other side of road : \( C_z = 1.19 \)

\[ N = 0.265 \times 5.47 \times 1.0 \times 1.0 \times 1.19 \times 1.0 = 1.72 \text{ accidents per kilometre.} \]

Almost 13,000 accidents are recorded on Dutch motorways every year. About a third of these involve a single vehicle, and these can be grouped as follows:

- accidents involving a fixed object
- accidents such as skidding or the vehicle ending up in a ditch.

VTI RAPPORT 380A
On average, 3,050 accidents a year on Dutch motorways (on the main carriageway) involve a fixed object, and about 80% of these are collisions with crash barriers (including RIMOBs). The remaining 20% involve other obstacles on the shoulder. Accident records also show that in this last category of accidents, the number of people injured is 2.5 times as great as in collisions involving crash barriers (23.8% as against 9.6%). The risk of injury in collisions with fixed objects can therefore be reduced considerably by using protective structures.

3 DEVELOPING THE RIMOB

The RIMOB impact attenuator was developed in the early 1980s as a shield for isolated obstacles on road shoulders which could not be protected in any other way. Other countries had already been developing structures for a similar purpose. One example involved the use of sand-filled buffer barrels. However, safety left much to be desired, especially in side-on collisions. Another disadvantage was that the barrels could not be connected to a guard rail. The RIMOB was developed in response to these shortcomings.

The design for the impact attenuator was based on a number of operational requirements, the most important of which are listed below:
- in a head-on collision the attenuator must bring the vehicle to a halt in an acceptable manner
- in a side-on collision the vehicle must be guided past the attenuator in an acceptable manner
- the impact attenuator must be suitable for fitting on the road shoulder
- the impact attenuator must be capable of modification for special situations
- the impact attenuator must be tailored to the characteristics of cars using Dutch roads.

The final design is an impact attenuator in which the kinetic energy released in a head-on collision is absorbed by the crumpling of aluminium tubes. Mass inertia and internal friction ensure energy is absorbed. The crumple tubes can be compressed to 20% of their original length. The structure consists of a nose segment and several box elements. In the standard design, the width increases from the front to the back (V-shaped, top angle 13°). The sides of the box elements consist of overlapping sections of guard rail profile.

In the event of a head-on collision, the structure telescopes over the required length. The crumple tubes, fixed axially in the box elements, absorb most of the kinetic energy of a colliding vehicle. In a side-on collision, the RIMOB behaves like a rigid guard rail, deflecting the vehicle and guiding it past the obstacle.

The foundation for the RIMOB is a concrete base with a rear wall. At the front, it is anchored laterally by the legs of the first element which form strips of guide rail. At the back, the last element is bolted to the concrete rear wall. As with a guard rail, all the parts of the RIMOB are galvanised, providing 15 to 20 years’ protection against corrosion.
Trials

Ten collision trials were carried out, nine with the V-shaped structure and one with a parallel model. The test car was an Opel Kadett (mass approx. 750kg). Three head-on collisions were carried out at a speed of 100 kph, two of them eccentrically with a 0.5m offset. Another three tests were also done off-centre, and three side-on collisions were performed at speeds of 80 and 65 kph. Measured deceleration remained within acceptable limits in the head-on collisions. The principle of box elements containing crumple tubes allows the structure to be adapted to suit individual circumstances. Three standards types have been developed (see figure 1):

- **V-270** V-shaped construction (top angle 13°) with width increasing from 1.10m at the front to 2.70m at the back. The whole 7.50m long structure is made up of seven 1.00m elements and a 0.50m nose segment;

- **V-185** V-shaped construction with width increasing from 1.10m at the front to 1.85m at the back. The structure is 6.50m long, made up of six elements and a nose segment;

- **P-110** Parallel construction, 1.10m wide and 4.50m long, consisting of four elements and a nose segment.

![Diagram](image)

Figure 1 Rimob type V-270, type V-185 and type P-110
The V-270 should always be the preferred choice, since it has the highest energy-absorbing capacity. Vehicles weighing 1200kg travelling at 100 kph can be brought to a standstill without difficulty. Where there is insufficient room for the V-270, the V-185 can be used or, in the last resort, the P-110. The P-110 can also be used at roadworks where a 70 kph limit is in force. In principle, the three standard types should cater for every situation.

4 MAINTENANCE AND REPLACEMENT

A damaged RIMOB is replaced completely within days of a collision. It takes about 30 minutes to remove the old structure and fit the new. The attenuator is therefore only out of action for a short time, and traffic delays are kept to a minimum during repair. The damaged structure is returned to the factory for dismantling and recycling of any usable parts. The average cost of replacing and repairing an accident-damaged RIMOB is NLG 6,350 (at 1991 prices).

5 RIMOB APPLICATIONS

The RIMOB is used to shield obstacles in the following situations:

At exits and where roads fork. The RIMOB was developed first and foremost to provide adequate protection in such situations. Poles and gantry posts are often located here, immediately after the gore. In such cases, a guide rail does not provide adequate protection in the danger zone, since there is not enough room for it to be anchored immediately after the gore. Anchoring a RIMOB impact attenuator is a relatively safe solution.

On verges and shoulders. In view of the collision risk, a RIMOB is sometimes preferable to a guard rail here for protecting isolated obstacles. A minimum length of about 100m is required for a guard rail and its termination. In a side-on collision, a RIMOB acts like a rigid guard rail but is only about 10m long. Where obstacles have to be shielded on verges between lanes carrying traffic in the same direction, a RIMOB is usually cheaper than a guard rail. Small isolated obstacles such as poles for signboards can be shielded by a RIMOB without an extra guard rail. For longer objects, the RIMOB can still be used and the guard rail connected to it extended. Once past the obstacle, this rail can either be terminated or connected to the existing guard rail.

As the starting point for a guard rail. A RIMOB can be used where there is insufficient room for the normal lead-in section of a guide rail (minimum length 24 + 50 = 74m).

In temporary situations, such as roadworks. Here RIMOBs have the advantages of rapid installation and space-saving dimensions.
New installations or replacements can be carried out rapidly. The concrete base only needs to be laid once, and the actual RIMOB is simply bolted to it. Complete replacement after a collision has so far seemed the best procedure.

6 EVALUATION

An evaluation was made in 1989 to examine whether the RIMOB offers adequate protection in practice. Data on manufacture, installation, location and accidents were compiled. The evaluation looked at the following aspects:

- whether the RIMOB complied with the operational requirements in practice
- the seriousness of accidents with the RIMOB
- whether site criteria for the RIMOB needed modifying
- what other modifications could be proposed to improve the RIMOB.

Compliance with the operational requirements was tested by a combination of site inspections and examination of photographs of damaged RIMOBs and accident reports. Seventy-nine RIMOBs involved in collisions were examined in this way.

Both lateral and vertical stability proved adequate. The side rails were found to have bent outwards slightly in side collisions, but there was no evidence of buckling. No unacceptable vehicle behaviour was recorded in the vertical direction - there were no cases of vehicles driving under the structure or landing on top of it.

It was found that the elements did not always telescope properly in practice. Sometimes an element was partly compressed before all the available space in the preceding element had been used. This does not detract from the RIMOB's performance, but does increase repair costs.

In heavy collisions, some transverse supports (carried on casters) inclined backwards or forwards instead of being pushed backwards upright. This reduces the energy-absorbing capacity of the element involved, and brings the buffer element into play earlier.

The nose segment appears to perform well, deforming to accommodate the front of vehicles hitting it from different directions. The cover plates, which also provide lateral stability, performed well. Predeformation in the upper and lower plates ensures that they buckle in the right direction. Other operational requirements are discussed in the section on accidents.

Accidents with the RIMOB

Between 1982 and February 1992 there were 185 collisions with RIMOBs. The exact number is known because repairs are carried out each time a RIMOB is damaged, and the road authorities are compensated. Only 38 accident forms have been traced in 1989, so there is general information about less than 25% of the accidents. The reason for this is that accident forms do not state separately if a RIMOB is involved.
Photos of all damaged RIMOBs are available, however, and a great deal of information has been deduced from these.

<table>
<thead>
<tr>
<th>Type of Rimob</th>
<th>Locations abs.</th>
<th>%</th>
<th>Collisions abs.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-270</td>
<td>175</td>
<td>74</td>
<td>154</td>
<td>83</td>
</tr>
<tr>
<td>V-185</td>
<td>46</td>
<td>20</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>V-150</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>P-110</td>
<td>14</td>
<td>6</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>235</td>
<td>100</td>
<td>185</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2 Number of rimobs installed and collisions

Table 2 gives an overview of RIMOBs installed between 1982 and February 1992, and accidents. The V-270 is the commonest RIMOB, 75% being of this type. V-185s account for 20% and the P-110 for 6% of installations. Only one V-150 has been installed.

The RIMOB is usually installed on verges between a carriageway and a parallel road (40%) and in gore areas (30%). If all sites (until June 1989) are considered, a RIMOB will be involved in a collision on average once every five years (0.2 times per year). Taking only sites with accidents, the probability is one collision a year. The largest number of collisions with a RIMOB at a single site is 3.7 a year.

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>light vehicle</td>
<td>43</td>
<td>91,5</td>
</tr>
<tr>
<td>642 - 1414 KG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delivery van</td>
<td>1</td>
<td>2,1</td>
</tr>
<tr>
<td>1515 KG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lorry</td>
<td>3</td>
<td>6,4</td>
</tr>
<tr>
<td>6210 - 16150 KG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3 Collisions according to type of vehicle.
Table 3 gives a breakdown of RIMOB collisions by vehicle type. This has only been ascertained for 47 collisions, but of these over 90% involved private cars. No collisions involving two-wheelers were recorded. Photographs of all damaged RIMOBs were used to establish the angle of approach and the first point of impact (Table 4).

<table>
<thead>
<tr>
<th>point of impact</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>frontal center line</td>
<td>36</td>
<td>45,6</td>
</tr>
<tr>
<td>frontal off-set</td>
<td>15</td>
<td>19,0</td>
</tr>
<tr>
<td>frontal at an angle</td>
<td>6</td>
<td>7,6</td>
</tr>
<tr>
<td>Frontal/side</td>
<td>16</td>
<td>20,3</td>
</tr>
<tr>
<td>Side</td>
<td>3</td>
<td>3,8</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>3,8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>79</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Table 4 Overview of RIMOB collisions by point of impact.

Photographs were also used to determine the degree of compression of the RIMOB (Table 5). The impact speed in head-on collisions was then calculated from the degree of compression and the vehicle mass. The results for 33 collisions are given in Table 6.

<table>
<thead>
<tr>
<th>Compression (m)</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
<td>19</td>
<td>30</td>
</tr>
<tr>
<td>1 - 2</td>
<td>16</td>
<td>25</td>
</tr>
<tr>
<td>2 - 3</td>
<td>16</td>
<td>25</td>
</tr>
<tr>
<td>3 - 4</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>4 - 5</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>5 - 6</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>6 - 7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>64</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Table 5 Overview of RIMOB collisions by degree of compression.
Table 6 shows that in two-thirds of collisions the speed of impact is between 41 and 80 kph. Impact speeds under 20 kph were not found. This is probably related to the fact that compression was less than 50 cm in 12 accidents. Nothing more is known about nine of these 12 accidents. Not surprisingly, vehicles involved in these minor bumps are able to continue under their own steam. Four collisions involved impact speeds greater than 100 kph.

The 38 accident forms available give the following account of the seriousness of the accidents:
- 32 accidents without injury
- six accidents causing injury, including two hospital admissions.

These figures suggest the probability of injury is 16%. Since the other unrecorded accidents probably involved minor collisions (RIMOB compression is less than one metre in 30% of collisions) the real figure can be assumed to be much lower. A probability of injury of between 5 and 10% is considered more likely. This is an acceptable figure, given that the probability of injury in collisions with the guard rail on motorways (main carriageways) is 9.6%.

7  COST BENEFITS

Capital costs for an impact attenuator average NLG 15,430, depending on type and location. Depreciating half the cost over a 16-year life works out at NLG 500 a year. Total annual costs including loss of interest are estimated at NLG 2000 per unit.

In 1985, the Ministry commissioned McKinsey & Company to make a study of road safety trends in the Netherlands. The cost of road accidents was calculated taking account of the following factors:
- net loss of production as a result of sick leave or death capitalised over expected remaining life
- material damage
- medical expenses
- the costs of police, the courts and the fire brigade.

On this basis, a road death costs on average NLG 184,000. Injury costs NLG 47,000 with an average of 1.2 injured persons in each accident where injury is reported.

The return period for damage to an impact attenuator is once in five years. (But note that one attenuator has been damaged 3.7 times a year - the benefits here are 3.7 x 5 or about 18 times higher).

With no impact attenuator, then the probability of a collision with a fixed object (injury accident) is about once in twenty years (1 accident every 5 years with a 25% chance of injury), and the probability of road death is once in 100 years.

The cost of death and injury at this hypothetical fixed object is therefore:

\[(47,000 \div 20) + (184,000 \div 100) = \text{NLG 4190 a year.}\]

NB. It is estimated that the damage caused to both car and attenuator in a collision is equivalent to that which the car alone would have suffered in collision with a fixed object.

The saving on accident costs is therefore about NLG 4,000 a year per RIMOB, compared with capital costs of NLG 2,000 a year per RIMOB.

8 CONCLUDING REMARKS

The RIMOB impact attenuator that has been developed appears to live up to expectations, whether in head-on or side-on collisions. Serious injuries have been avoided, in spite of collisions at speeds in excess of 100 kph. Slight injuries were reported in only six recorded accidents out of 38. No deaths have occurred in 190 collisions.

Lateral and vertical stability appears to be adequate. The final buffer element has not been affected by any of the collisions. A secondary collision took place in one accident, involving material damage only. Experience with the RIMOB as a structure is also overwhelmingly positive.

All in all, safety on motorways has been improved with the RIMOB. Effectiveness measured by cost-benefit analysis can be said to be good.
Harmonisation of European Standards for Road-Safety-Systems

Bernd Wolfgang Wink
Manager International Division
Volkmann & Rossbach GmbH & Co KG
Germany
ABSTRACT

Harmonisation of European Standards for Road-Safety-Systems
Road Safety Barriers

1. Performance parameters - a hard work to achieve
demonstrated by the ASI-Method

2. Minimum Installation-Parameters - an inevitable requirement for improvement
of road safety all over Europe

3. Results of the "Harmonisation of European Standards for Safety Barriers"
and their influence to other areas of interest like

a) harmonized accident statistics
b) harmonized police-reports about accidents
c) closer cooperation between national, european and international Bodies and
   Industries due to common interests in Research and Development
d) increasing personal relation- and friendship between representatives of the
   participating countries with the positive effects of better understanding and
   cooperation - aiming to increase road safety.
HARMONISATION OF EUROPEAN STANDARDS FOR ROAD-SAFETY-SYSTEMS
demonstrated
on behalf of the Sub-Group CEN/TC 226, WG1, Safety Barriers
or better said 'Road-Restraint-Systems'
presented by

BERND WOLFGANG WINK
ECONOMIST
MANAGER INTERNATIONAL DIVISION in

VOLKMANN & ROSSBACH GMBH & CO.KG
Hohe Str. 11-19
D-5430 Montabaur/Germany
Phone: 2602/1350
Fax: 2602/13549
Tx: 869639 leit d

on the occasion of the

INTERNATIONAL CONFERENCE
ROAD SAFETY IN EUROPE

Berlin, Germany
September 30 - October 2, 1992
Harmonisation is in general a very positive and gentle expression. One of its special attributes is that it doesn't give evidence of the huge amount of problems, troubles, fighting discussions, illusions and dis-illusions and compromises having passed before reaching Harmonisation.

Safety Barriers are a good example for the above mentioned procedure.

The performance-parameters and the application of ASI-Method - Acceleration-Severity-Index - for measuring the energy-absorbing effects of a road-restraint-system have given to all members of the CEN/TC 226, WG 1 a hard time. We had to evaluate at least 3 systems being alternatives, each of them with its pro and contras. One system was the FLAIL-SPACE-METHOD, being applied in USA, first of all. The other one is the THIV-Method, applied in UK, preferably, and the other is ASI, well known in Continental Europe, but coming from USA originally.

After hard discussion regarding the fixing of the limit of the ASI-Value we agreed to create a classification with 3 classes like

\[
\begin{align*}
\text{ASI} &\leq 1.0 \\
\text{ASI} &\leq 1.4 \\
\end{align*}
\]

and

ASI, unlimited, for systems being applied, if the safety of third parties - like schools, chemical factories etc. - is of higher priority than the life of the driver or the passenger of the crashing vehicle. In other words, in cases when we have to stop the car by all means, no matter what will happen to the persons involved in the crash directly.

But in order to put not too much pressure on the representatives of the different countries, the delegation of EC and EFTA agreed to measure according to the THIV-Method, too, and after 5 years of experience it will be decided which of both systems will be applied further on.
Once finished with this problem of finding the right method of measuring the energy-absorbing-effects of existing systems, you will find half a page in our proposal, only, not getting any imagination about the hard work being behind this achievement.

Another example for such type of hard working until reaching an agreement between all parties was the definition of the test-criteria like weight, speed and angle of the crashing vehicles. But we made it and now we call it harmonized (according the opinion of our working group in CEN/TC 226, naturally). Final decision will be taken in the coming years by the EC, as we know.

According to my understanding harmonized Standards for Road-Safety-Systems like Safety Barriers all over the EC and EFTA-Member-States have a very positive side-effect.

They give us the opportunity to introduce European-wide minimum-installation-requirements for safety-barriers, on a mandatory condition. If we are capable to convince the EC-Authorities to decide on this matter positively, including a European Budget or financial package for its verification, it might be one of the most important achievements in connection with the already very often cited Harmonisation-Program.

Other significant side-effects with a European touch are European wide accepted

- test institutes
- test criteria
- test vehicles and

the EC-Mark - giving evidence for growing European feelings and getting rid of the bad smell of discrimination.

Outlook and final remarks:

According to my personal understanding European Harmonisation is a very promising, but ambitious aim. For Road-Safety it is even more - extremely difficult as a general matter and extremely important for all of us as human beings - looking to safety as one of the key-values of our life!

I remember about the initial hurdles in front of us, as we started with the Working Group 'Safety Barriers' in IRF.
When representatives of many countries meet with the intention to elaborate the harmonization of national standards, very difficult or originally invincible seeming situations will be caused by different reasons.

Main reasons are:

1. Variety of the national standards

2. Tendency to prevail most of the elements of the national standard in the commitment of the harmonized (European) standard.

3. Instinctive defence against criticism on the particular national standard

4. Partial loss of objectivity, if the national lobby has the obligation to push strongly for the national standard

5. Incomplete information about the respective national standards and the existing research projects

6. Poor cooperation between the research institutes and the authorities of the European Countries

7. Poor cooperation between the authorities on international level

8. Vague definitions of the problems

9. Deadline-pressure and communication problems (language barriers)

10. Poor organization, waste of time and half-hearted compromise-solutions

These enumerated reasons need not to supervene together, but it occurs very often.

In spite of these problems the intensive engagement on the subject "Harmonisation of Safety Barrier-Systems" within the IRF-WG has come to a series of conclusions, being partially a valuable guide-line for the later created CEN/TC 226, WG 1.

For example

Relatively early we have recognized in our working group that we have to get rid of the idea of a harmonized, uniform European standard for a particular European Safety-Barrier-System.

It should and must not be our intention to search for such a uniform standard. This decision we have to leave to the forces of market, to which I will return again, later.
In examining the variety of Safety-Barrier-Systems, we easily recognize that we can divide them in a so-called

Hard - Ware and Soft - Ware - Component

We in our group have decided to forget about the hard-ware and concentrate our efforts upon the harmonization of the software. Only in this case we find a real point of attachment helping us in the process of harmonisation.

We said - leave the systems as they are, but confront them with Safety-Performance-Parameters, being accepted and approved by all authorities and the industry of the different countries. In this way the chaff separates from the wheat and no lobbyist or fanatic of National Standards is able to criticize.

In regarding the idea of Safety and defining it by the general condition to comply with uniform and internationally accepted performance-parameters, we have reached the solution of the decisive problem for the harmonization of Safety-Barrier-Systems.

The fact, that these uniform Parameters cause or result in a serie of inevitable standardizations, is logical.

A special feature assumes in this context the field of

"Installation of Safety Barrier Systems"

After the initial attempt to leave this field to the forces of the free market, too, you quickly recognize the illusion.

Why?:

1. Our intention is the permanent improvement of safety for the road users and involved third parties.

2. We have recognized, that we will be most effective for the improvement of safety, if we overcome the national barriers by the commitment of uniform European-Safety-Performance-Parameters for all systems. The systems, which comply with these conditions after performing uniform tests is approved and has to prove its quality and feasibility on the market.

In a long lasting process of selection the most successful systems will prevail, respectively a permanent dynamic development process results in better and better systems on the market.

This is the intention!

However concerning the installation of these systems we are of the opinion that this complex should not be left to the free play of market forces.
There is no doubt that safety-barriers as hardware are only half of the solution - the installation-requirements are of the same importance and an essential part of safety-barriers as an effective life-saving Road-Safety-System.

The decision about the location and circumstances for the implementation of safety-barriers should not be left to each of the member-states. It must be avoided that each country has a different definition about road-safety.

Never forget - Safety is indivisible!

Consequently it may not or should not be that in a certain country the national guide-lines urge to install Safety-Barriers at a slope with the gradient of x and in an other country only with a gradient of y. Or passive safety devices have to be installed in front of an obstacle in a distance of x meters from the edge of the carriageway and in an other country only in a distance of y meters.

In this case minimum conditions have to be fixed for all countries. Naturally the countries can additionally improve the safety, but a nominal standard in the sense of Minimum-Installation-Parameters should be effective in all countries; but mandatory.

At the end I would like to tackle a widely but most of the time un-officially treated item. I call it

Deformability and Rigidity
A contradiction or completion in the world of safety barriers?

In my eyes we are living since some years with an obvious contradiction in our market of passive safety devices

- on one hand we are working hard for the improvement of road-safety and

- on the other hand we have to realize a growing tendency to rigid barrier-systems

Especially since I am member of the European Community Working Group for the Harmonisation of the European Standards for Road-Safety-Systems I am strongly involved in this conflict between deformable and rigid safety barrier-systems. This conflict is obviously not only a problem of the related Industry, but also in Research and Administration.
But in fact: The problem can be solved.

It is not a question of

if we should install a deformable or rigid system at a specific location on road, but

where we have to install them.

After intensive discussions in our European Committee we have come to a reasonable agreement, based on safety-performance parameters like the Acceleration Severity Index (ASI). The interest of the corresponding industries like steel for deformable and concrete for rigid systems have not been taken into consideration, finally.

The solution is as follows:

For normal road-categories and road sections

the deformable/energy-absorbing barrier systems should be mandatory

For special road sections, when the protection of third parties - which are not directly involved in the accident like railways, chemical factories, schools etc. - has a higher priority than the life of the driver or passenger of the crashing vehicle,

more rigid systems will be applied.

But in reality, on our roads, big mistakes are very often made due to the Research efforts in solving special problems like reducing the danger resulting from crashing heavy vehicles loaded with fuel, oil etc. Therefore they concentrate on the very spectacular accidents and often forget about the normal and most probable ones, which have to be controlled as far as possible.

That's why it happens more and more that preventing an errant heavy vehicle from crashing into the oncoming traffic, a very rigid barrier system is installed. But we forget that with this installation we are creating a big problem for the most frequent type of accident, which is with smaller vehicles (the accident-rate in Germany is around 90 % with smaller vehicles to 10 % with heavier ones).
In my opinion it is a must for every Engineer to intensify research and try to develop safer barrier-systems, but always keeping the deceleration-values at a tolerable level. And trying or urged to do so, he has to rely on reasonable Standards and Performance-Requirements.

His main target has to be to develop barrier-systems combining the tolerable energy-absorbing effects of a deformable (steel) barrier-system with the strong blocking effect of a rigid wall. But this has to be in a way that more of the critical accidents (increasing nowadays tremendously) can be controlled tolerably without bringing the most frequent accidents into the dilemma of not being restrained as before - by the systems approved and applied until today (especially in Europe).

That is why we see more and more special designed steel safety barriers with higher retention capacity on our roads, - at least as I know and see from Germany.

This is in my opinion the right direction to go - but we knew before and go on knowing that there will never be a system capable to control all kind of accidents without negative results for at least one of the parties involved!

What we have to agree to is, that under special circumstances even a rigid wall has its good reason for being installed - but only, if we have to put more weight on the protection of third parties like roadside schools, chemical factories, water-protected area etc. than on the life of the driver or passengers of the crashing vehicle.

Result of that reflection is that acc. to the special local situation and level of priority all the range of the approved barrier-systems have their reason to be applied. But there is no doubt at all that the deformable energy-absorbing systems with an ASI-Value of £ 1,0 are the ones which have to be installed in the major sections of our roads. This instruction is clearly stated in the proposal of our CEN/TC 226, WG 1 and accepted by all members of our committee.

Having finished my global and sometimes eco-technical remarks I want to conclude my statement with another very positive human side-effect coming from our joint efforts to harmonize the Standards for Road-Safety Systems in Europe - it is the feeling of coming closer to each other, unifying knowledge and experience regardless of the countries and education we are coming from - even becoming friends - and all that under the umbrella of Safety.

Thanks for your attention.
Statens väg- och trafikinstitut (VTI) svarar för forskning och utveckling inom vägbyggnad, vägunderhåll, vägtrafik, järnvägar, järnvägstrafik, fordon, trafikantbeteende, trafiksäkerhet och trafikmiljö.

The Swedish Road and Traffic Research Institute (VTI) is responsible for research and development in road construction, maintenance, traffic, railroads, rail transport, vehicles, road user behaviour, traffic safety and environment.

<table>
<thead>
<tr>
<th>Adress</th>
<th>Telefon</th>
<th>Fax</th>
<th>Telex</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-581 95 Linköping</td>
<td>Nat 013-20 40 00</td>
<td>Nat 013-14 14 36</td>
<td>50125 VTISGI S</td>
</tr>
<tr>
<td>Sweden</td>
<td>Int + 46 13 20 40 00</td>
<td>Int + 46 13 14 14 36</td>
<td></td>
</tr>
</tbody>
</table>